Immersion freezing: singular vs. time-dependent models

S. Arabas[1,2], J.H. Curtis[1], I. Silber[3], A. Fridlind[4], D.A Knopf[5], M. West[1] & N. Riemer[1]

1: atmos.illinois.edu

2: uj.edu.pl

3: met.psu.edu

4: giss.nasa.gov

5: stonybrook.edu

funding:

ASR Atmospheric System Research

Atmospheric Physics Seminar, Insitute of Geophysics, University of Warsaw (virtual), April 22 2022

super-particles as a probabilistic alternative to bulk or bin μ-physics

JAMES | Journal of Advances in Modeling Earth Systems

COMMISSIONED MANUSCRIPT
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Confronting the Challenge of Modeling Cloud and Precipitation Microphysics

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Key Points:
- Microphysics is an important component of weather and climate models, but its representation in current models is highly uncertain

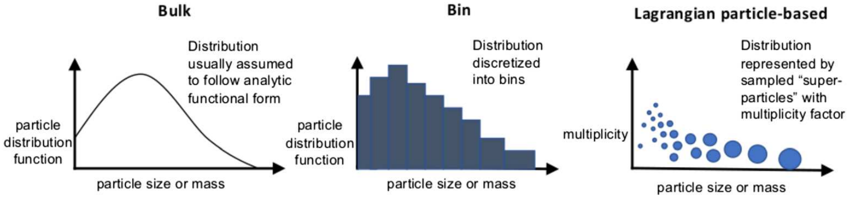

Figure 3. Representation of cloud and precipitation particle distributions in the three main types of microphysics

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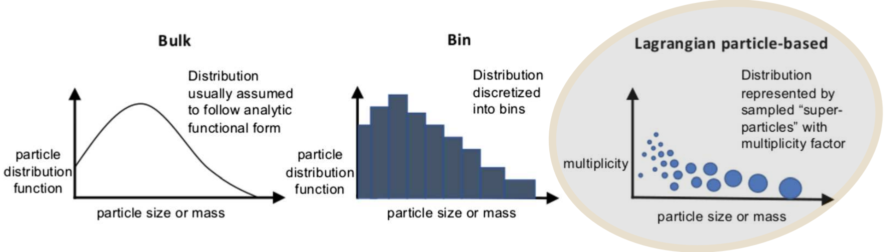

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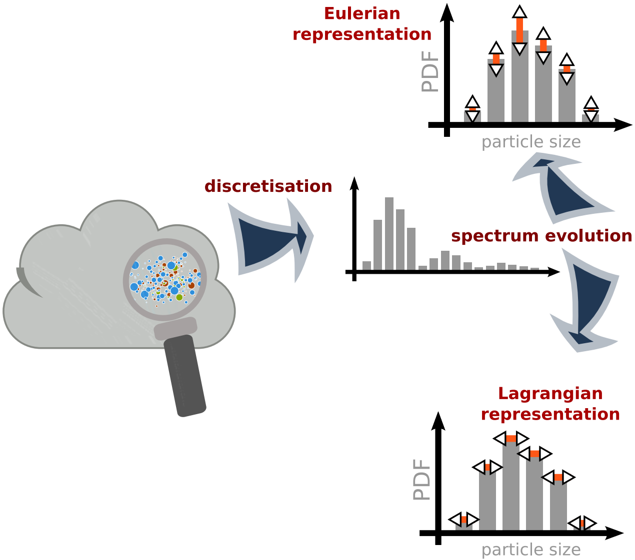

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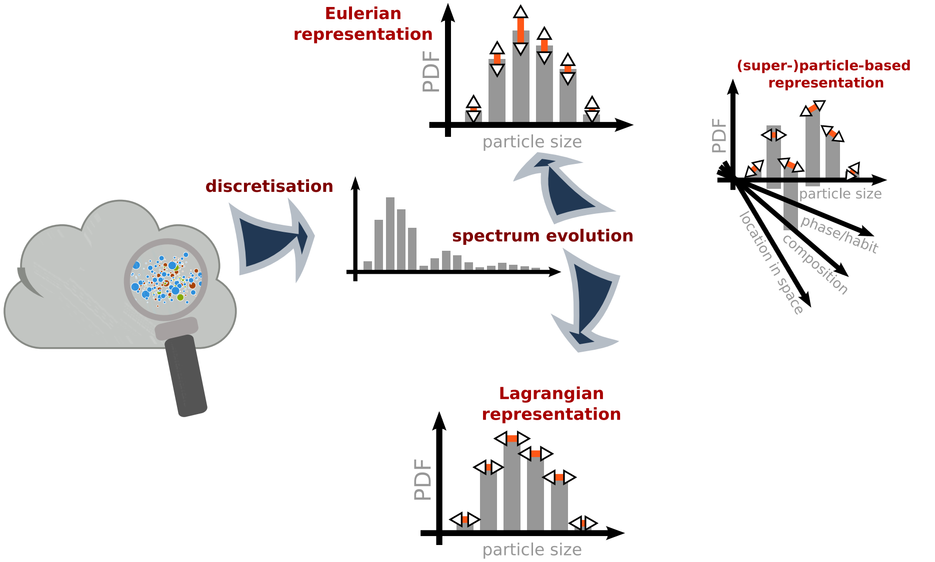

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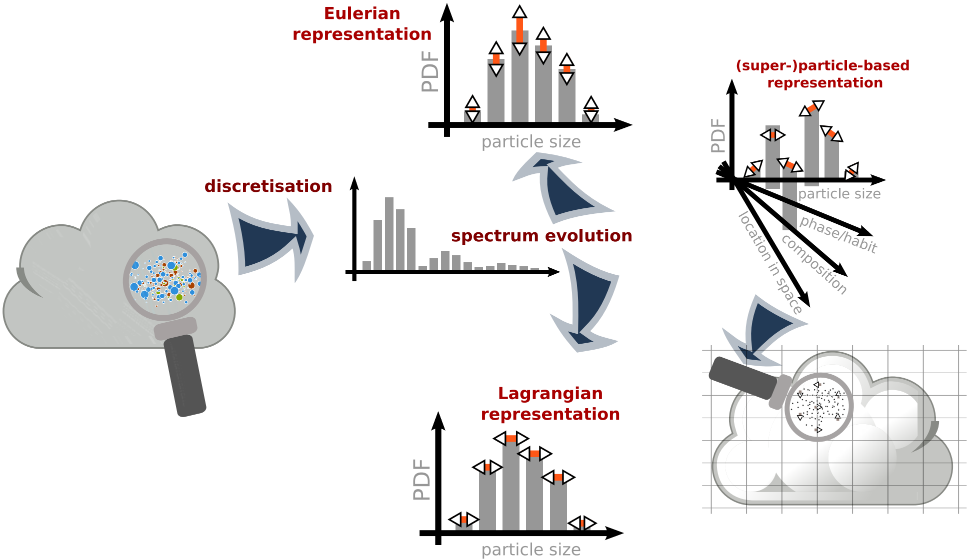

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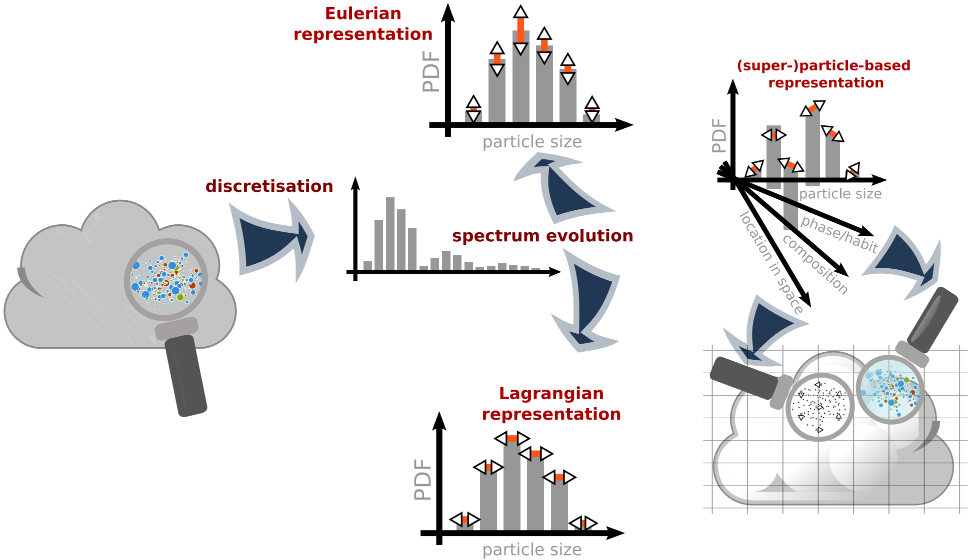

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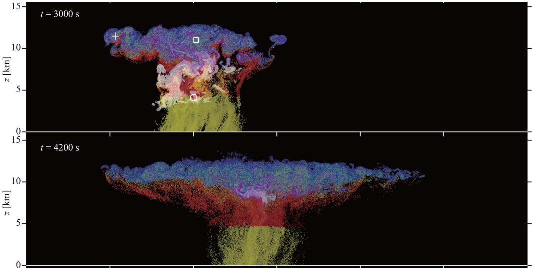

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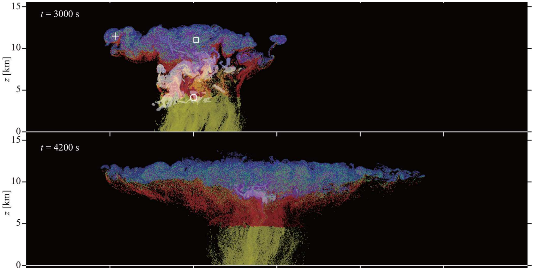

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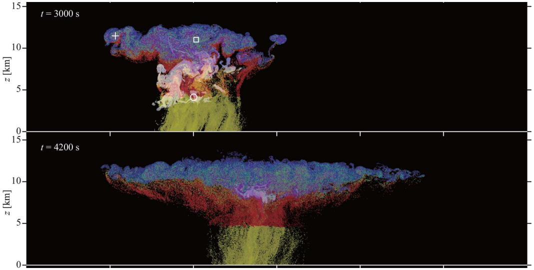

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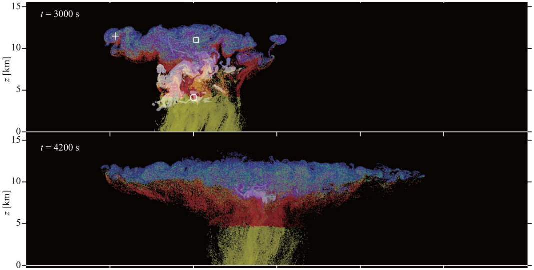

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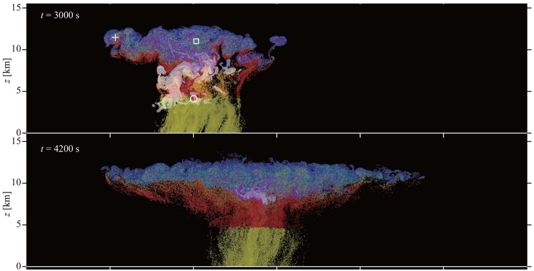

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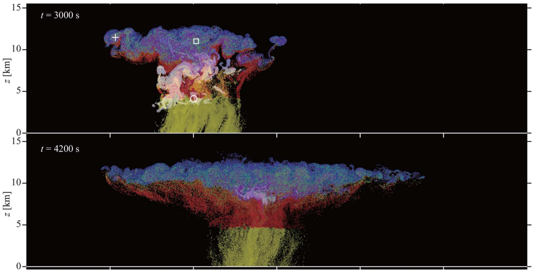

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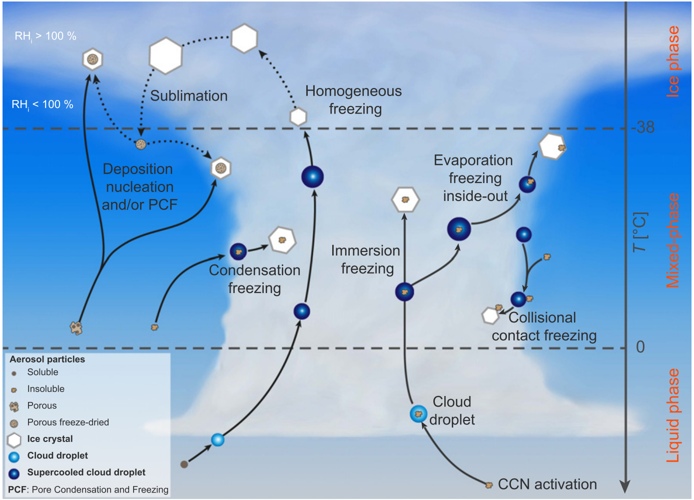
immersion freezing and other ice crystal formation pathways in clouds



Kanji et al. 2017, graphics F. Mahrt, https://doi.org/10.1175/AMSMONOGRAPHS-D-16-0006.1

immersion freezing: bacteria and the Olympics

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

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- Very ice active Snomax protein aggregates are fragile and their ice nucleation ability decreases over months of freezer storage
- Partitioning of ice active protein aggregates into the immersion oil reduces the droplet's measured freezing temperature
- Caution is warranted in the use of

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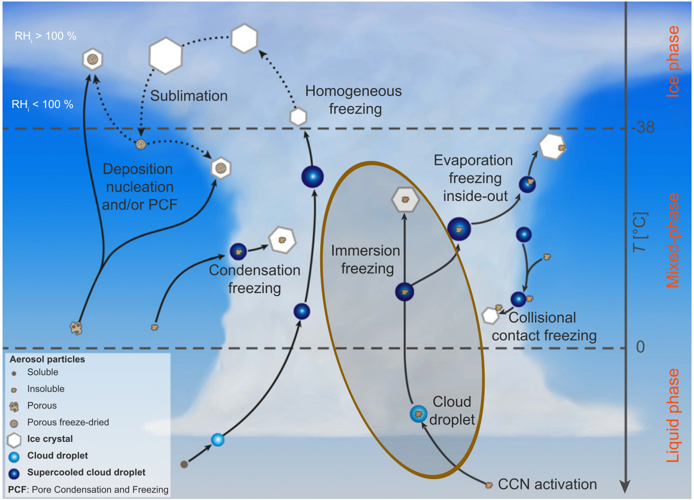

Kanji et al. 2017, graphics F. Mahrt, https://doi.org/10.1175/AMSMONOGRAPHS-D-16-0006.1

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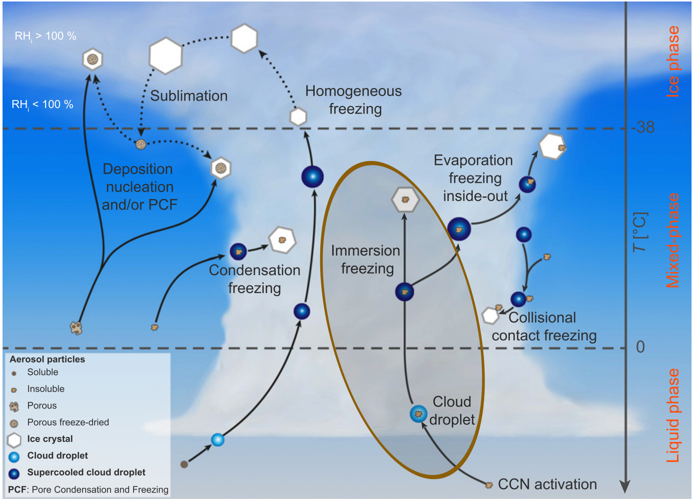

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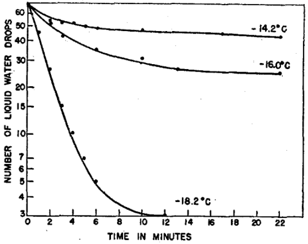

Fraction of water drops remaining unfrozen as a function of time.

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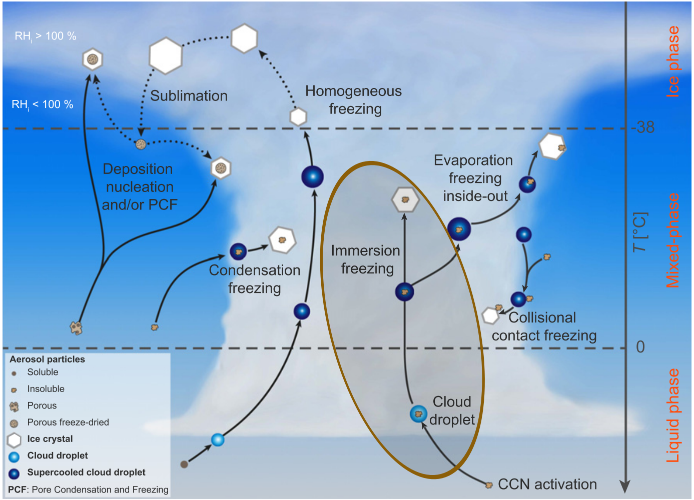

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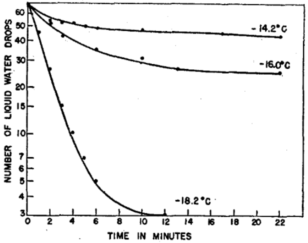

Fraction of water drops remaining unfrozen as a function of time.

Vali 2014 (ACP)

"Interpretations of the experimental results face considerable difficulties ... two separate ways of interpreting the same observations; one assigned primacy to time the other emphasized the temperature-dependent impacts of the impurities ... dichotomy – the stochastic and singular models"

Marshall et al. 1961 (Nubila 4(1))

Heterogeneous Nucleations is a Stochastic Process

by

J. S. MARSHALL

McGill University, Montreal, Canad.

Presented at the International Congress on the Physics of Clouds (Hailstorms) at Verona 9-13 August 1960.

http://cma.entecra.it/Astro2_sito/doc/Nubila_1_1961.pdf

Poissonian model of freezing & Ice Nucleation Active Sites (INAS)

theory (in modern notation)
(Bigg '53, Langham & Mason '58, Carte '59, Marshall '61)

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freezing temperature T_{fz} as a super-particle attribute

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spectrum of T_{fz} even for monodisperse A

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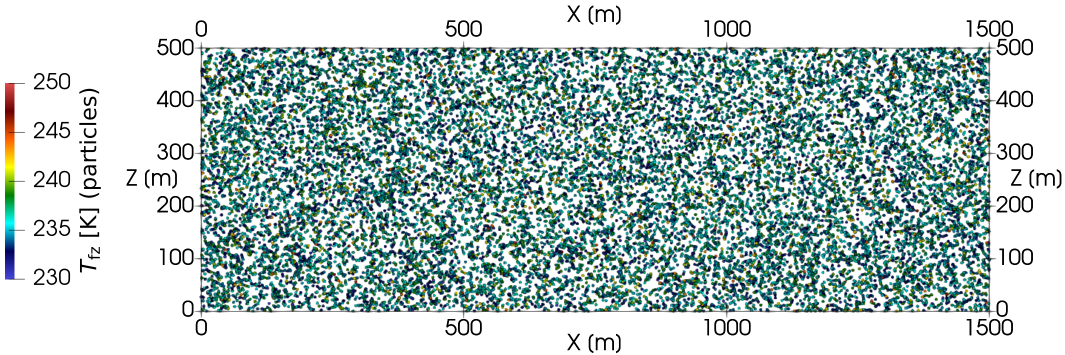

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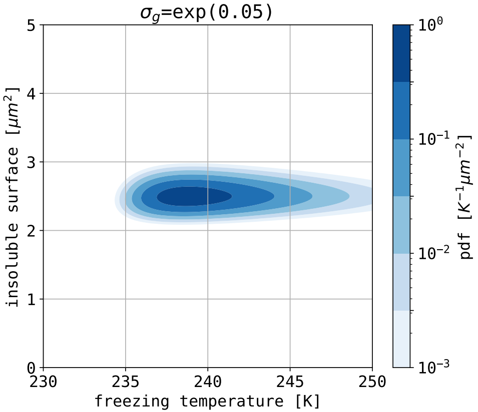

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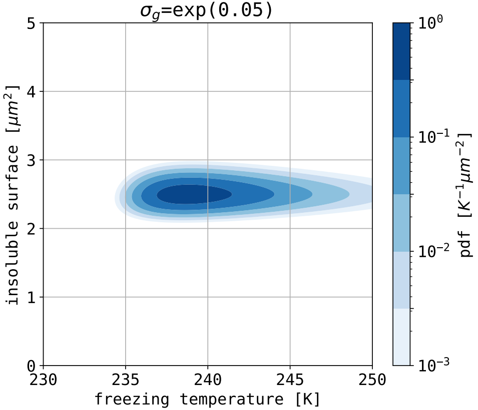

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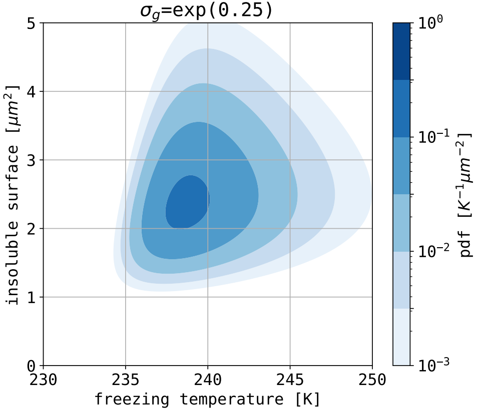

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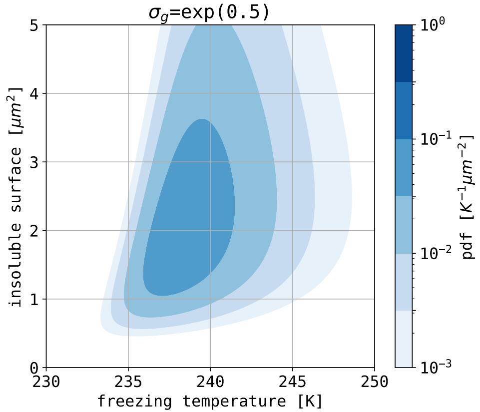

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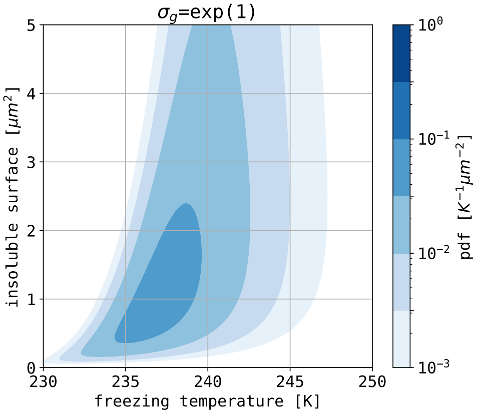

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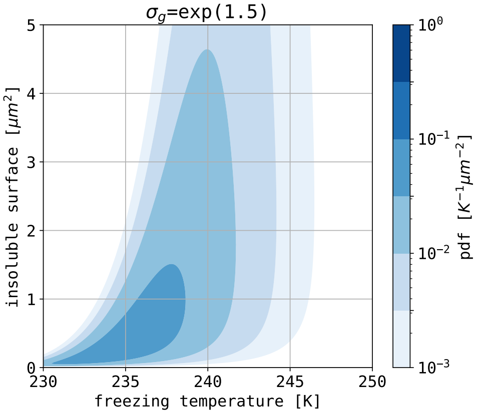

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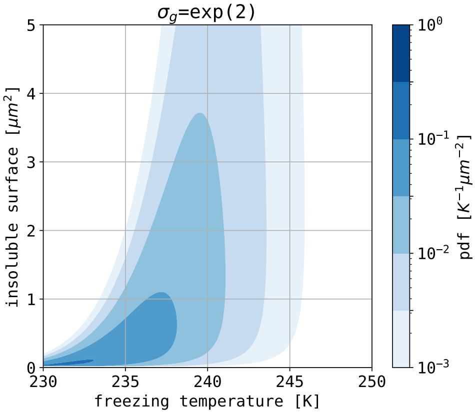

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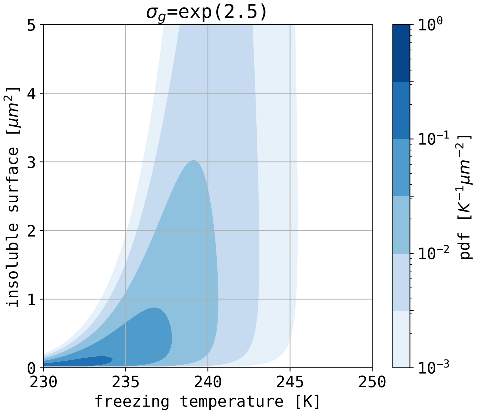

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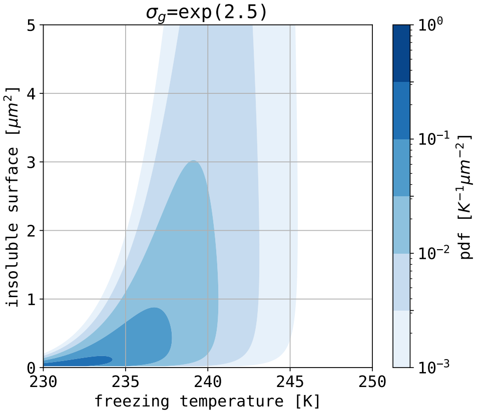
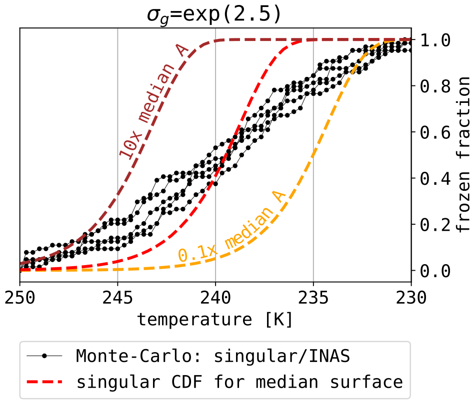


box model (or single grid cell)



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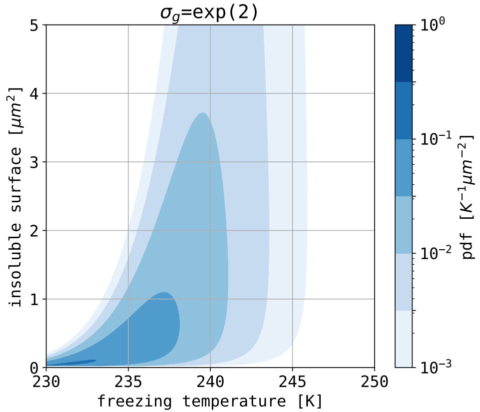

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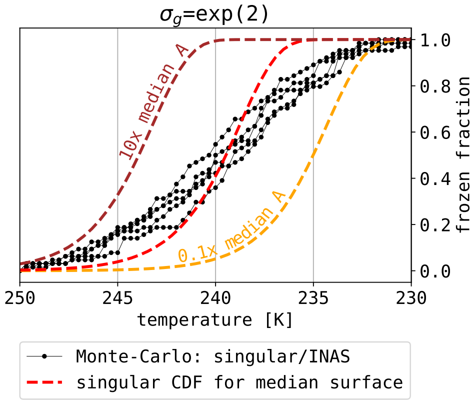

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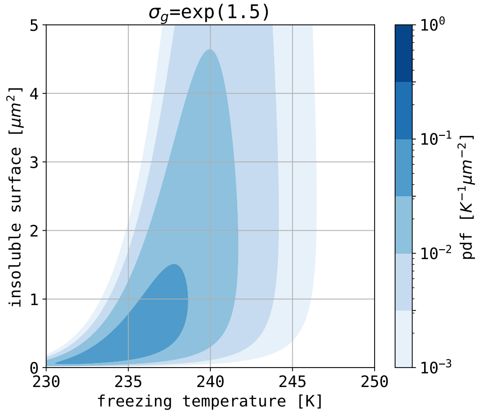

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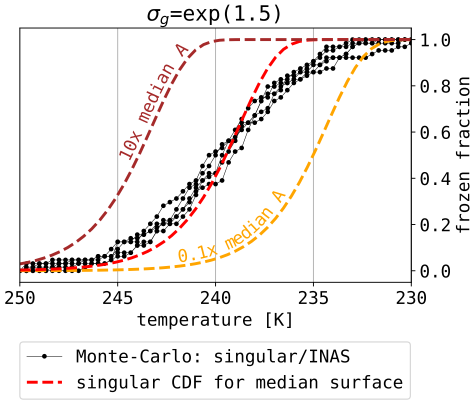

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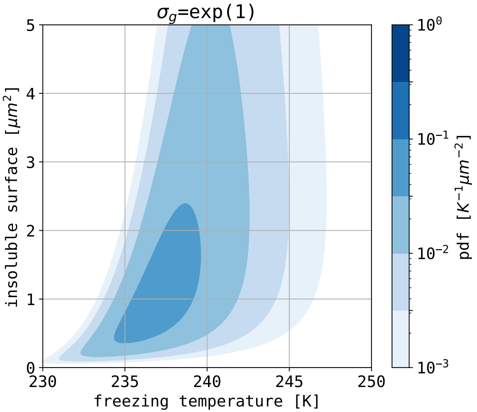

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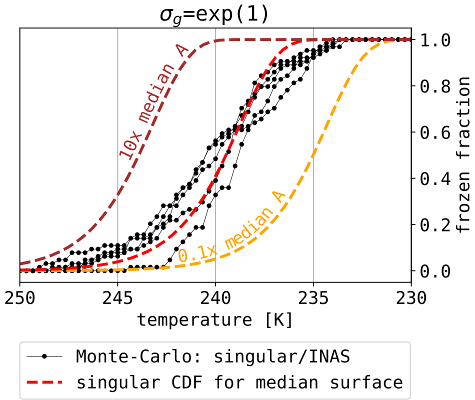

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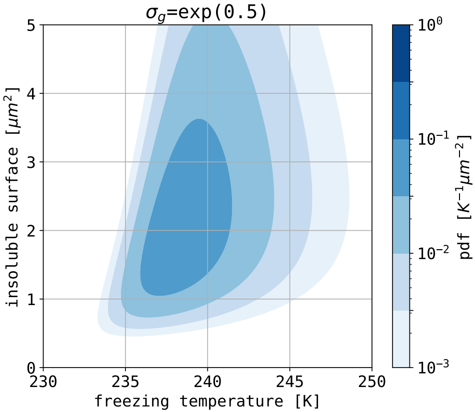

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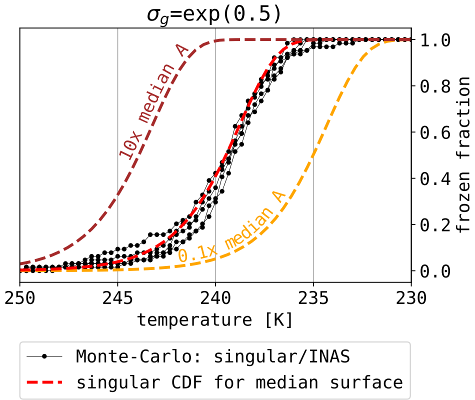

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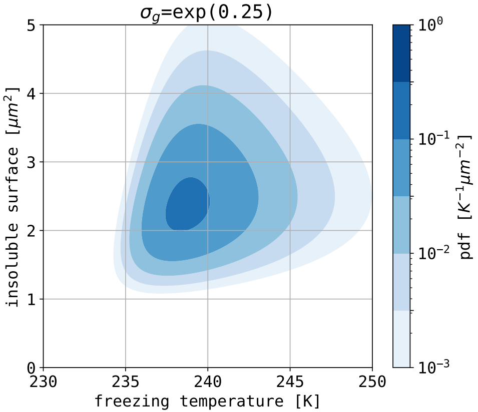

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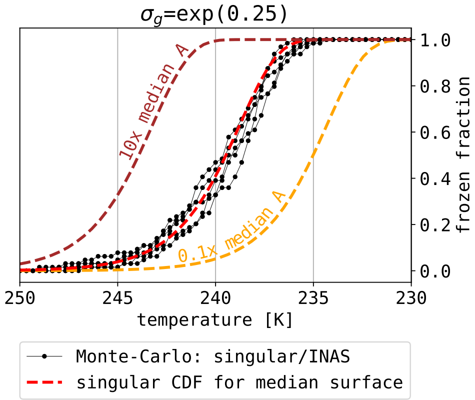

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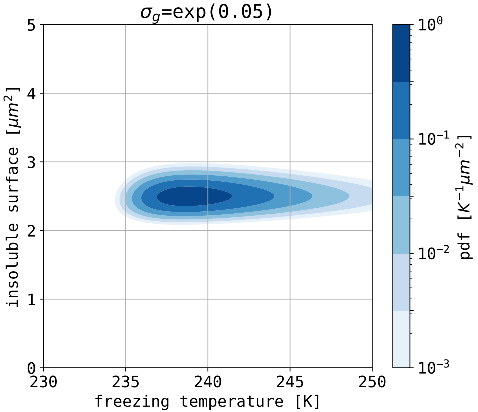

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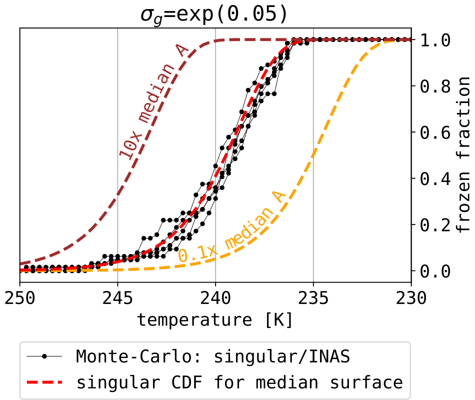

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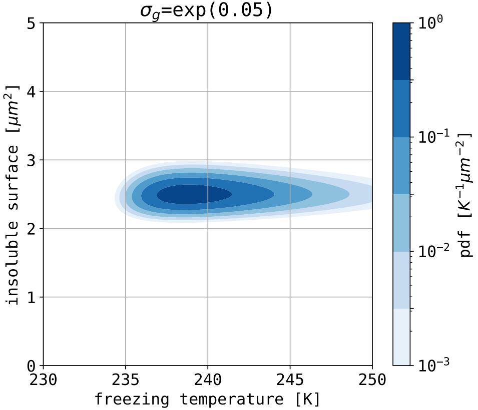

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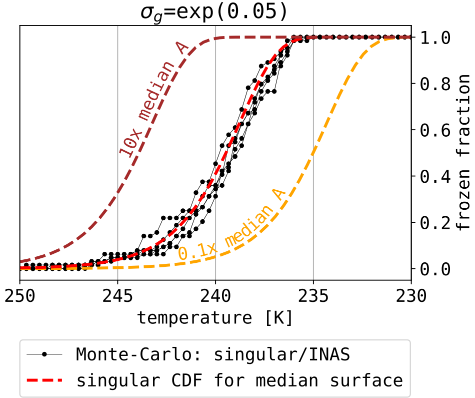

– "singular" particle-based model is capable of representing polydisperse INP
– depicted limitations stemming from monodisperse INP assumption

particle-based freezing: singular (Shima et al.) / time-dependent (this work)

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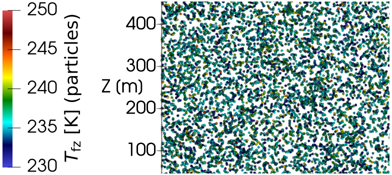
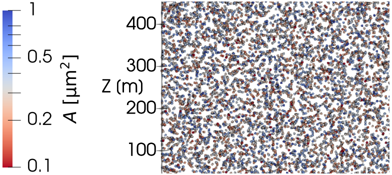


time-dependent (ABIFM)



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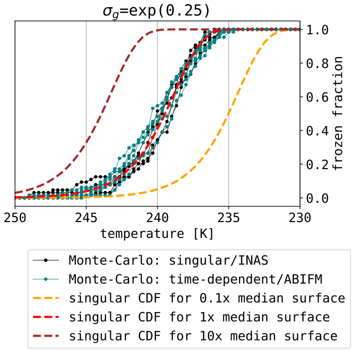

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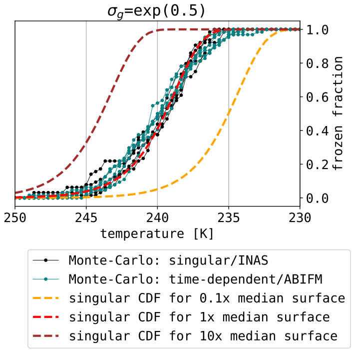

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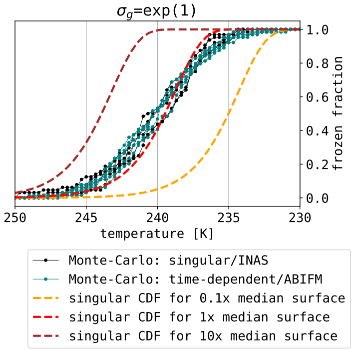

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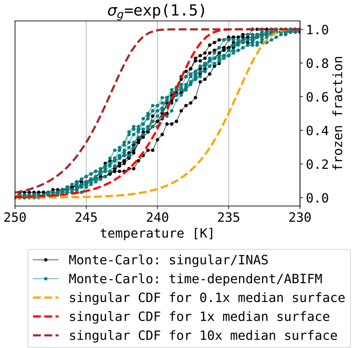

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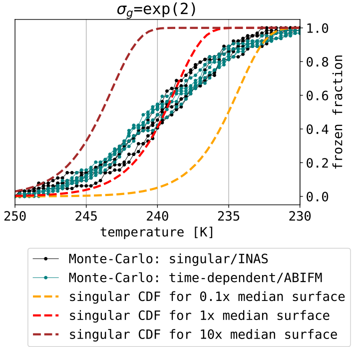

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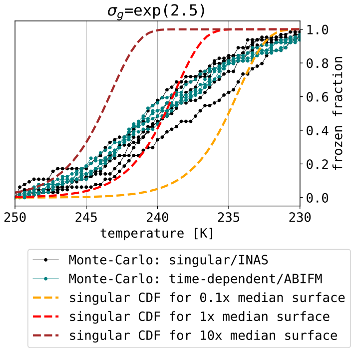

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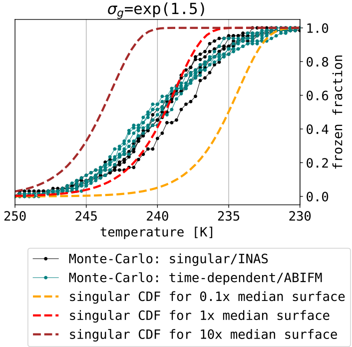

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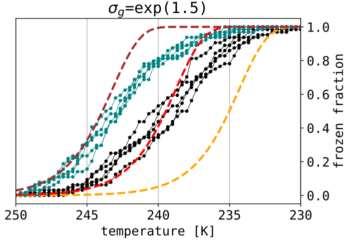

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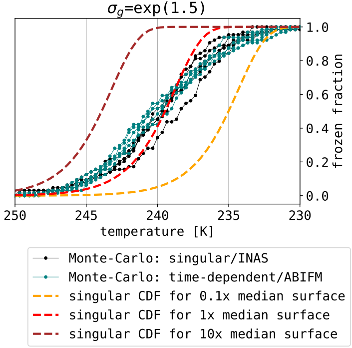

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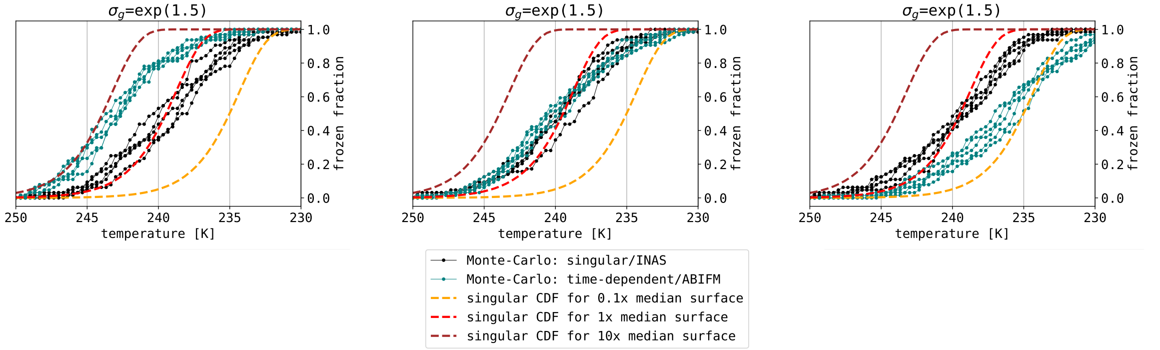

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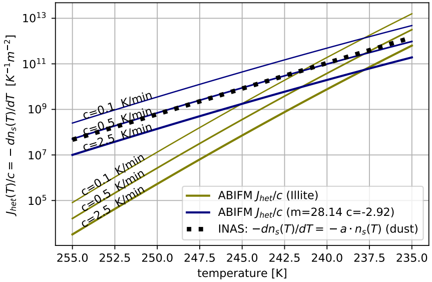

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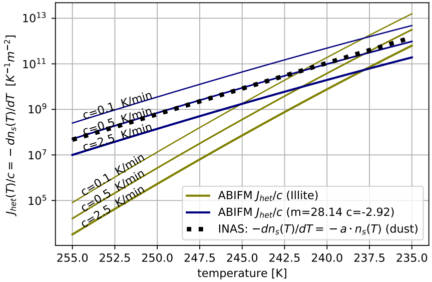

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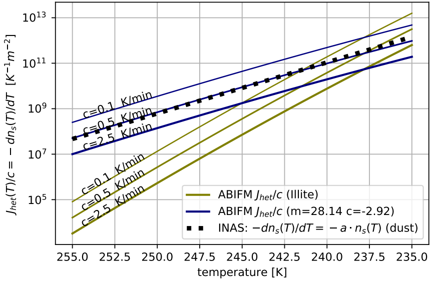

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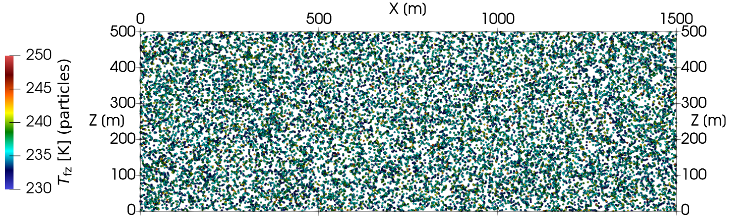
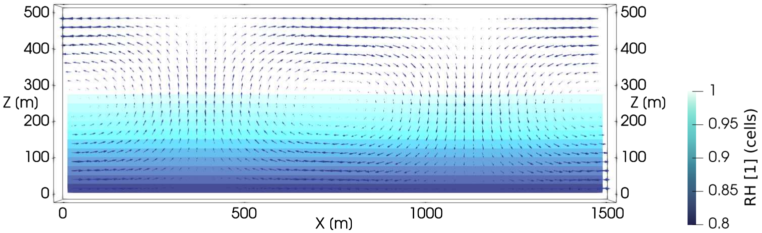
particle-based μ-physics + prescribed-flow test (aka KiD-2D)[a,b,c,d,e]

Lagrangian component (PySDM)



Eulerian component (PyMPDATA)



[a] concept: Gedzelman & Arnold '93

[b] stratiform: Morrison & Grabowski '07

[c] particle-based: Arabas et al. '15

[d] KiD-2D: github.com/BShipway/KiD

[e] here: SHEBA case (Fridlind et al. '12)

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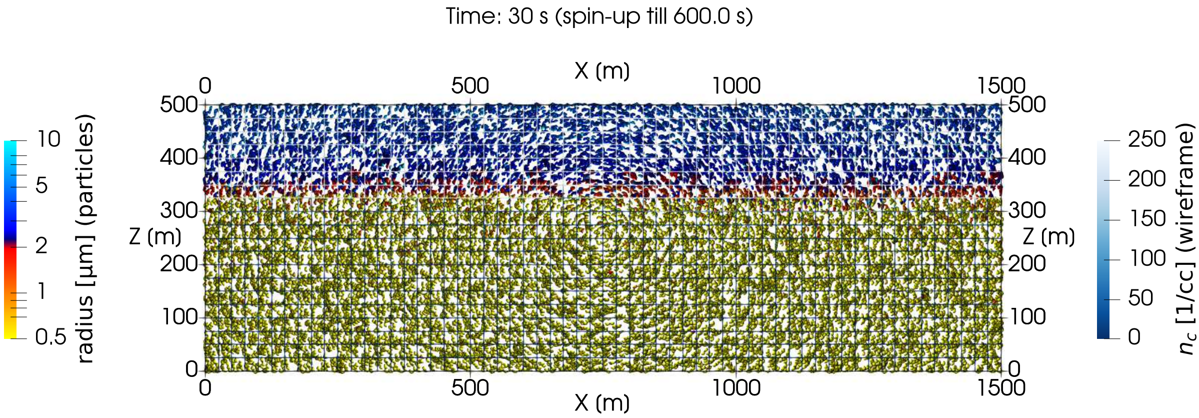

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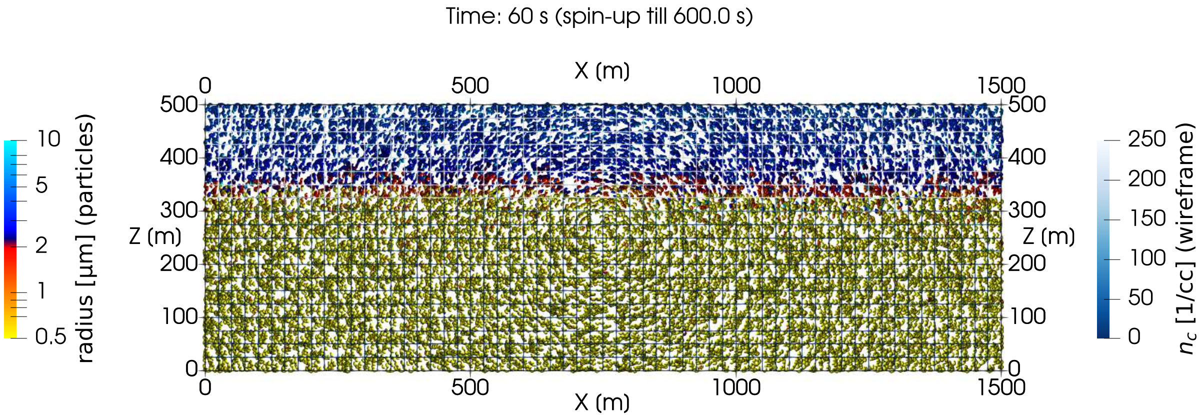

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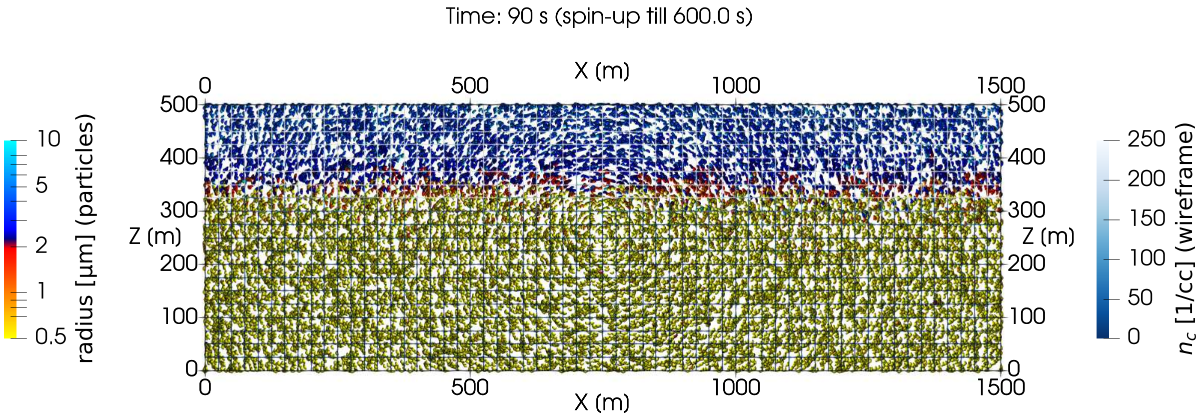

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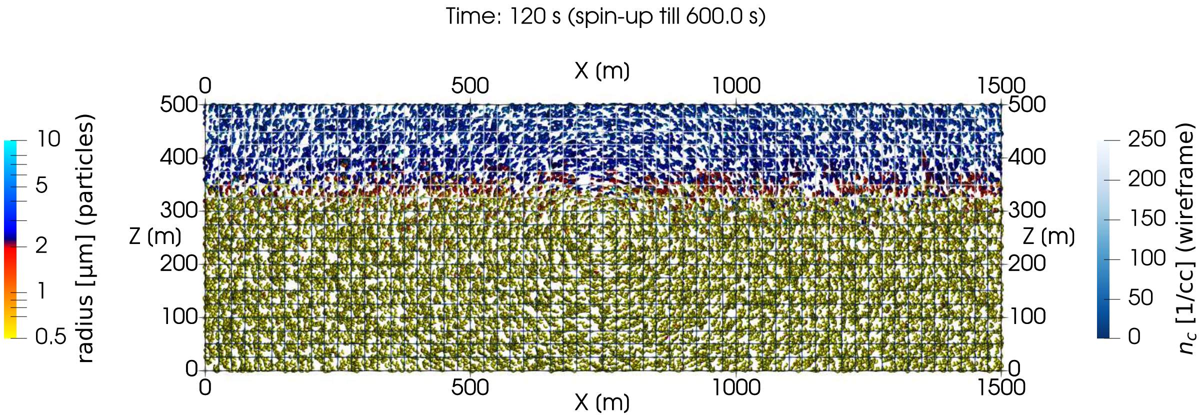

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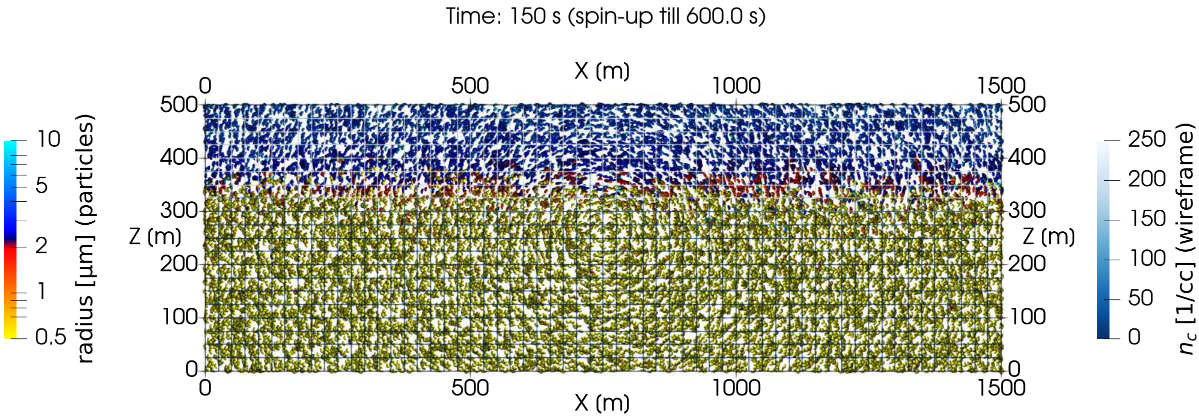

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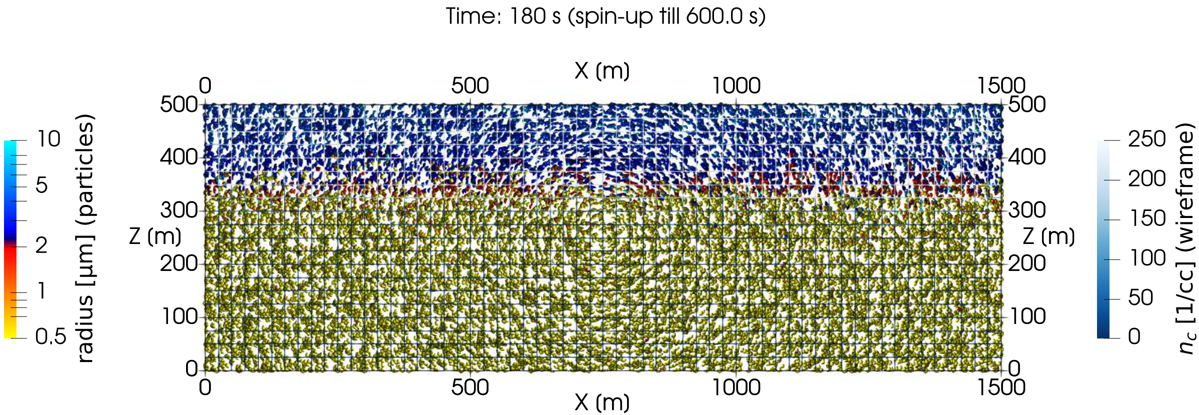

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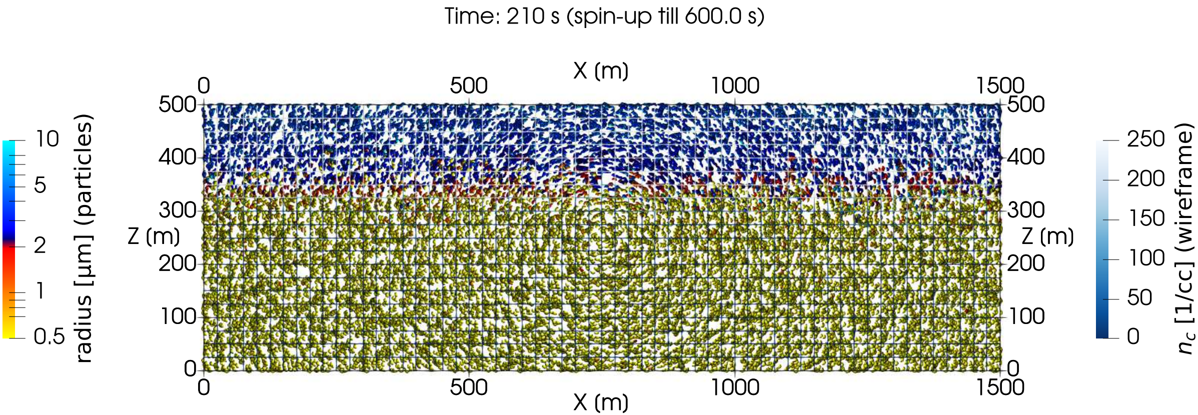

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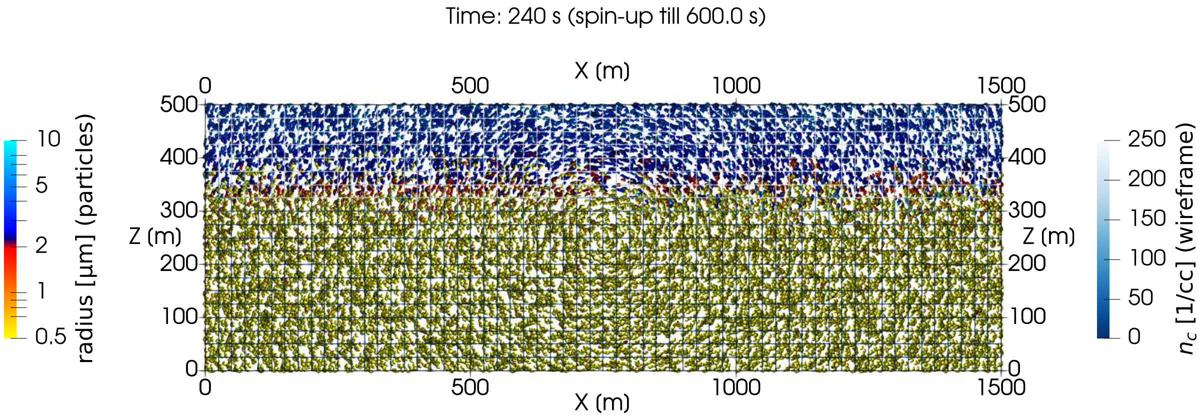

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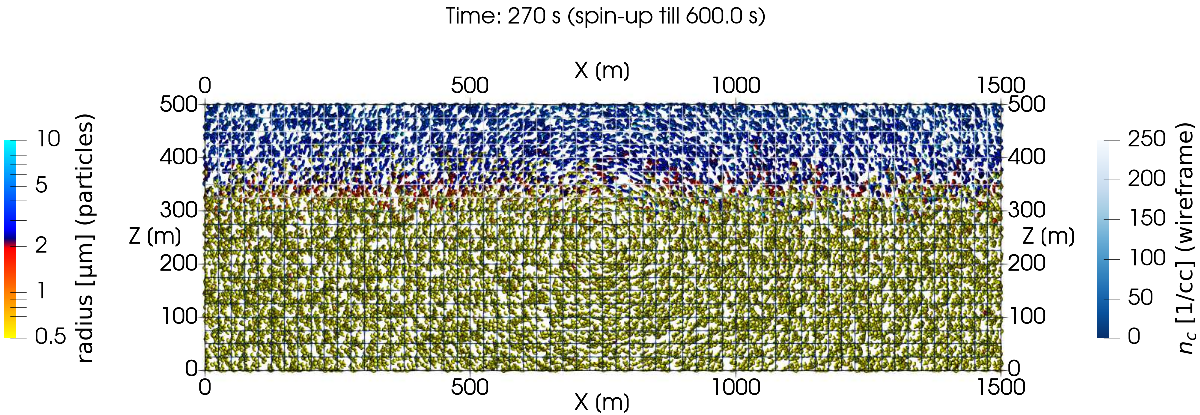

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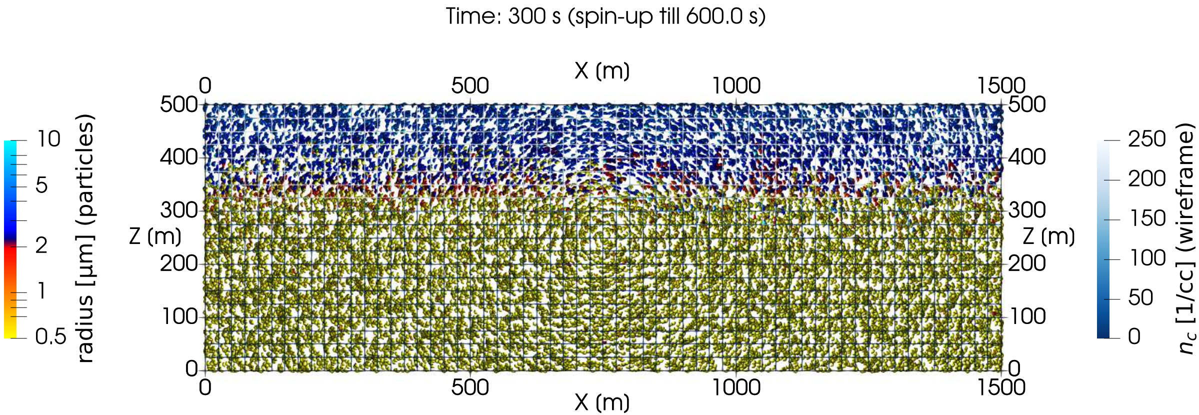

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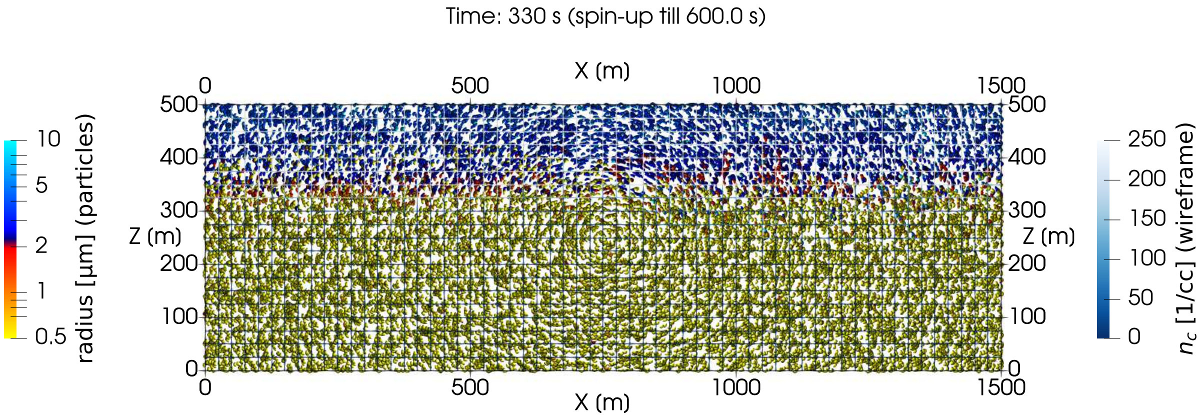

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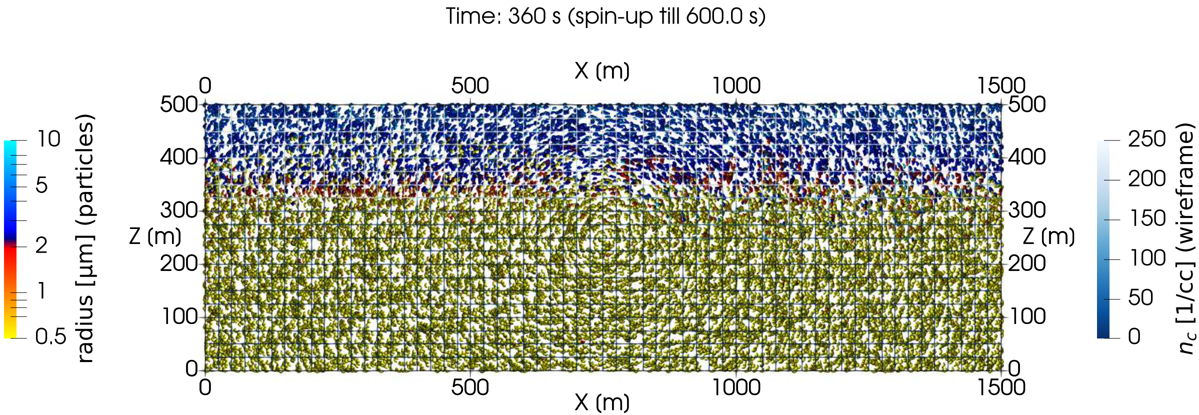

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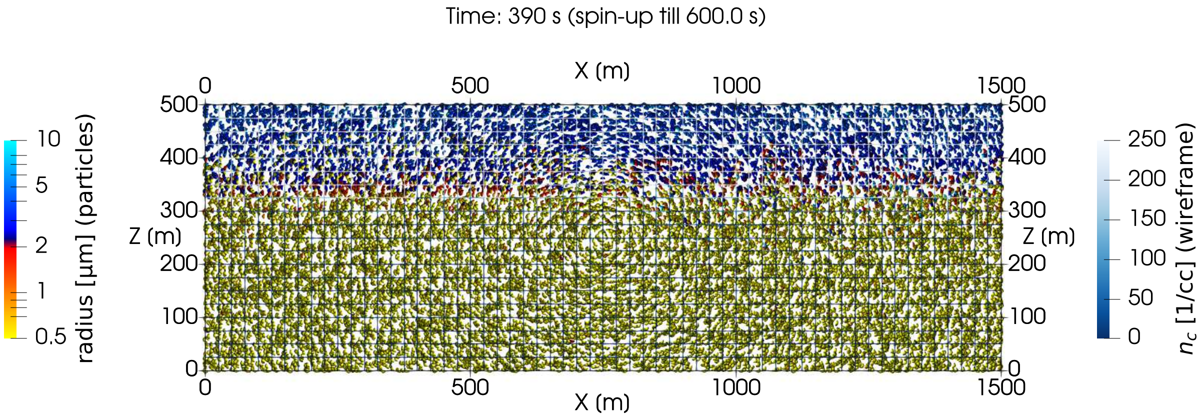

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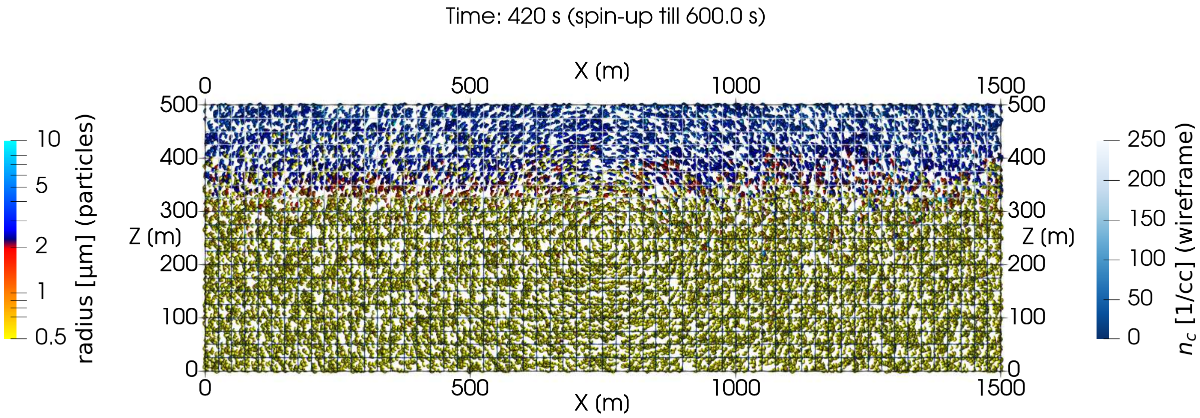

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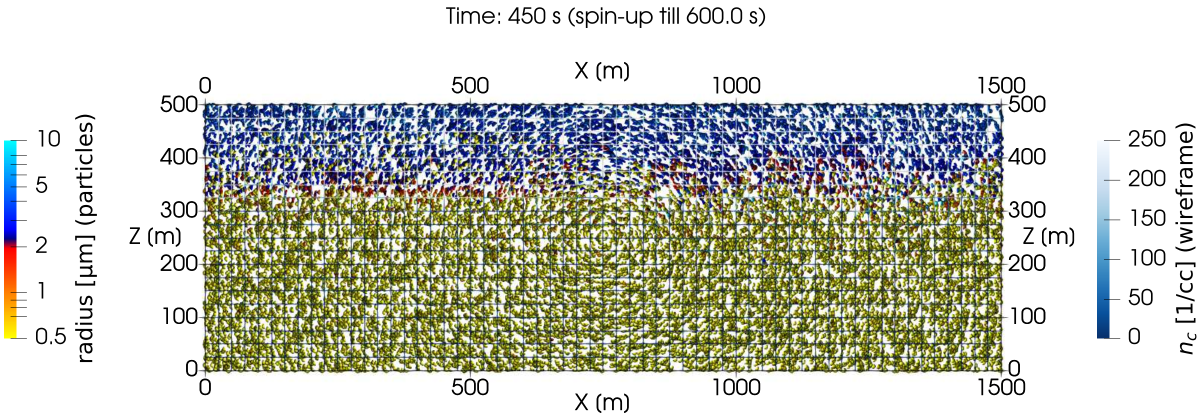

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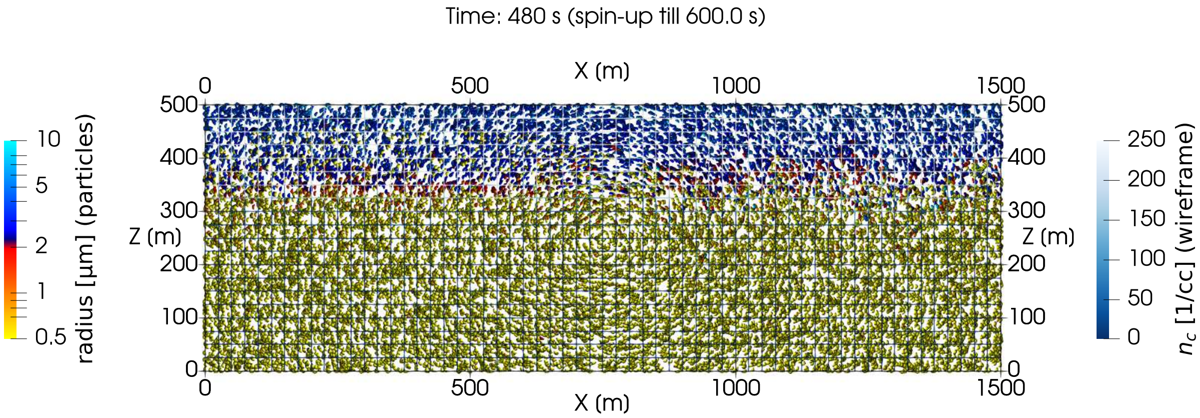

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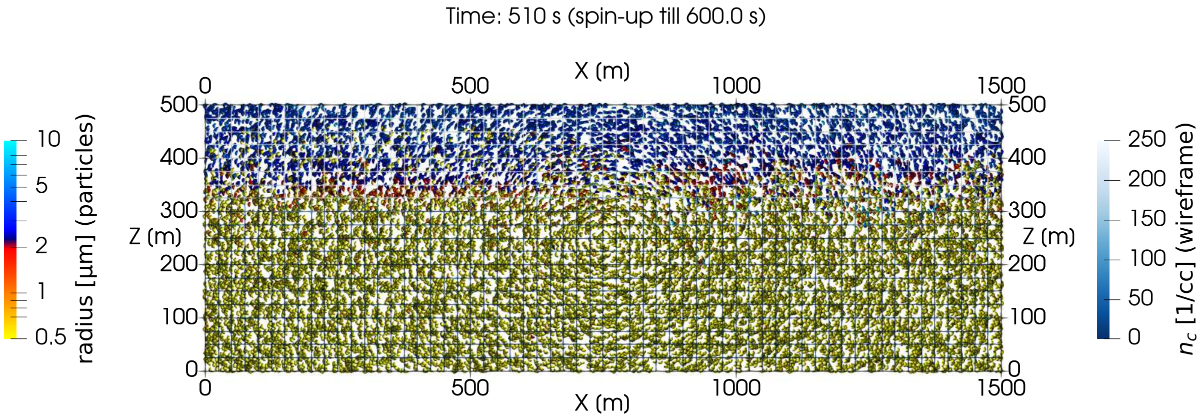

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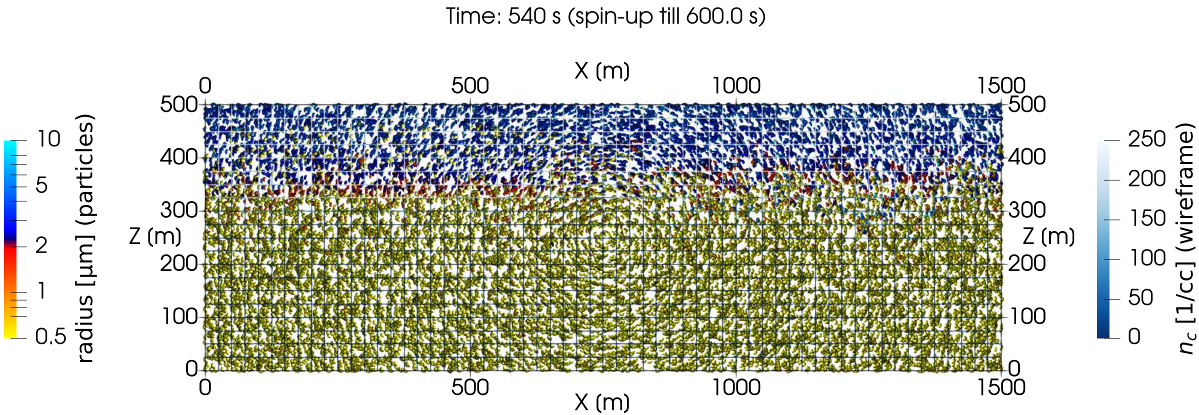

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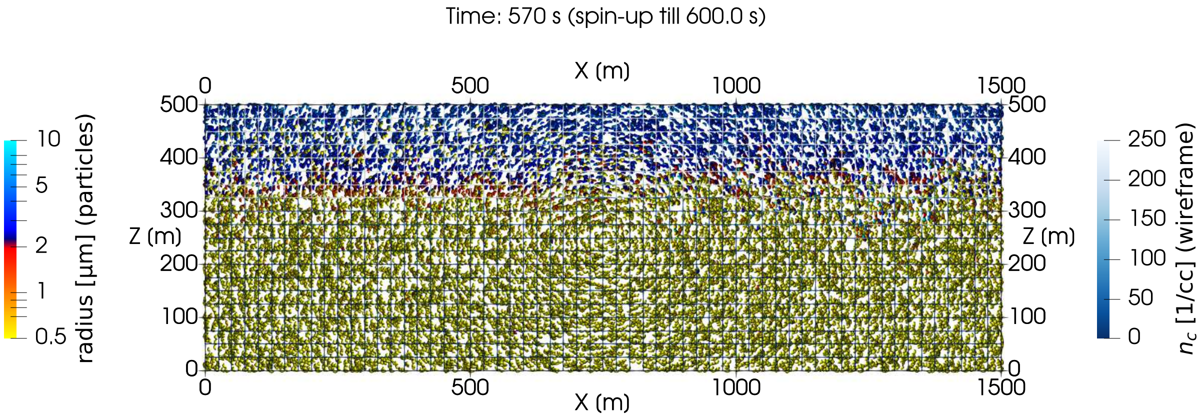

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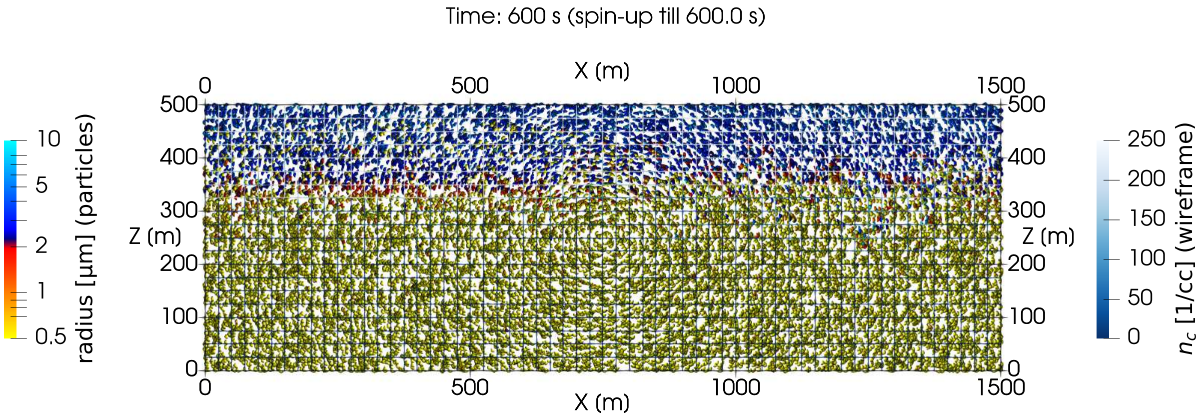

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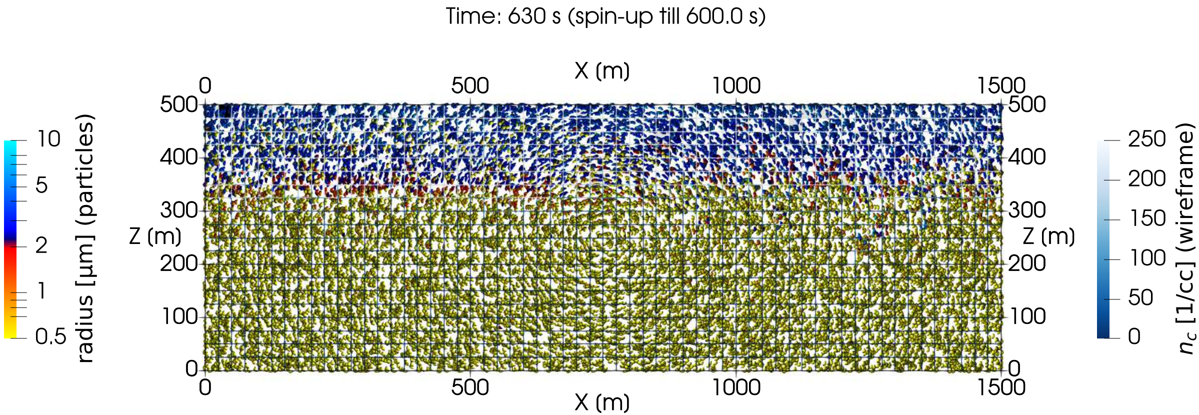

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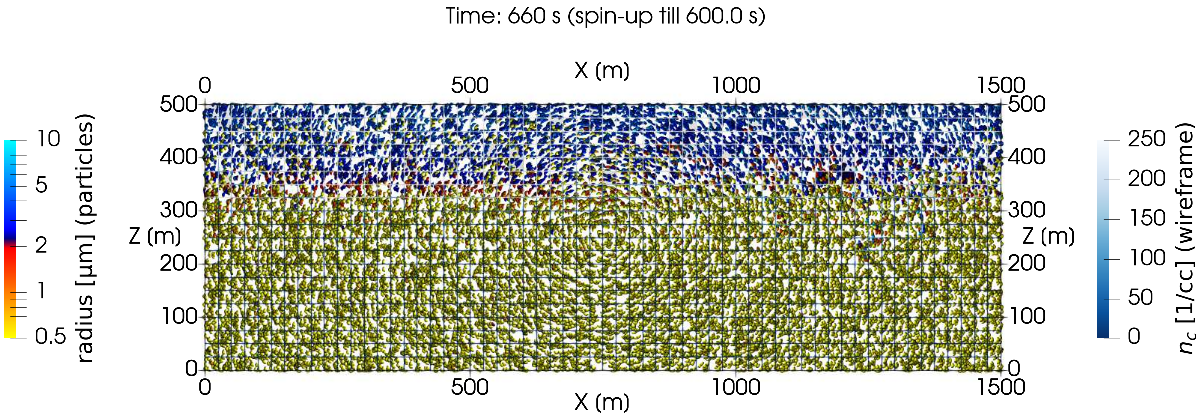

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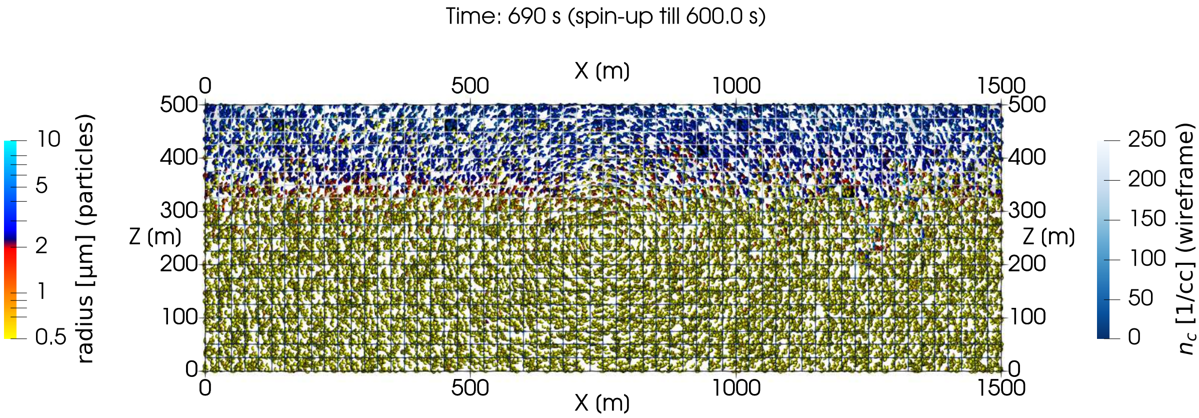

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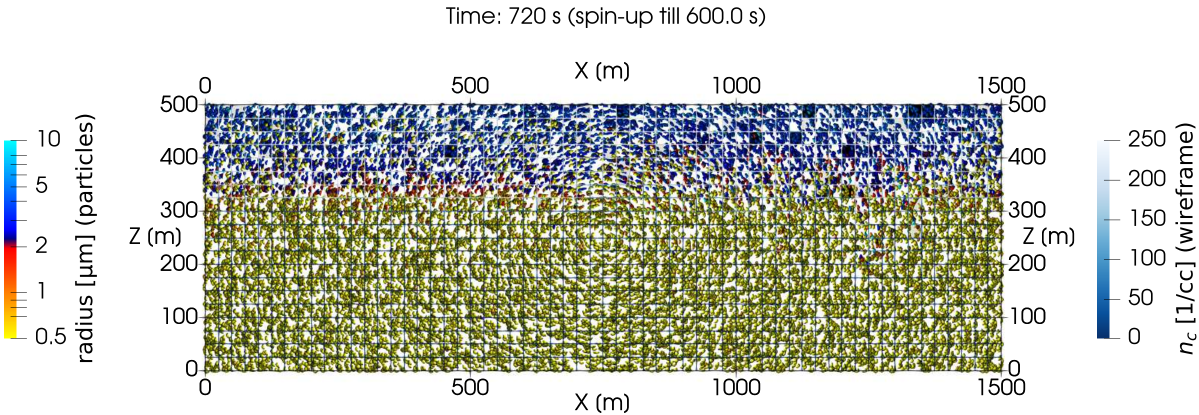

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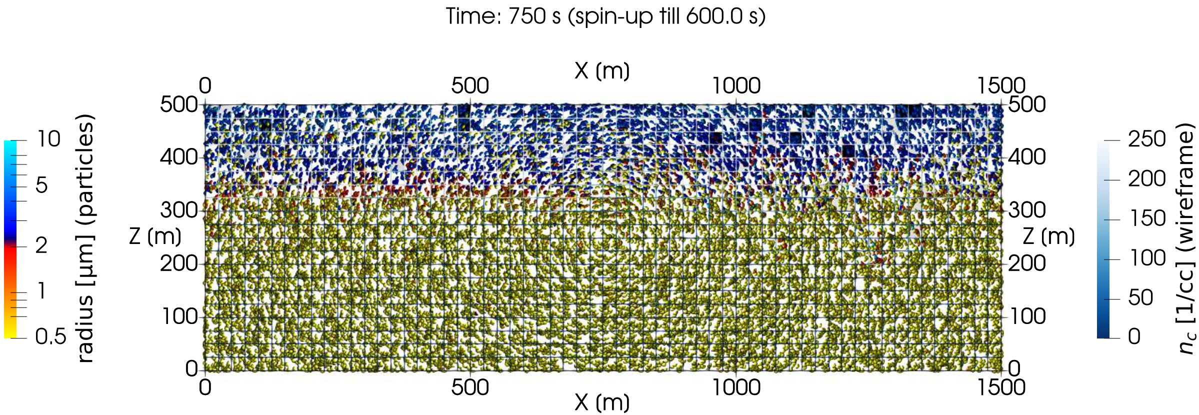

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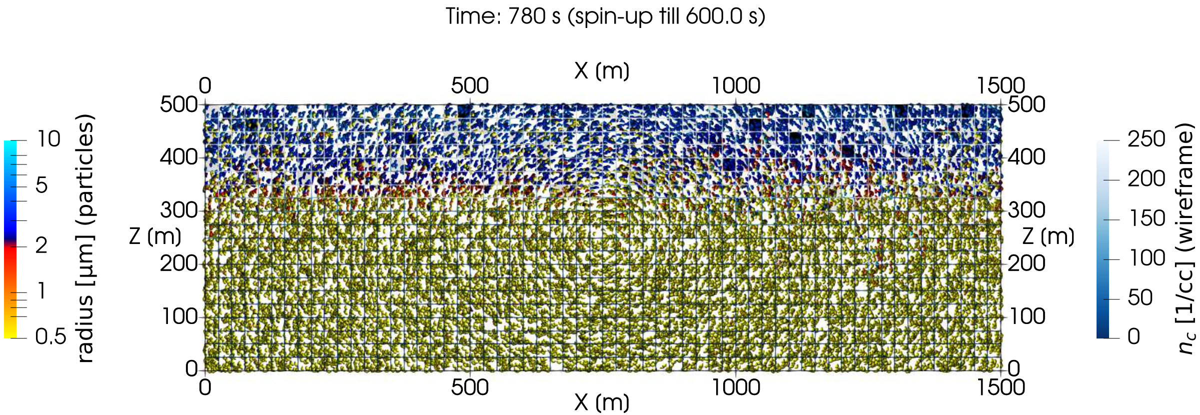

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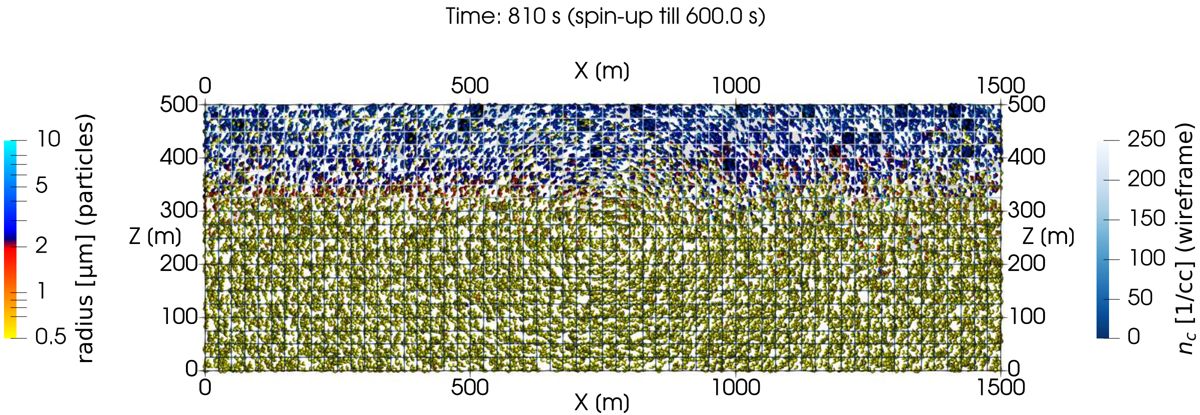

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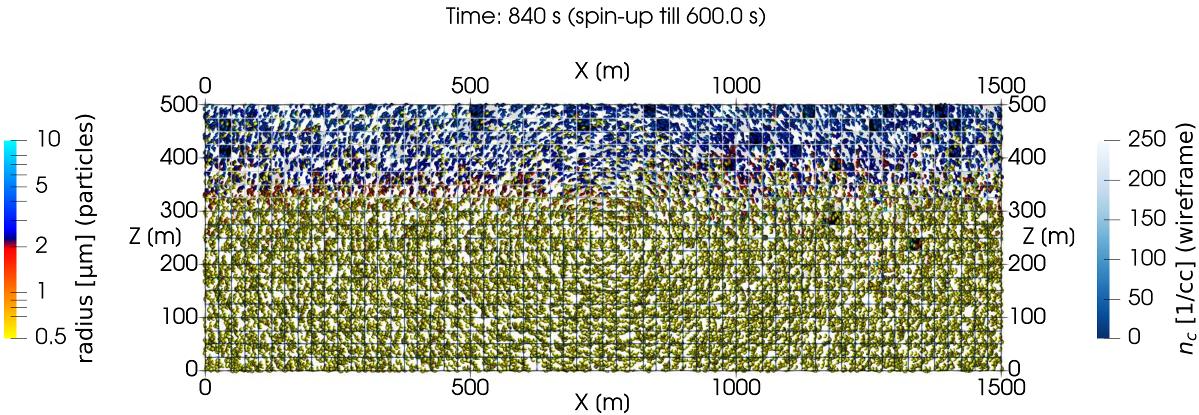
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based μ-physics + prescribed-flow test



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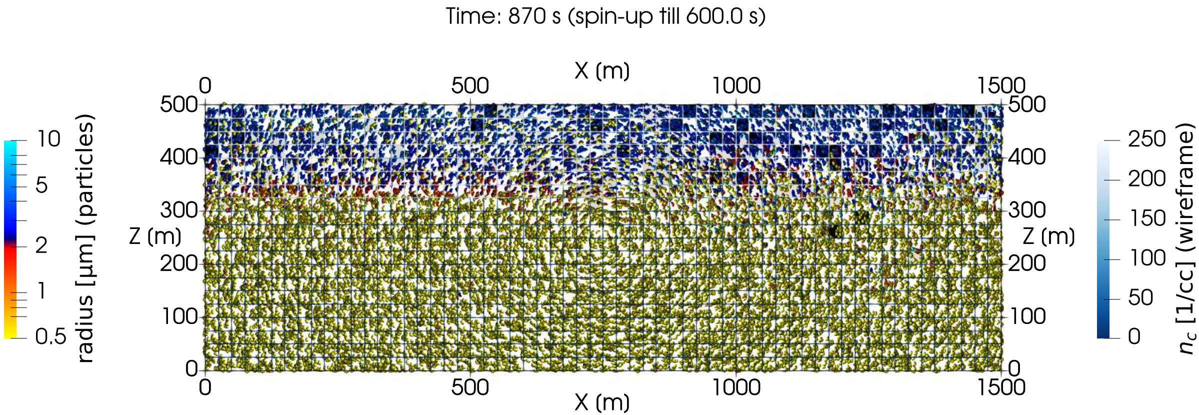

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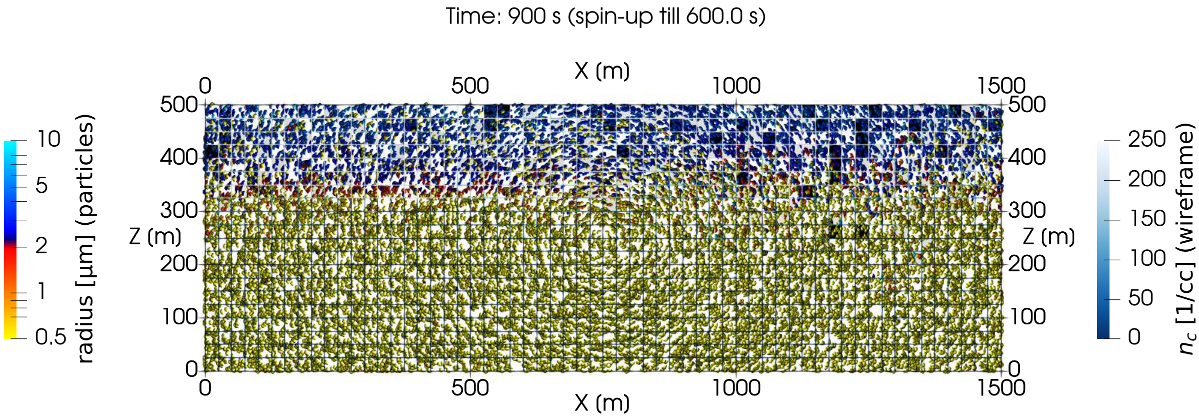

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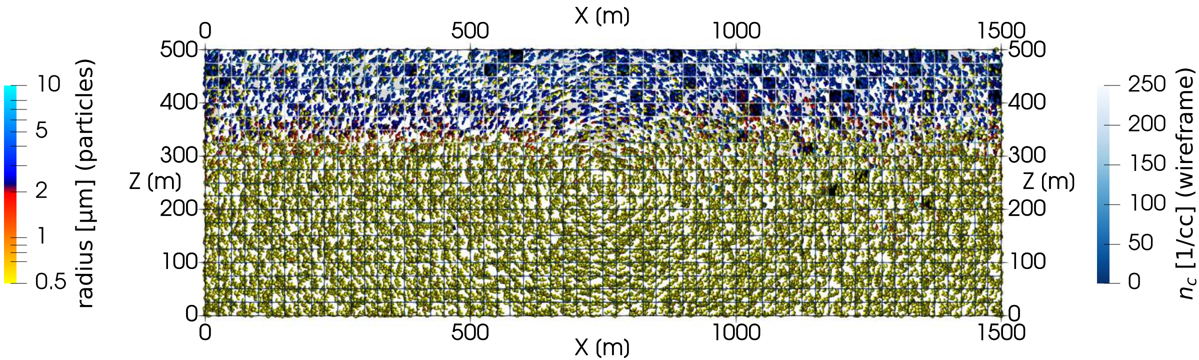
Time: 930 s (spin-up till 600.0 s)



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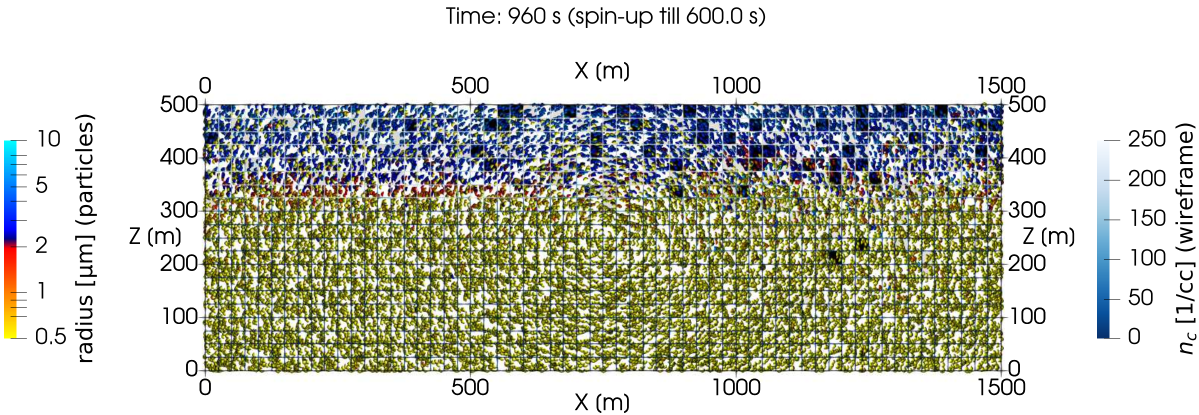

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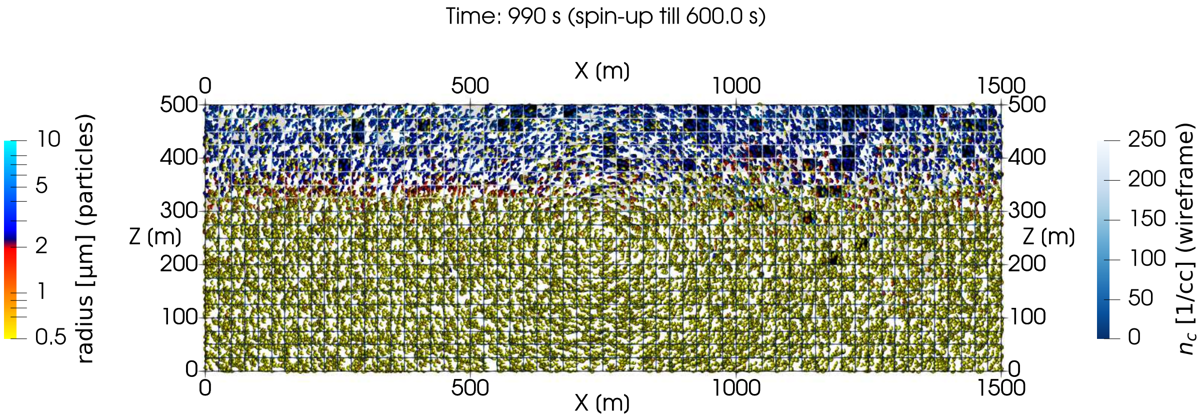

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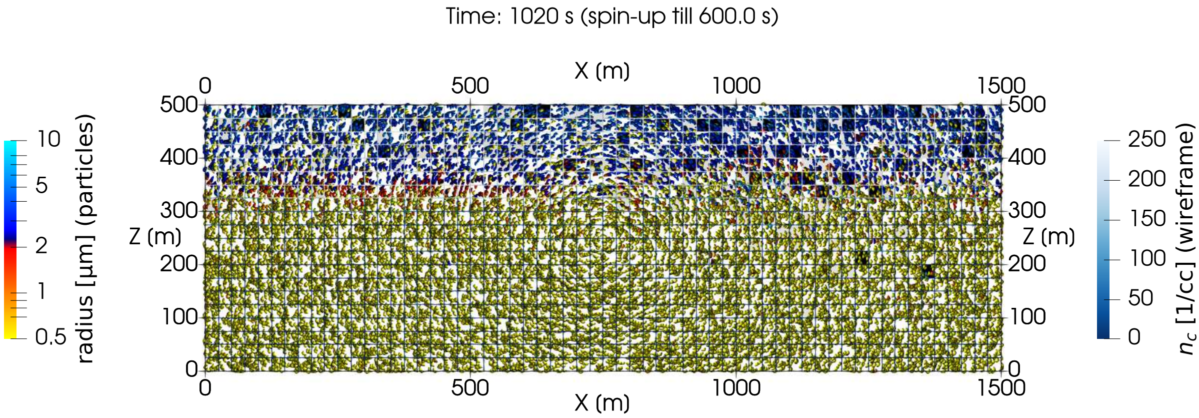

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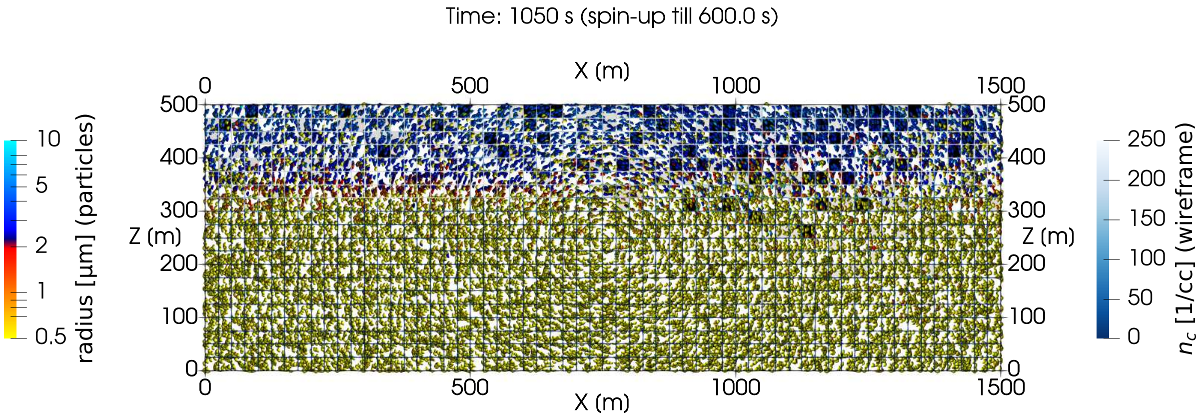

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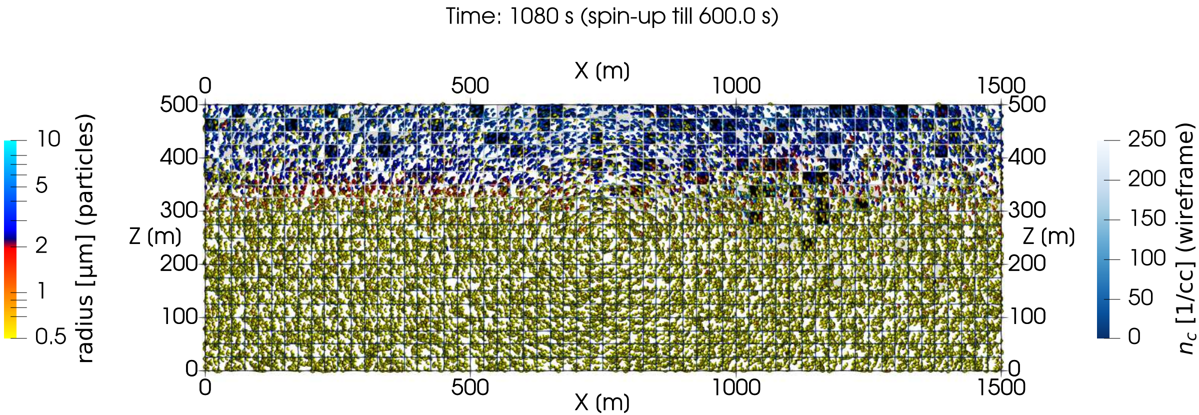

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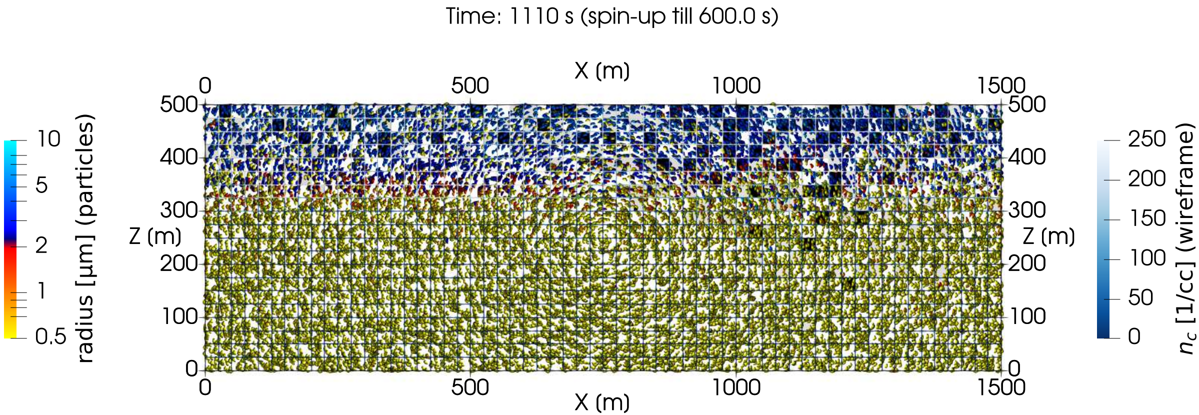

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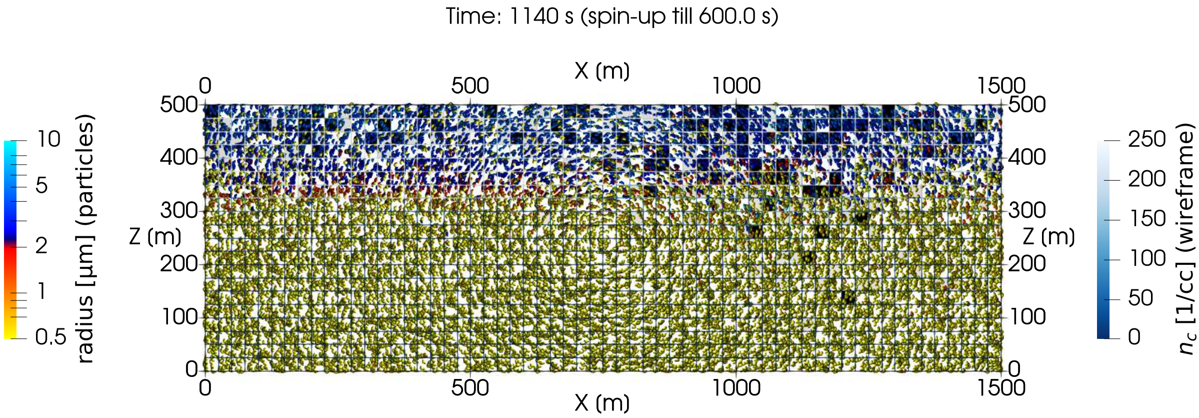

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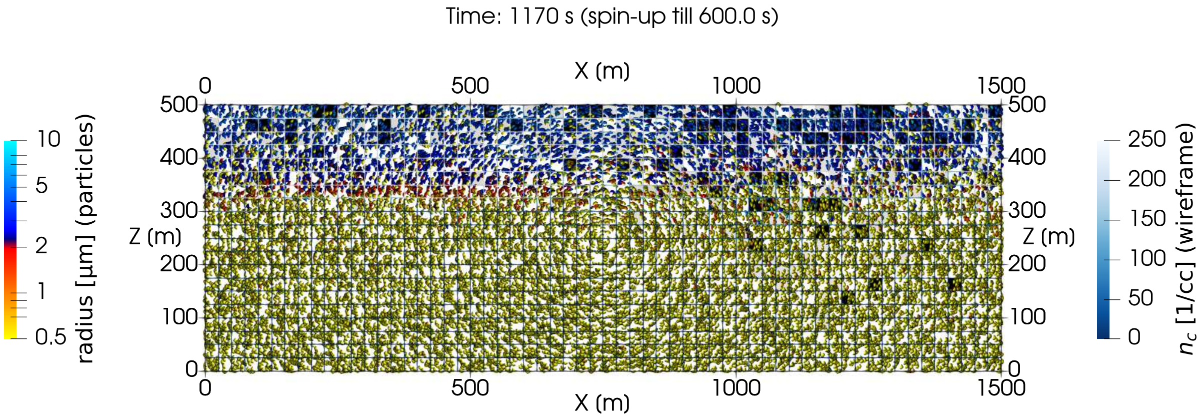

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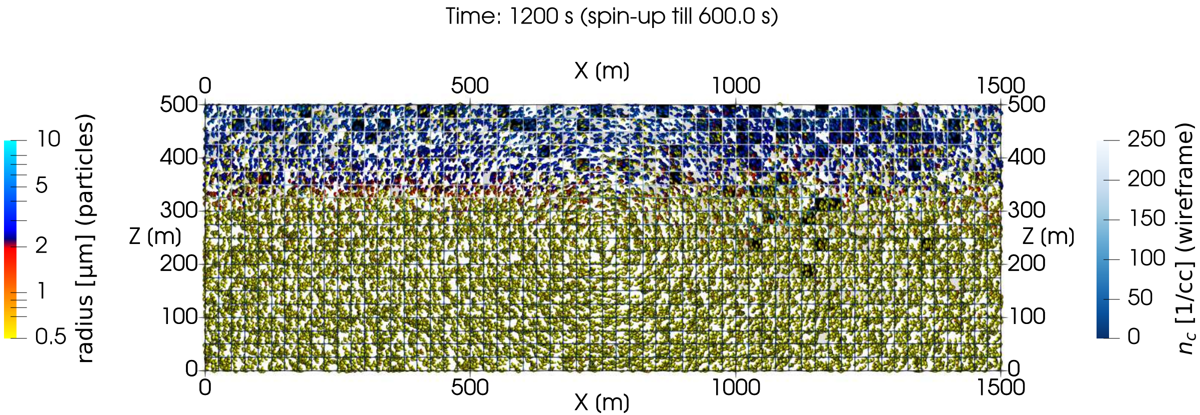

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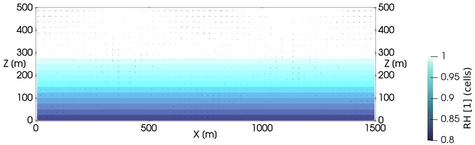
testing three flow regimes and two immersion freezing representations

$w_{max} \approx 1/3$ m/s



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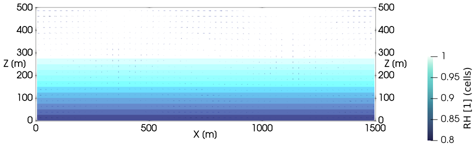

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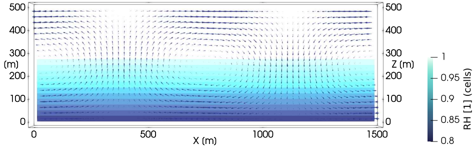

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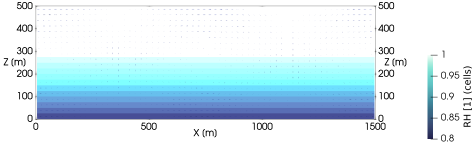

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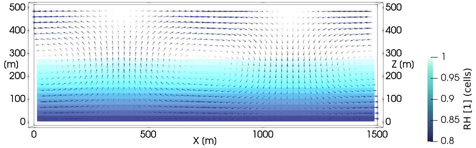

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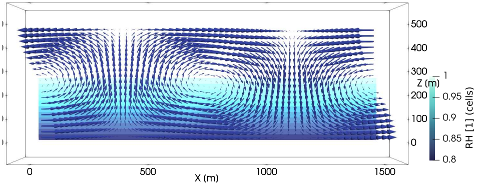

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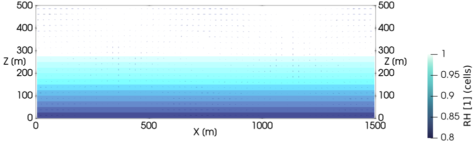

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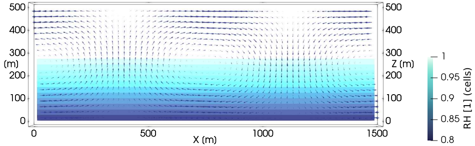

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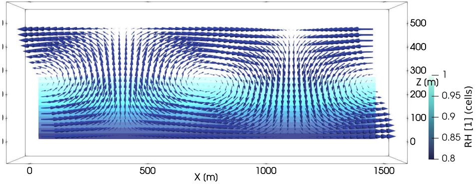
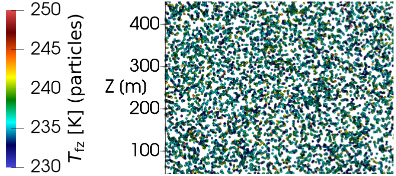
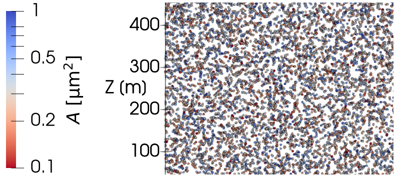


singular (INAS)



time-dependent (J_{het})



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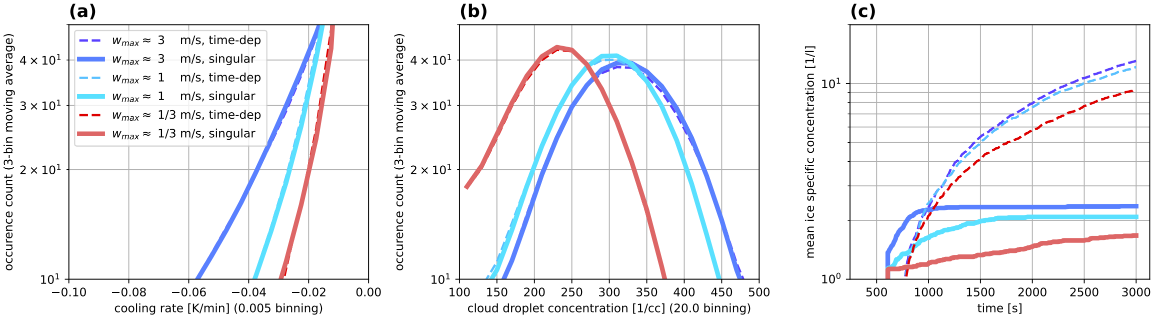

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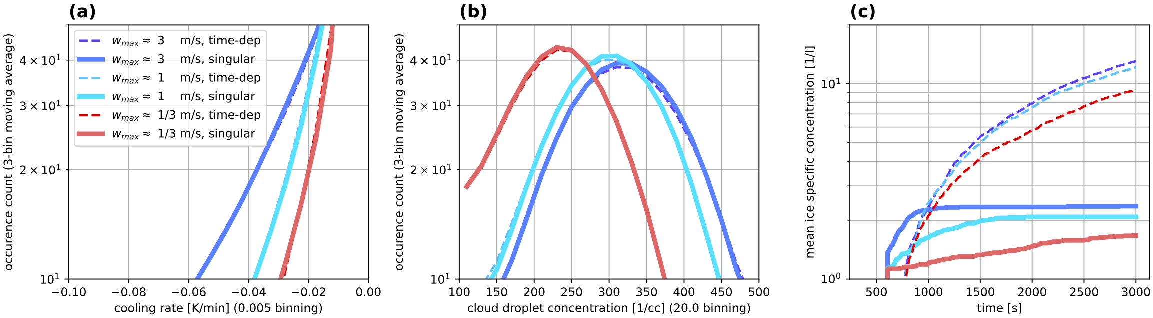

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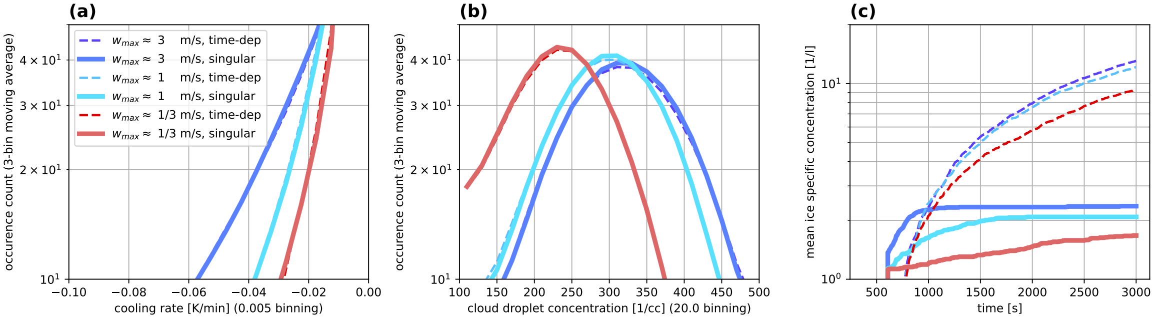

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- CPU time trade off: time dependent ca. 3-4 times costlier

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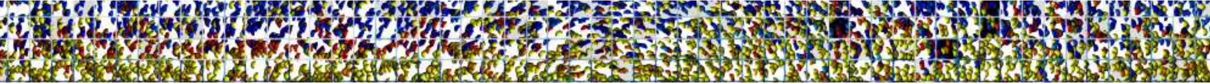

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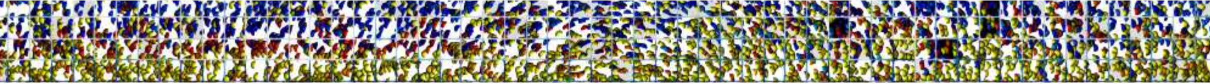

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ASR Atmospheric System Research
DOE ASR grant no. DE-SC0021034

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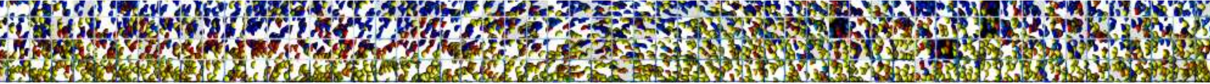

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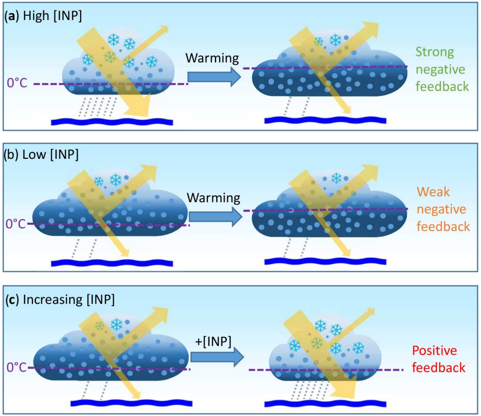
Thank you for the invitation!

Opinion: Cloud-phase climate feedback and the importance of ice-nucleating particles

Benjamin J. Murray[1], Kenneth S. Carslaw[1], and Paul R. Field[1,2]

Atmospheric Chemistry and Physics Open Access EGU
Atmos. Chem. Phys., 21, 665–679, 2021
https://doi.org/10.5194/acp-21-665-2021



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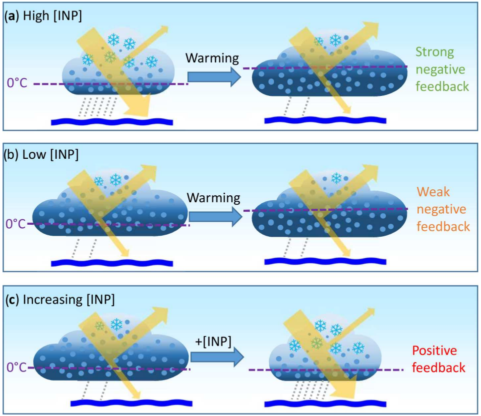

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INPs, cloud-phase feedback, modelling challenges

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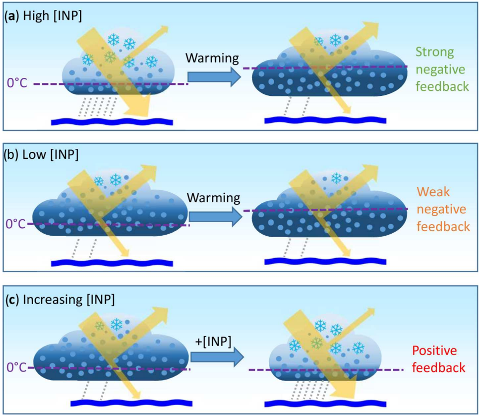

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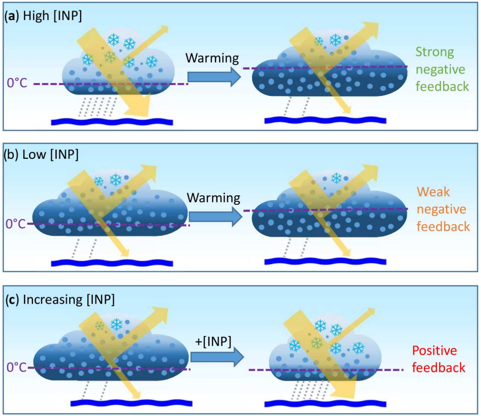

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- *"must also represent the INP removal processes, which in turn depend on a correct representation of the microphysics"*