Immersion freezing in particle-based aerosol-cloud microphysics models: comparing singular and time-dependent schemes

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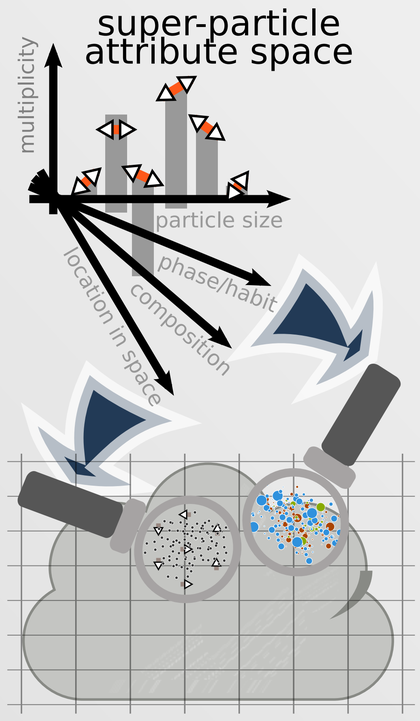
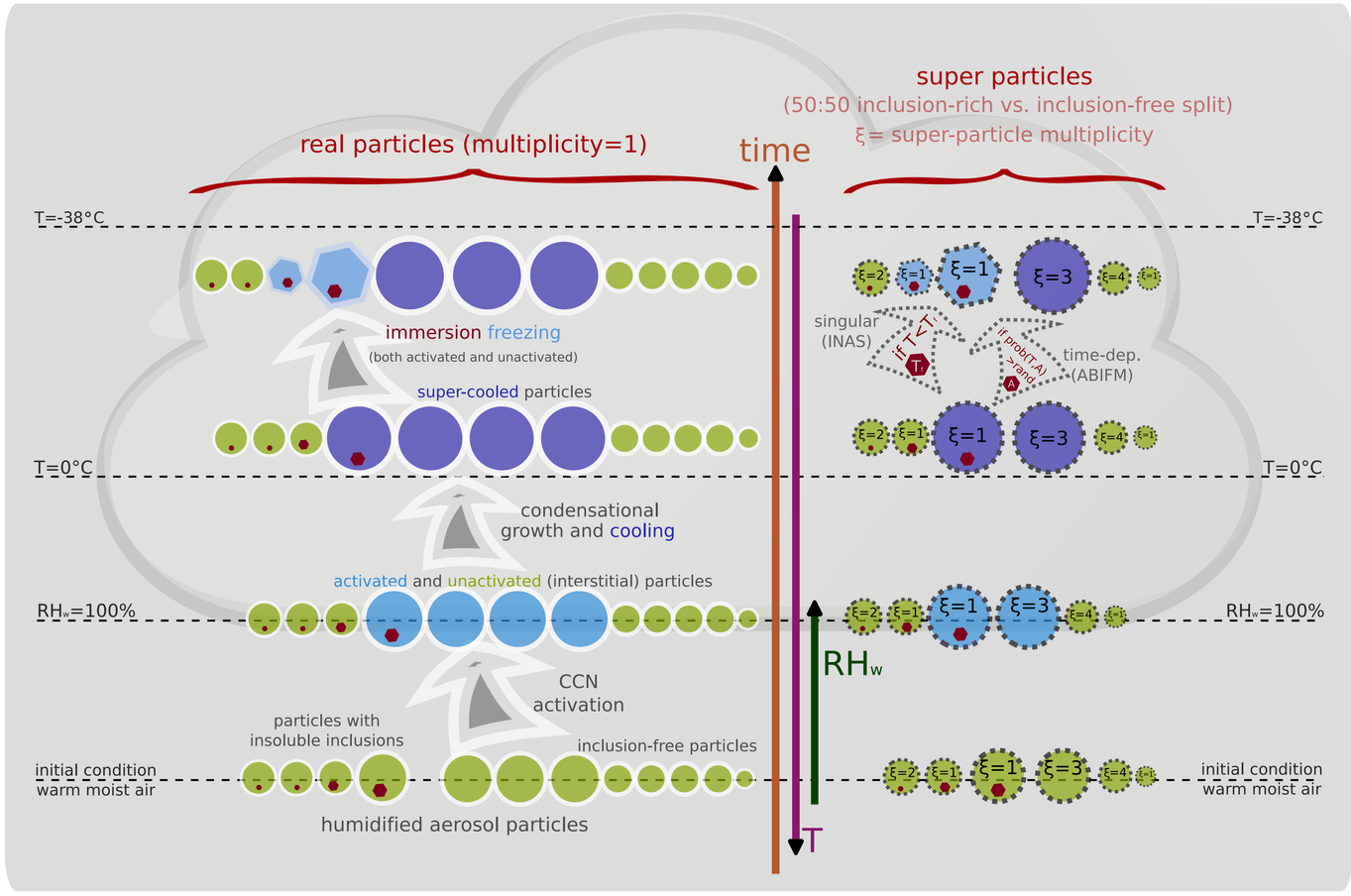
Key concepts

- aerosol particles, water droplets and ice crystals modelled with super-particles (each representing a large multiplicity of real-world particles)

- immersion freezing using stochastic Monte-Carlo schemes:
  - singular (INAS): as in Shima et al. 2020
  - time-dependent (ABIFM): as in Alpert & Knopf 2016

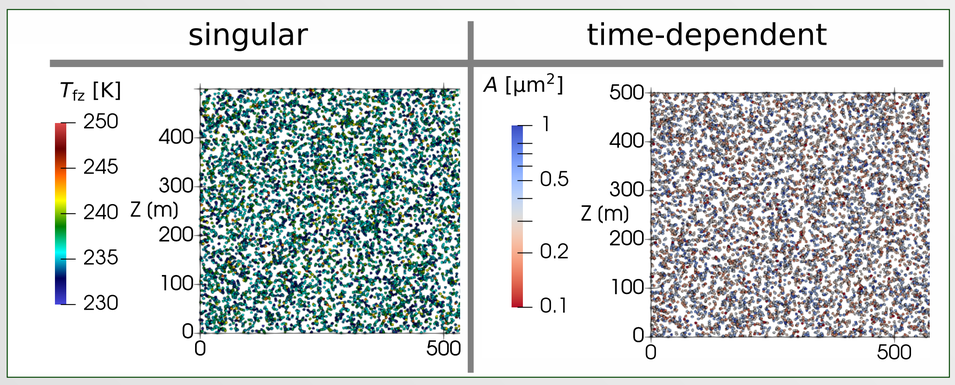
singular	time-dependent
freezing temperature as particle attribute, randomly sampled at t=0 from INAS-based probability density f.	immersed insoluble surface as particle attribute, used to evaluate freezing probab. in each step
instrumental cooling rate (AIDA chamber) embedded in INAS fits	actual cooling rate in the simulated environment used
temperature as the only variable triggering freezing (saturation assumed)	freezing can be triggered employing dependence on supersaturation

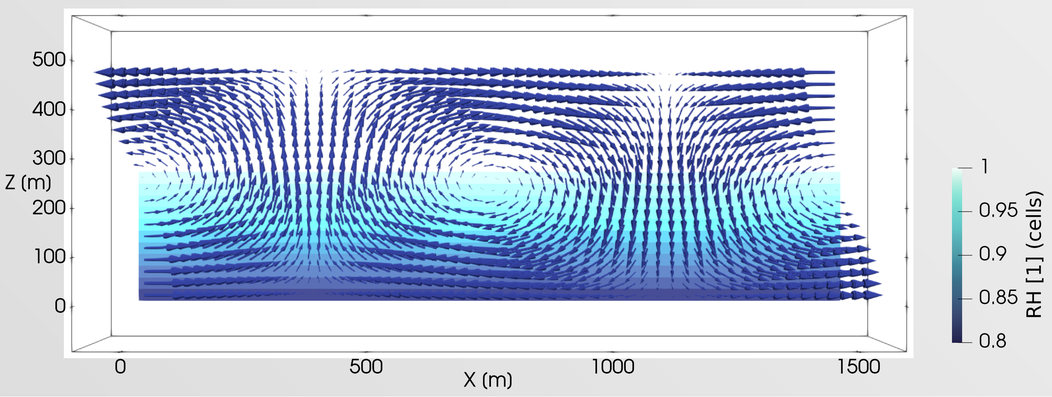




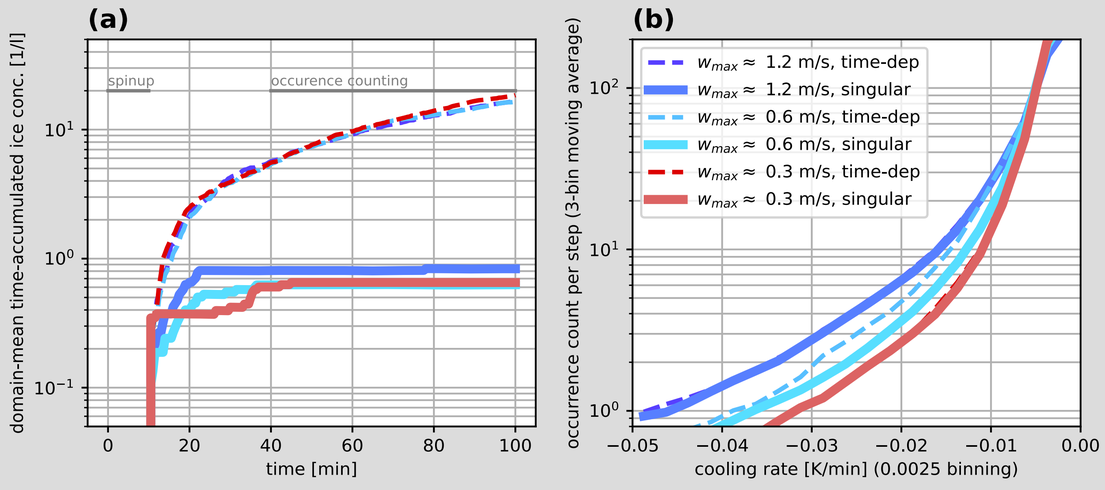
2D flow-coupled simulations: setup

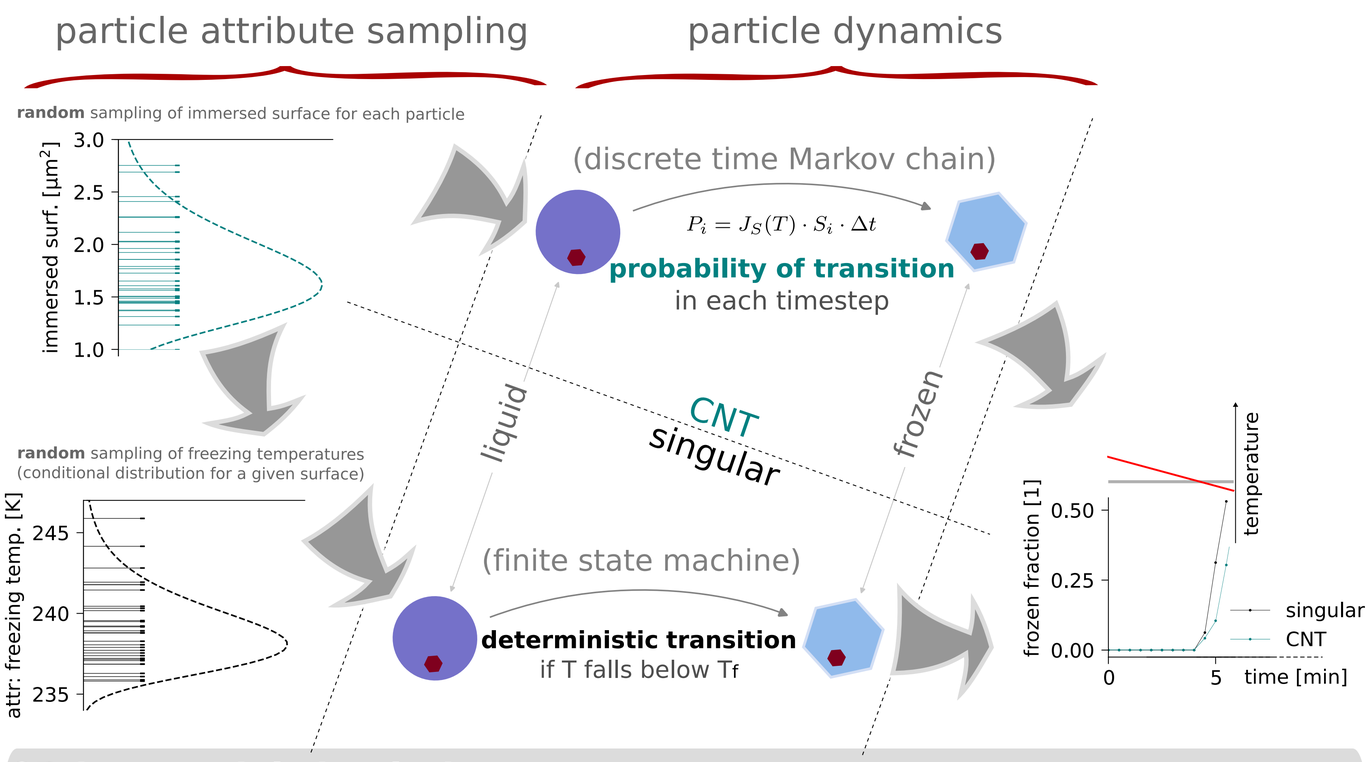
- prescribed-flow setup (Morrison & Grabowski '07)
- stratiform cloud deck, periodic boundary conditions
- 16 inclusion-rich + 16 inclusion-free super-particles per 25 m×25 m cell (on average, random positions at t=0)
- Niemand et al. 2012 AIDA-based dust params for INAS and ABIFM



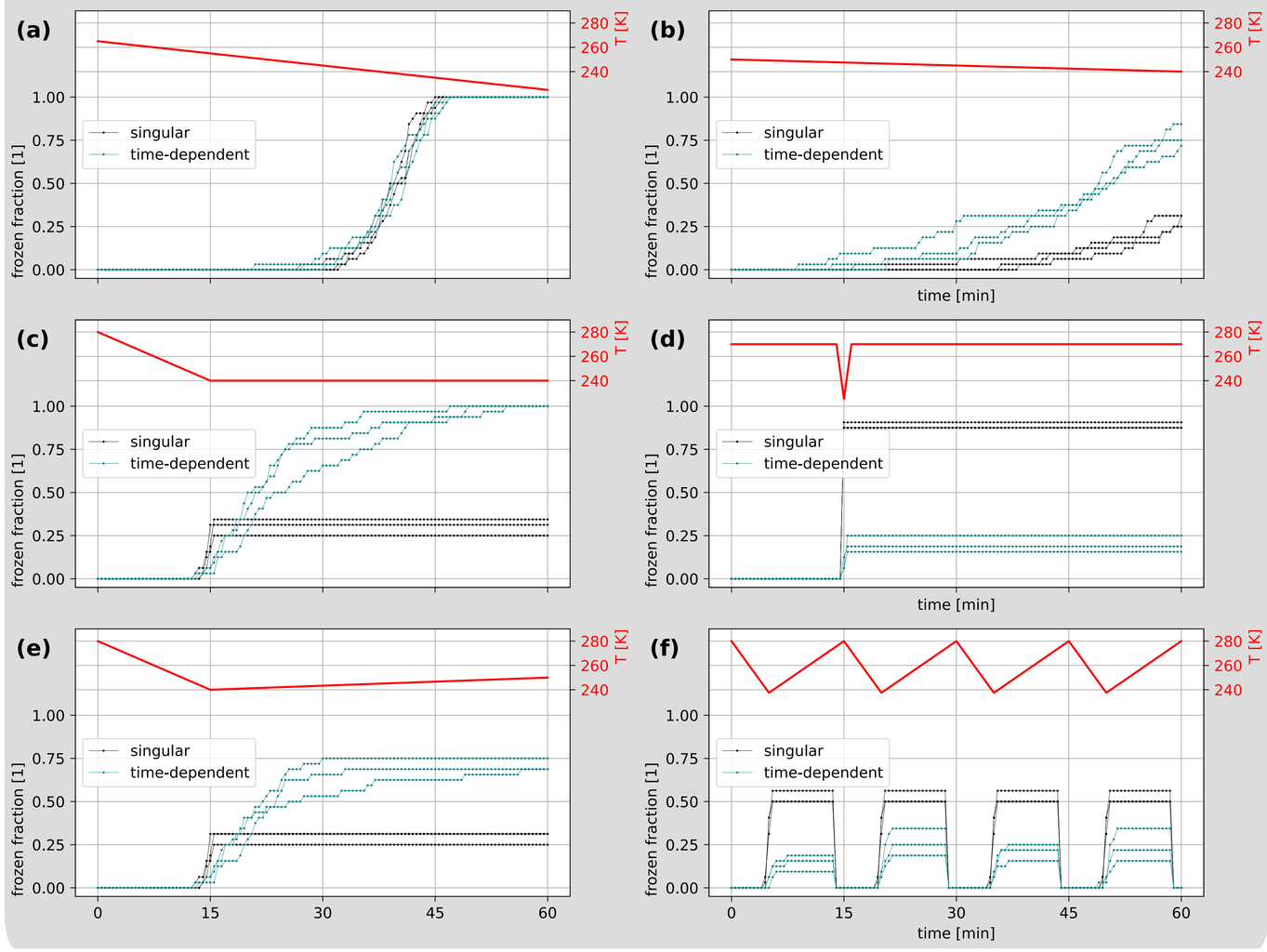


2D flow-coupled simulations: domain-wide statistics





0D box-model simulations



Key takeaways:

- both singular and time-dependent immersion freezing models cast in particle-based and probabilistic simulation framework
- models tested using 2D prescribed-flow simulation setup
- ice concentrations obtained with time-dependent model are robust to flow regime, order of magnitude higher than from singular scheme, and do not feature an a priori bound
- particle-based schemes by-design resolve INP-reservoir dynamics

References:
- probabilistic singular INAS-based scheme: **Shima et al. 2020**, doi:10.5194/gmd-13-4107-2020
- probabilistic time-dep. ABIFM-based scheme: **Alpert & Knopf 2016**, doi:10.5194/acp-16-2083-2016
- 2D kinematic modelling framework: **Morrison & Grabowski 2007**, doi:0.1175/JAS3980
- mineral dust parameters from AIDA measurements: **Niemand et al. 2012**, doi:10.1175/JAS-D-11-0249.1
- PySDM microphysics package extended & used herein: **Bartman et al. 2022**, doi:10.21105/joss.03219

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