

Immersion freezing in particle-based aerosol-cloud microphysics: a probabilistic perspective on singular and time-dependent models

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stonybrook.edu

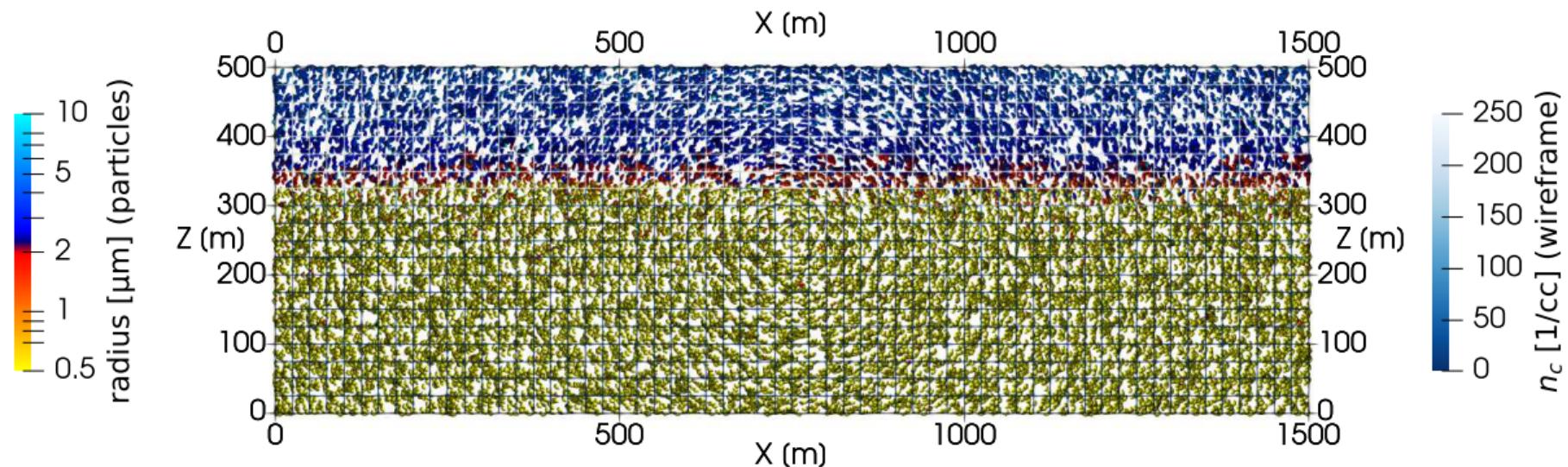


2023 ARM/ASR Joint User Facility/PI Meeting, Rockville, MD

Breakout session: Primary and secondary ice production and impacts on mixed-phase and ice clouds

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

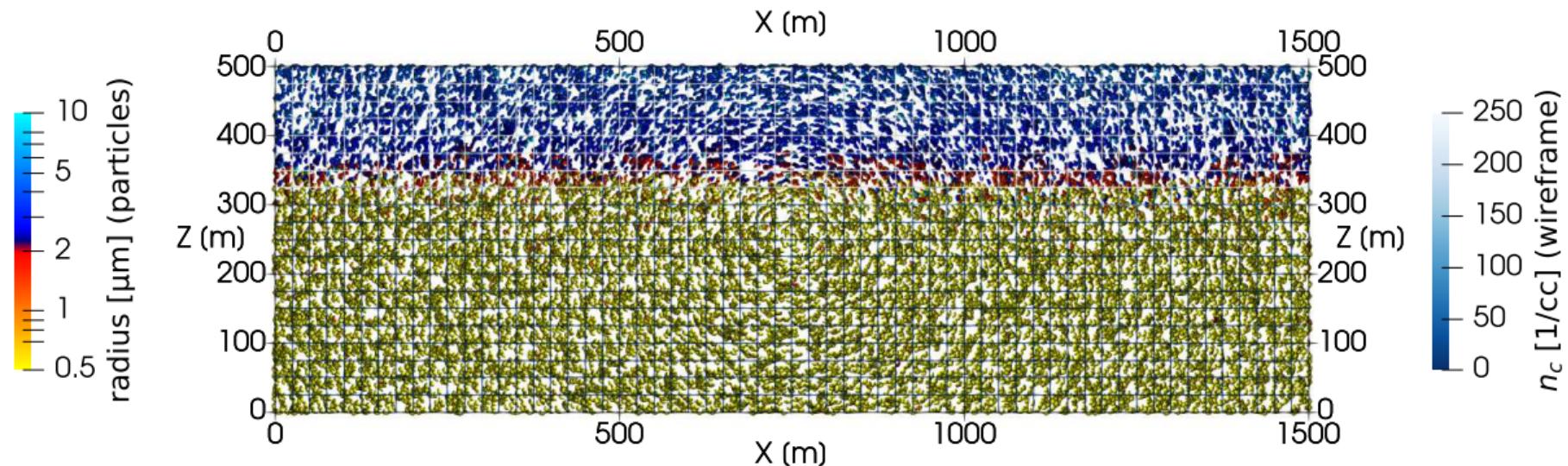
Time: 30 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \text{ } \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

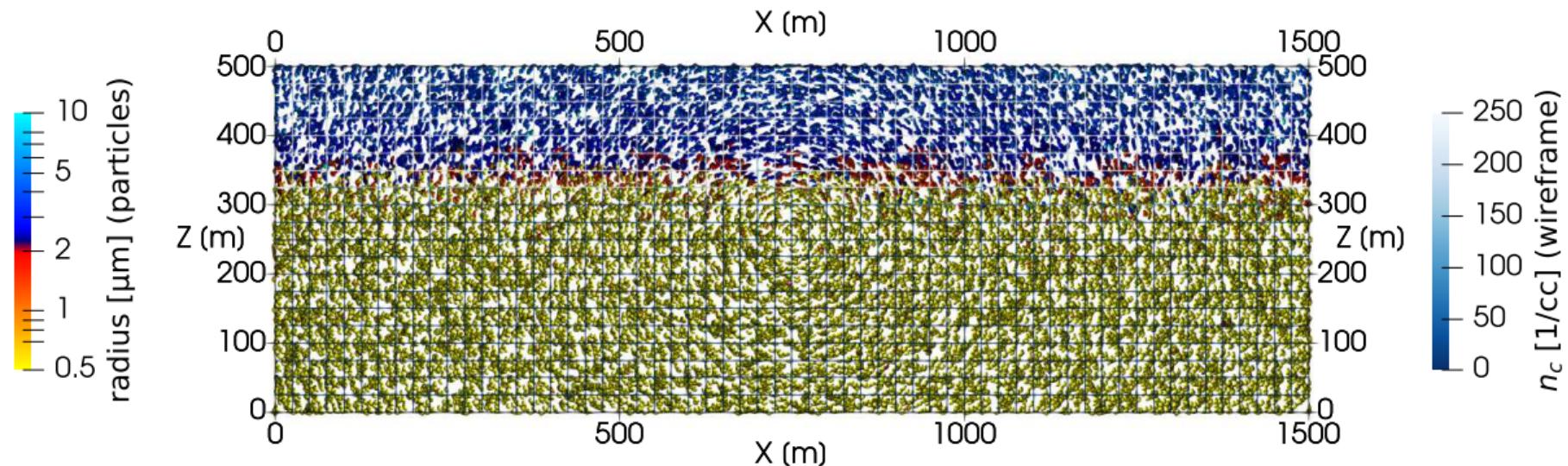
Time: 60 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \text{ } \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

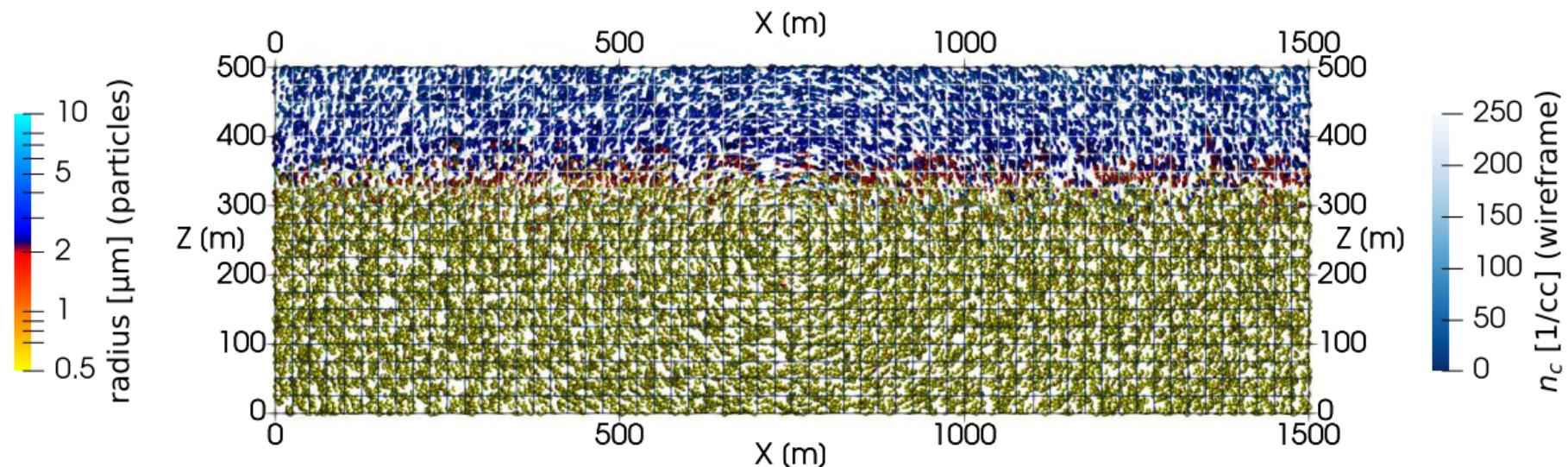
Time: 90 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

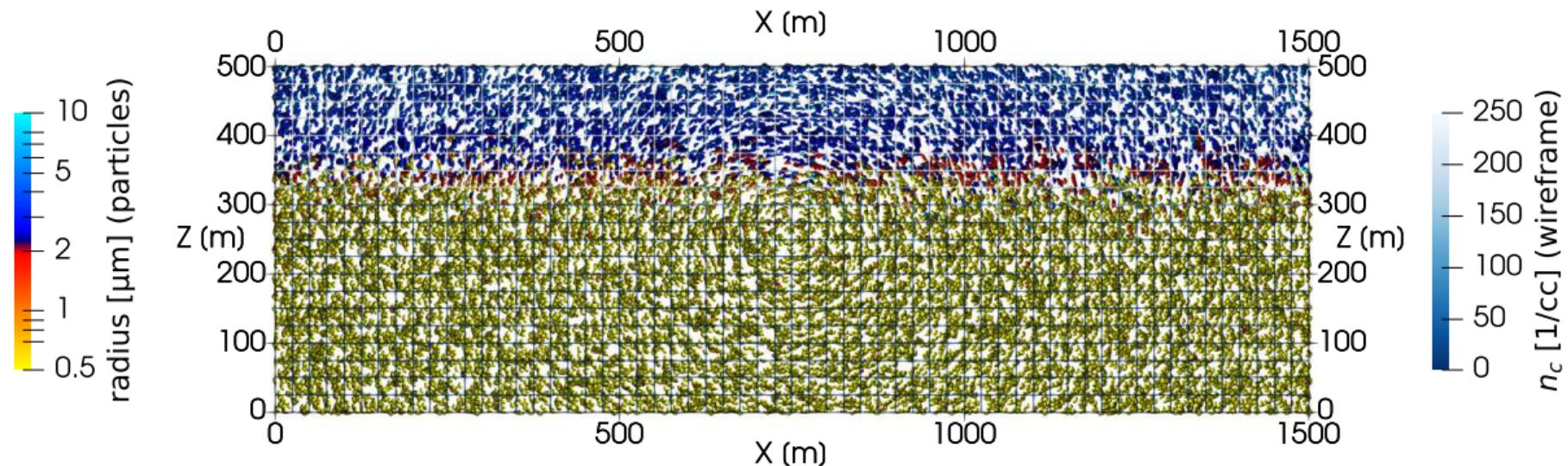
Time: 120 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

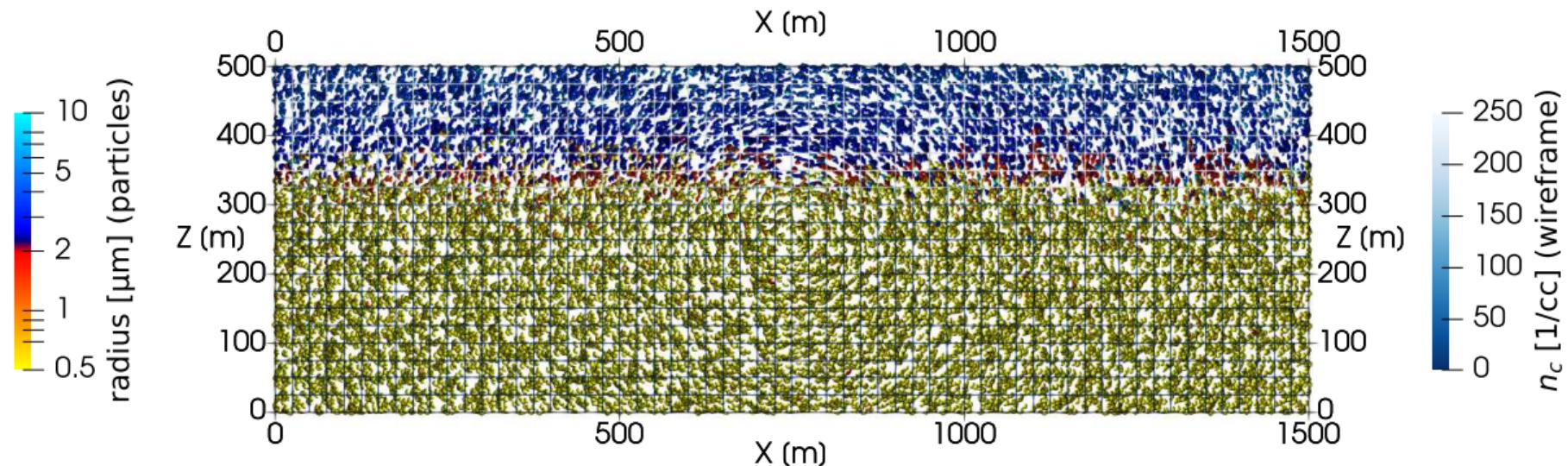
Time: 150 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \text{ } \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

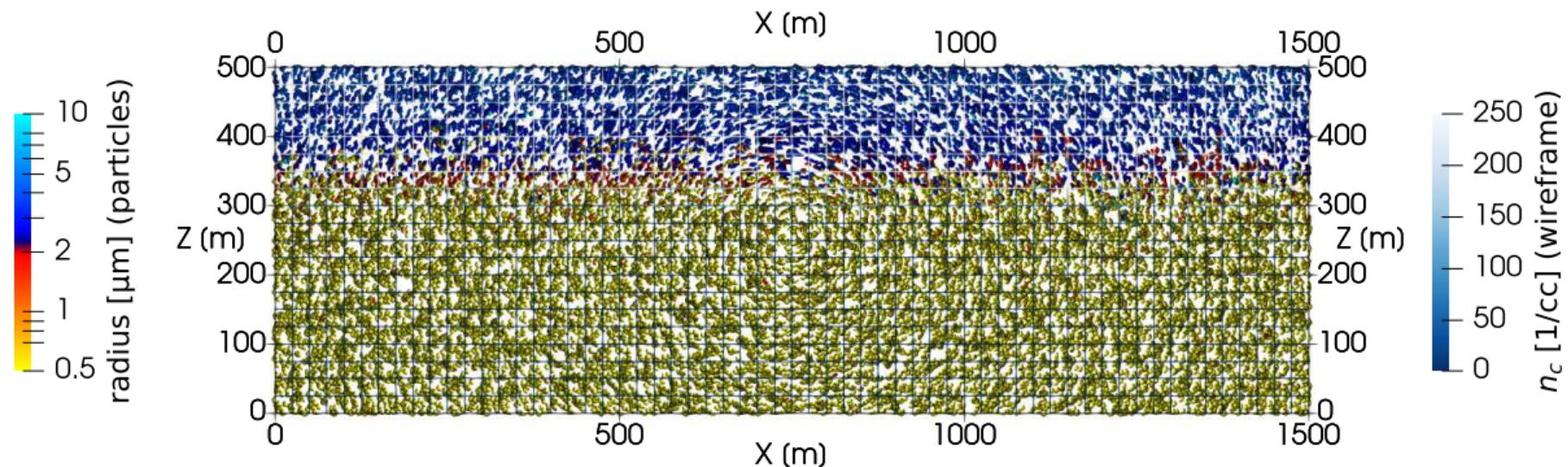
Time: 180 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

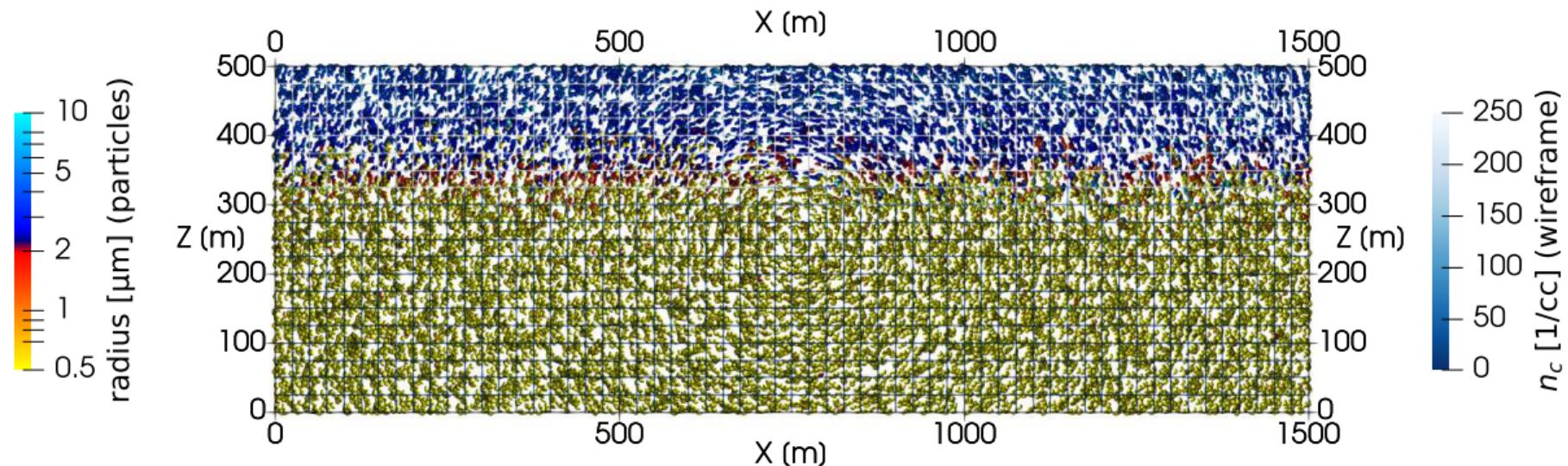
Time: 210 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \text{ } \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

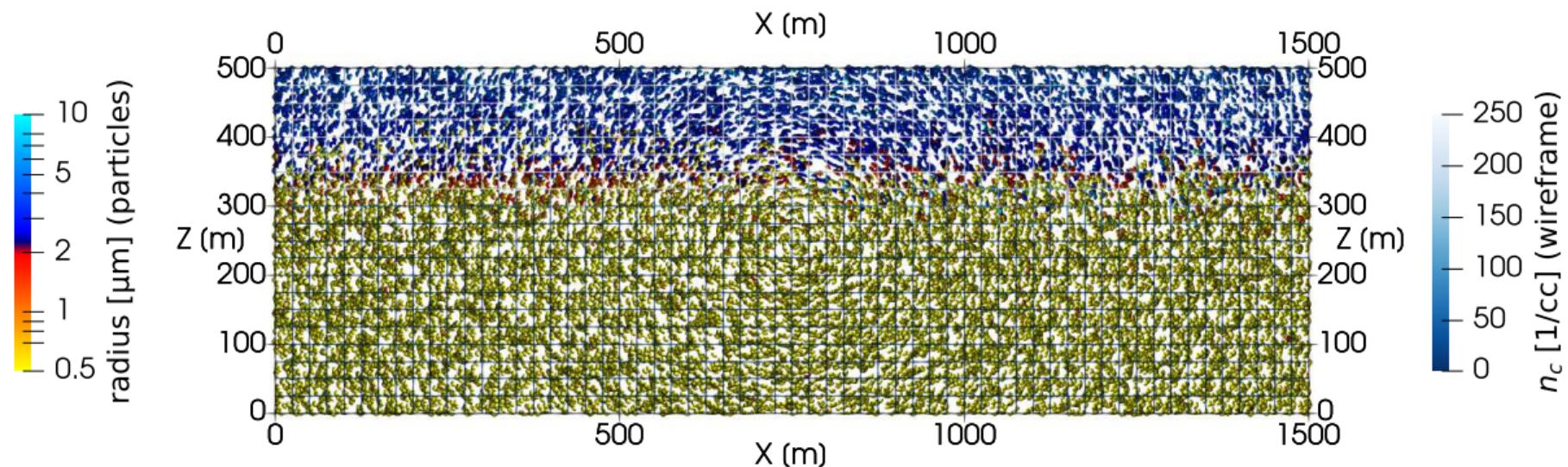
Time: 240 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

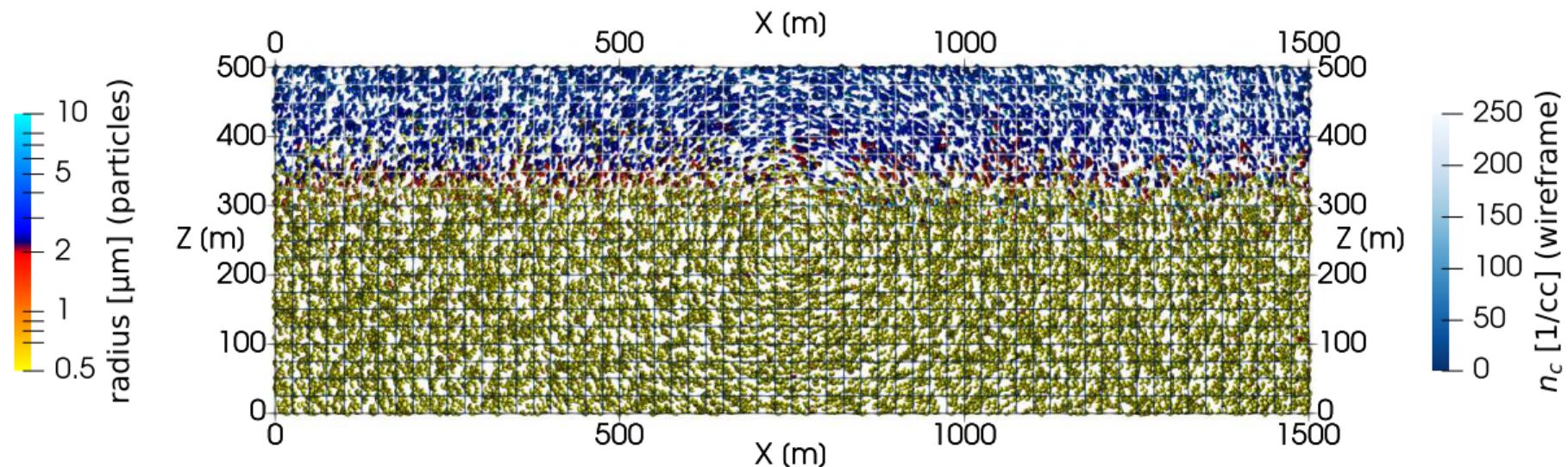
Time: 270 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

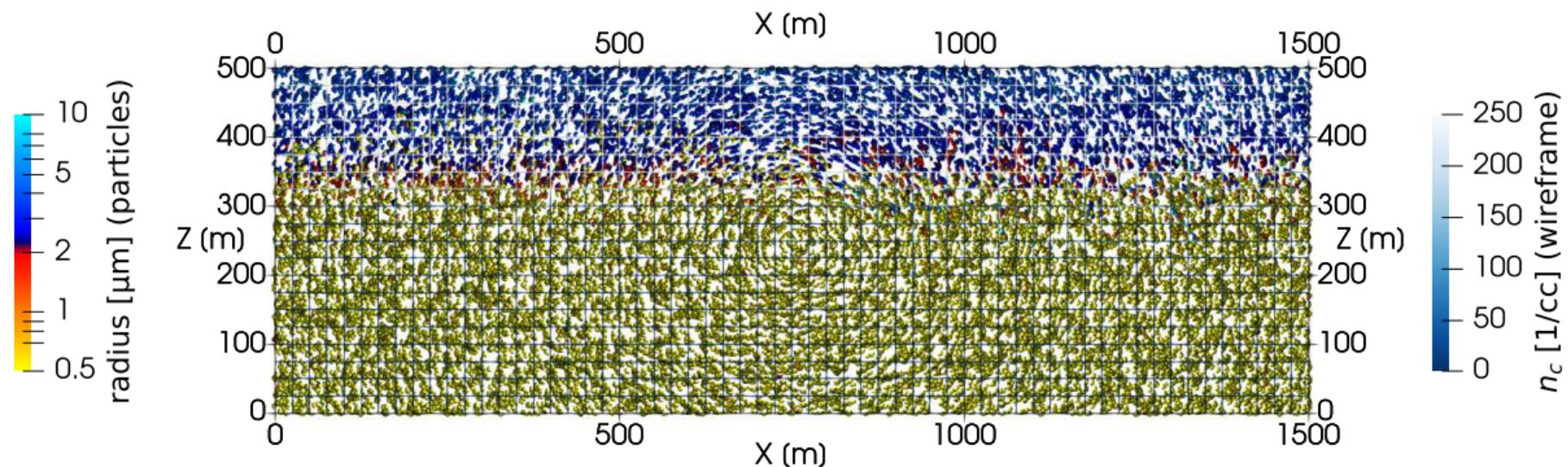
Time: 300 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \text{ } \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

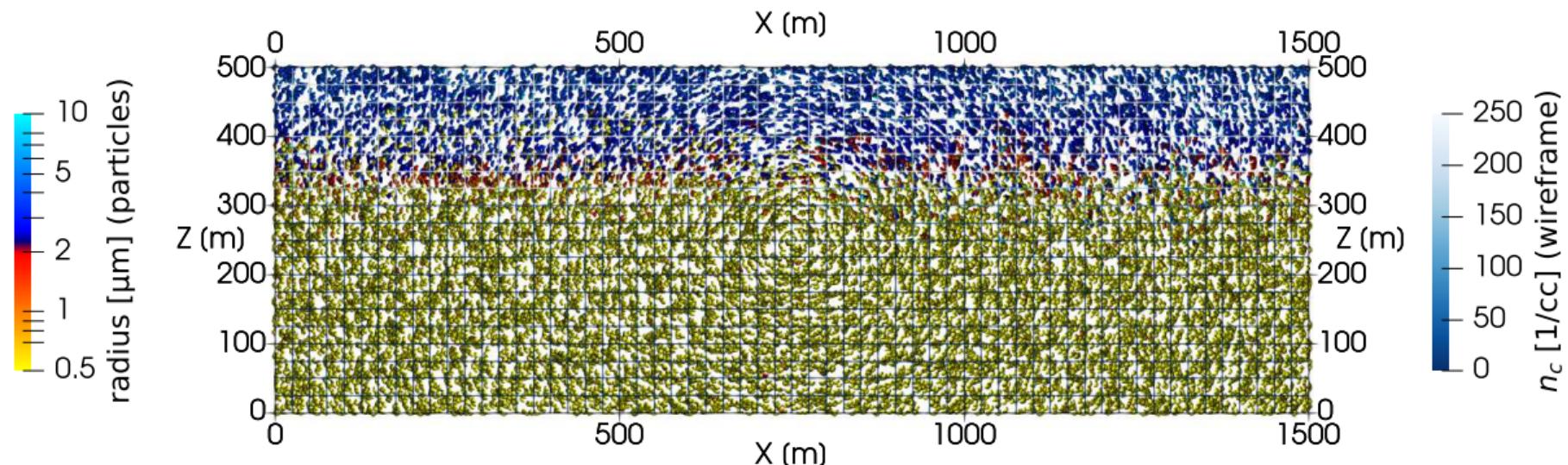
Time: 330 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

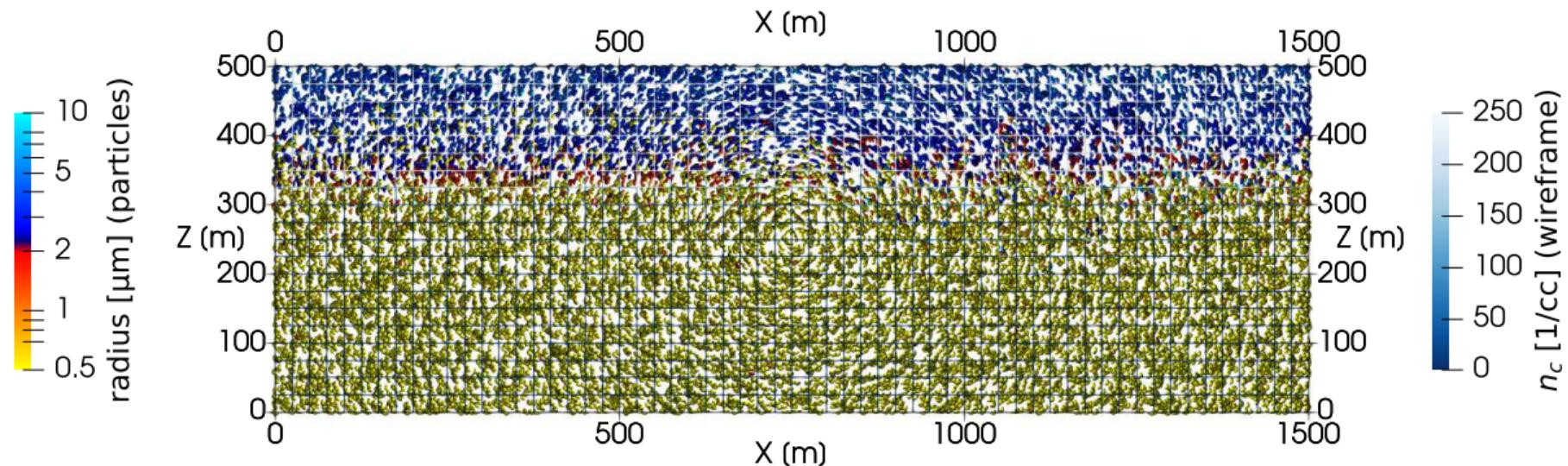
Time: 360 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

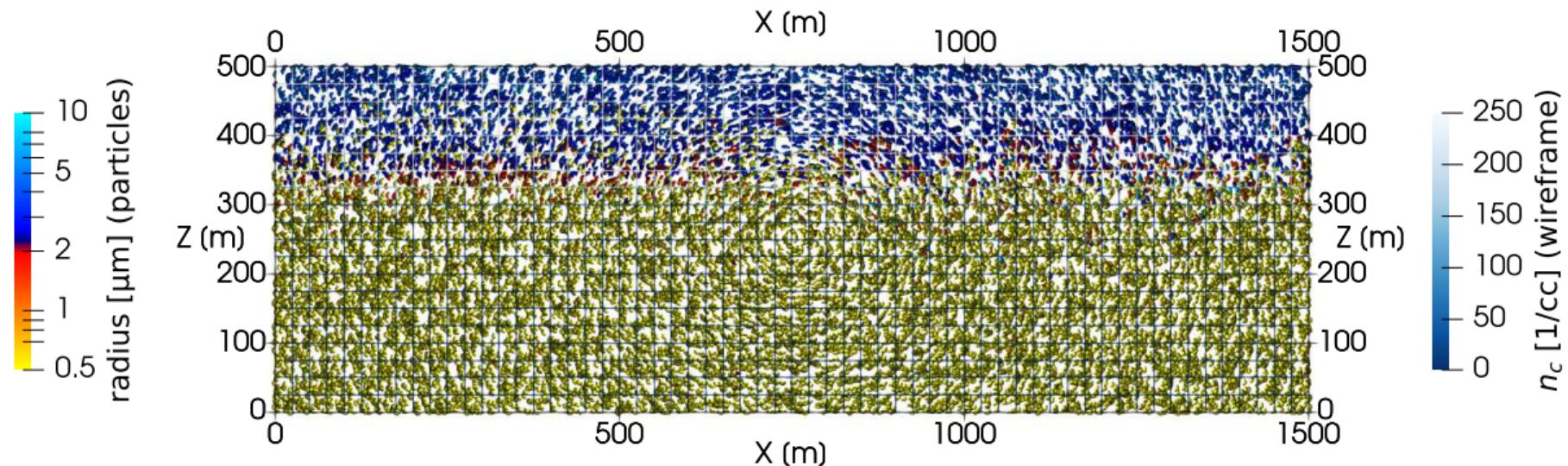
Time: 390 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \text{ } \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

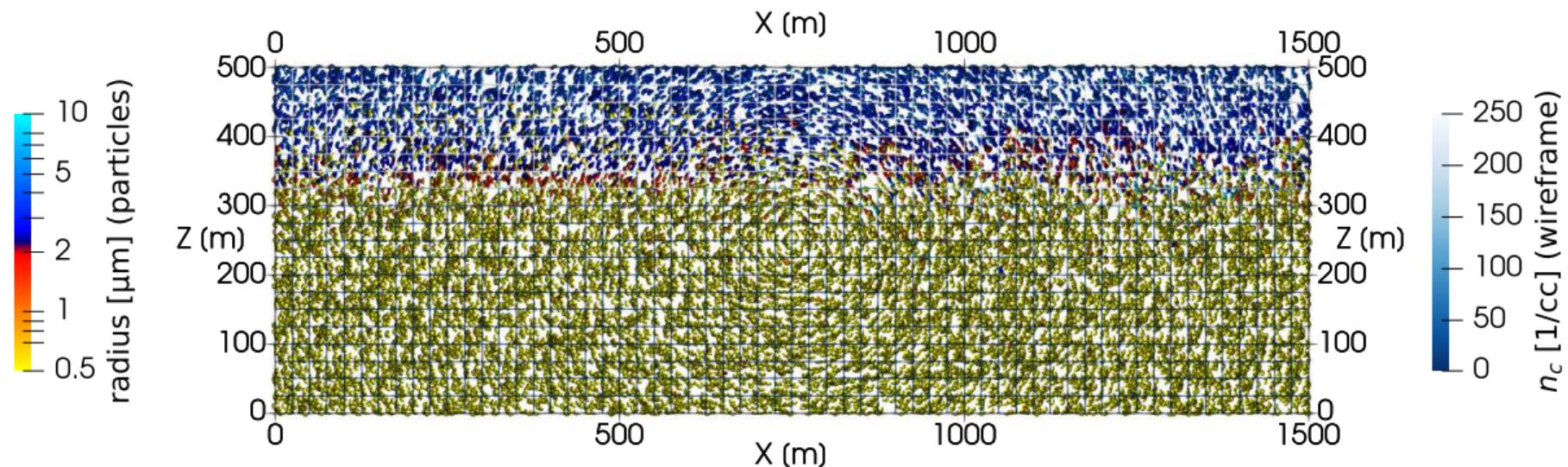
Time: 420 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \text{ } \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

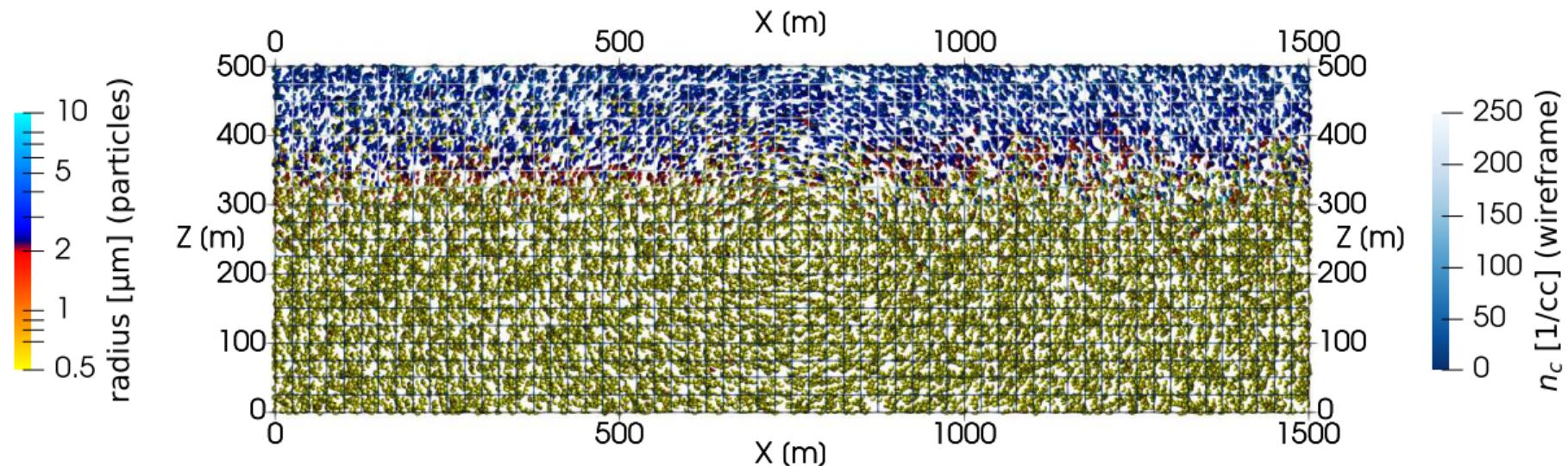
Time: 450 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

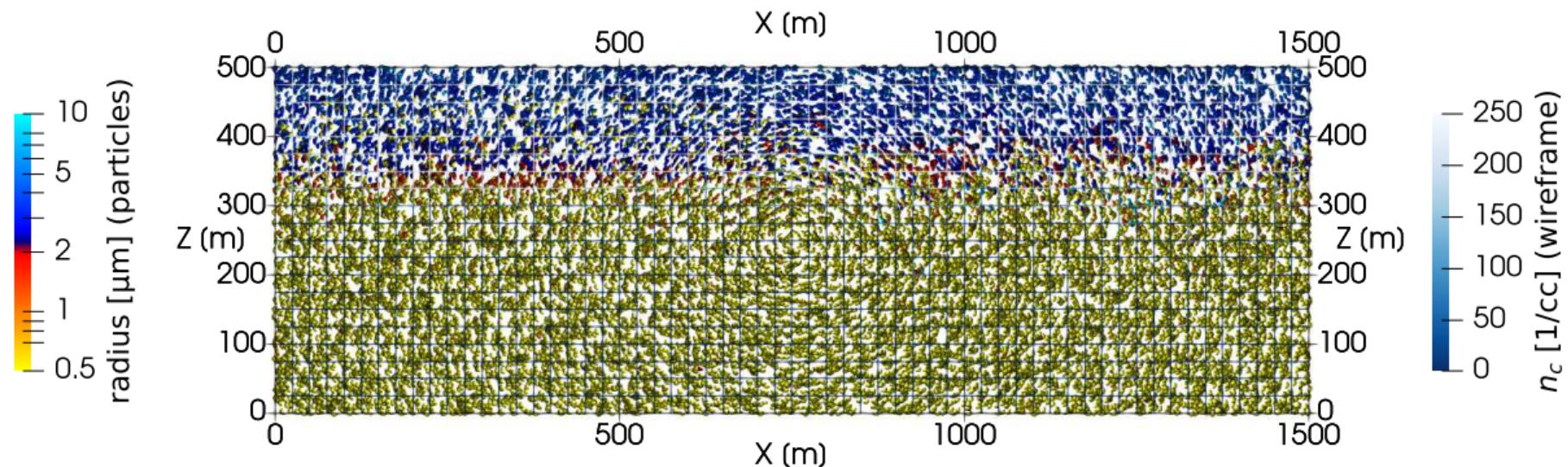
Time: 480 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

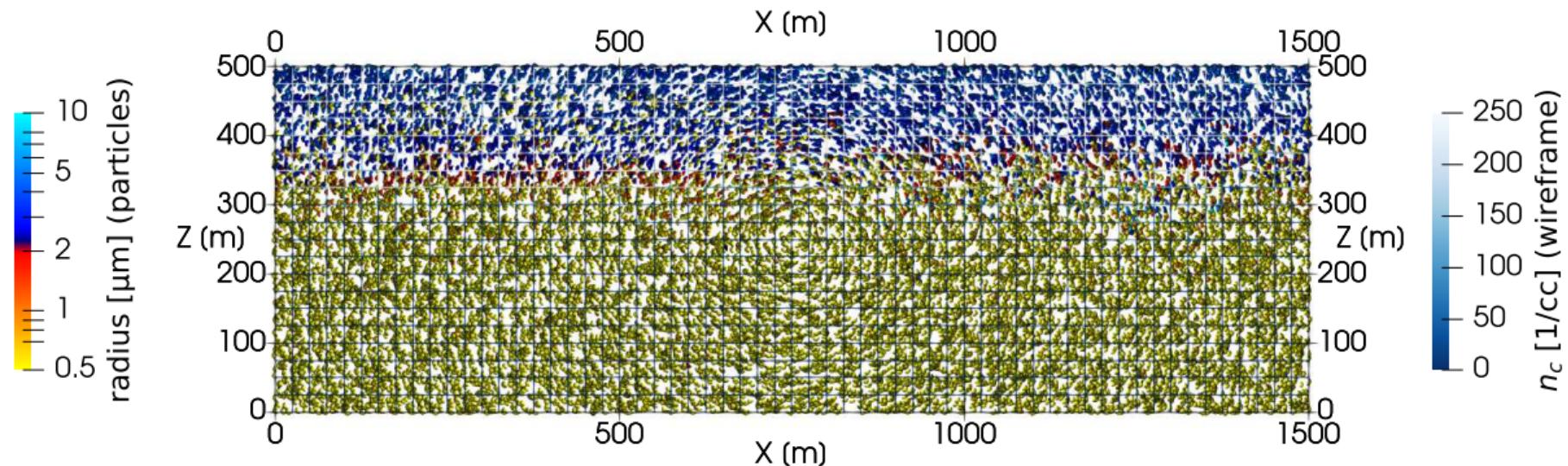
Time: 510 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \text{ } \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

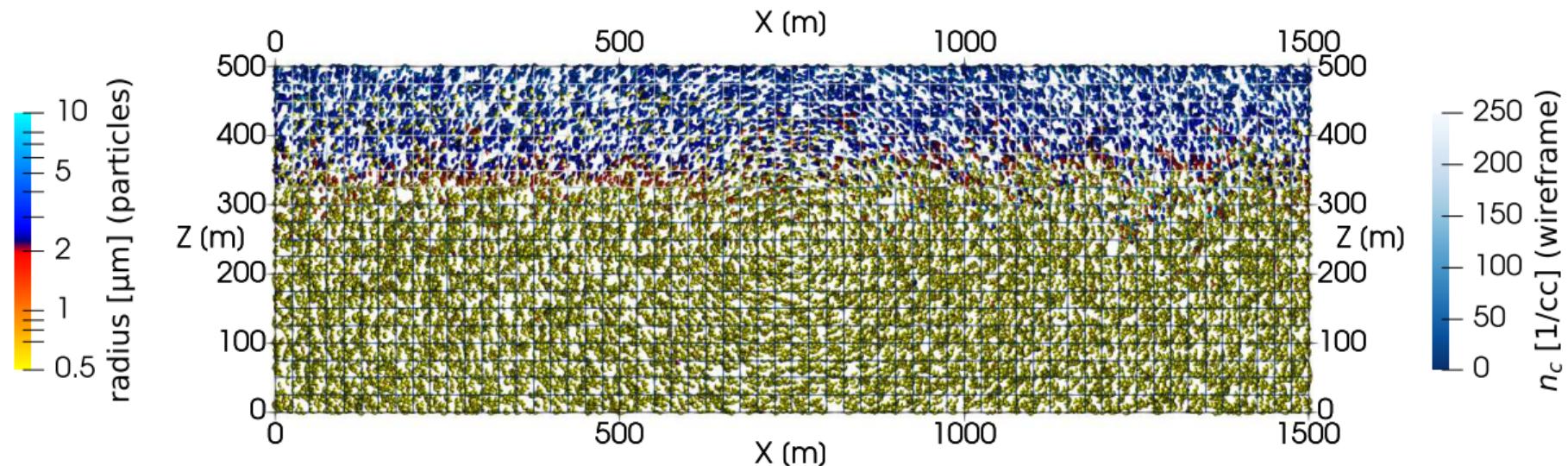
Time: 540 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

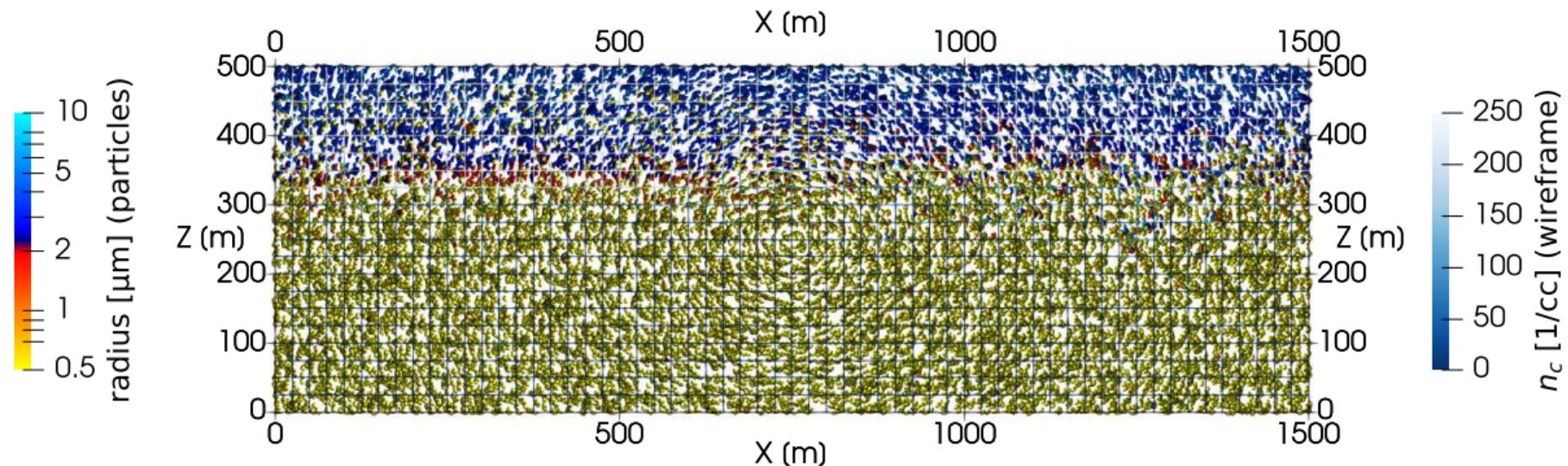
Time: 570 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \text{ } \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

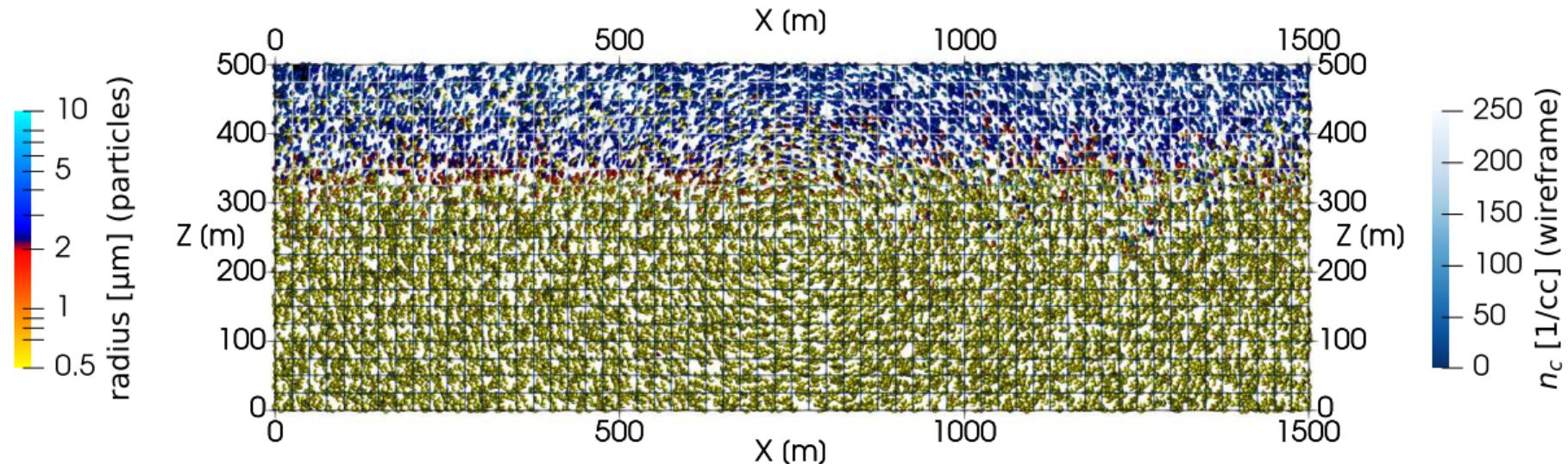
Time: 600 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \text{ } \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

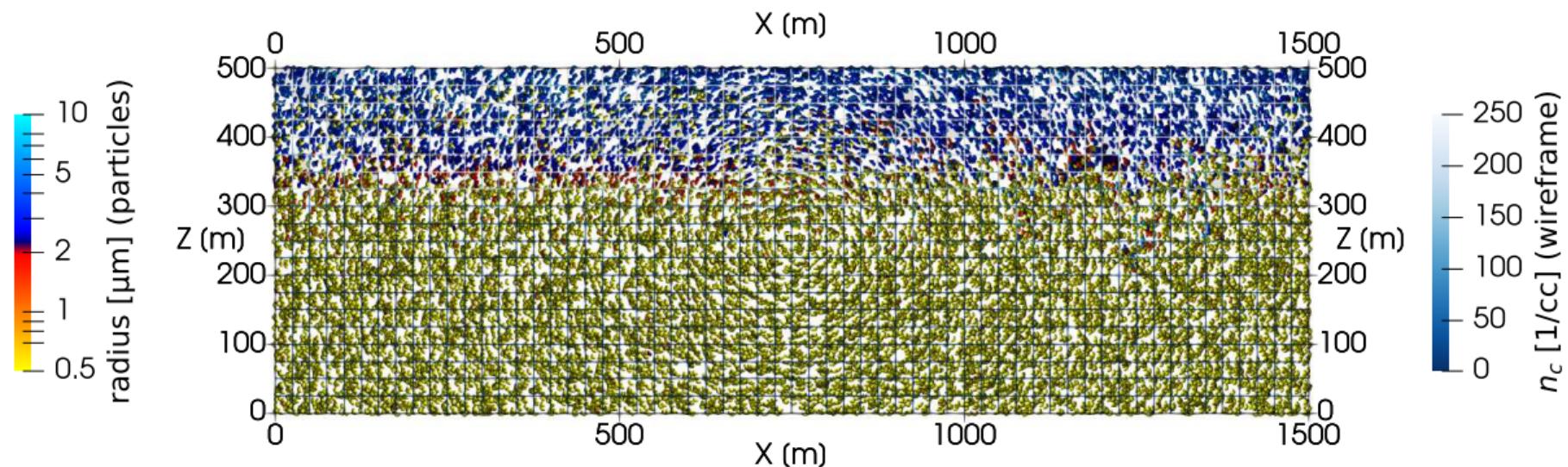
Time: 630 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

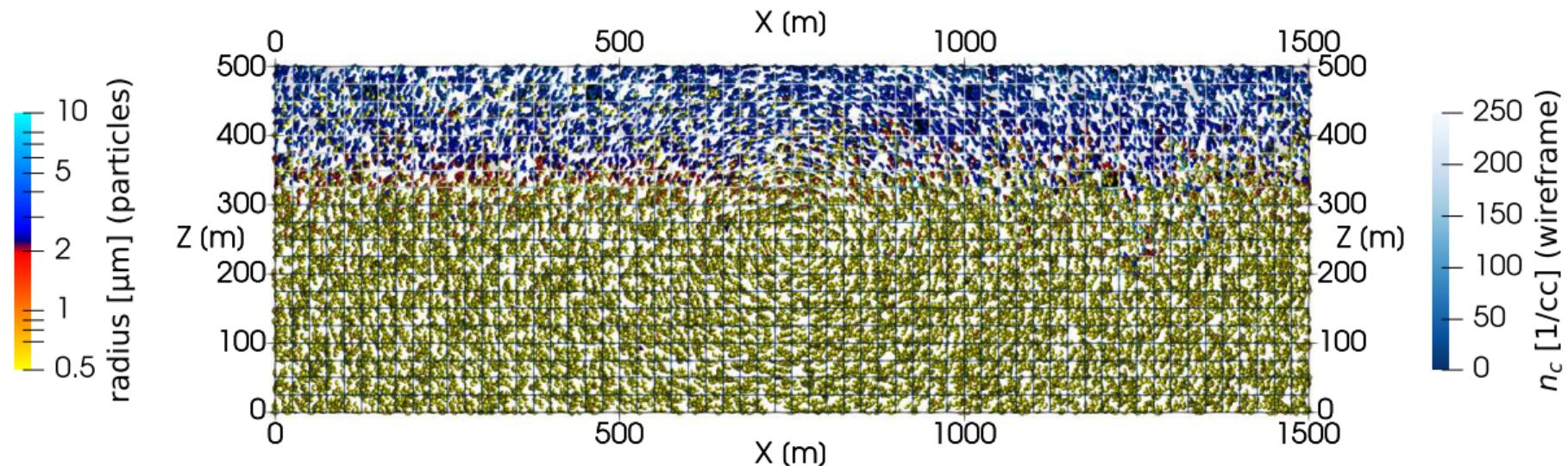
Time: 660 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

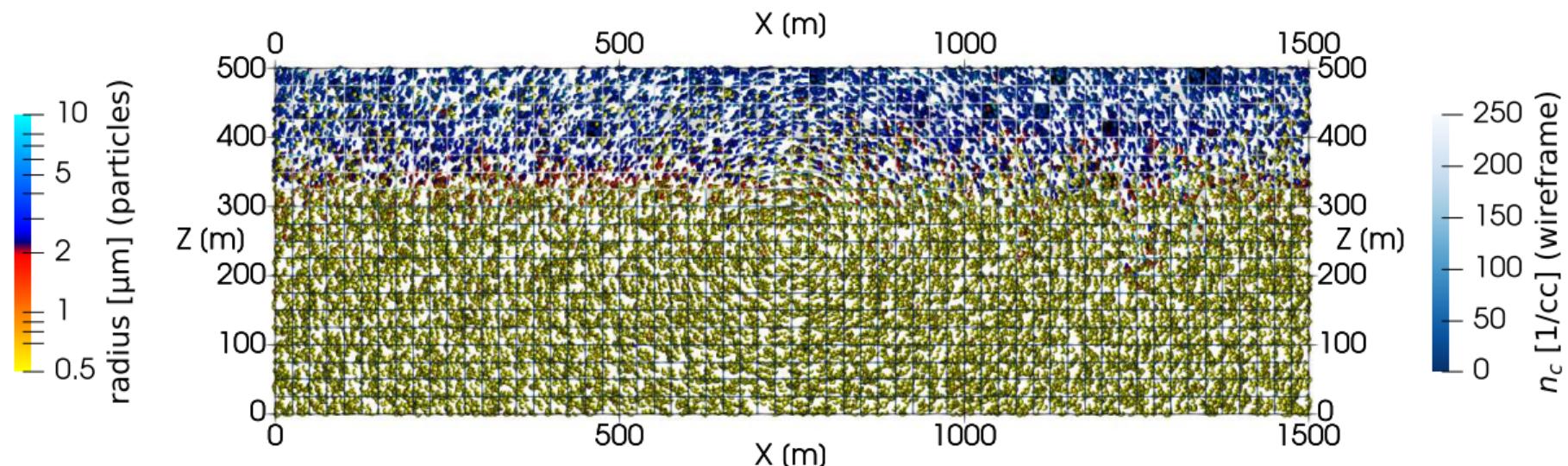
Time: 690 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
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particle-based probabilistic aerosol-cloud μ -physics (super droplets)

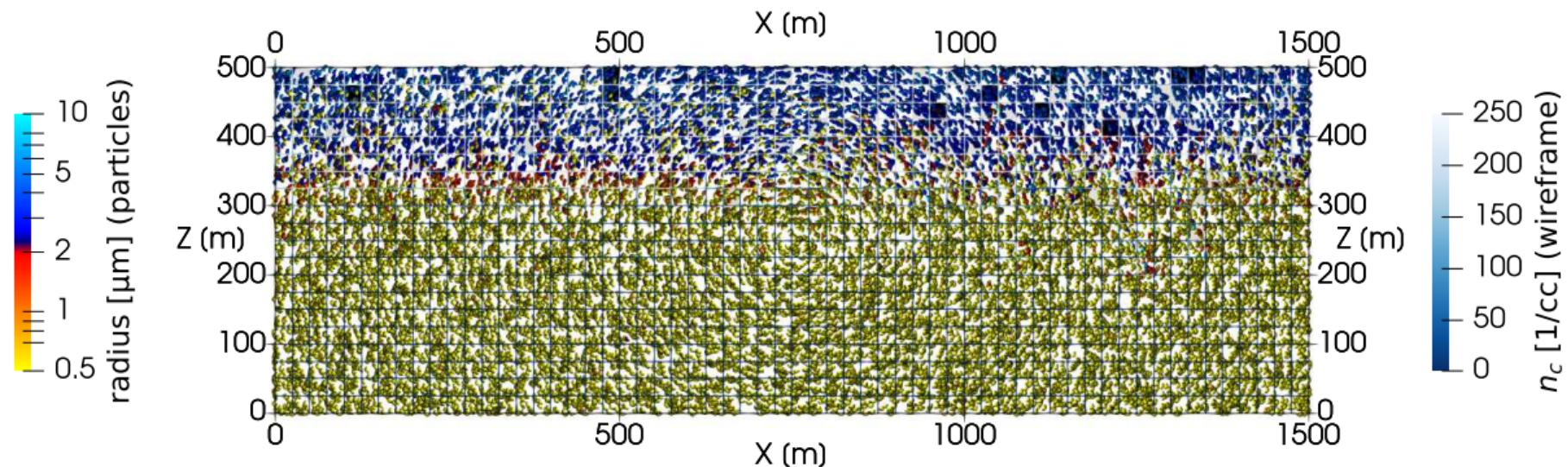
Time: 720 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \text{ } \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

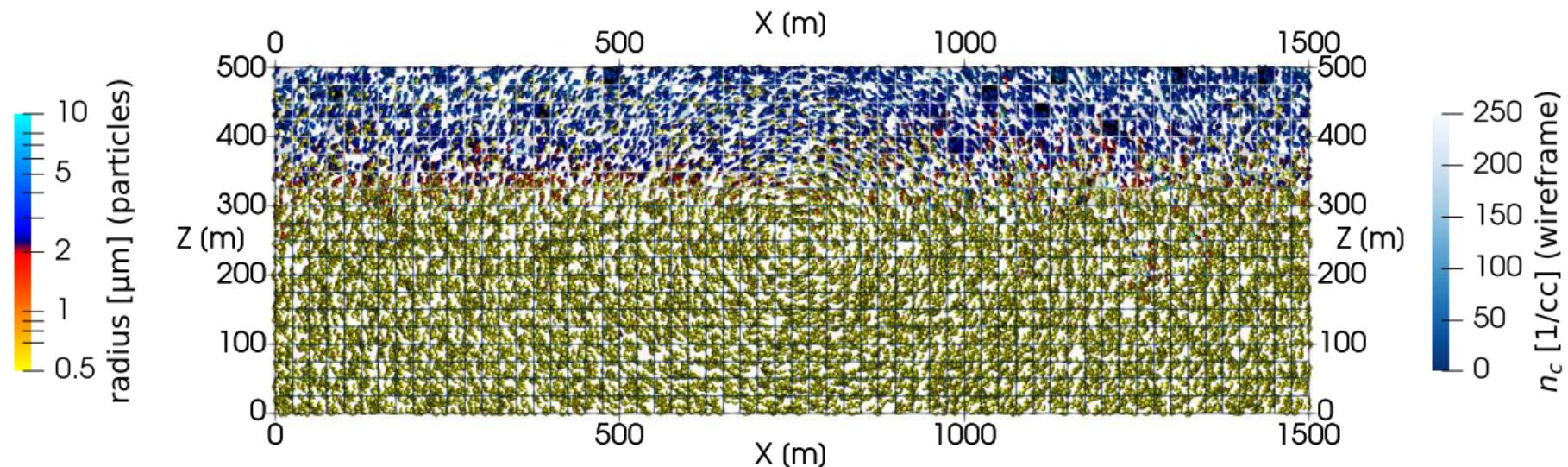
Time: 750 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

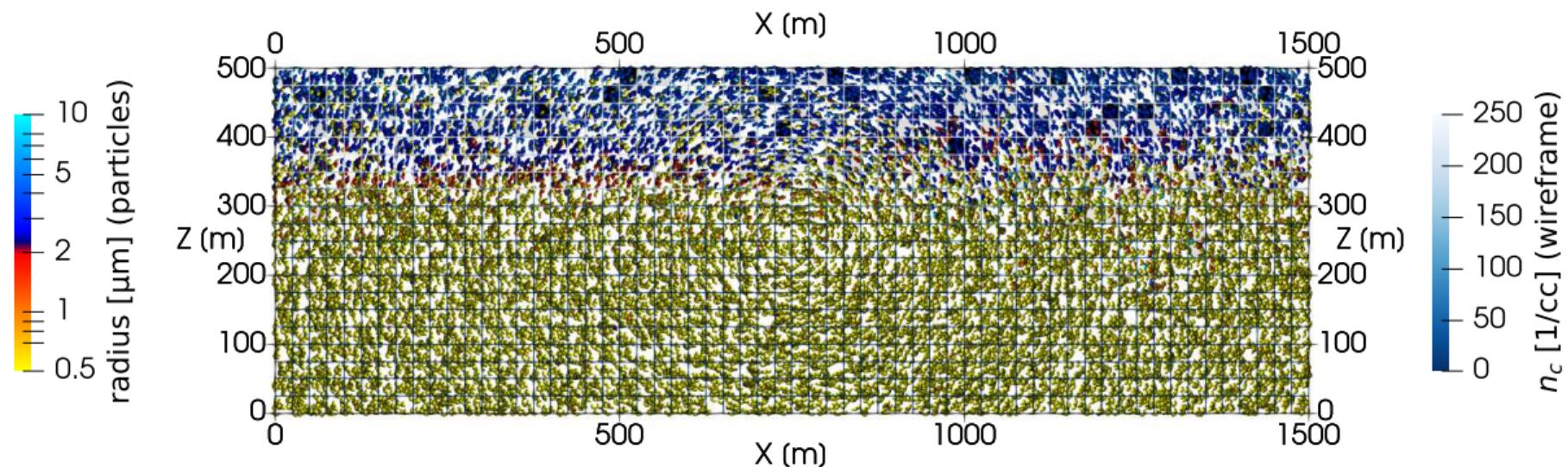
Time: 780 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

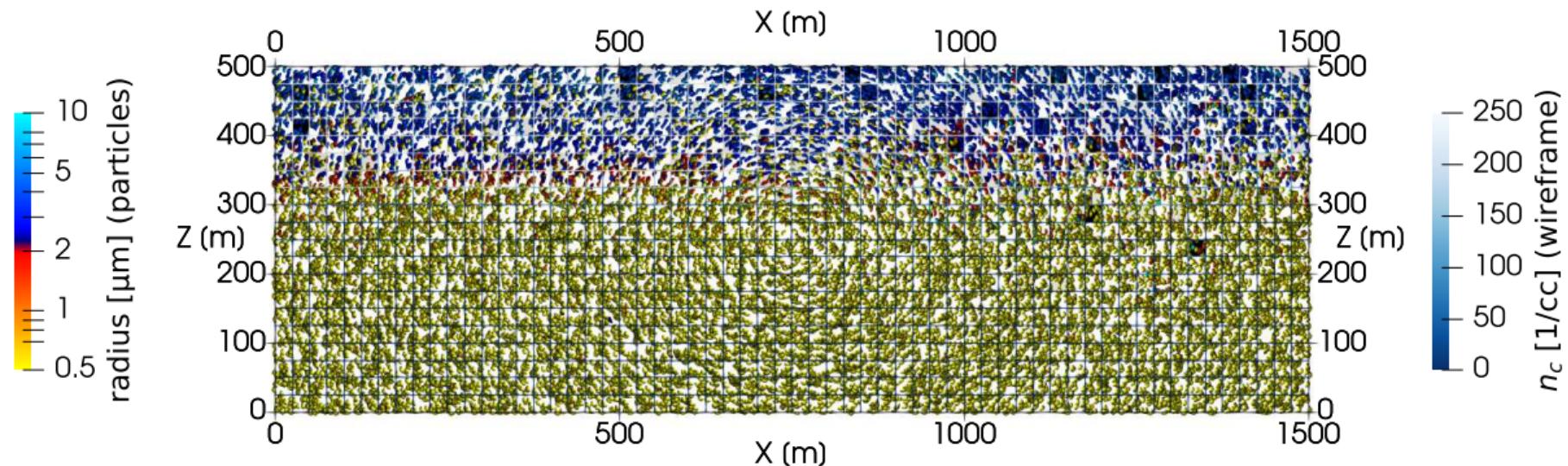
Time: 810 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

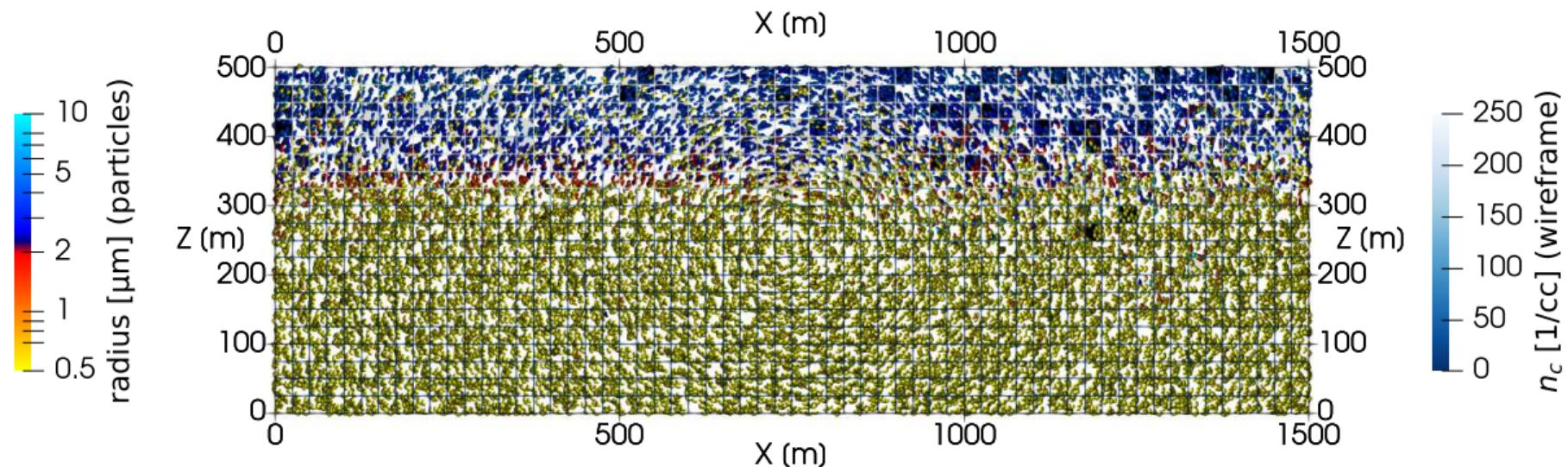
Time: 840 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

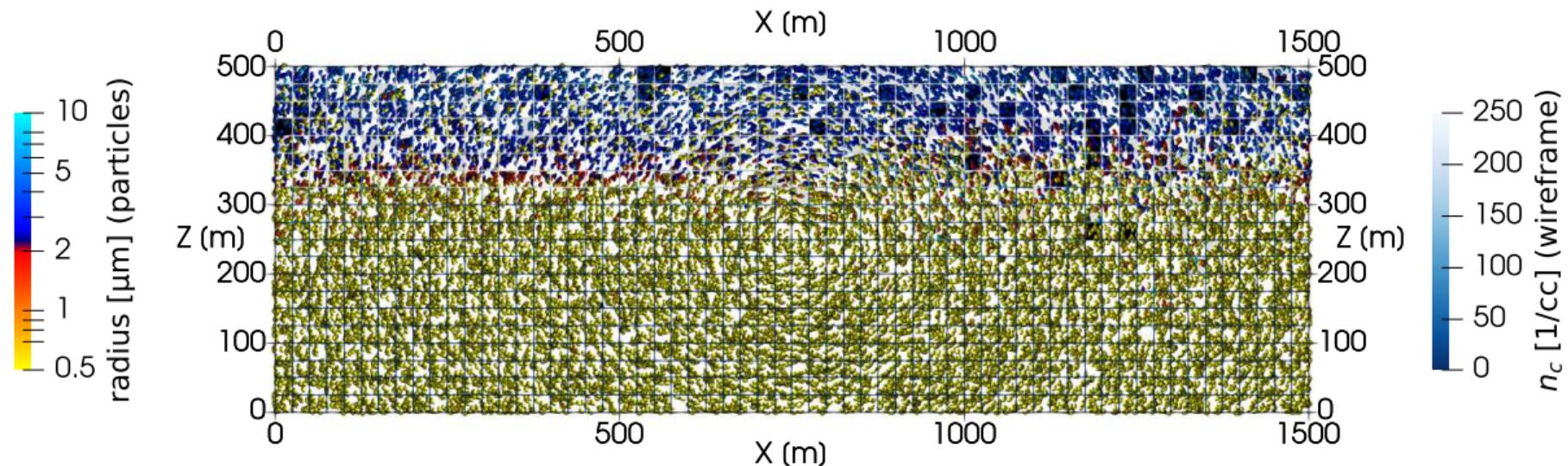
Time: 870 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

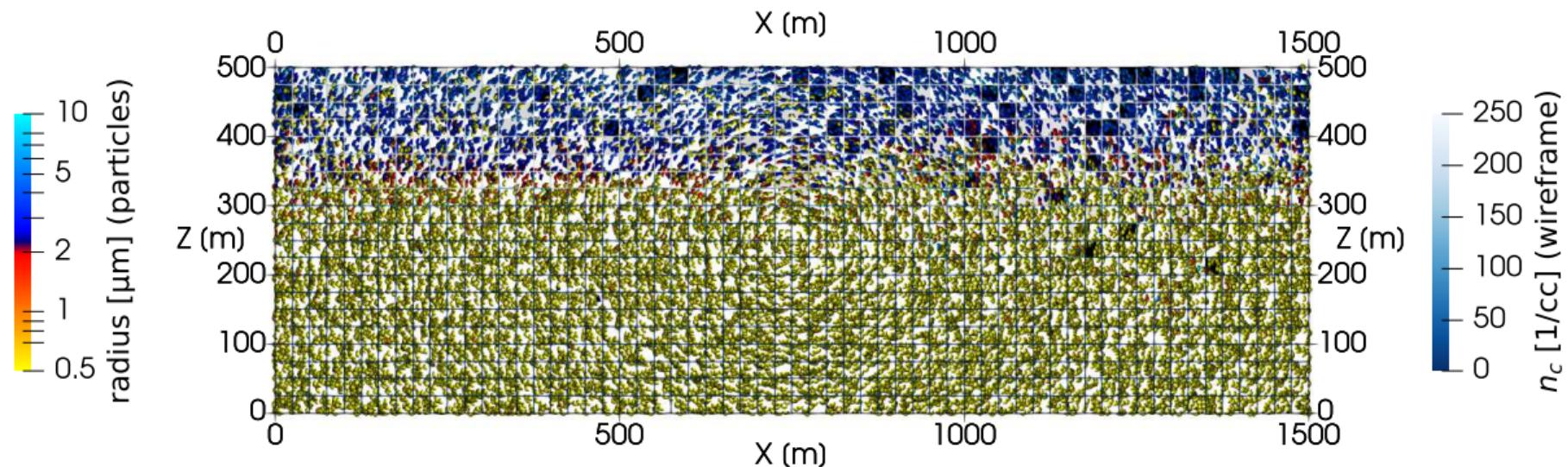
Time: 900 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \text{ } \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

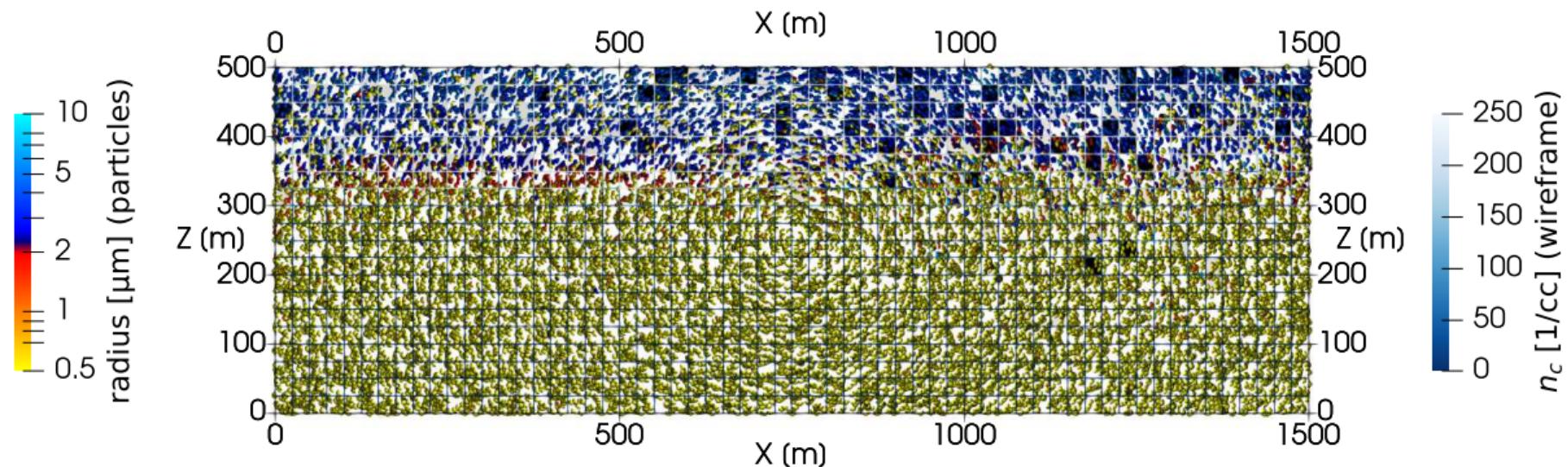
Time: 930 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

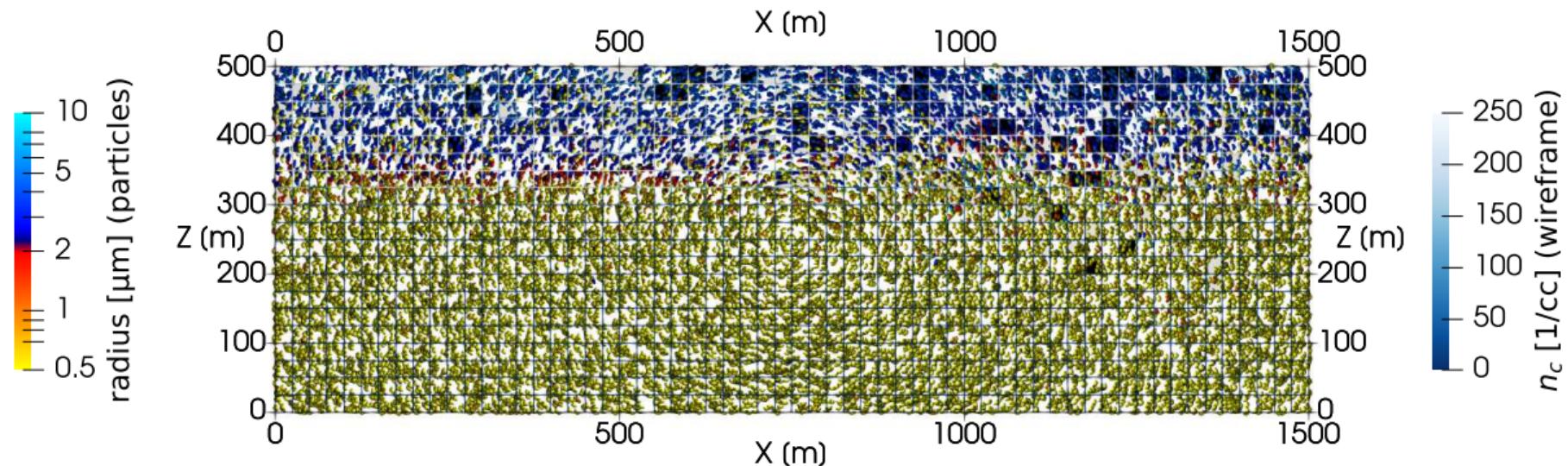
Time: 960 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
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particle-based probabilistic aerosol-cloud μ -physics (super droplets)

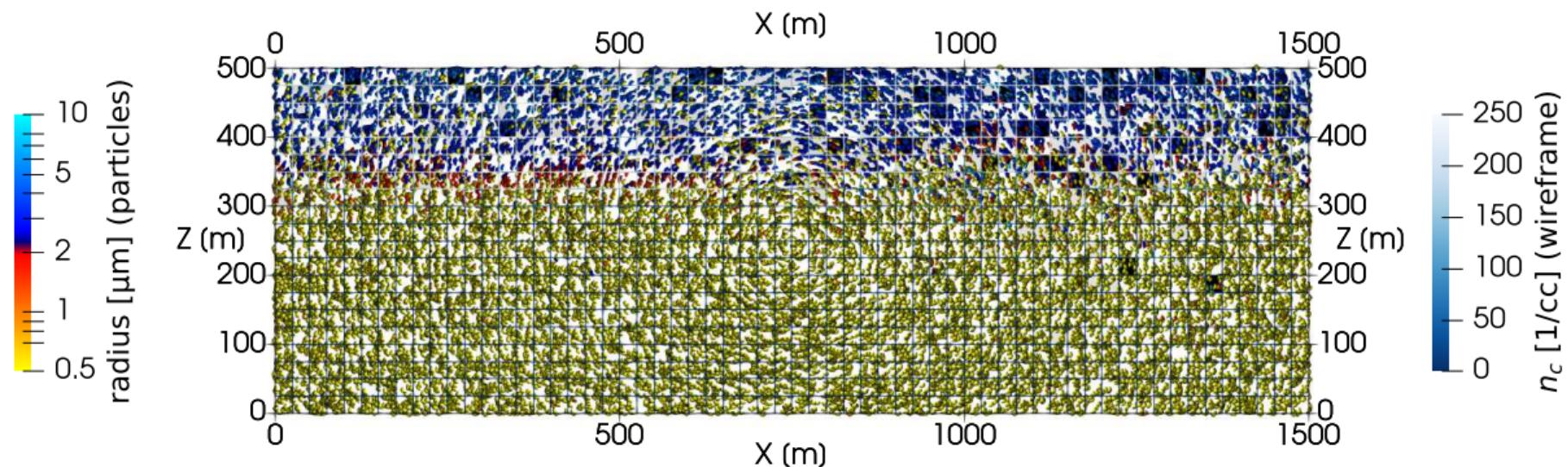
Time: 990 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \text{ } \mu\text{m}$, $\sigma_g = 2.55$)
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particle-based probabilistic aerosol-cloud μ -physics (super droplets)

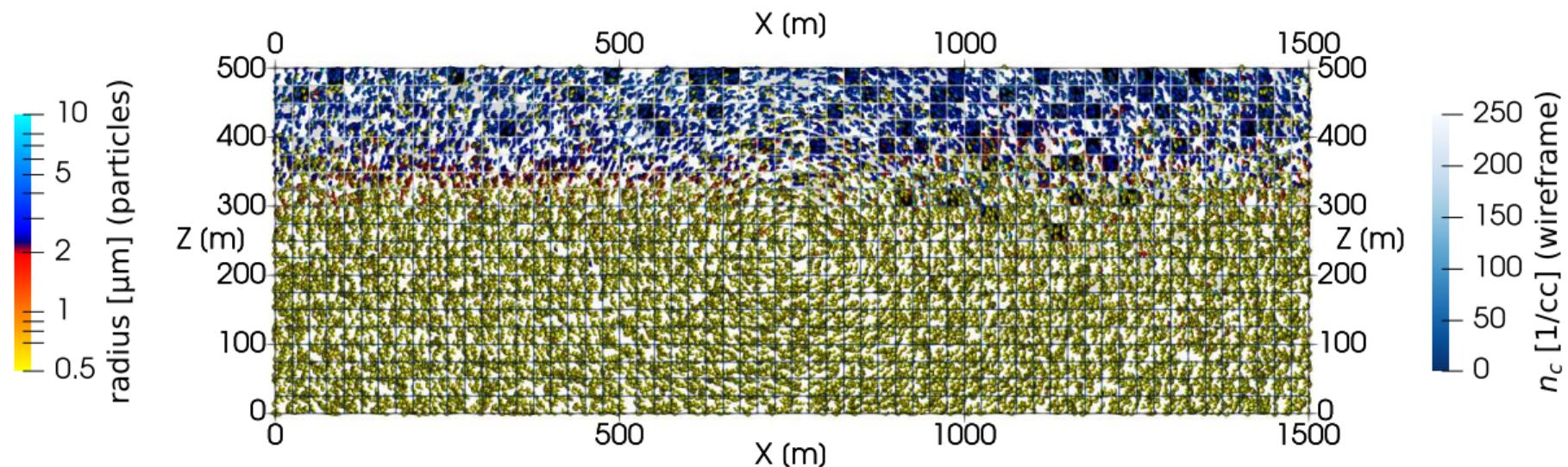
Time: 1020 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \text{ } \mu\text{m}$, $\sigma_g = 2.55$)
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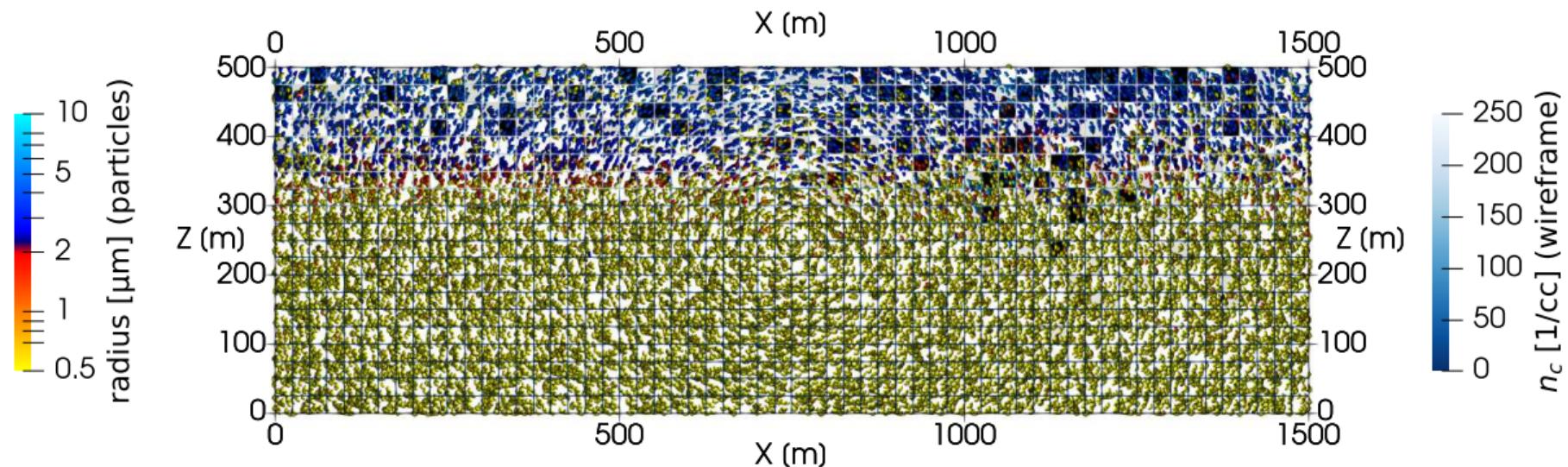
Time: 1050 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

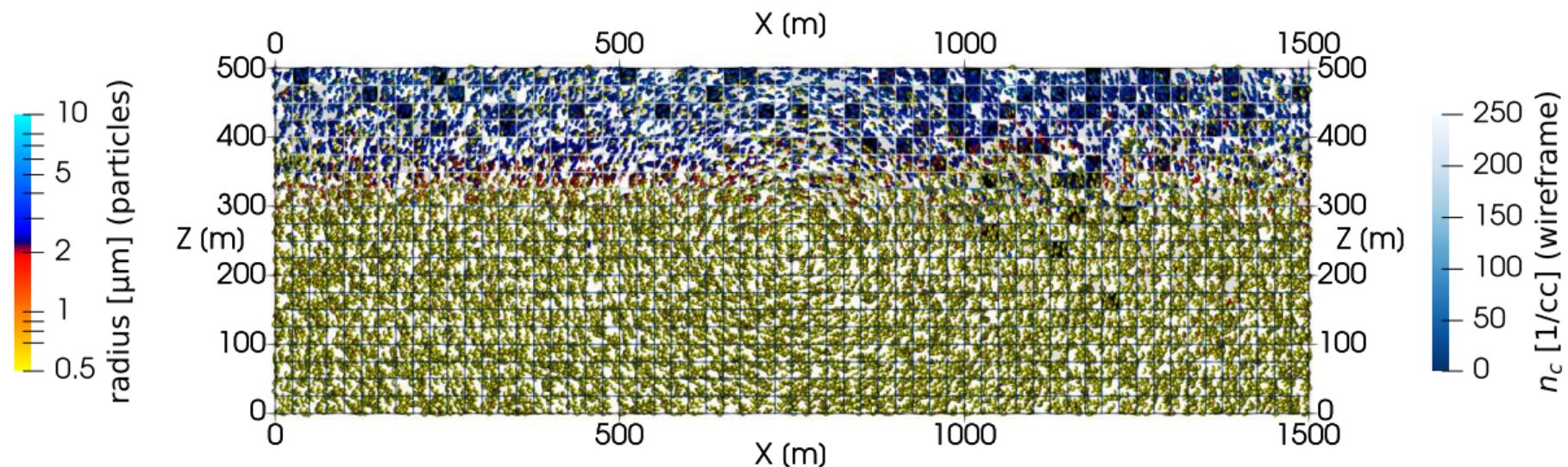
Time: 1080 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

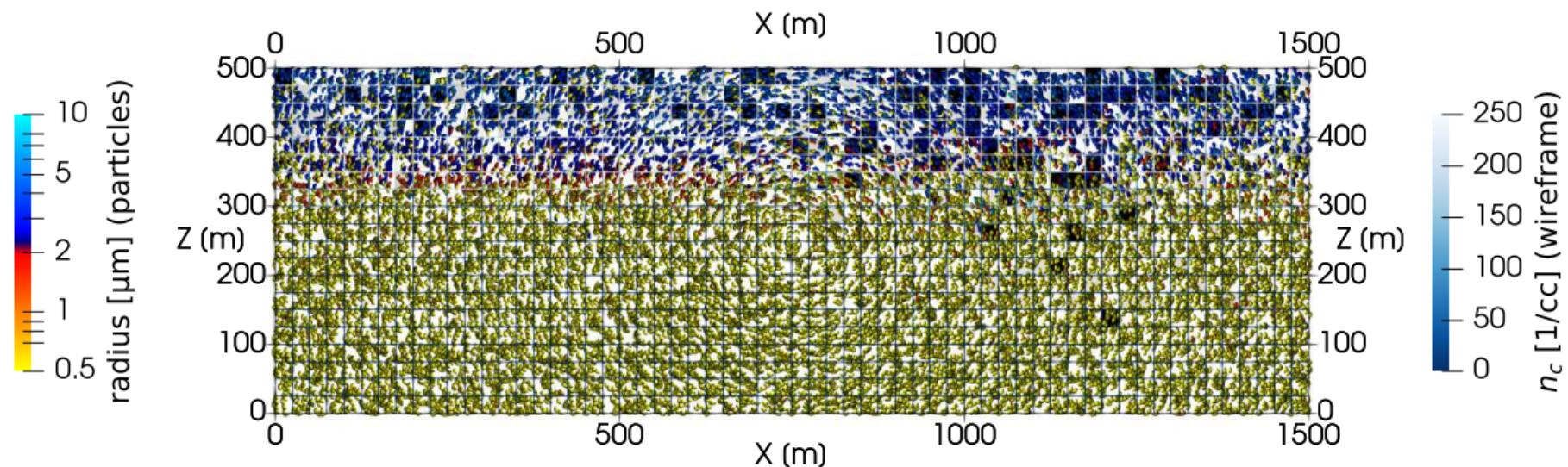
Time: 1110 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

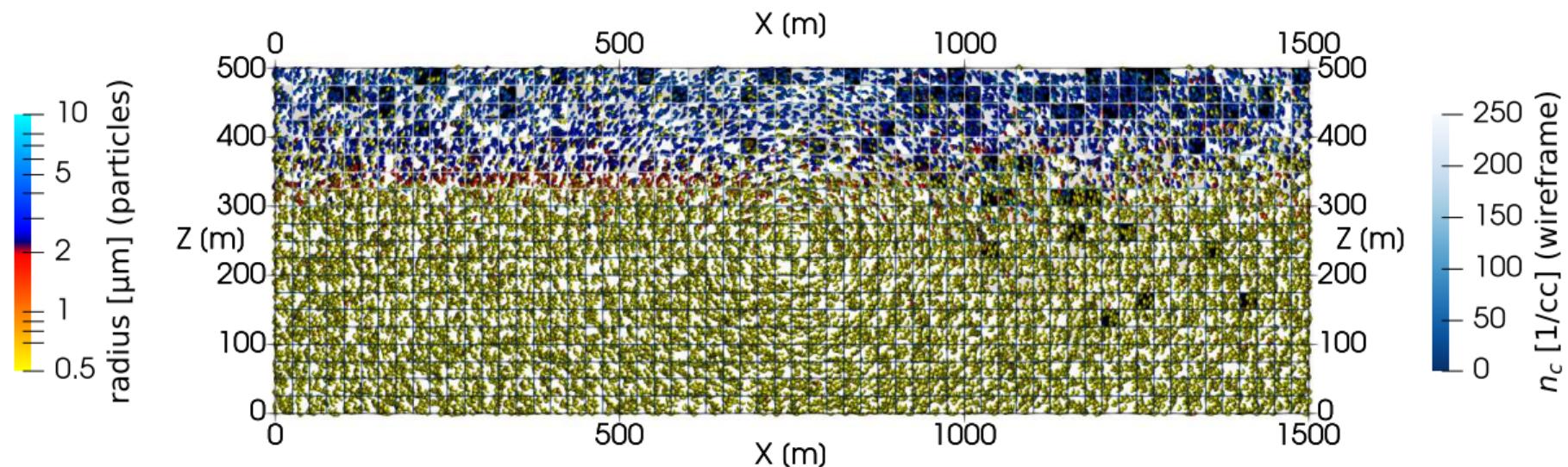
Time: 1140 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

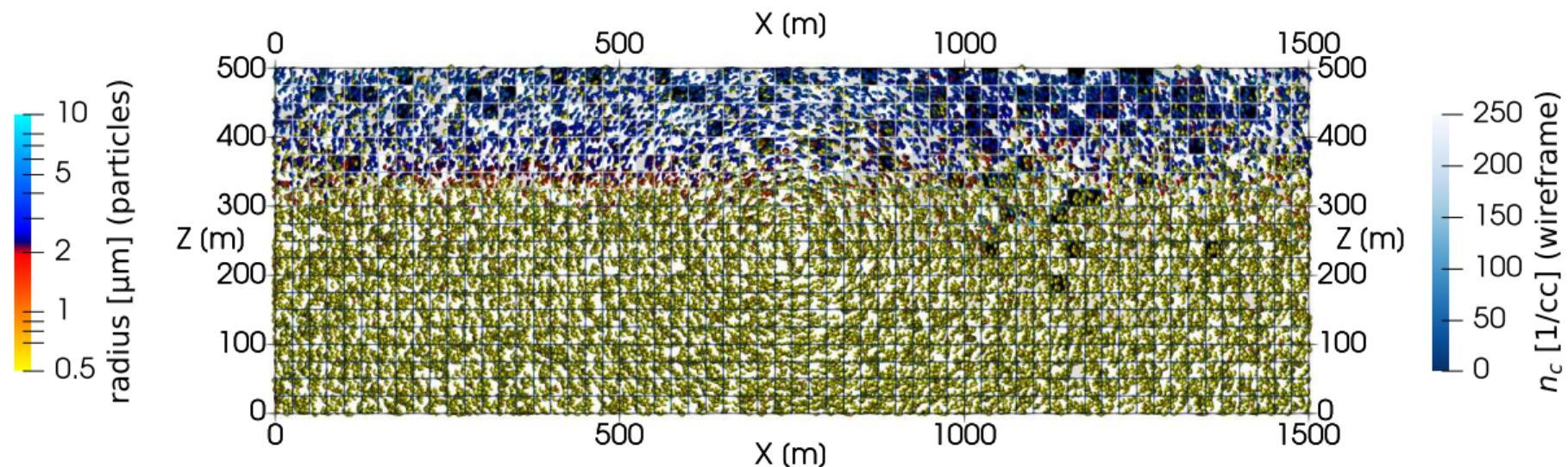
Time: 1170 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

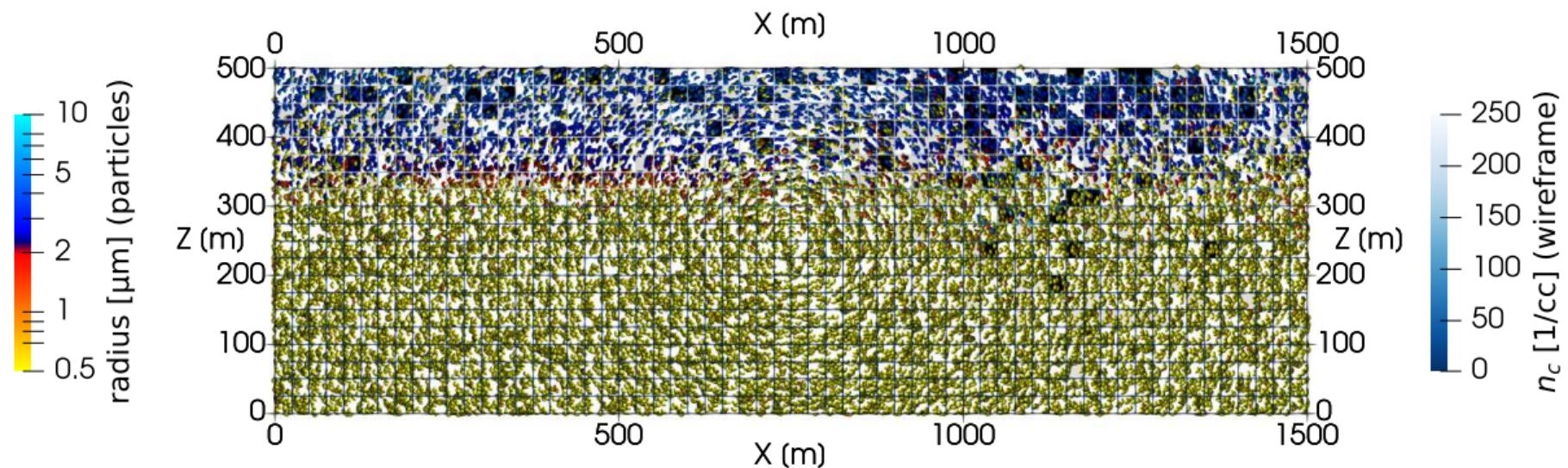
Time: 1200 s (spin-up till 600.0 s)



16+16 super-particles/cell for INP-rich + INP-free particles
 $N_{\text{aer}} = 300/\text{cc}$ (two-mode lognormal) $N_{\text{INP}} = 150/L$ (lognormal, $D_g = 0.74 \mu\text{m}$, $\sigma_g = 2.55$)
spin-up = freezing off; subsequently frozen particles act as tracers

particle-based probabilistic aerosol-cloud μ -physics (super droplets)

Time: 1200 s (spin-up till 600.0 s)



100% Python, 100% open-source, 100% runs "in the cloud" (Google Colab, jupyterhub, ...)

new open-source HPC Python packages

PySDM 2.20
Released Apr 21, 2023
[pip install PySDM](#)

Pythonic particle-based (super-droplet) warm-rain/aqueous-chemistry cloud microphysics package with box, parcel & 1D/2D prescribed-flow examples in Python, Julia and Matlab

Navigation

- Project description
- Release history
- Download files

Project links

- Homepage
- Documentation
- Source
- Tracker

Statistics

- Github statistics:
 - Stars: 40
 - Forks: 23
 - Open issues: 101
 - Open PRs: 13

PyMPDATA 1.0.11
Released Apr 26, 2023
[pip install PyMPDATA](#)

Numba-accelerated Pythonic implementation of MPDATA with examples in Python, Julia and Matlab

Navigation

- Project description
- Release history
- Download files

Project links

- Documentation
- Source
- Tracker

Statistics

- Github statistics:
 - Stars: 10
 - Forks: 10
 - Open issues: 25
 - Open PRs: 3

PyPartMC 0.5.0
Released Aug 3, 2023
[pip install PyPartMC](#)

Python interface to PartMC

Navigation

- Project description
- Release history
- Downloads

Project links

- Documentation
- Source
- Tracker

Statistics

- Github statistics:
 - Stars: 15
 - Forks: 6
 - Open issues: 51
 - Open PRs: 5

Jupyter notebooks with examples

- Urban plume scenario demo (in [PartMC](#))
- dry-wet Particle size Equilibrium with PartMC and PySDM ([PartMC](#))

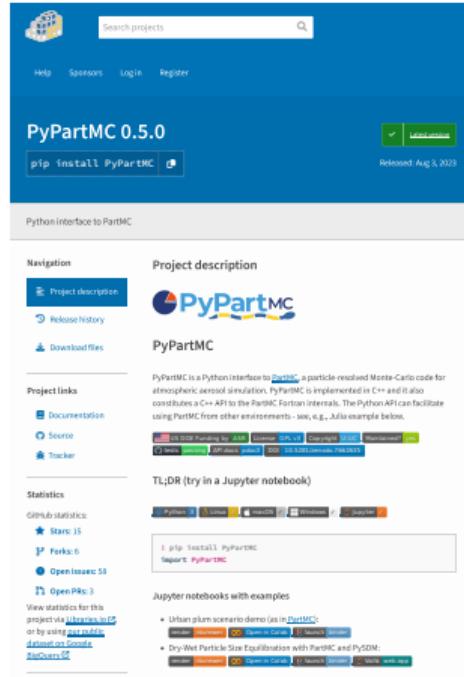
new open-source HPC Python packages



The screenshot shows the GitHub project page for PySDM 2.20. At the top, there's a search bar and navigation links for Help, Sponsors, Log in, and Register. Below that, the project title "PySDM 2.20" is displayed with a green "Install" button and a release date of April 21, 2023. The main content area includes a brief description: "Pythonic particle-based (super-droplet) warm-rain/aqueous-chemistry cloud microphysics package with box, parcel & 1D/2D prescribed-flow examples in Python, Julia and Matlab". A "Project description" section for PySDM follows, containing a table of contents, a "Release history" section with a link to the GitHub releases page, and a "Download files" section with links to PyPI, GitHub, and Julia registries. A "Project links" sidebar lists links to the homepage, documentation, source code, and tracker. A "Statistics" sidebar shows GitHub statistics: Stars: 40, Forks: 23, Open issues: 101, and Open PRs: 13. The bottom of the page features the Jagiellonian University logo and a footer with Caltech and Illinois logos.



The screenshot shows the GitHub project page for PyMPDATA 1.0.11. It has a similar layout to the PySDM page. The project title "PyMPDATA 1.0.11" is shown with a green "Install" button and a release date of April 26, 2023. The main content area describes it as a "Numba-accelerated Pythonic implementation of MPDATA with examples in Python, Julia and Matlab". A "Project description" section for PyMPDATA follows, with a table of contents, a "Release history" section, and a "Download files" section. A "Project links" sidebar includes links to documentation, source code, and a tracker. A "Statistics" sidebar shows GitHub statistics: Stars: 19, Forks: 10, Open issues: 25, and Open PRs: 3. The bottom of the page features the Jagiellonian University logo and a footer with Caltech and Illinois logos.



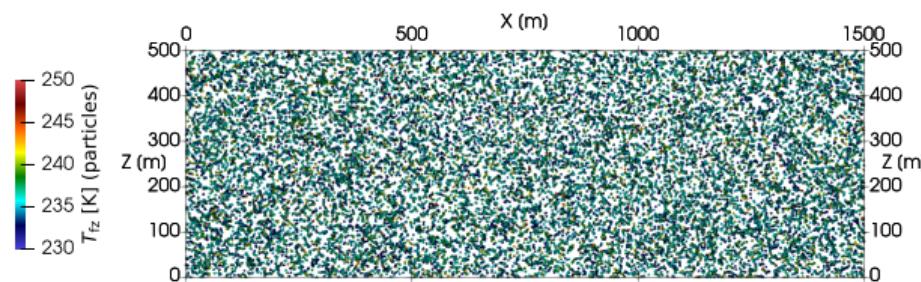
The screenshot shows the GitHub project page for PyPartMC 0.5.0. The layout is consistent with the others. The project title "PyPartMC 0.5.0" is shown with a green "Install" button and a release date of August 3, 2023. The main content area describes it as a "Python interface to PartMC". A "Project description" section for PyPartMC follows, with a table of contents, a "Release history" section, and a "Download files" section. A "Project links" sidebar includes links to documentation, source code, and a tracker. A "Statistics" sidebar shows GitHub statistics: Stars: 15, Forks: 6, Open issues: 51, and Open PRs: 3. The bottom of the page features the Jagiellonian University logo and a footer with Caltech and Illinois logos.



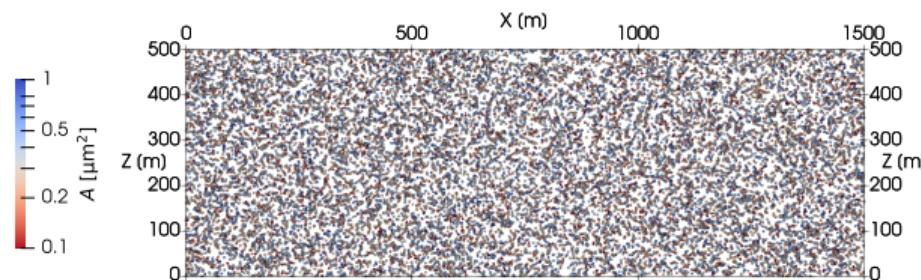
Caltech ILLINOIS

Monte-Carlo immersion freezing: singular vs. time-dependent

singular Monte-Carlo (as in Shima et al. '20)



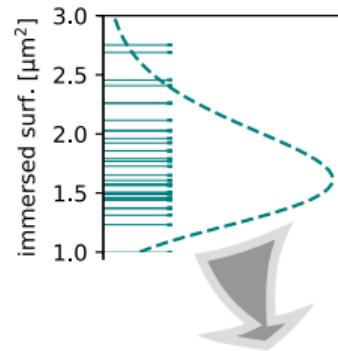
time-dependent Monte-Carlo (as in Alpert & Knopf '16)



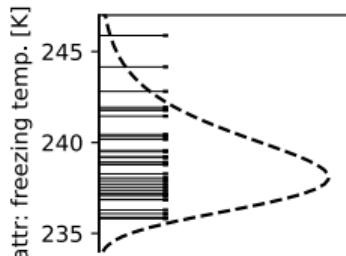
Monte-Carlo immersion freezing: singular vs. time-dependent

particle attribute sampling

random sampling of immersed surface for each particle



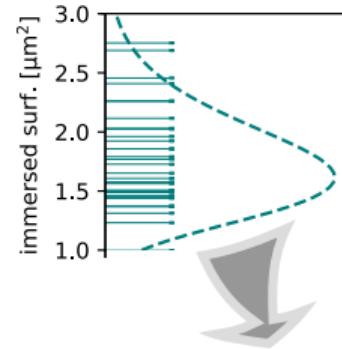
random sampling of freezing temperatures
(conditional distribution for a given surface)



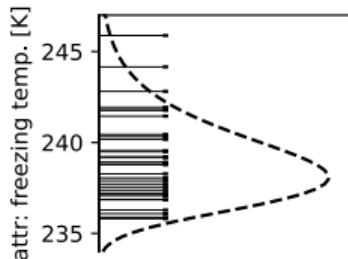
Monte-Carlo immersion freezing: singular vs. time-dependent

particle attribute sampling

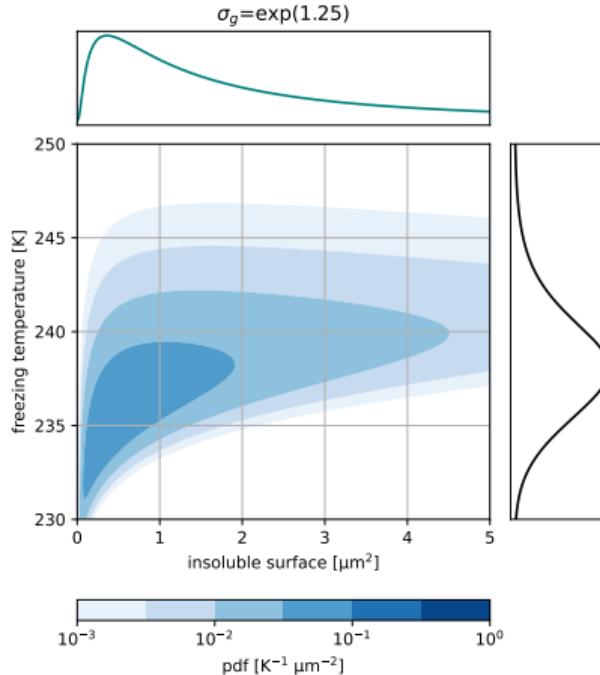
random sampling of immersed surface for each particle



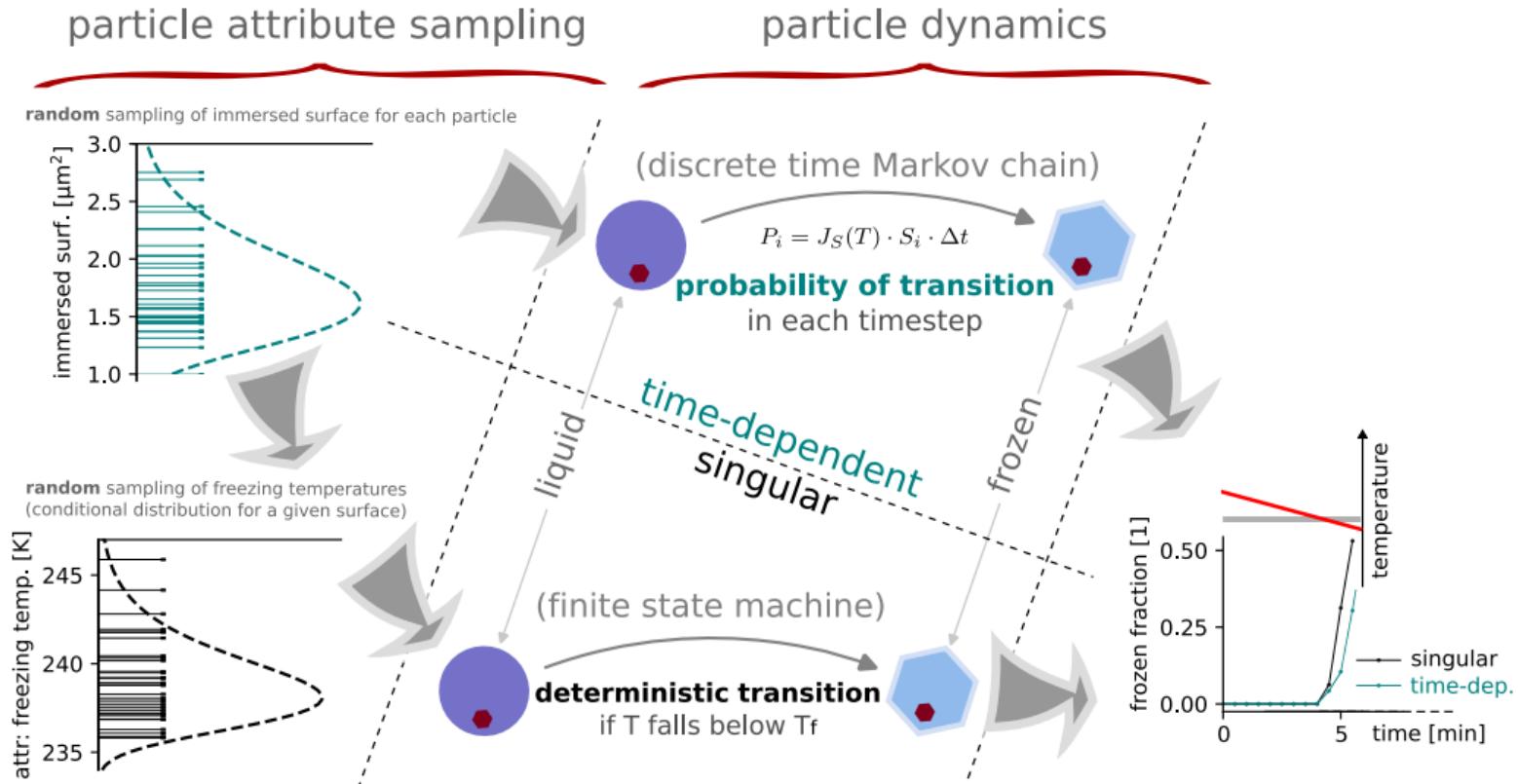
random sampling of freezing temperatures
(conditional distribution for a given surface)



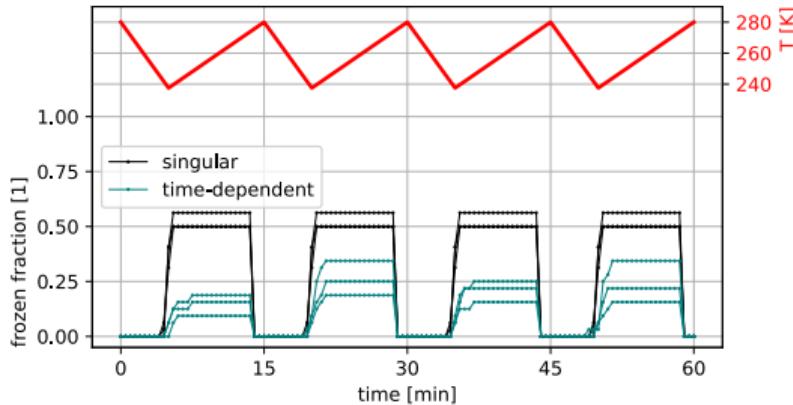
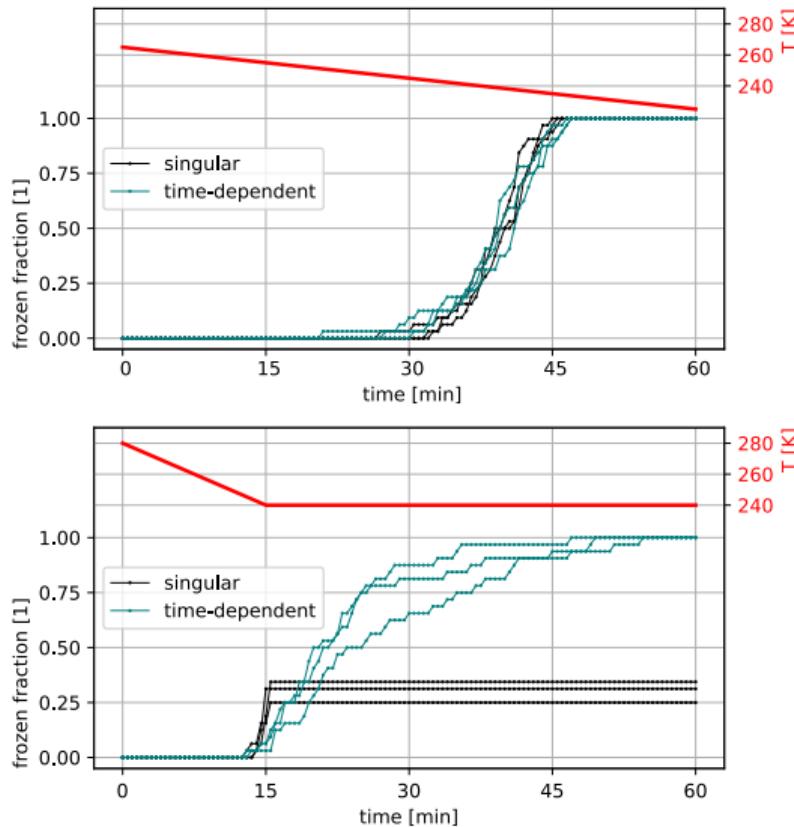
for singular: sampling from
INAS-derived pdf



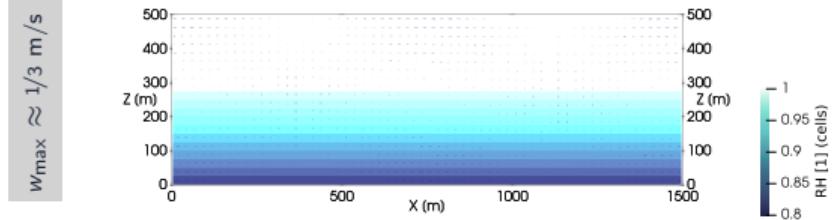
Monte-Carlo immersion freezing: singular vs. time-dependent



cooling-rate response (box model): singular vs. time-dependent



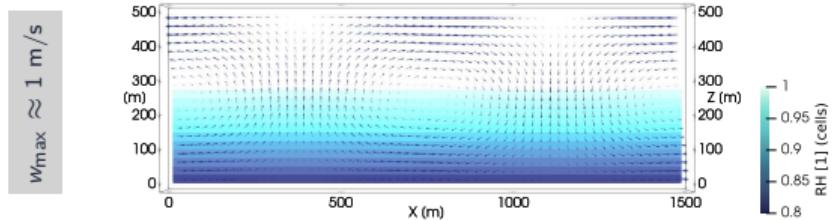
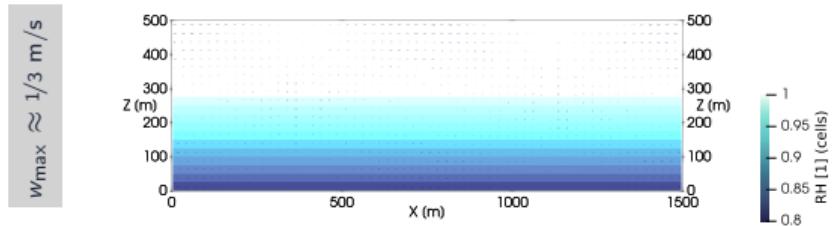
cooling-rate response (2D flow): singular vs. time-dependent



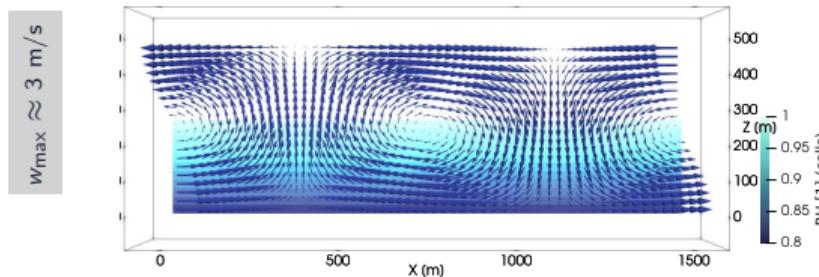
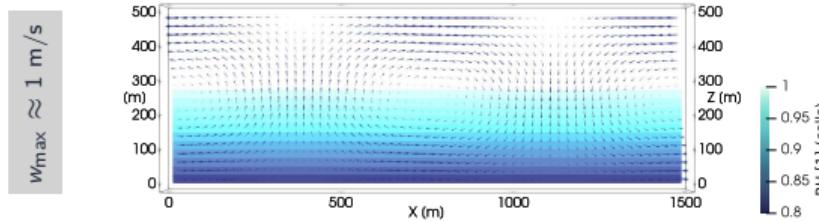
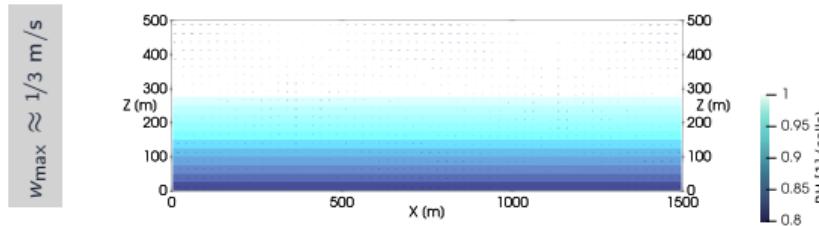
$w_{\max} \approx 1 \text{ m/s}$

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

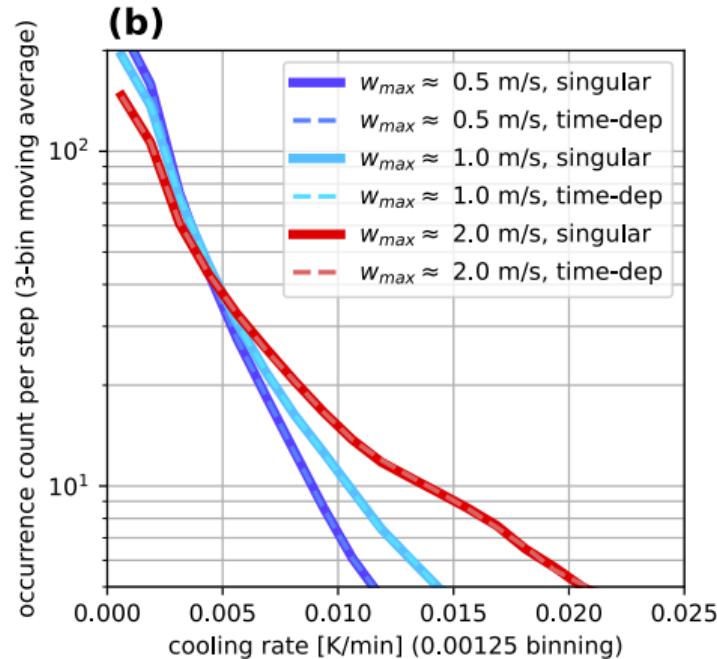
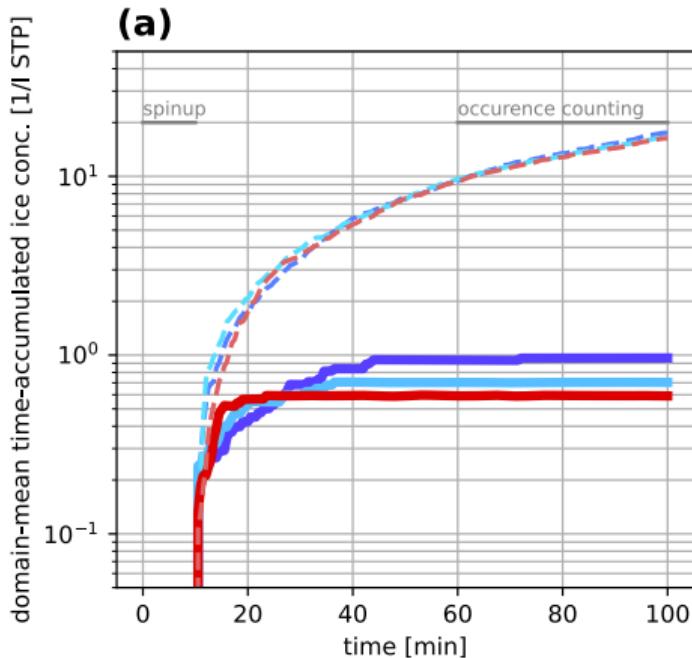
cooling-rate response (2D flow): singular vs. time-dependent



cooling-rate response (2D flow): singular vs. time-dependent

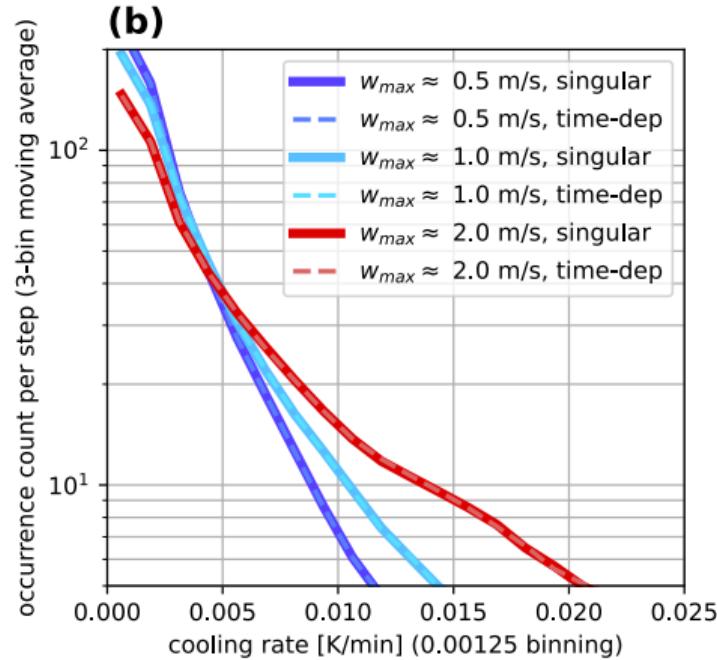
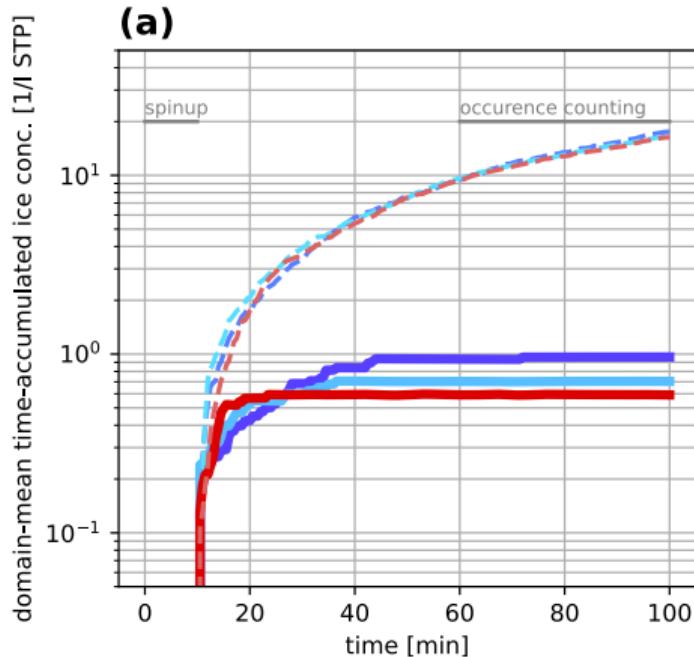


cooling-rate response (2D flow): singular vs. time-dependent



- ▶ singular vs. time-dependent markedly different (as in box model for $c \ll 1K/min$)

cooling-rate response (2D flow): singular vs. time-dependent



- ▶ singular vs. time-dependent markedly different (as in box model for $c \ll 1\text{K}/\text{min}$)
- ▶ diverse cooling rates even in a simple flow (far from $c \sim 1$ K/min for AIDA)

stay tuned: Arabas et al. 2023
(in prep.; e-print uploaded to arXiv)

100% Python & open-source: github.com/open-atmos

contact:
sylwester.arabas@agh.edu.pl