In Search for a Robust Representation of Cloud Microphysics for Aerosol-Cloud-Aerosol Interactions

S. Arabas[1], M. Andrejczuk[2], W. Grabowski[3], A. Jaruga[1], Z. Lebo[3], H. Pawłowska[1]

SIAM Conference on Mathematical and Computational Issues in Geosciences, Padua, June 2013

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2: Department of Physics, University of Oxford, UK
3: National Center for Atmospheric Research, Colorado, USA

Aerosol-cloud-aerosol interactions: conceptual picture

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background image: vitsly.ru / Hokusai

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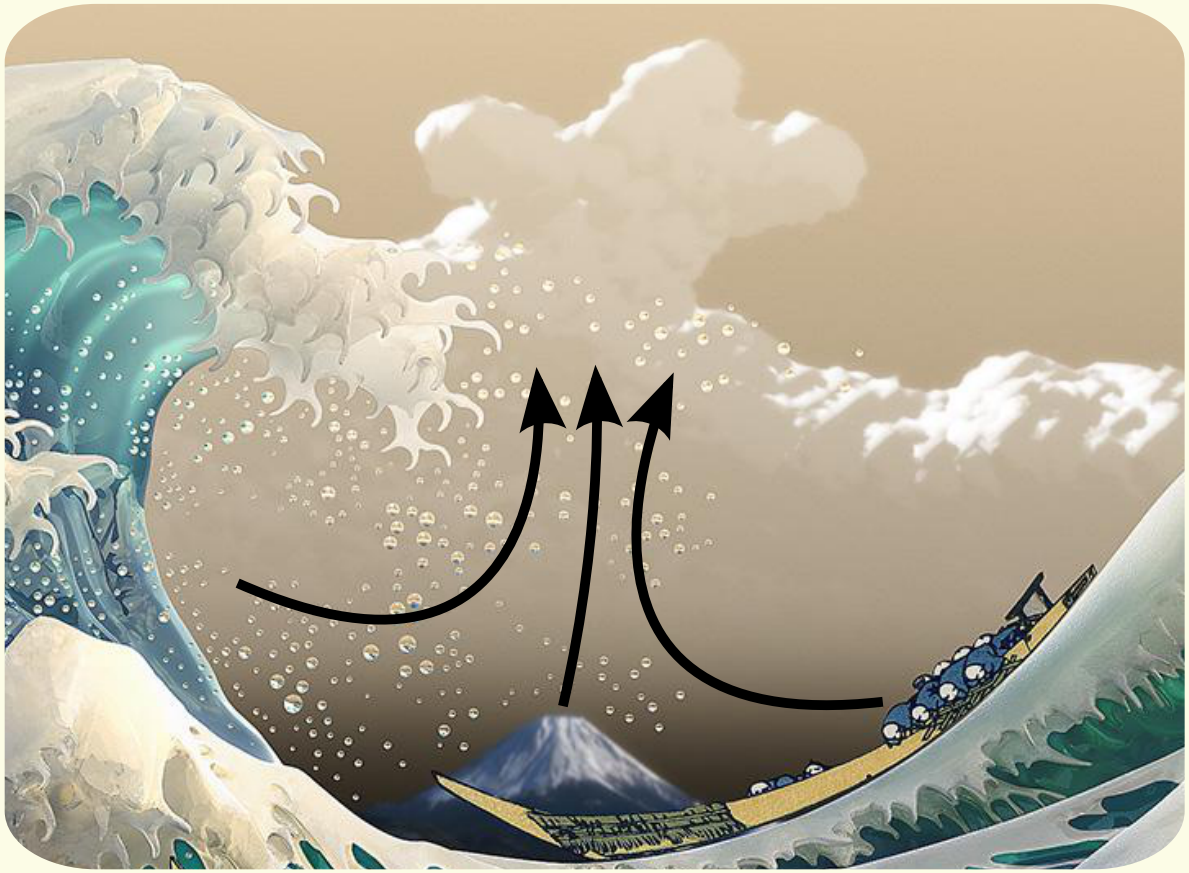
- aerosol particles of natural and anthropogenic origin act as condensation nuclei



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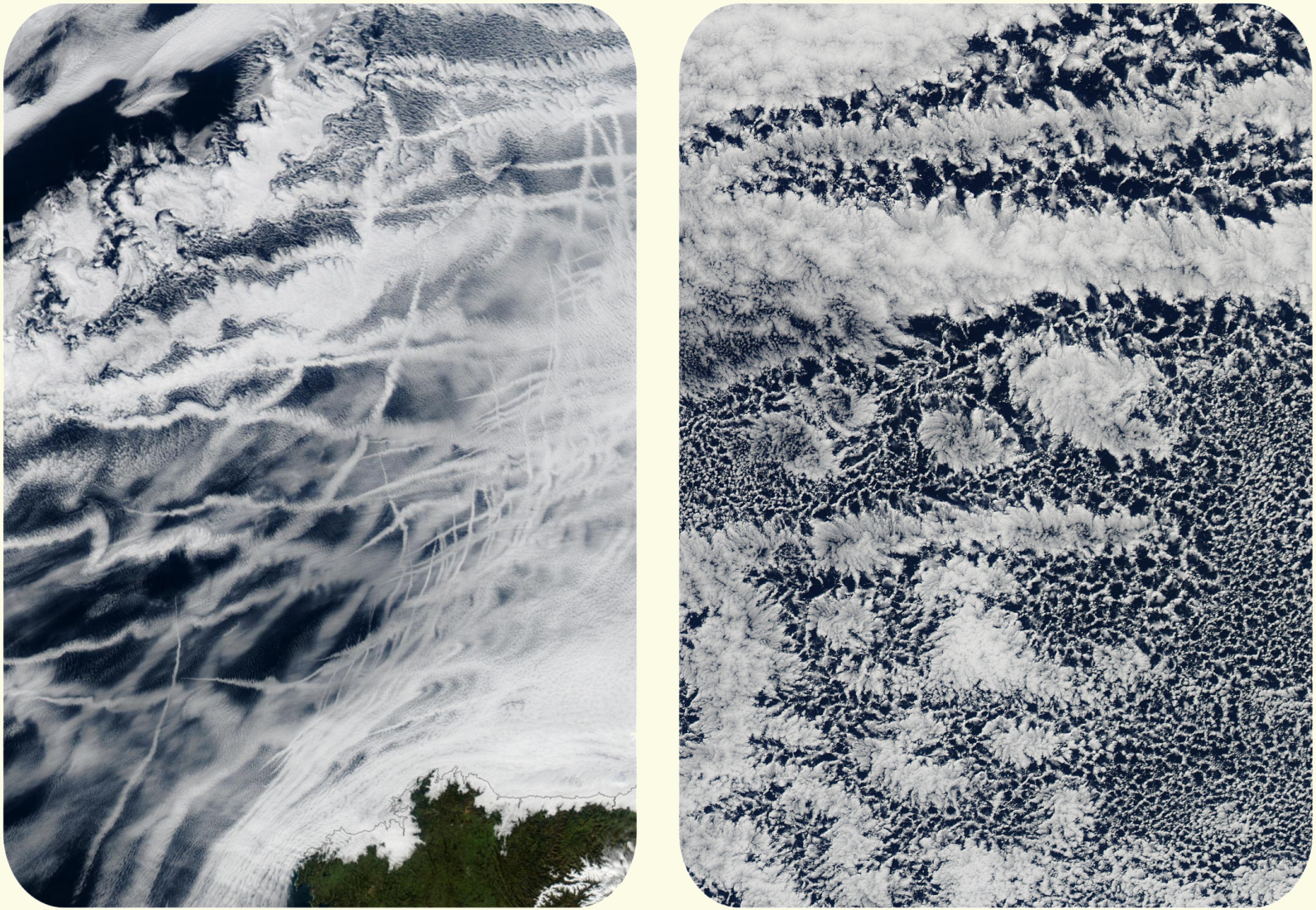
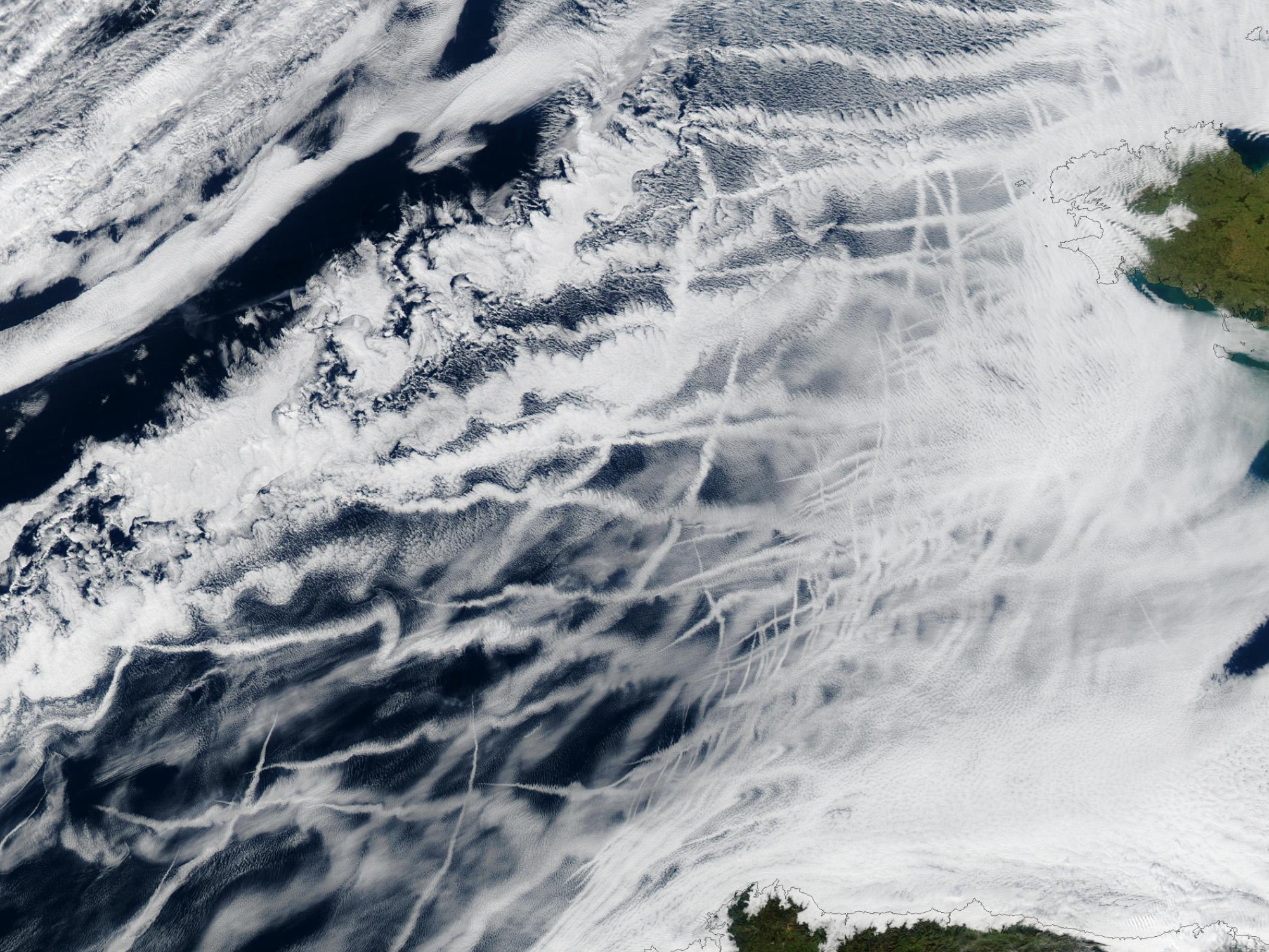
two-way interactions:
- aerosol characteristics influence cloud microstructure
- cloud processes influence aerosol size and composition

background image: vitsly.ru / Hokusai

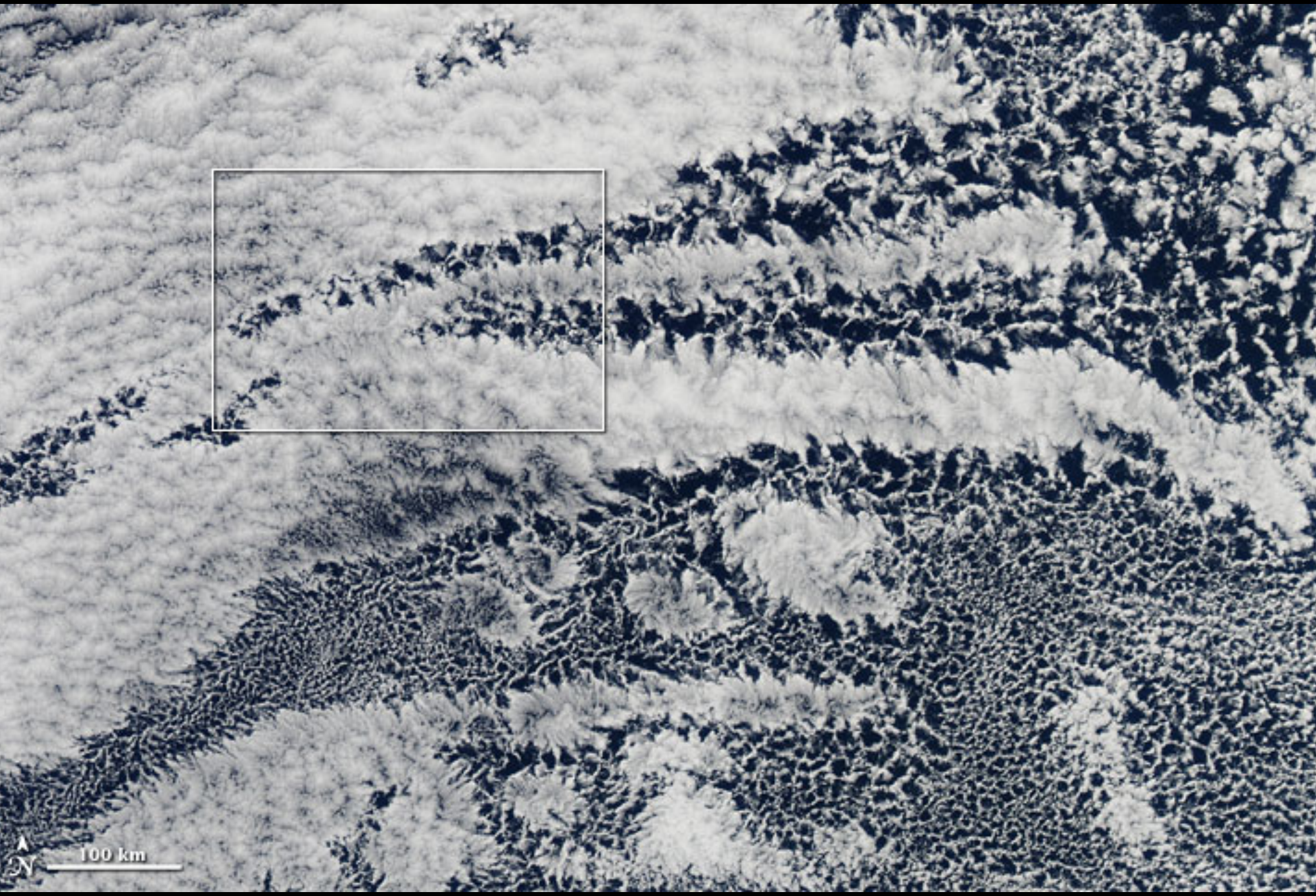
Aerosol-cloud-aerosol interactions: as seen from space

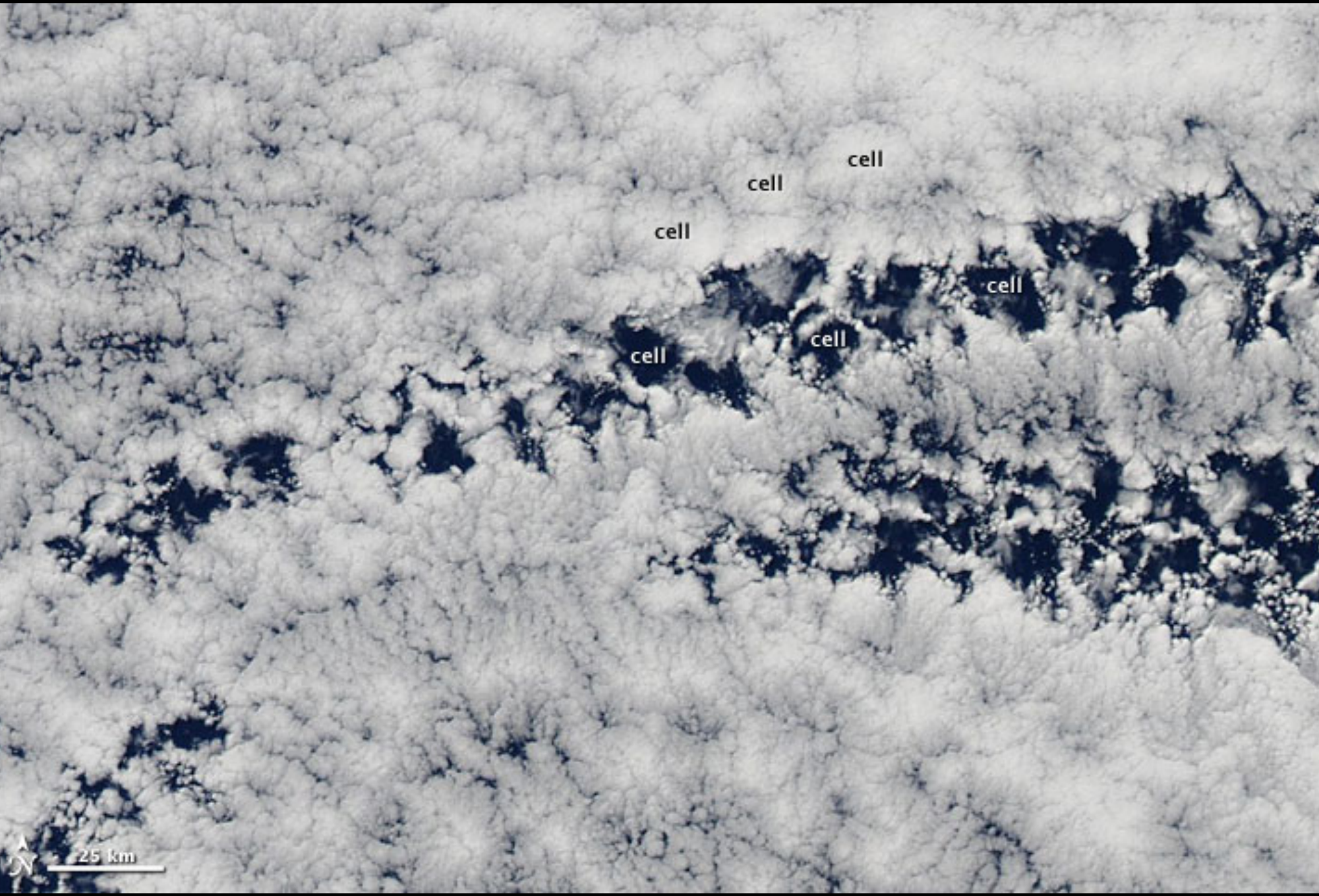


NASA/MODIS (27 Jan 2003 – Bay of Biscay; 17 Apr 2010 – off the coast of Peru)
http://visibleearth.nasa.gov/view.php?id=64992
http://earthobservatory.nasa.gov/IOTD/view.php?id=43795




NASA


N
100 km


cell
cell
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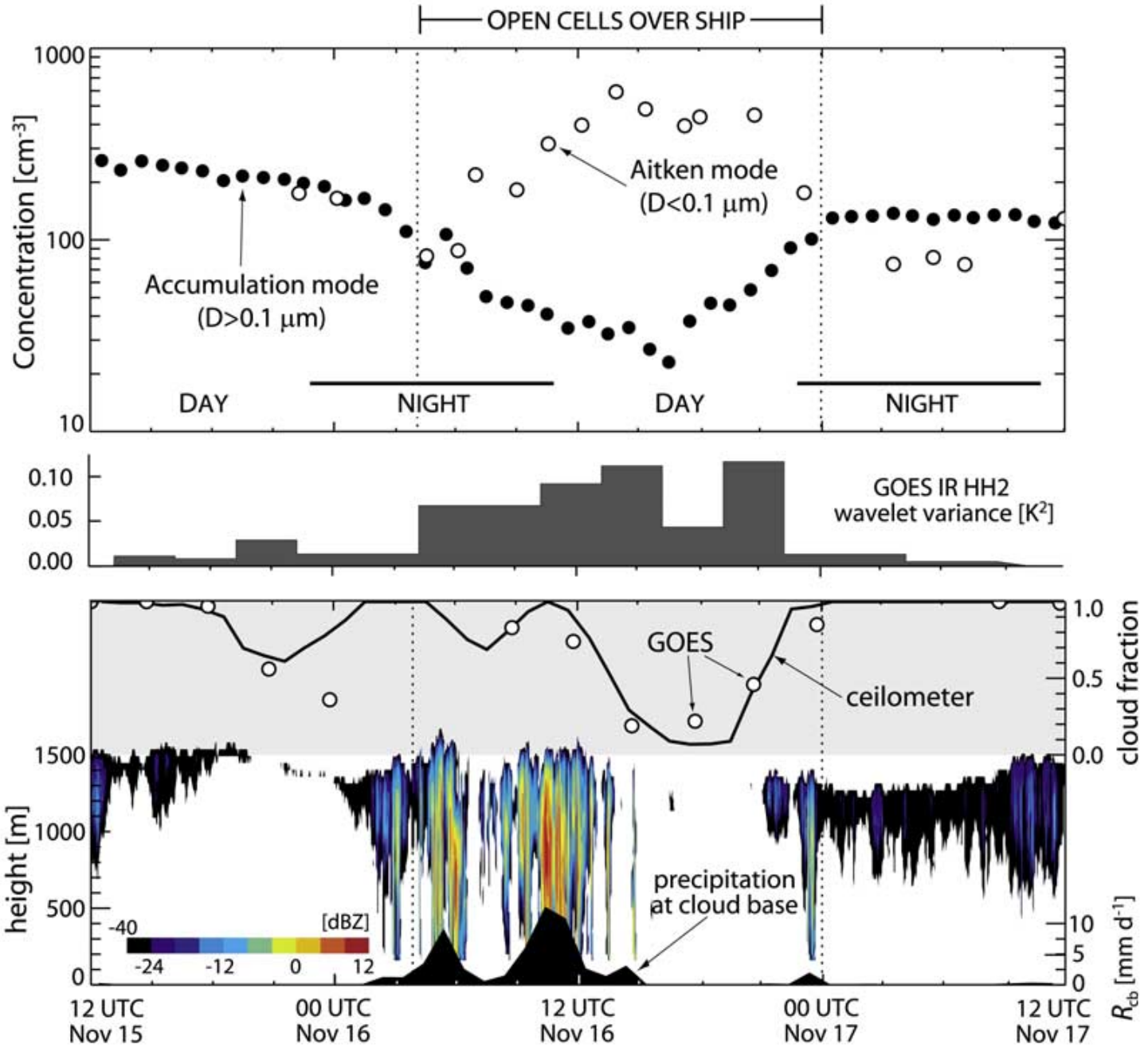
25 km



Wood et al. doi:10.1029/2007JD009371

Aerosol-cloud-aerosol interactions: modelling challenges

[1] cloud condensation nuclei

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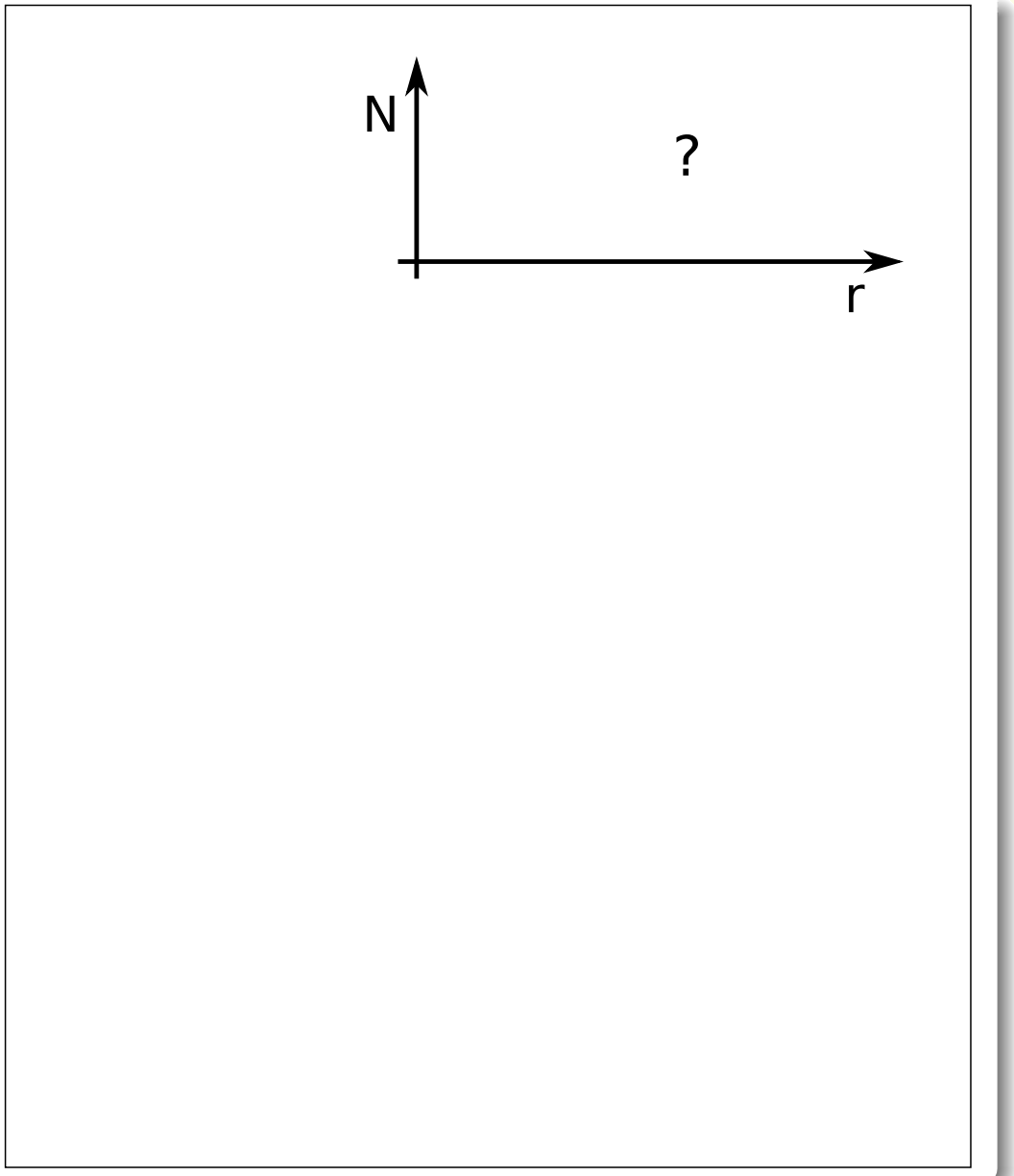
Aerosol, cloud and rain size spectra in LES

- single-moment bulk



Aerosol, cloud and rain size spectra in LES

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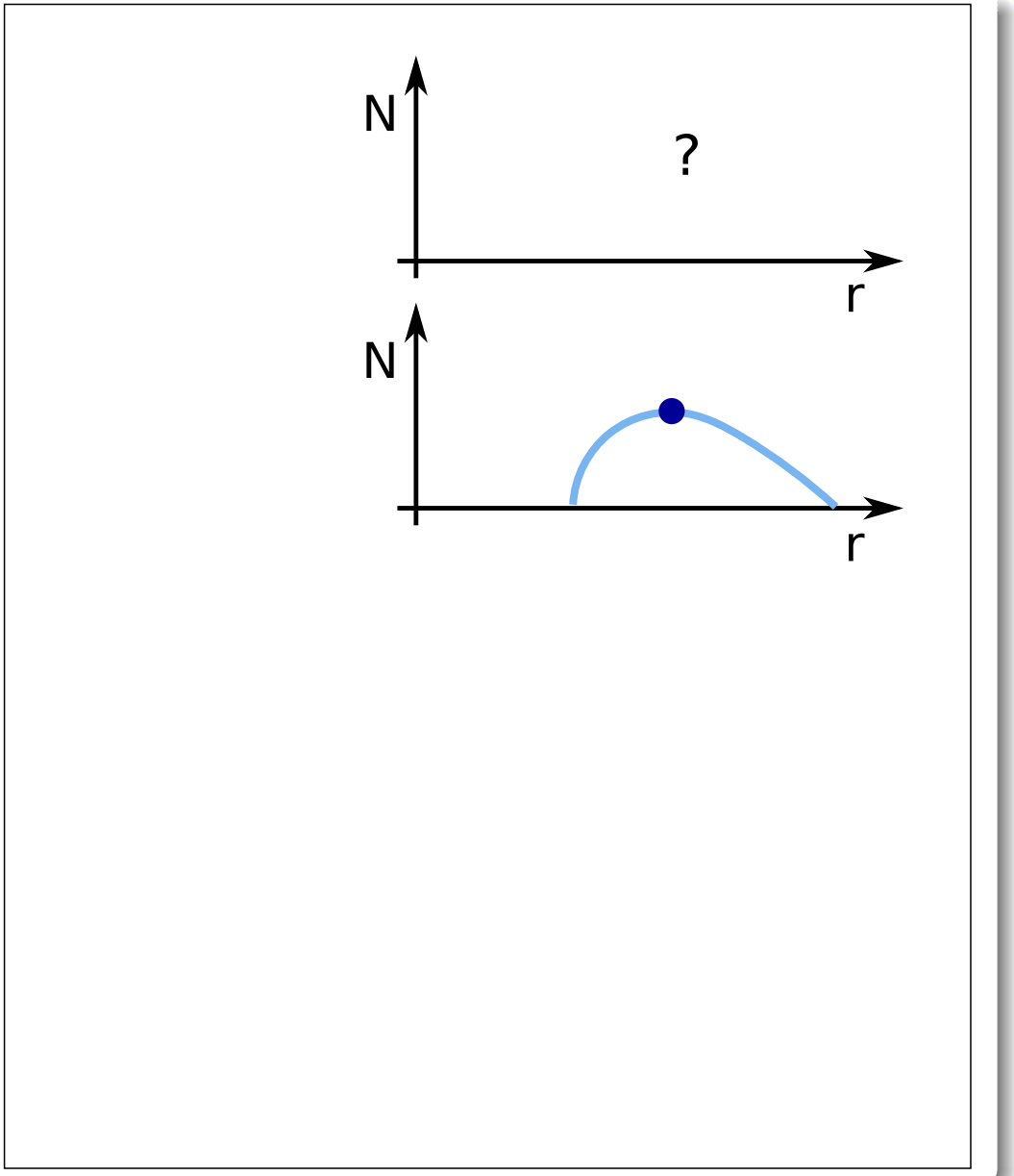

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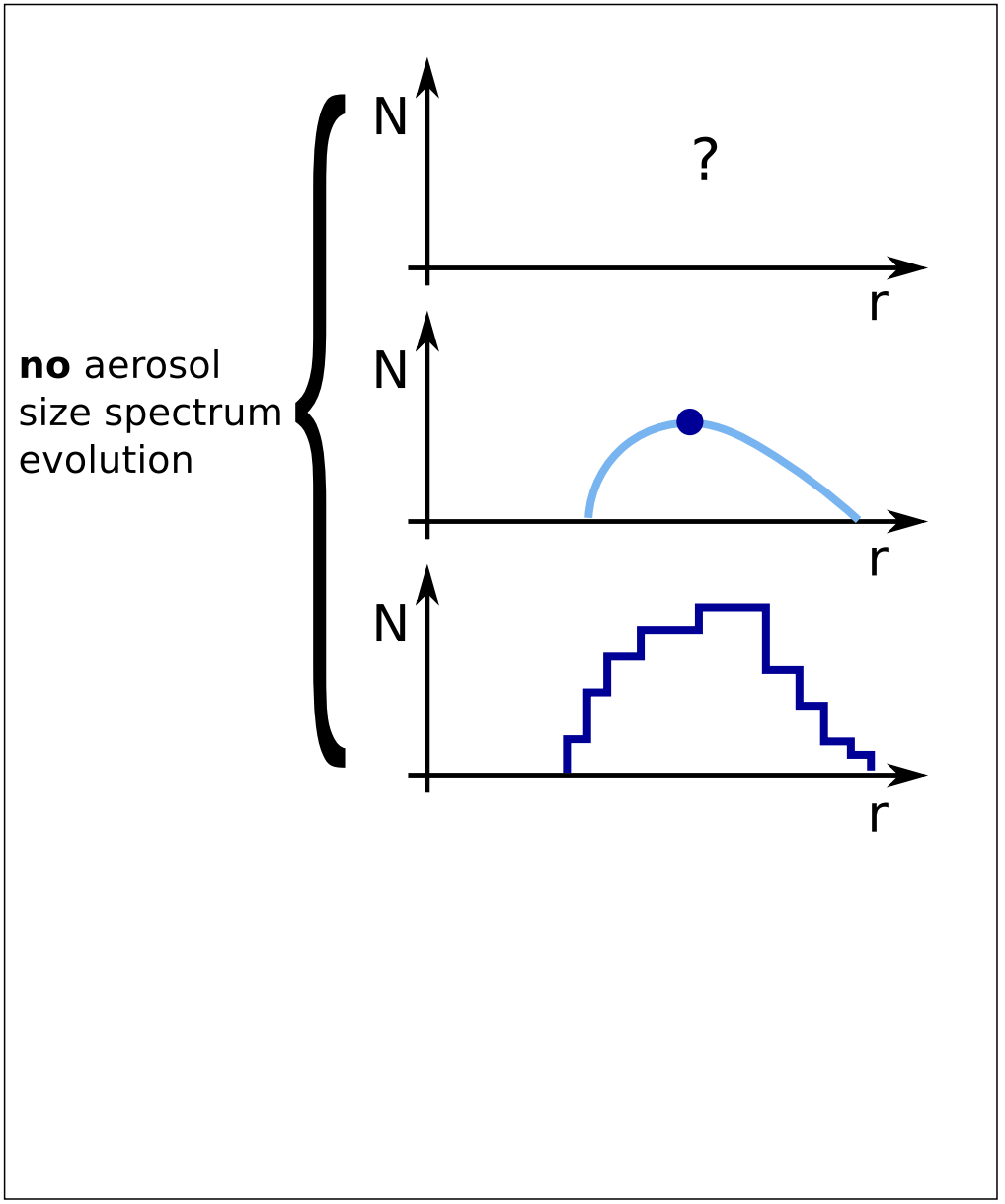

Aerosol, cloud and rain size spectra in LES

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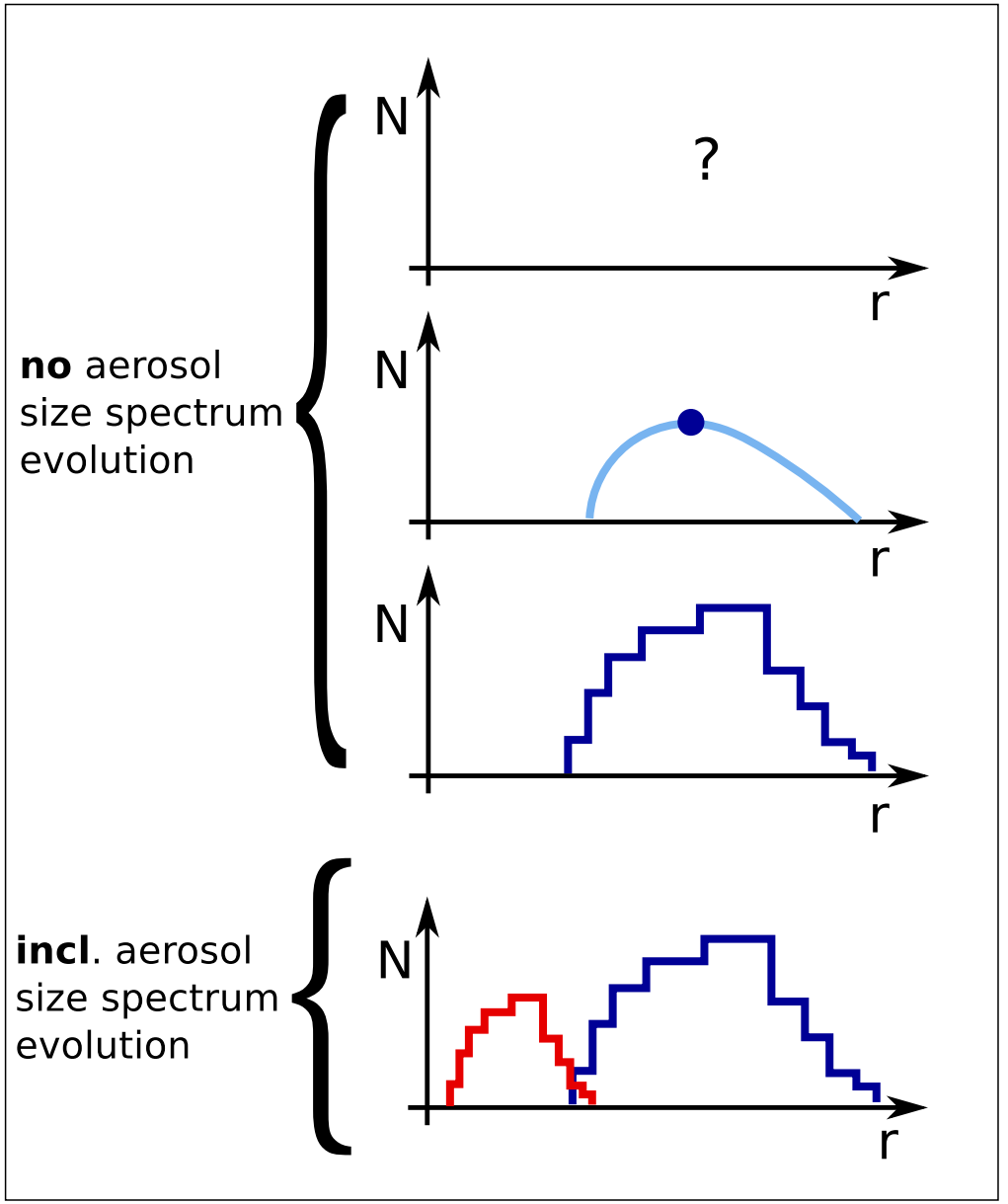
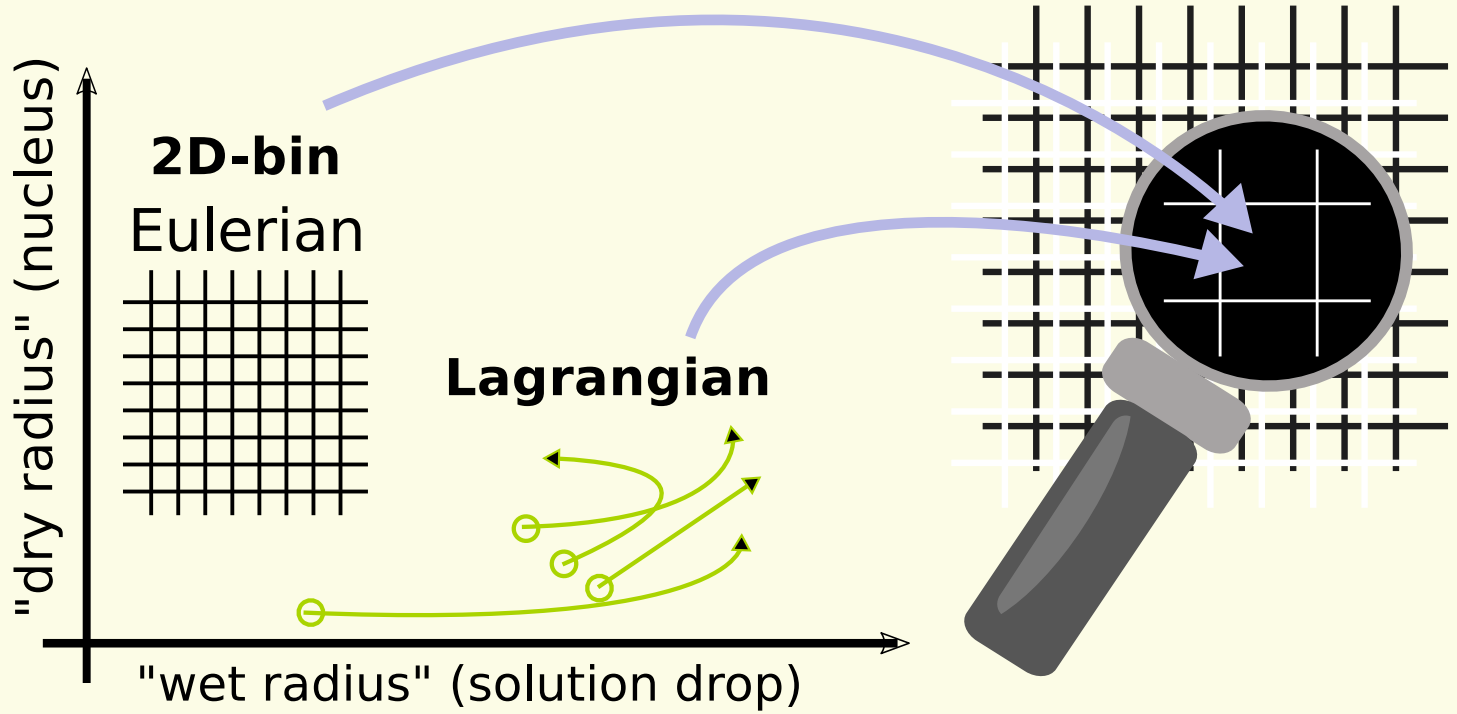
- multi-moment bulk
- „wet" size spectrum (bin)
- „wet vs. dry" 2D spectrum



Some recent examples (all dealing with warm-rain LES)

Andrejczuk et al. 2010		Lebo & Seinfeld 2011		Arabas & Shima 2013	
condensation:	Lagrangian	condensation:	Eulerian	condensation:	Lagrangian
collisions:	Eulerian	collisions:	Eulerian	collisions:	Lagrangian
		host model:	WRF	host model:	CReSS



Lagrangian condensation / Eulerian coalescence

Andrejczuk et al. 2010 (JGR)

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, D22214, doi:10.1029/2010JD014248, 2010

Cloud-aerosol interactions for boundary layer stratocumulus in the Lagrangian Cloud Model

M. Andrejczuk,[1] W. W. Grabowski,[2] J. Reisner,[3] and A. Gadian[1]

Received 23 March 2010; revised 1 September 2010; accepted 7 September 2010; published 30 November 2010.

[1] Lagrangian Cloud Model (LCM) is a mixed Eulerian/Lagrangian approach to atmospheric large eddy simulation (LES), with two-way coupling between Eulerian dynamics and thermodynamics and Lagrangian microphysics. Since Lagrangian representation of microphysics does not suffer from numerical diffusion in the radius space and solves full droplet growth equations, it may be considered an alternative for the bin approach. This paper documents the development of LCM to include collision/coalescence processes. The proposed algorithm maps Lagrangian parcels collision/coalescence events on the specified two-dimensional grid, with the first dimension spanning aerosol radius and the second dimension spanning the cloud droplet radius. The proposed approach is capable of representation of aerosol activation, deactivation, transport inside the droplets, and processing by clouds and in the future may be used to investigate details of these processes. As an illustration, LCM with collision/coalescence

Eulerian condensation / Eulerian coalescence

Lebo & Seinfeld 2011 (ACP)

Atmos. Chem. Phys., 11, 12297–12316, 2011
www.atmos-chem-phys.net/11/12297/2011/
doi:10.5194/acp-11-12297-2011

Atmospheric Chemistry and Physics

A continuous spectral aerosol-droplet microphysics model

Z. J. Lebo[1] **and J. H. Seinfeld**[1,2]

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[2]Chemical Engineering, California Institute of Technology, Pasadena, 91125, CA, USA

Received: 28 July 2011 – Published in Atmos. Chem. Phys. Discuss.: 22 August 2011
Revised: 4 November 2011 – Accepted: 24 November 2011 – Published: 8 December 2011

Abstract. A two-dimensional (2-D) continuous spectral aerosol-droplet microphysics model is presented and implemented into the Weather Research and Forecasting (WRF) model for large-eddy simulations (LES) of warm clouds. Activation and regeneration of aerosols are treated explicitly in the calculation of condensation/evaporation. The model includes a 2-D spectrum that encompasses wet aerosol particles (i.e., haze droplets), cloud droplets, and drizzle droplets in a continuous and consistent manner and allows for the explicit tracking of aerosol size within cloud droplets due to collision-coalescence. The system of differential equations

Lagrangian condensation / Lagrangian coalescence

Arabas & Shima 2013 (JAS)

Journal of the Atmospheric Sciences 2013 ; e-View
doi: http://dx.doi.org/10.1175/JAS-D-12-0295.1

Large Eddy Simulations of Trade-Wind Cumuli using Particle-Based Microphysics with Monte-Carlo Coalescence

Sylwester Arabas*

Institute of Geophysics, Faculty of Physics, University of Warsaw, Warsaw, Poland

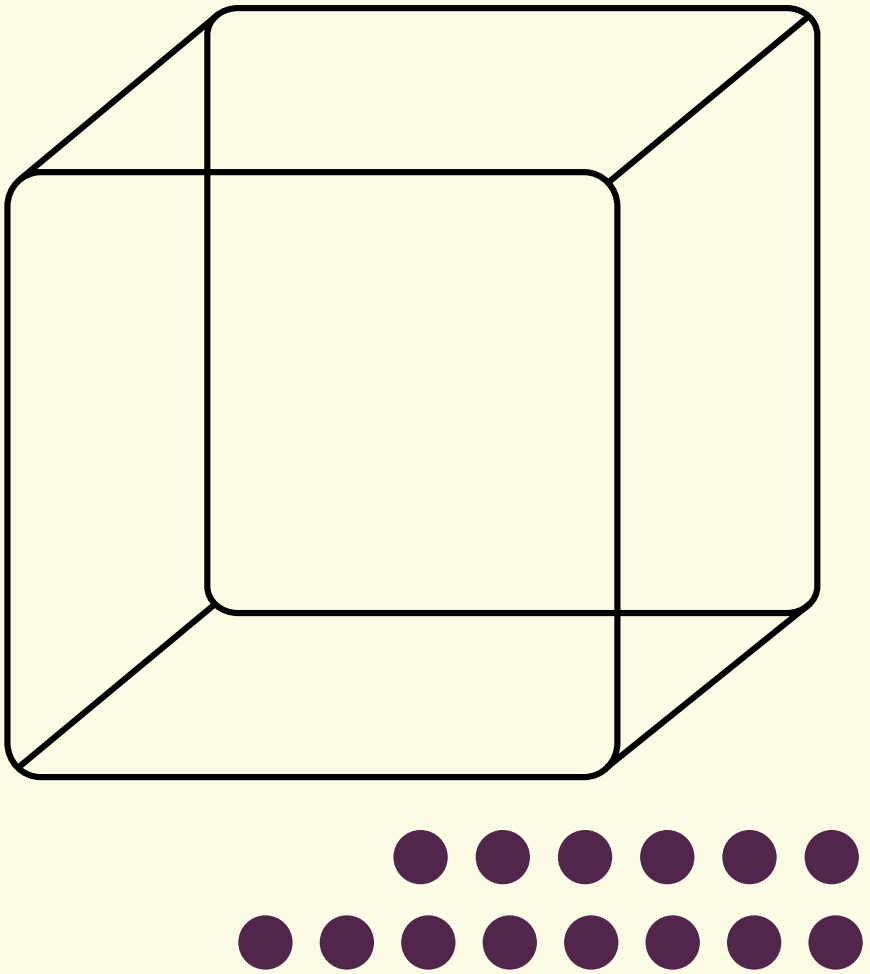
Shin-ichiro Shima[†,‡]

Graduate School of Simulation Studies, University of Hyogo, Kobe, Japan

Abstract

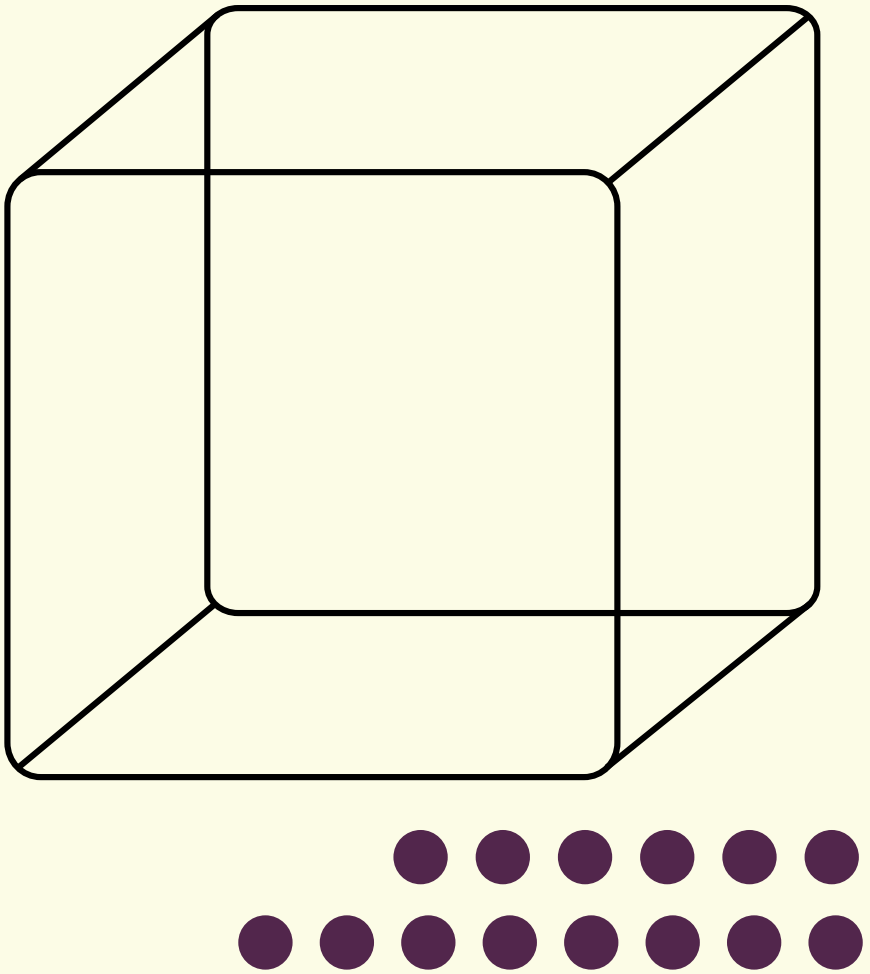
A series of simulations employing the Super-Droplet Method (SDM) for representing aerosol, cloud and rain microphysics in Large Eddy Simulations (LES) is discussed. The particle-based formulation treats all particles in the same way subjecting them to condensational growth and evaporation, transport of the particles by the flow, gravitational settling and collisional growth. SDM features a Monte-Carlo type numerical scheme for representing the collision and coalescence process. All processes combined cover representation of CCN activation, drizzle formation by autoconversion, accretion of cloud droplets, self-collection of raindrops and precipitation including aerosol wet deposition. The model set-up used in the study is based on observations from the Rain In Cumulus over the Ocean (RICO) field project. Cloud and rain droplet size spectra obtained in the simulations are discussed in context of previously-published analyses of aircraft observations carried out during RICO. The analysis covers height-resolved statistics of simulated cloud microphysical parameters such as droplet number concentration, effective radius and parameters describing the width of the cloud droplet size spectrum. A reasonable agreement with measurements is found for several of the discussed parameters. The sensitivity of the results to the grid resolution of the LES, as well as to the sampling density of the probabilistic Monte-Carlo type model is explored.

Lagrangian μ-physics: key concepts



Domain randomly populated with "μ-physics information carriers"
(aka super droplets)

Lagrangian μ-physics: key concepts



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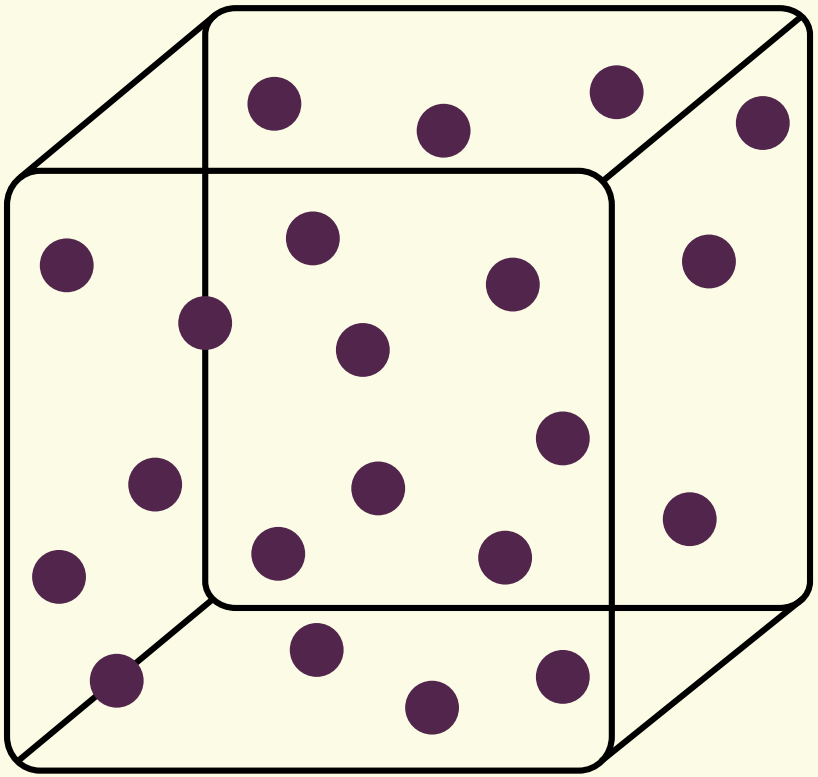

Domain randomly populated with "μ-physics information carriers" (aka super droplets)

carrier attributes:

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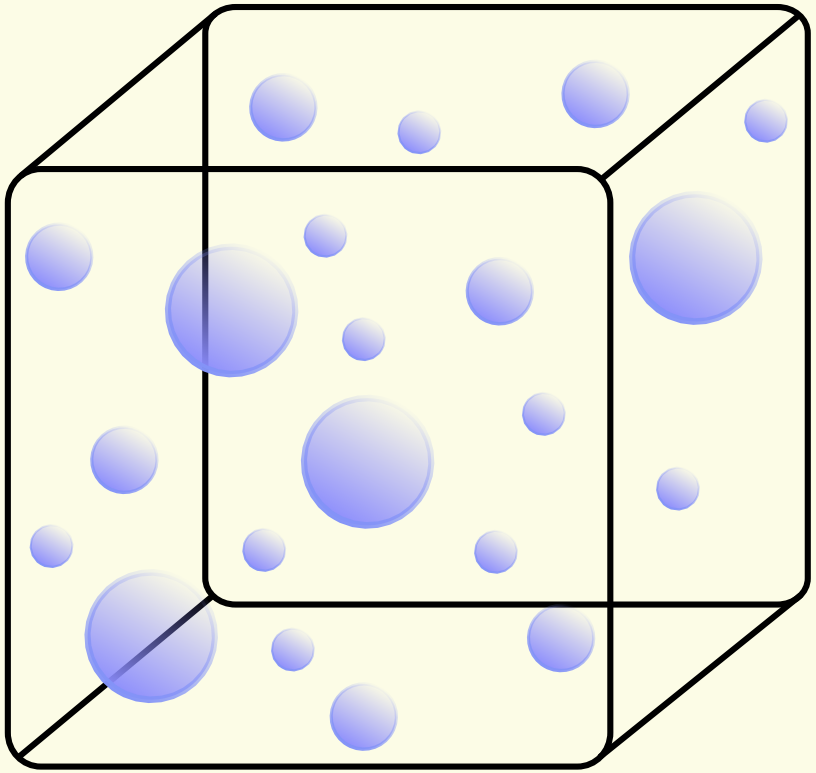
Lagrangian μ-physics: key concepts



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carrier attributes:

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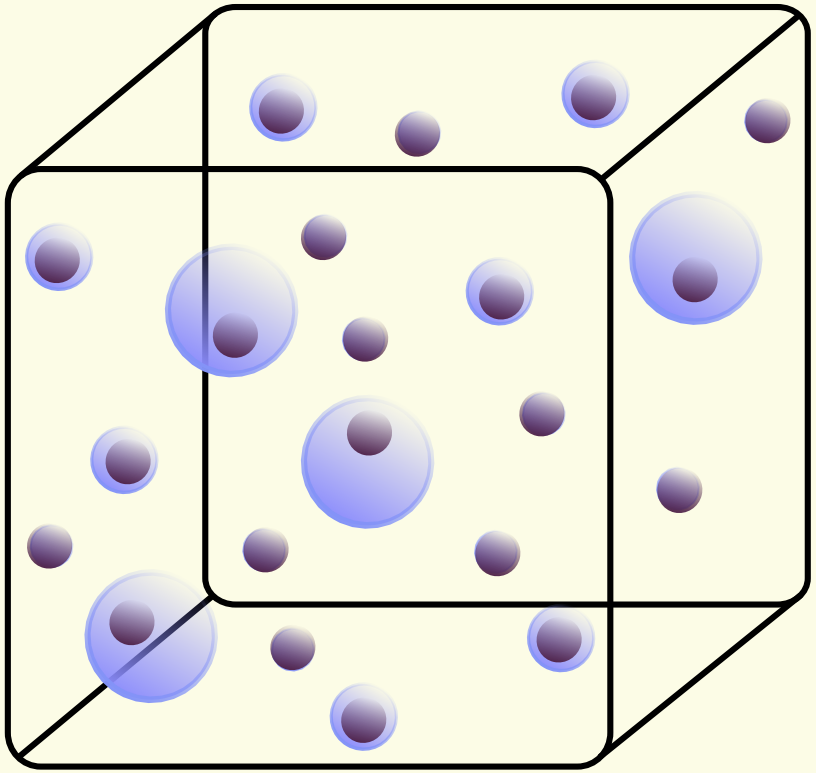

Domain randomly populated with "μ-physics information carriers" (aka super droplets)

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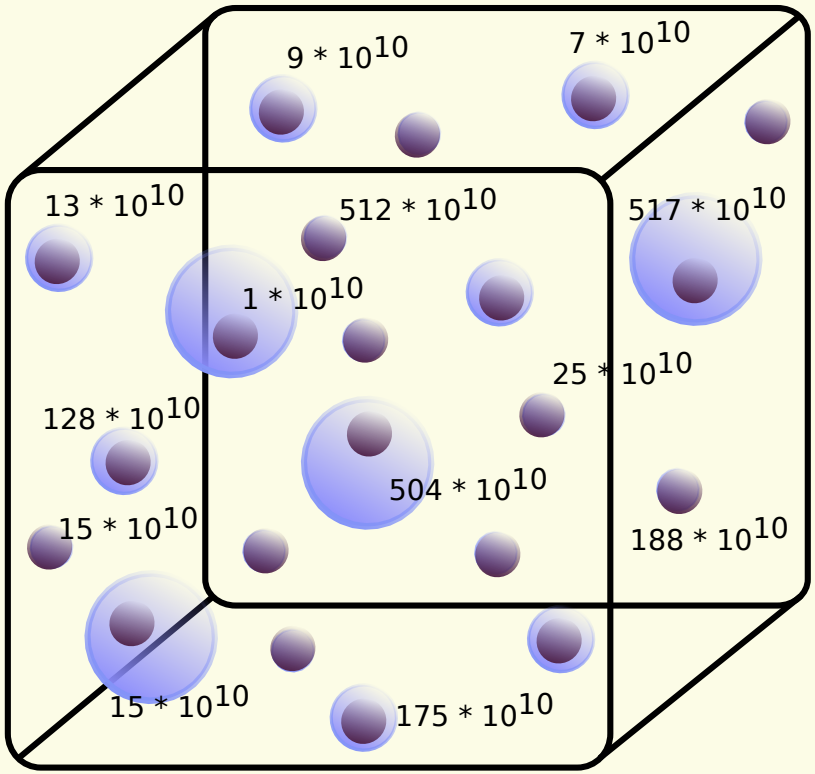

Domain randomly populated with "μ-physics information carriers" (aka super droplets)

carrier attributes:

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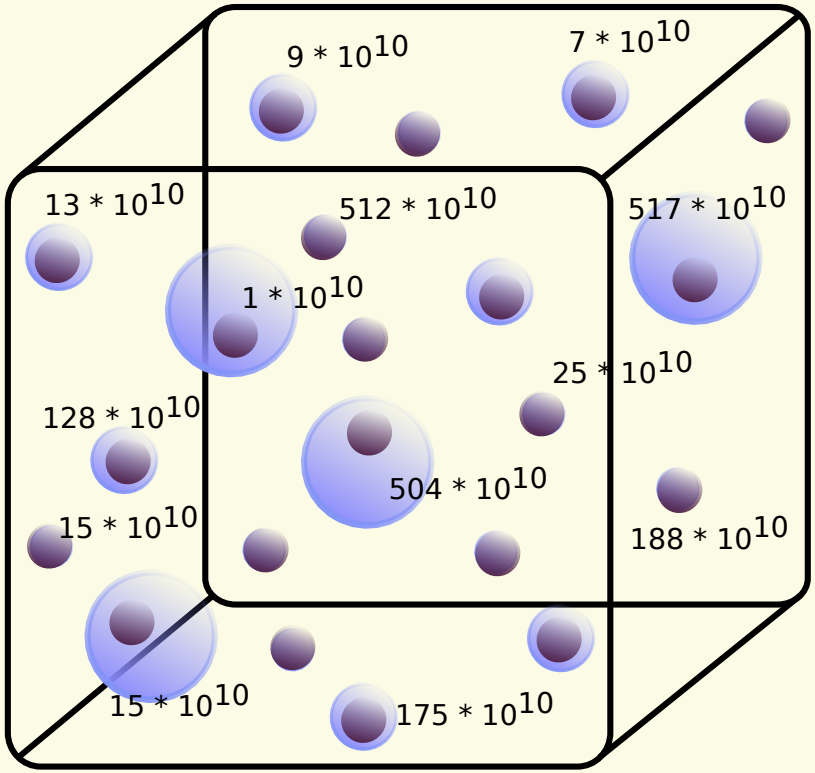
- dry radius
- multiplicity

Lagrangian μ-physics: key concepts



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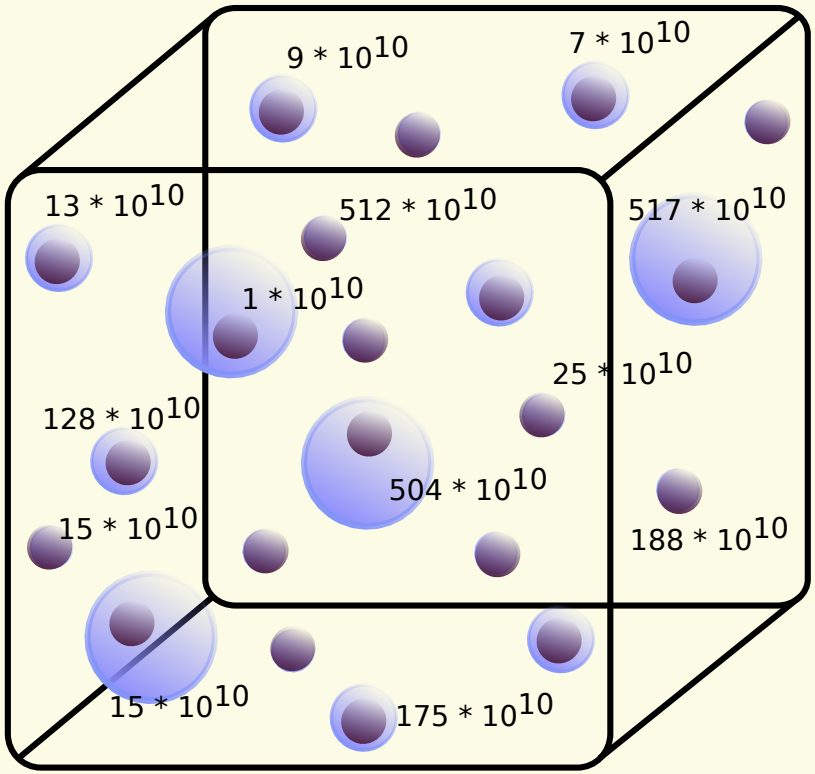

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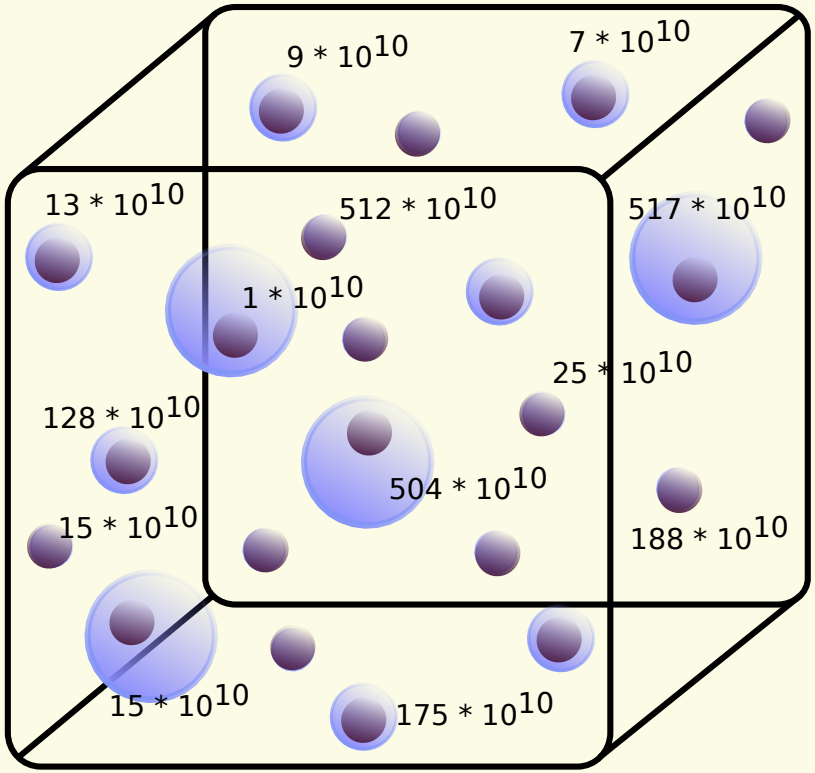

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(aqueous chemistry!)

Lagrangian μ-physics: coupling with the host model

Eulerian / PDE	Lagrangian / ODE

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	collisional growth
	sedimentation

Lagrangian μ-physics: coupling with the host model

Eulerian / PDE	Lagrangian / ODE
advection of heat advection of moisture	particle transport by the flow condensational growth collisional growth sedimentation
$\partial_t(\rho_d r) + \nabla \cdot (\vec{v} \rho_d r) = \rho_d \dot{r}$	$\dot{r} = \sum_{\text{particles} \in \Delta V} \ldots$
$\partial_t(\rho_d \theta) + \nabla \cdot (\vec{v} \rho_d \theta) = \rho_d \dot{\theta}$	$\dot{\theta} = \sum_{\text{particles} \in \Delta V} \ldots$

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advection of trace gases	in-particle aqueous chemistry
...	...

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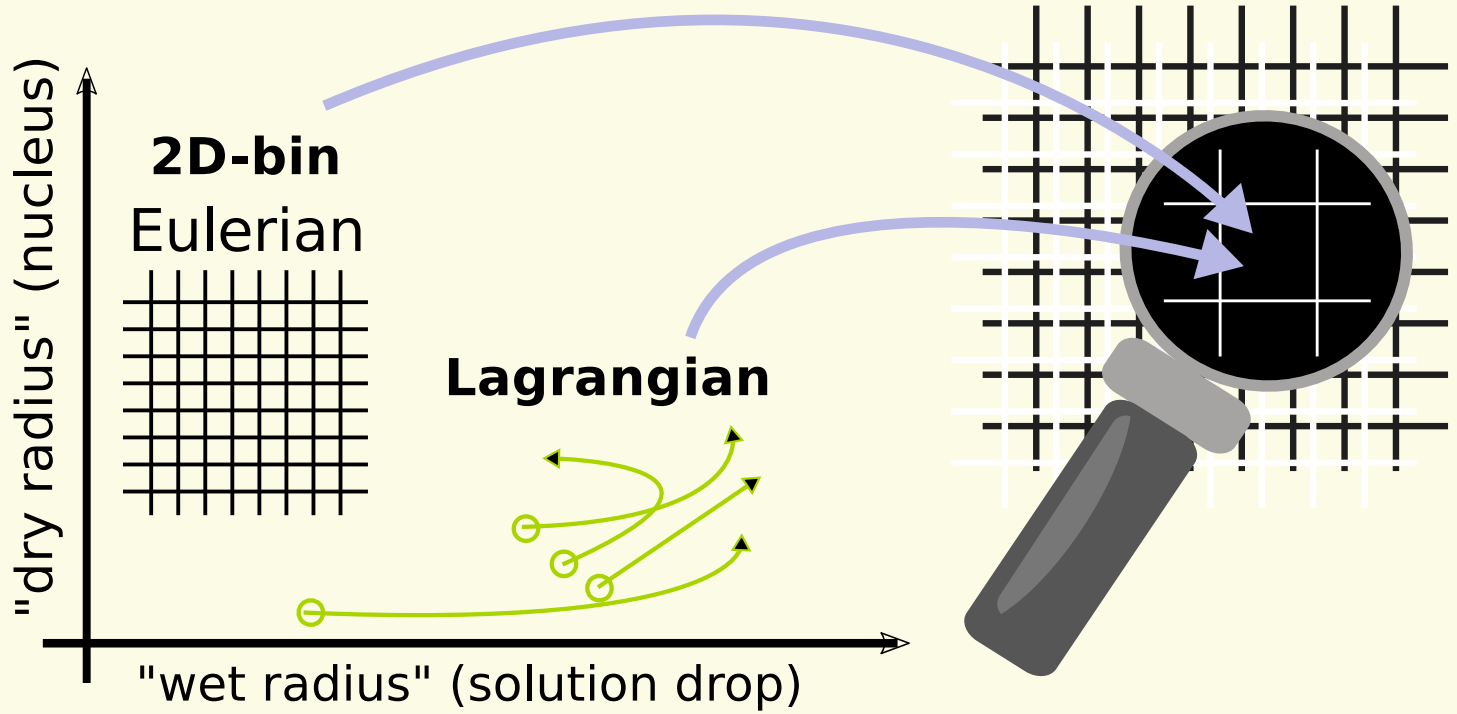


Comparison on occasion of the 8th ICMW

Muhlbauer et al. 2013 (BAMS)

REEXAMINATION OF THE STATE OF THE ART OF CLOUD MODELING SHOWS REAL IMPROVEMENTS

BY ANDREAS MUHLBAUER, WOJCIECH W. GRABOWSKI, SZYMON P. MALINOWSKI, THOMAS P. ACKERMAN, GEORGE H. BRYAN, ZACHARY J. LEBO, JASON A. MILBRANDT, HUGH MORRISON, MIKHAIL OVCHINNIKOV, SARAH TESSENDORF, JULIE M. THÉRIAULT, AND GREG THOMPSON

For nearly 30 years, International Cloud Modeling Workshops have been held traditionally every 4 years and typically during the week before the International Conference on Clouds and Precipitation (ICCP). That is exactly when the Eighth International Cloud Modeling Workshop[1] took place in summer 2012, this time in Poland.[2]

Rooted in the weather modification program of the World Meteorological Organization (WMO), the core objectives of the International Cloud Modeling Workshops have been focused on the numerical

EIGHTH INTERNATIONAL CLOUD MODELING WORKSHOP

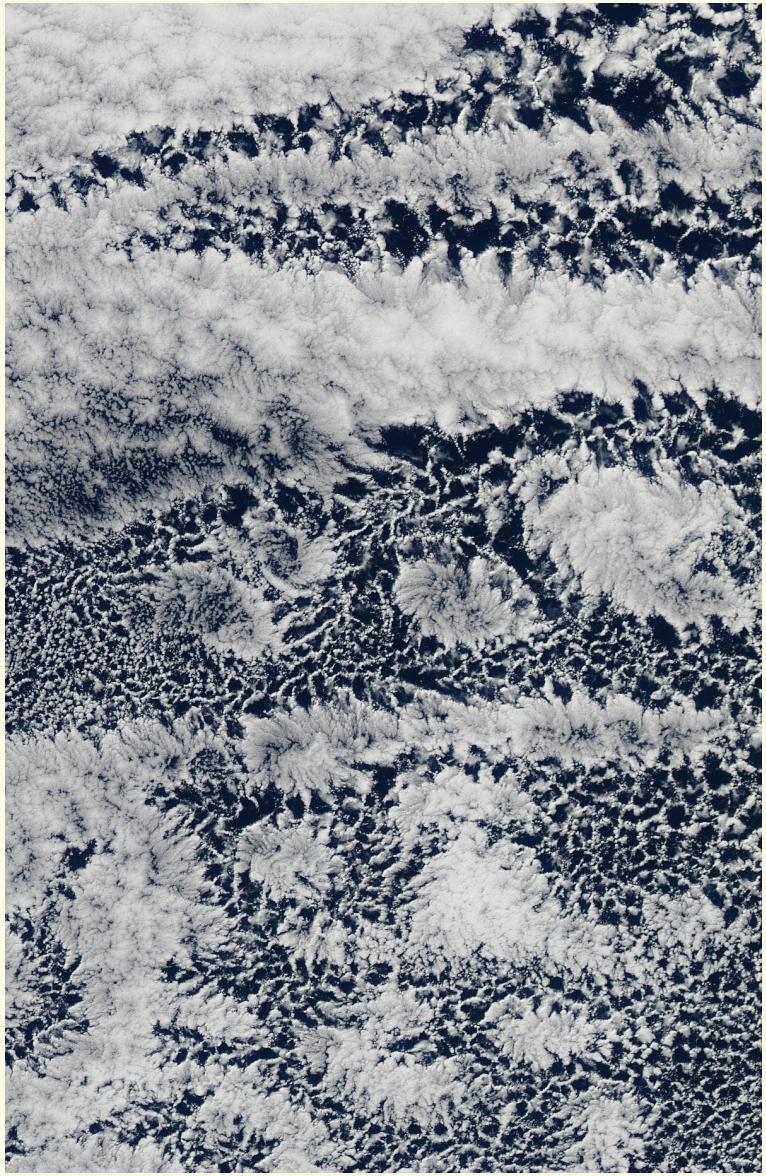
WHAT: Fifty-six scientists from 14 different countries and four continents carried on a nearly three-decade history of International Cloud Modeling Workshops that traditionally utilizes observationally derived case studies to provide a framework for model comparisons.
WHEN: 23–27 July 2012
WHERE: Warsaw, Poland

8th ICMW case 1: VOCALS-inspired Sc setup

8th ICMW case 1:

CASE 1: CCN PROCESSING BY DRIZZLING MARINE STRATOCUMULUS. This case of drizzling marine stratocumulus in the subtropical southeast Pacific is designed to investigate the accuracy and efficiency of various numerical approaches in simulating the processing of cloud condensation nuclei (CCN) by precipitating clouds. The case leaders are Wojciech Grabowski [National Center for Atmospheric Research (NCAR) Mesoscale and Microscale Meteorology (MMM)] and Zachary Lebo [NCAR Advanced Study Program (ASP)].

The case is motivated by the observed dramatic microphysical contrasts between adjacent areas of stratocumulus clouds with open and closed cellular characteristics and is based on aircraft observations from the Variability of the American Monsoon Systems (VAMOS) Ocean–Cloud–Atmosphere–Land Study (VOCALS) Regional Experiment (REx) research flight (RF) 6 that took place on 25 October 2008. The processing of CCN is assumed to play an important role in the transition from closed to open cellular convection and the development of "ultra-clean layers," which are regions of highly depleted aerosol concentrations. The major objective of this case is to provide numerical standards



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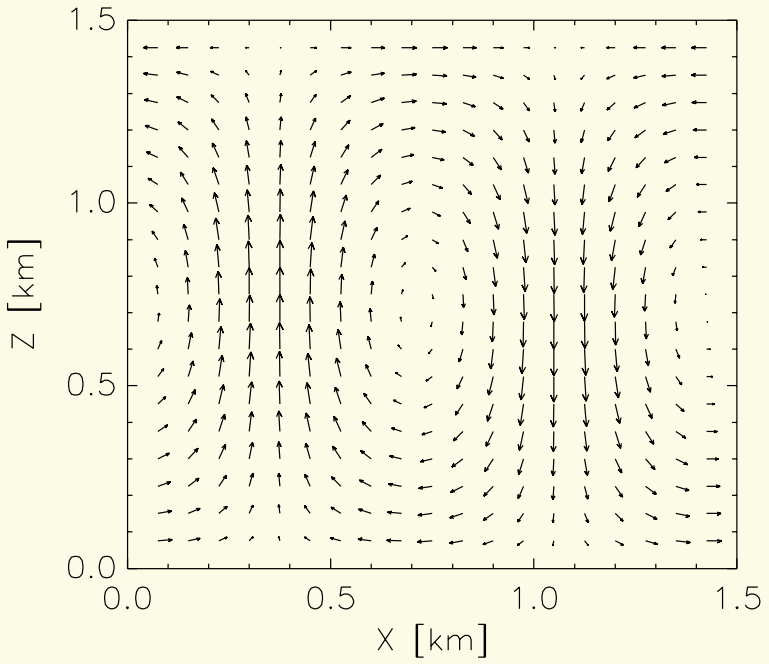

- 2D prescribed flow

8th ICMW case 1: VOCALS-inspired Sc setup

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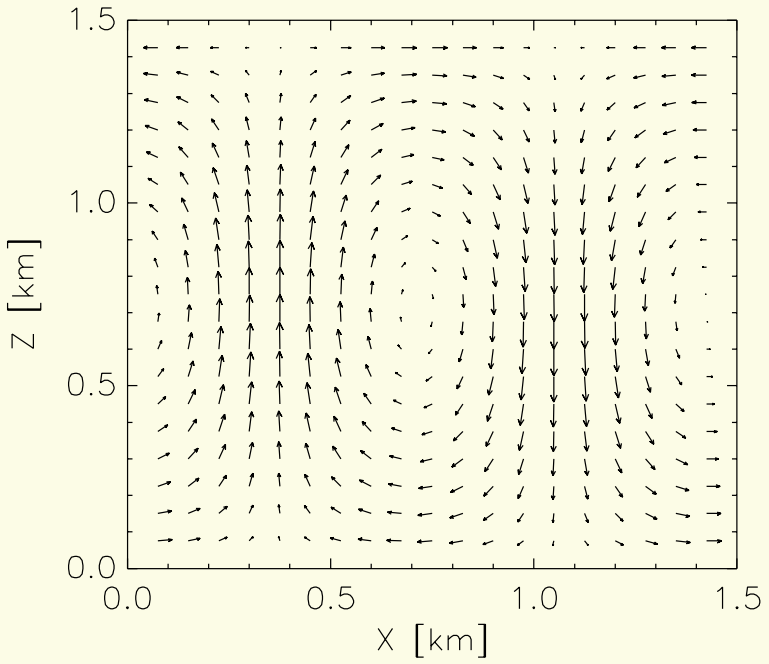
The case is motivated by the observed dramatic microphysical contrasts between adjacent areas of stratocumulus clouds with open and closed cellular characteristics and is based on aircraft observations from the Variability of the American Monsoon Systems (VAMOS) Ocean–Cloud–Atmosphere–Land Study (VOCALS) Regional Experiment (REx) research flight (RF) 6 that took place on 25 October 2008. The processing of CCN is assumed to play an important role in the transition from closed to open cellular convection and the development of "ultra-clean layers," which are regions of highly depleted aerosol concentrations. The major objective of this case is to provide numerical standards



- 2D prescribed flow
- single eddy spanning the domain

8th ICMW case 1: VOCALS-inspired Sc setup

8th ICMW case 1:

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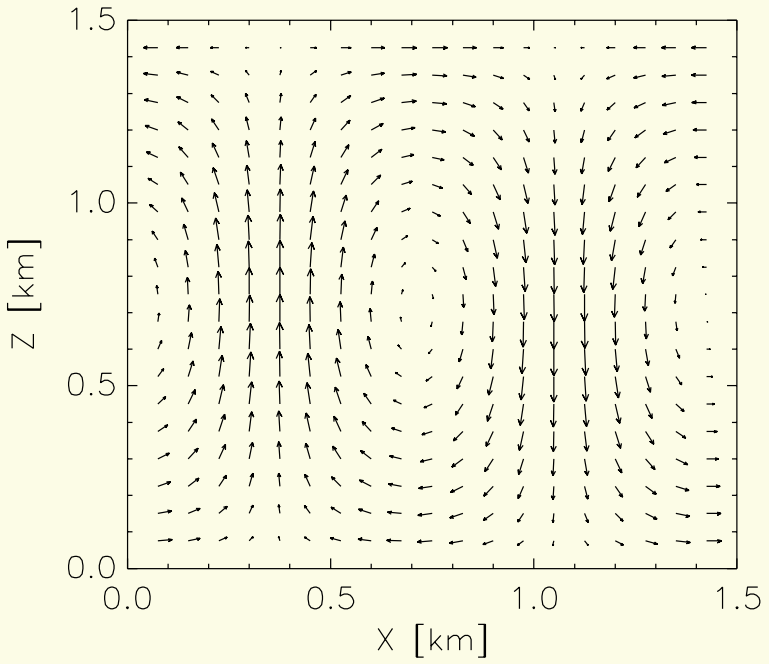

- 2D prescribed flow
- single eddy spanning the domain
- periodic boundaries

8th ICMW case 1: VOCALS-inspired Sc setup

8th ICMW case 1:

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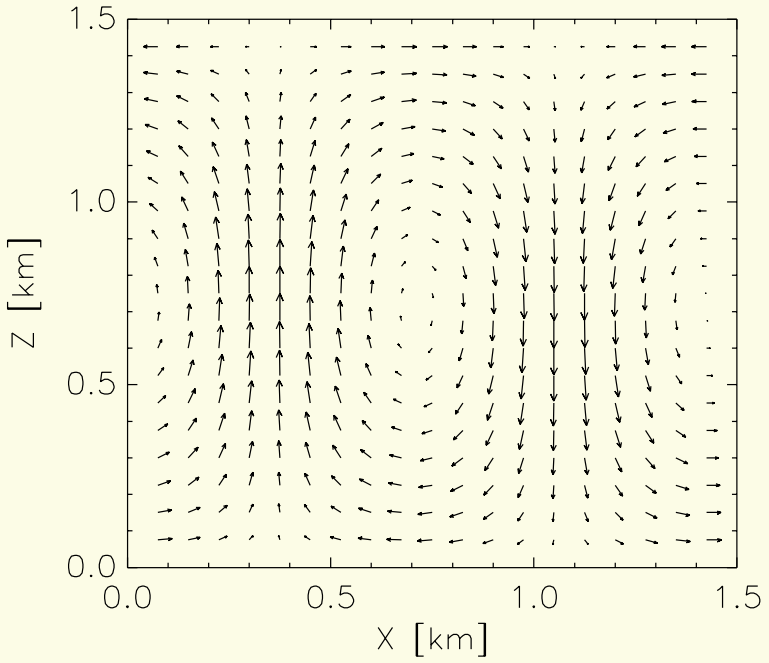
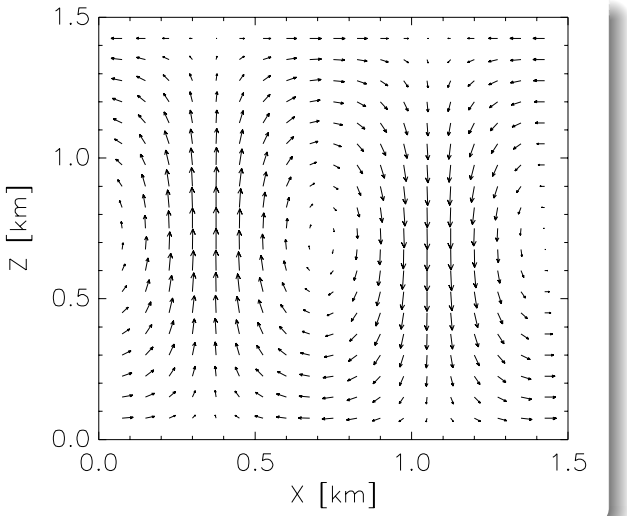
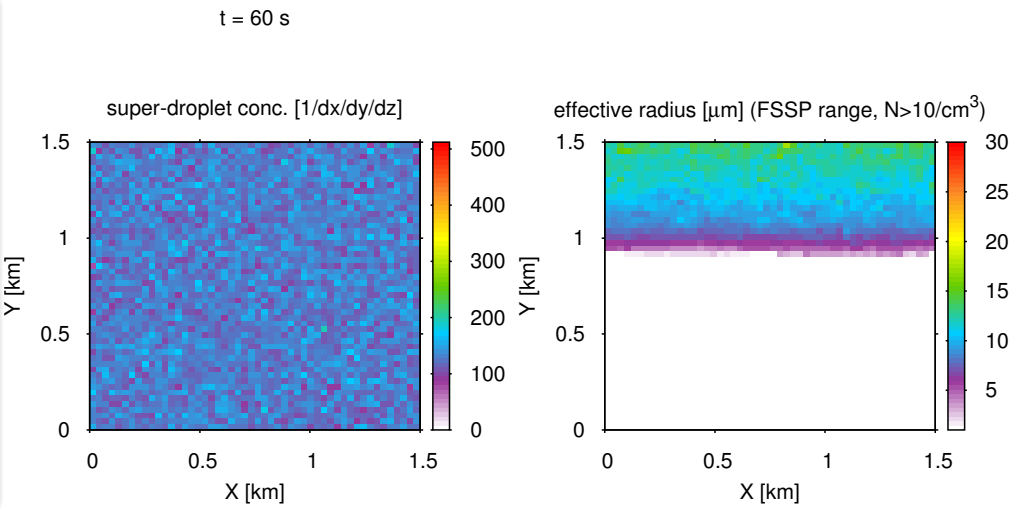
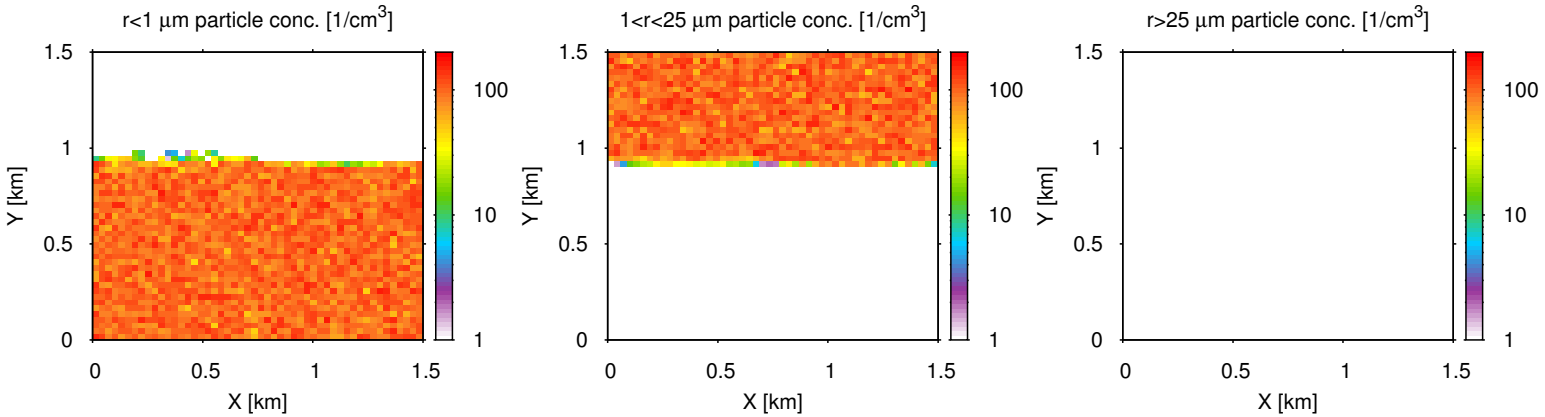


- 2D prescribed flow
- single eddy spanning the domain
- periodic boundaries
- Stratocumulus deck in the upper 1/3 of the domain

8th ICMW case 1 with Lagrangian/Monte-Carlo μ-physics







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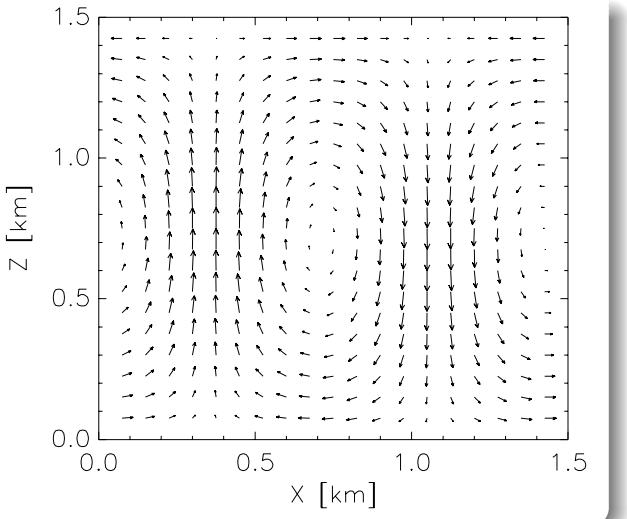

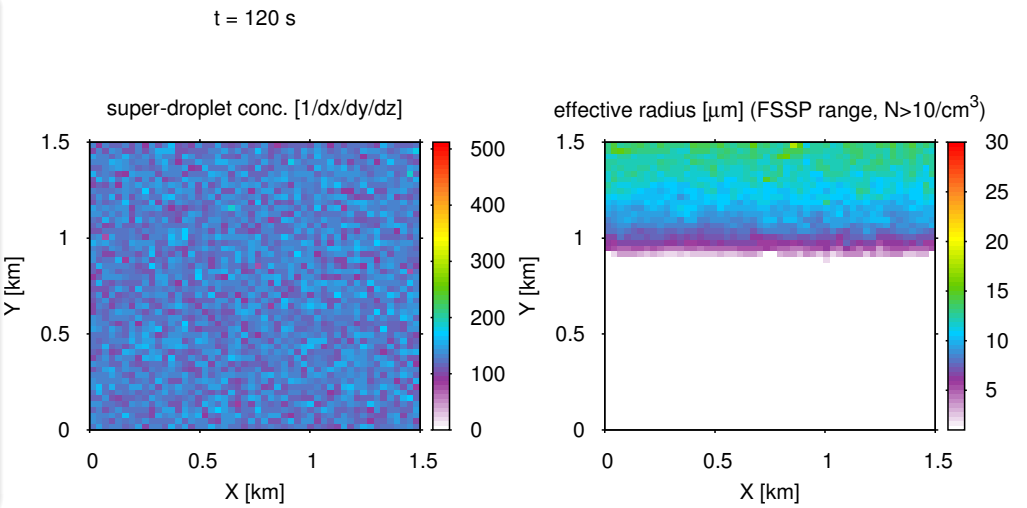

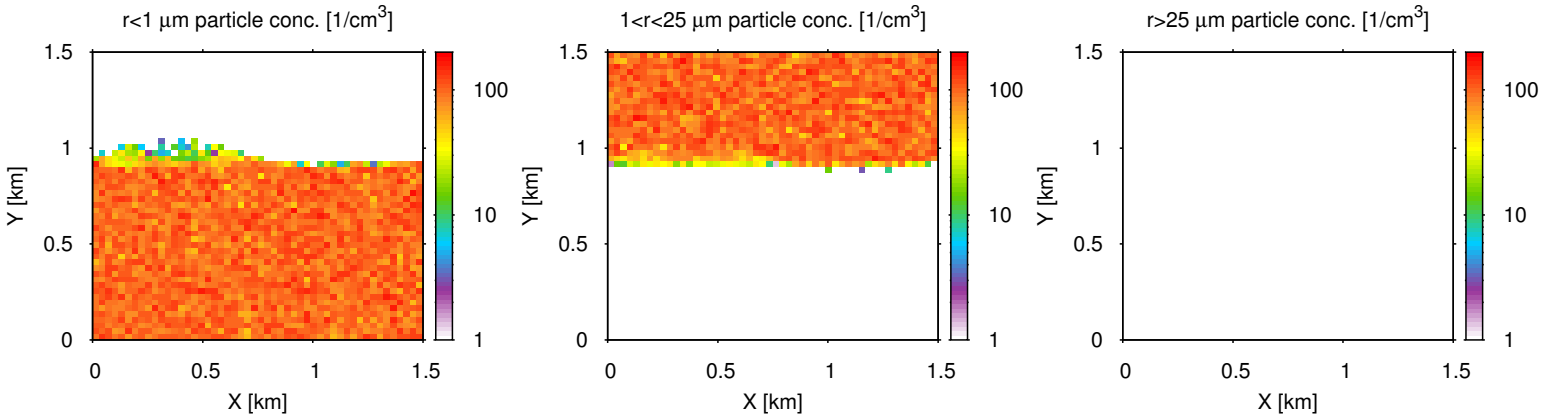

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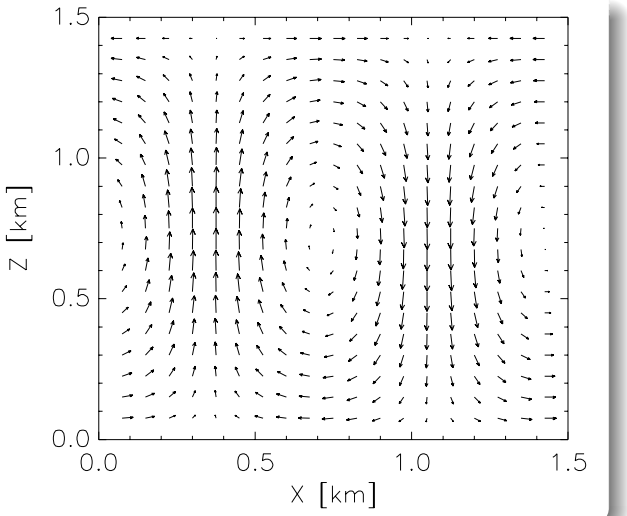

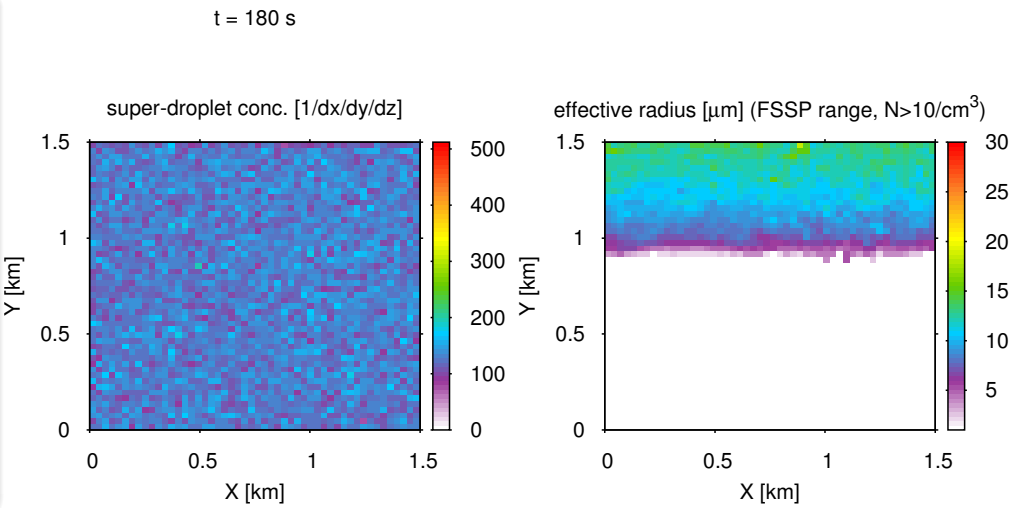

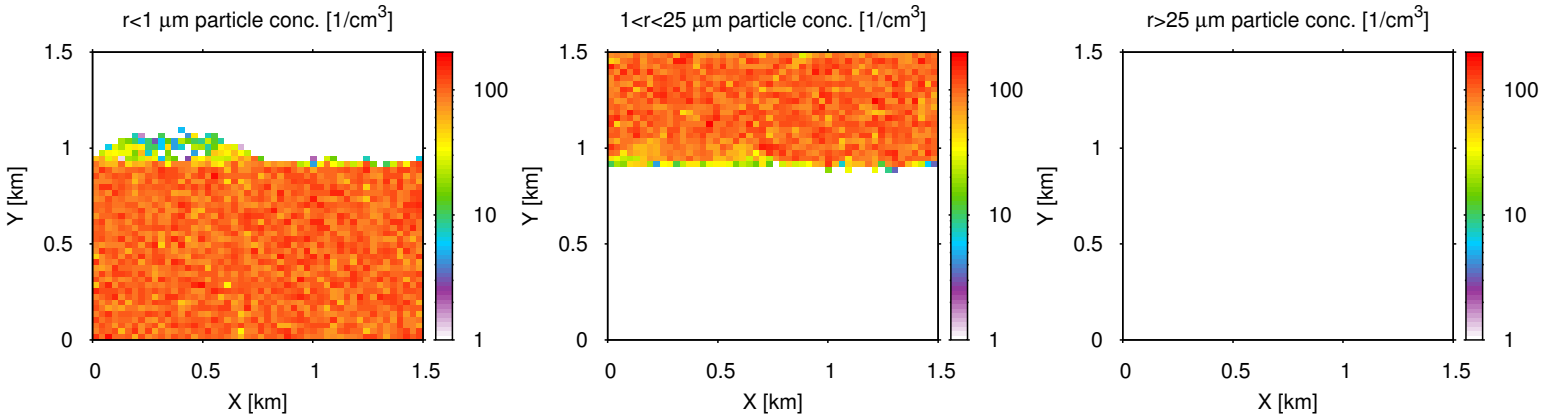

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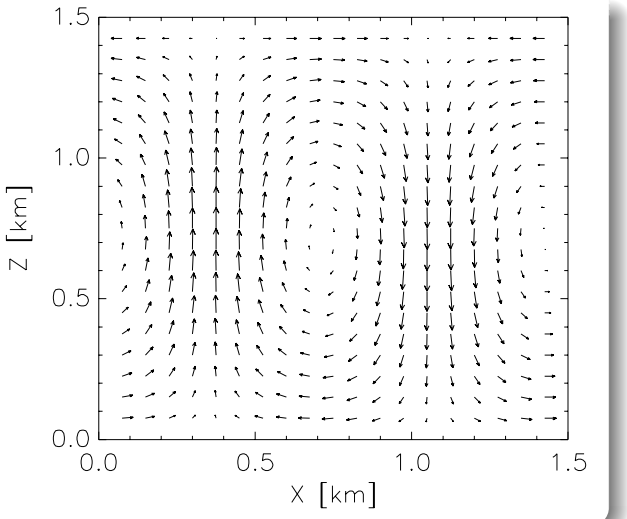

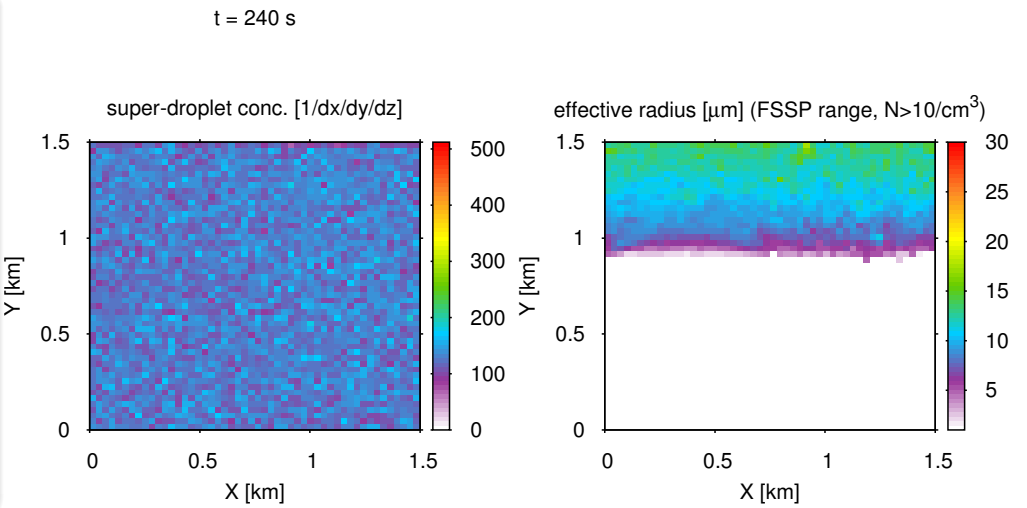

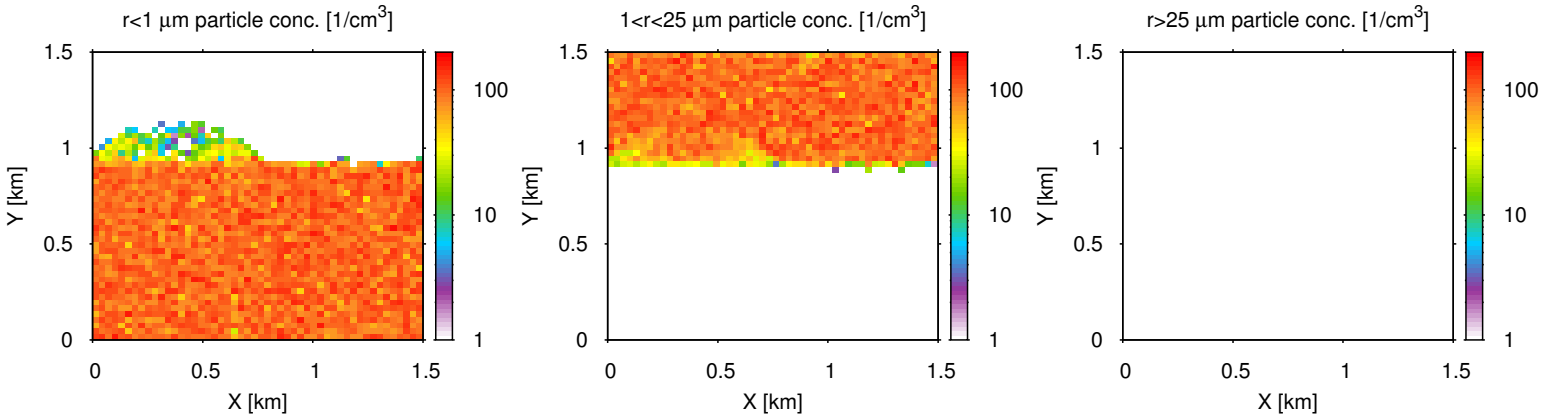

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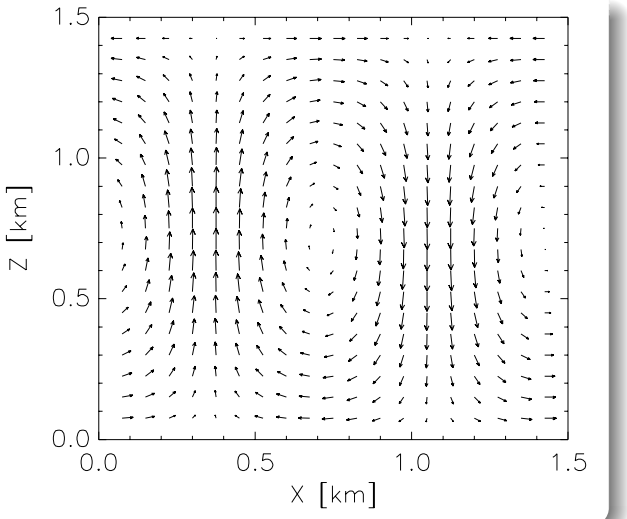

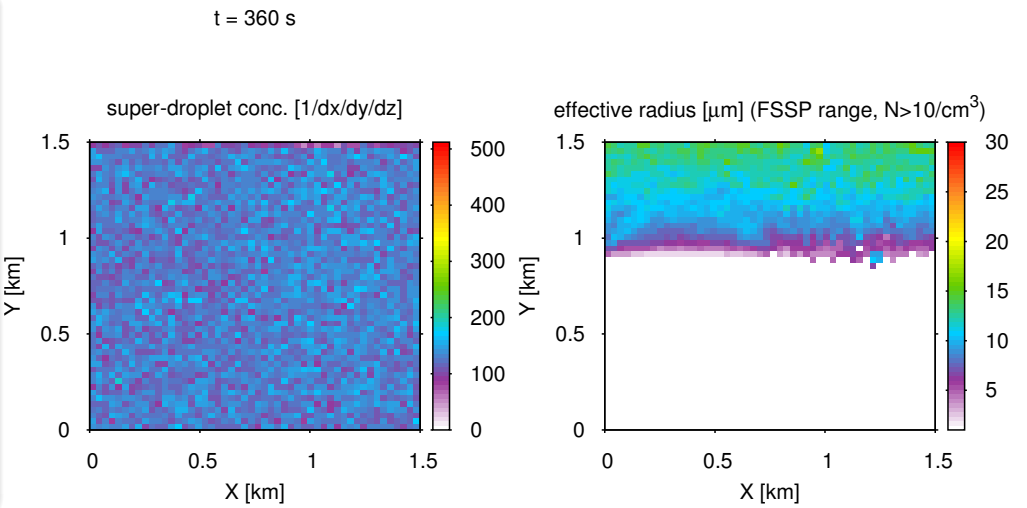

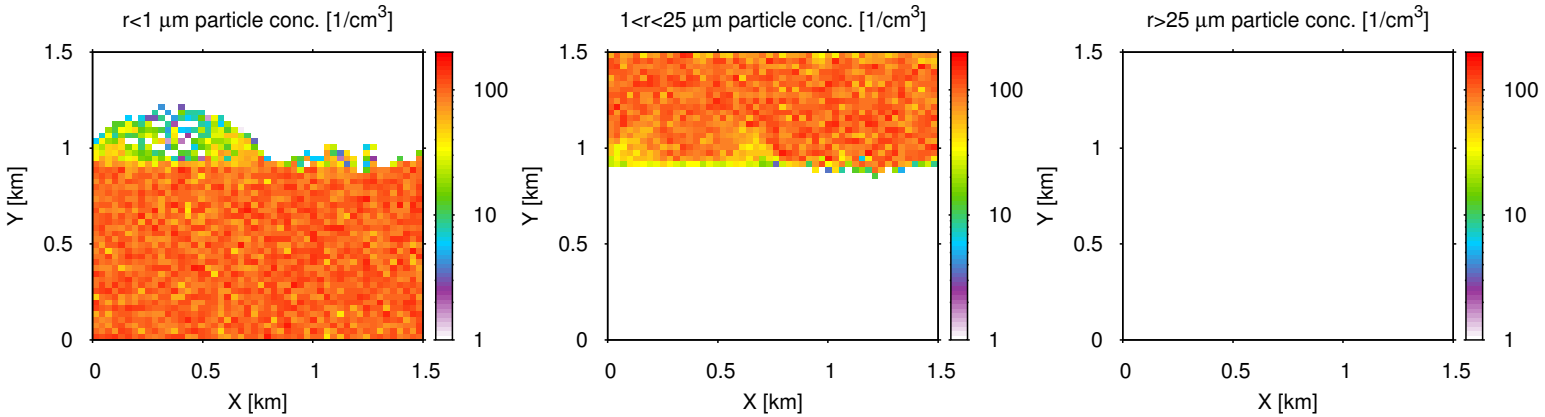

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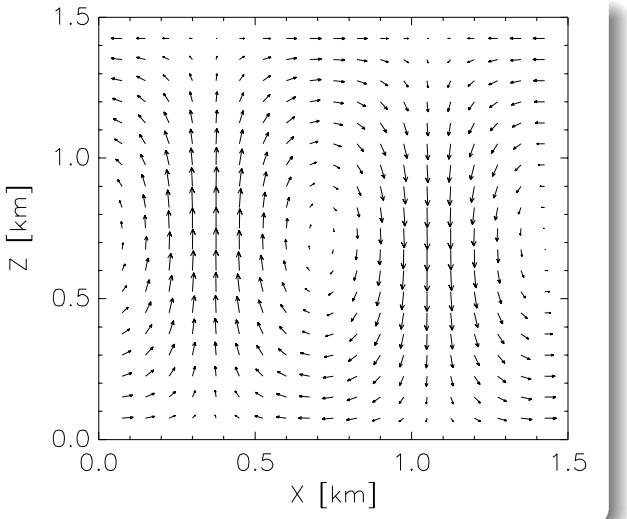

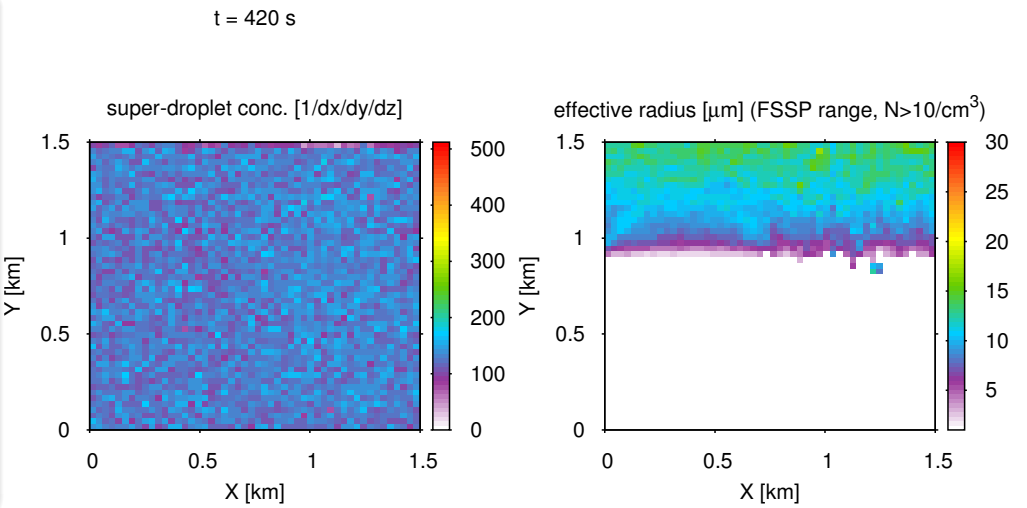

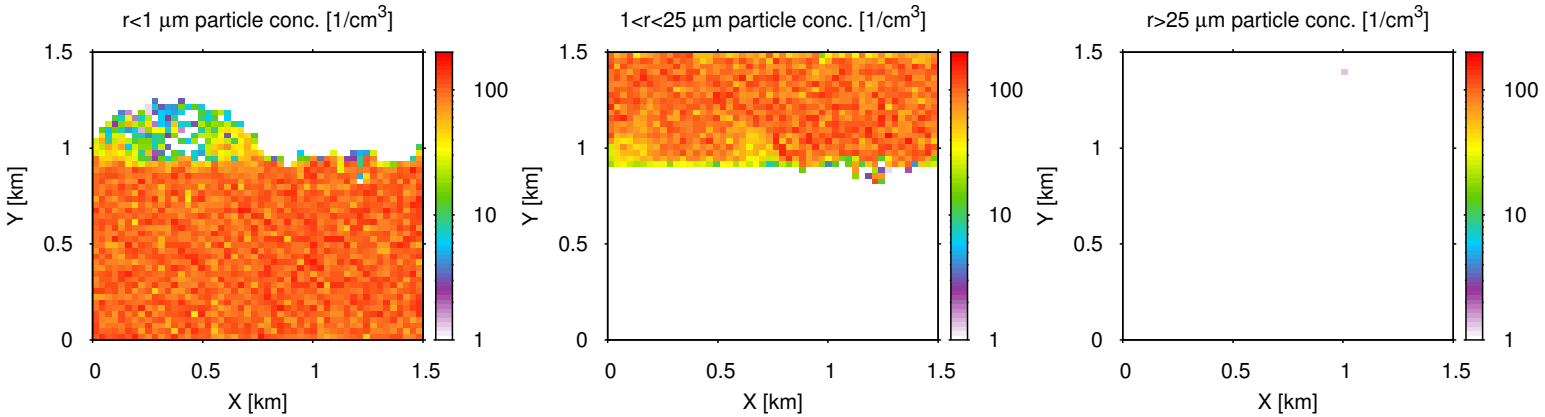

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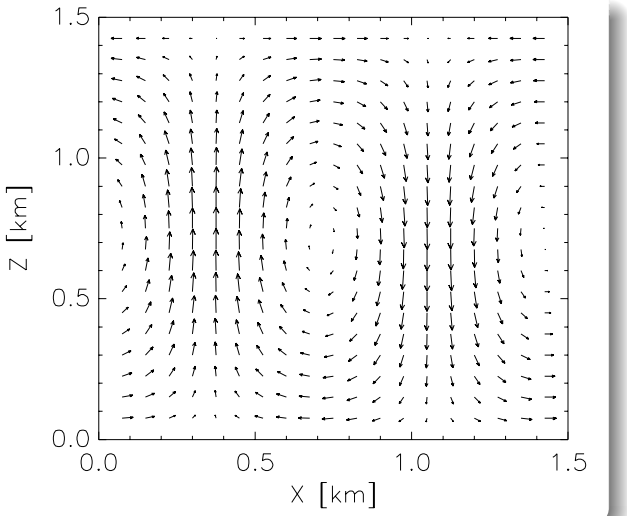

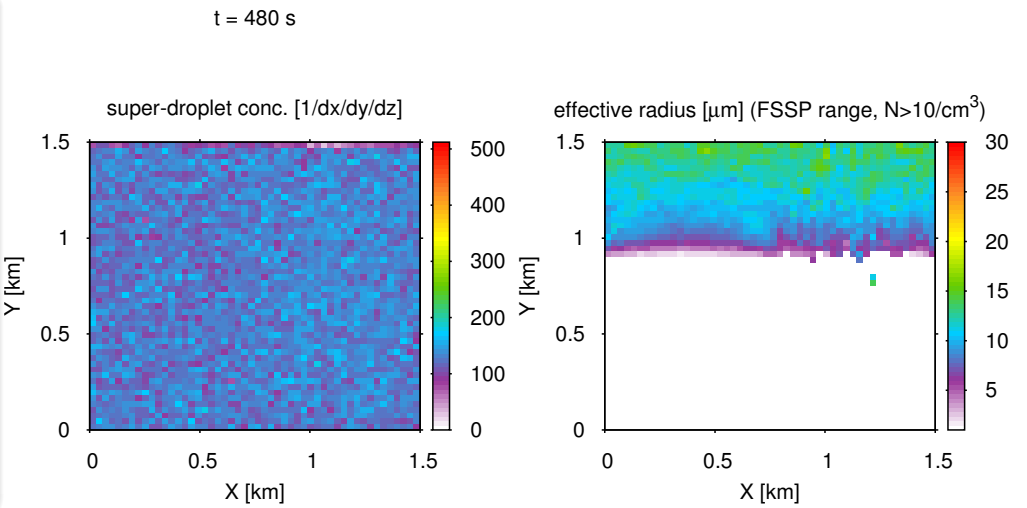

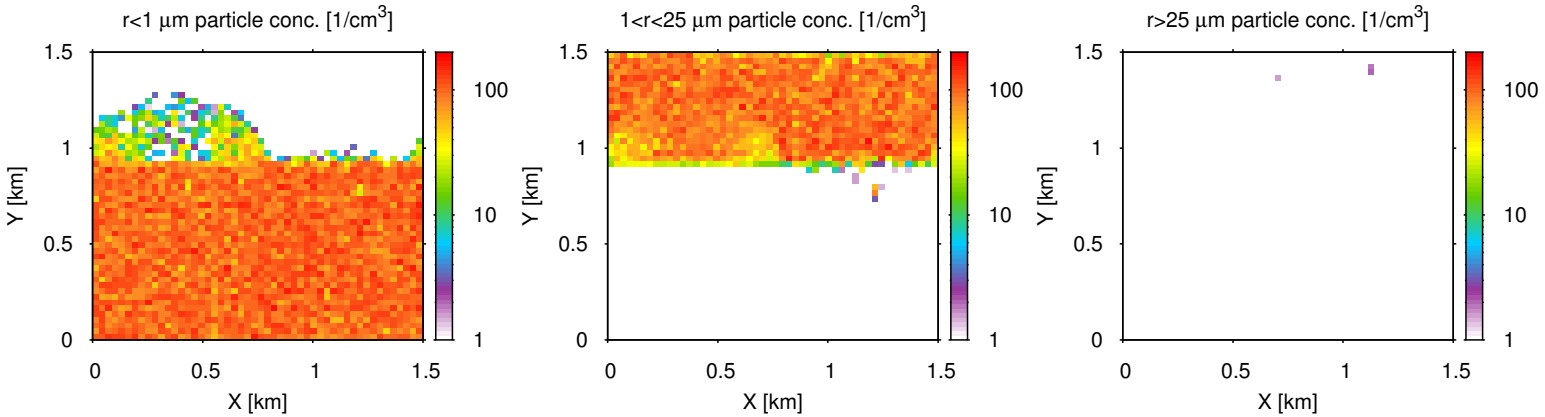

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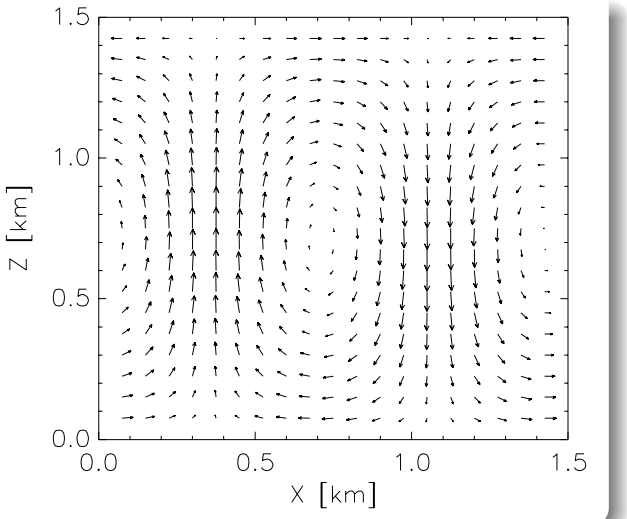

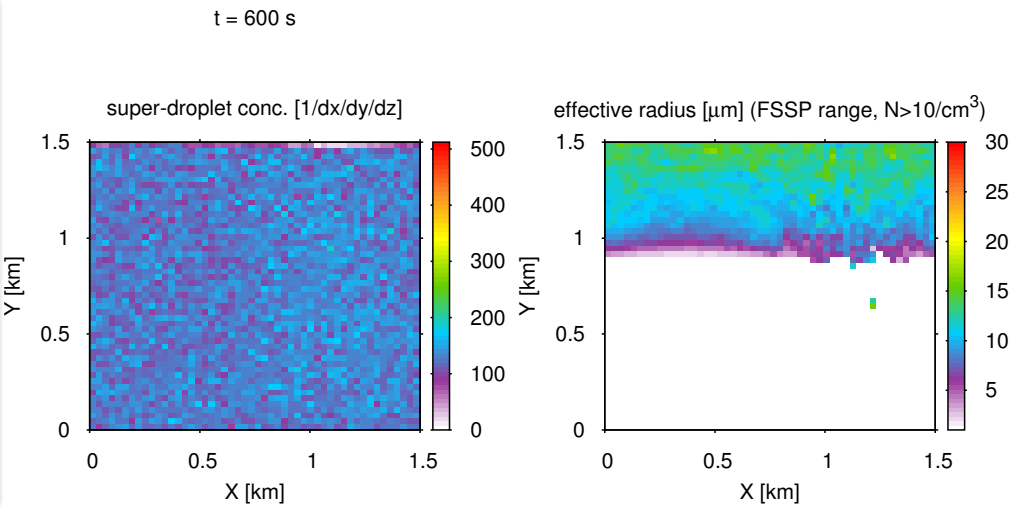

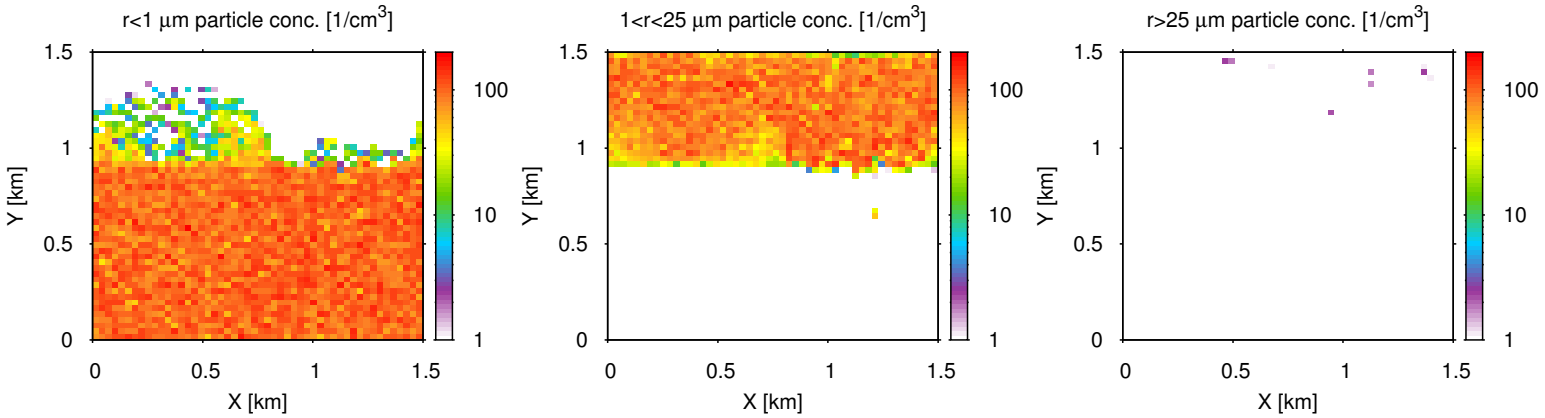

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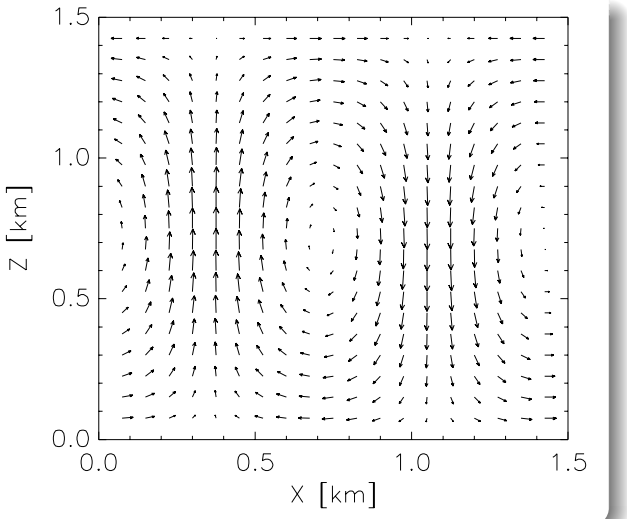

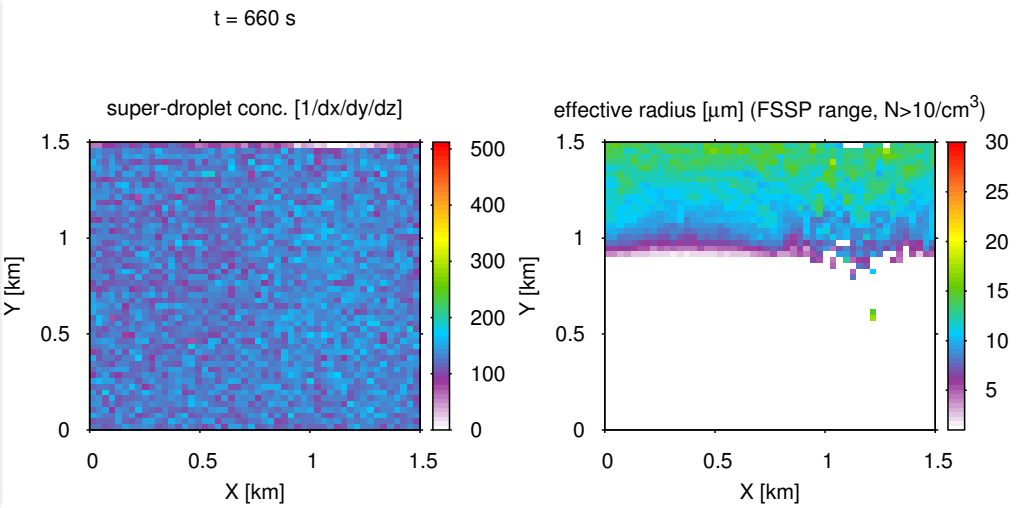

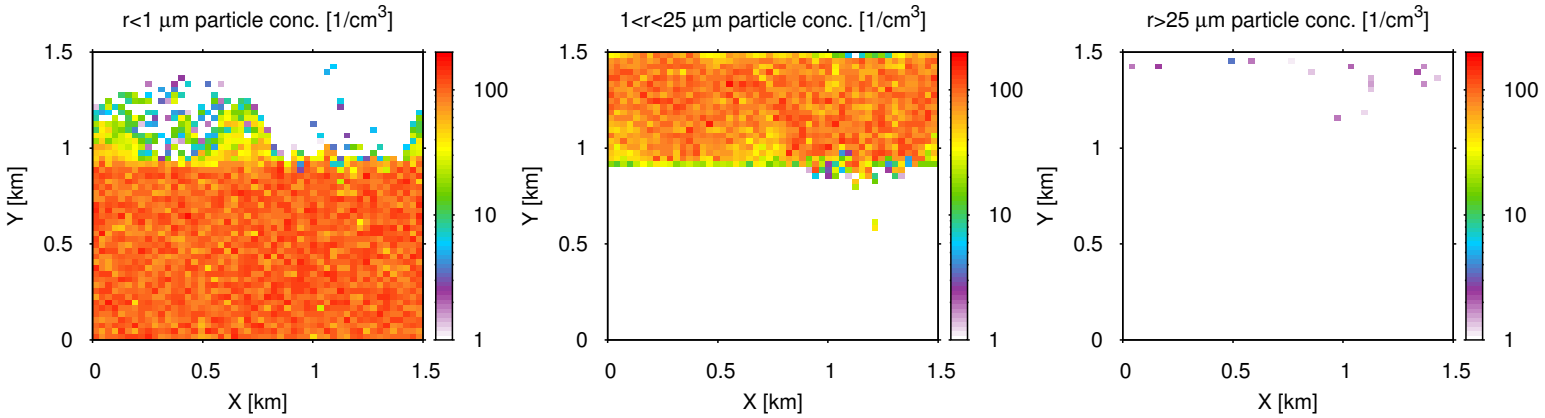

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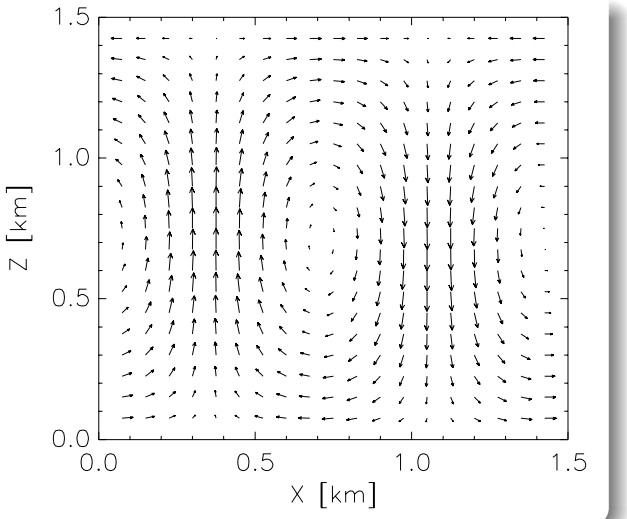

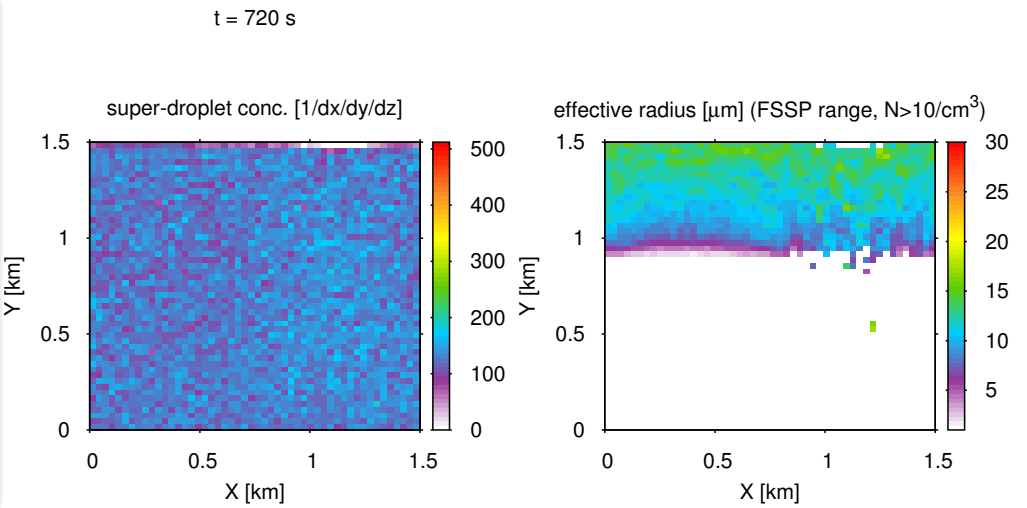

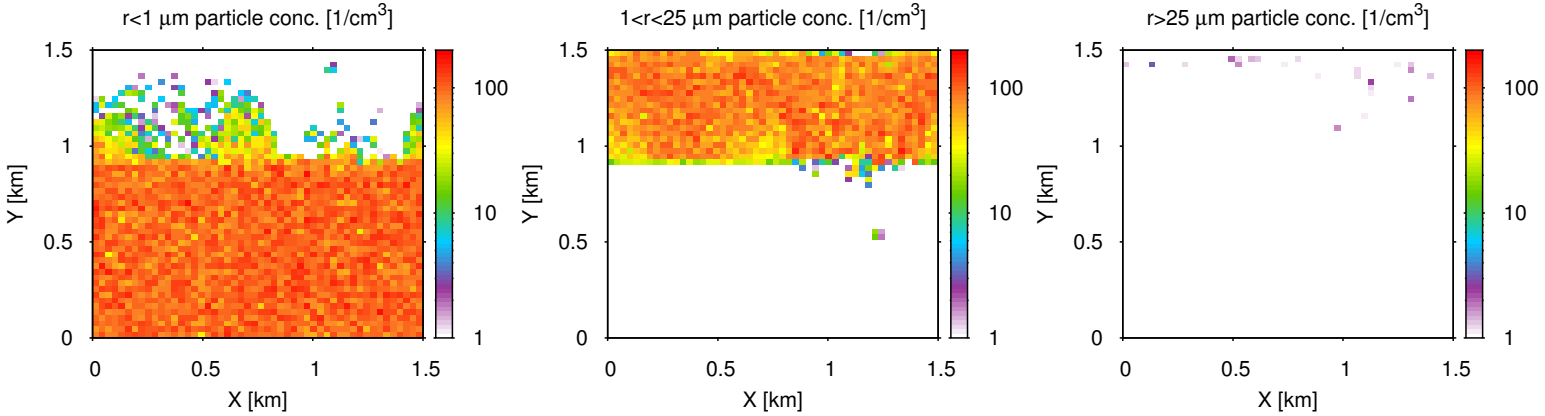

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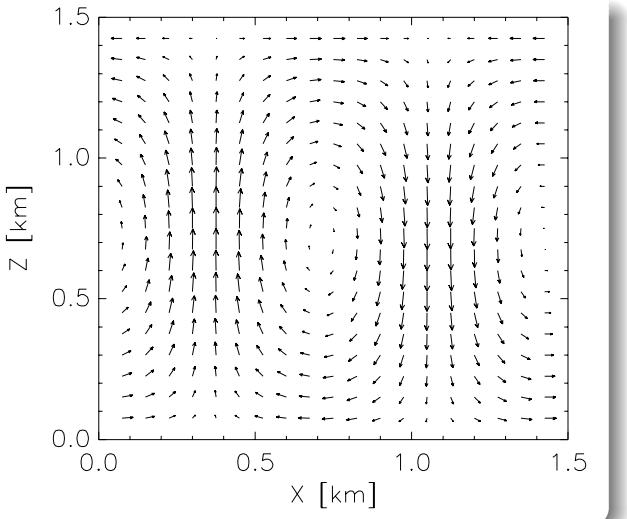
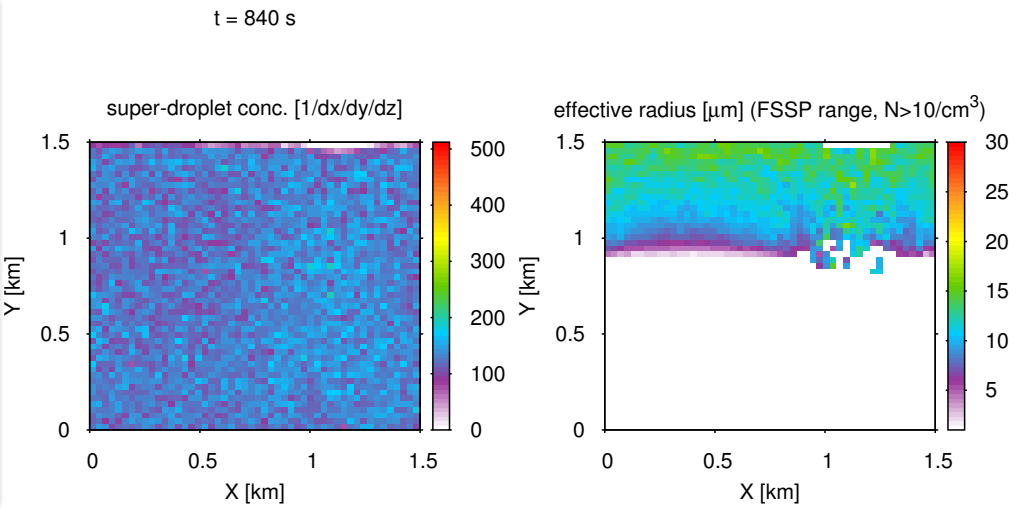
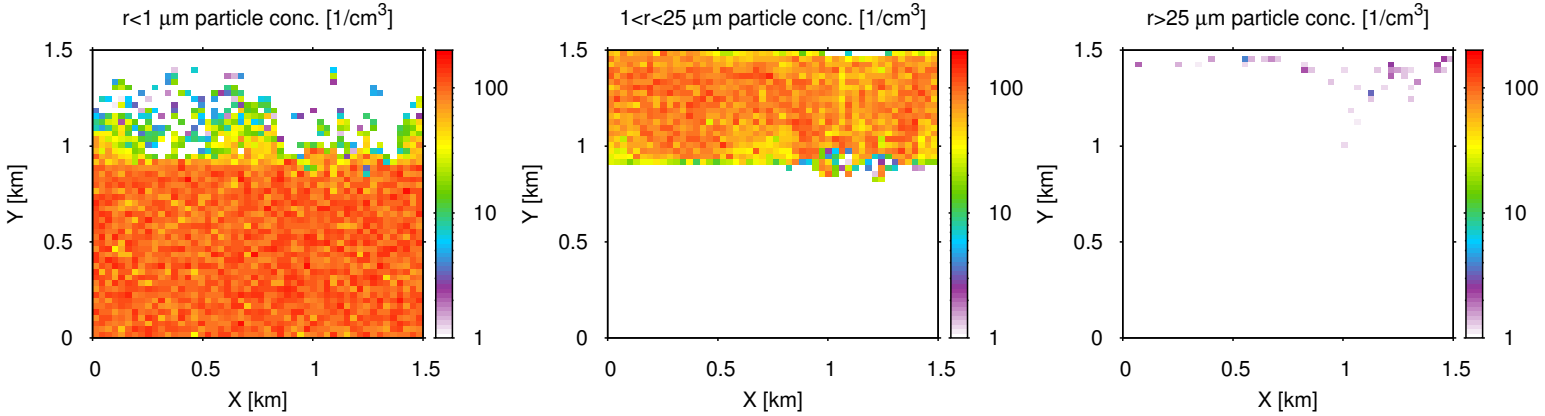
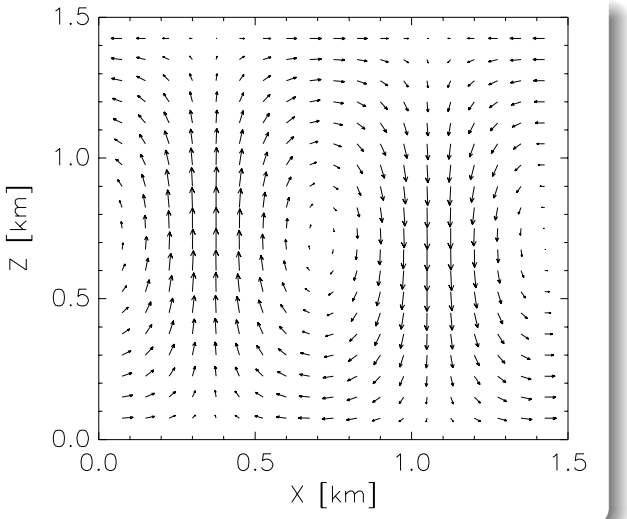
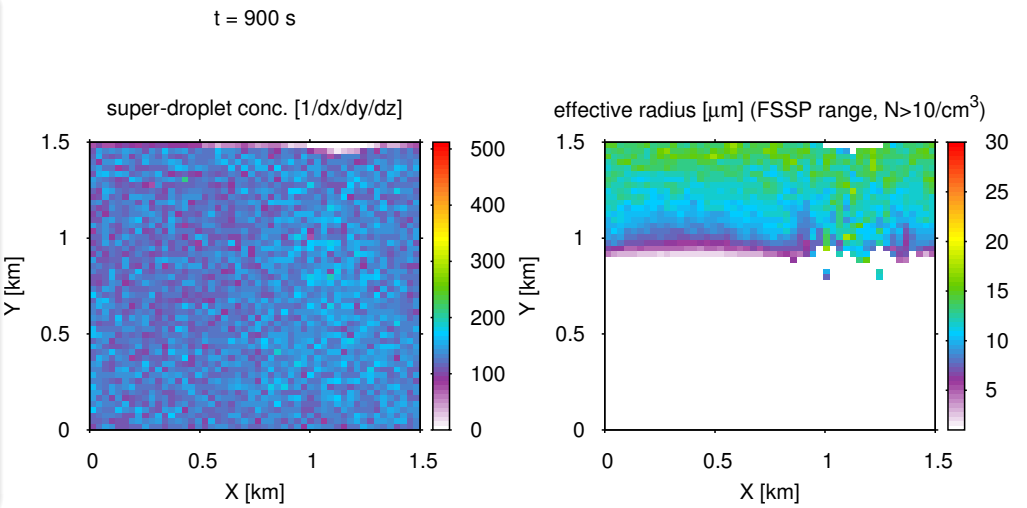


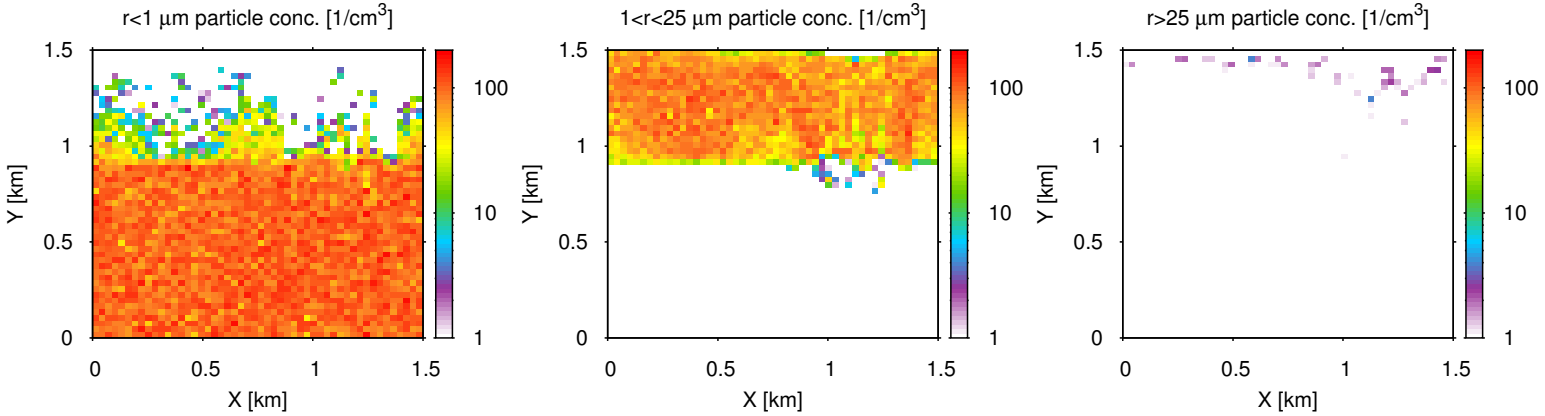




8th ICMW case 1 with Lagrangian/Monte-Carlo μ-physics







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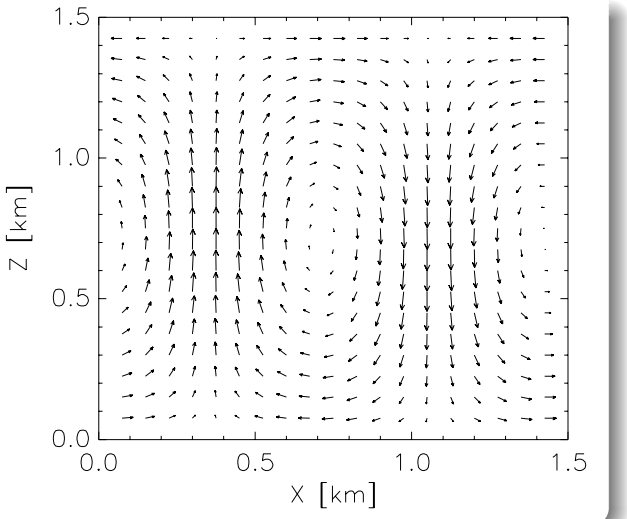

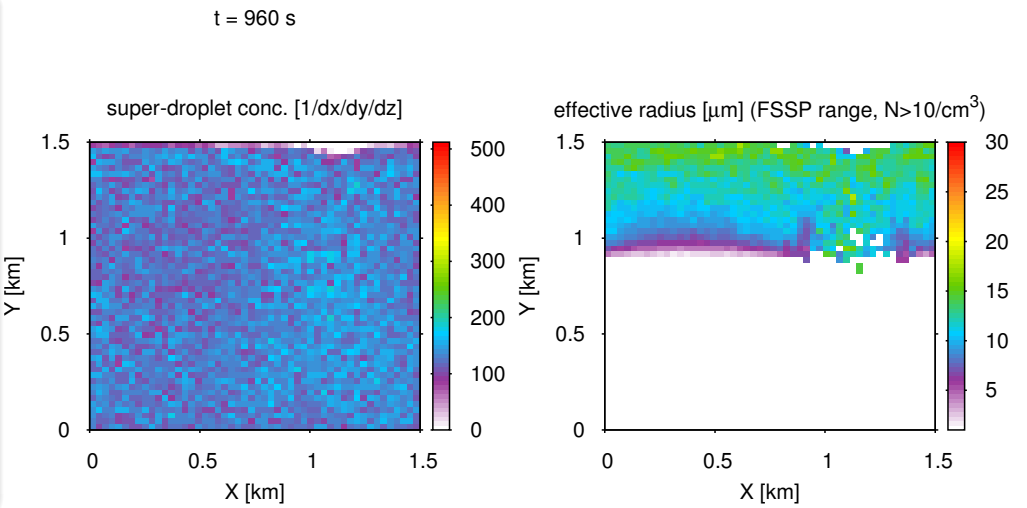

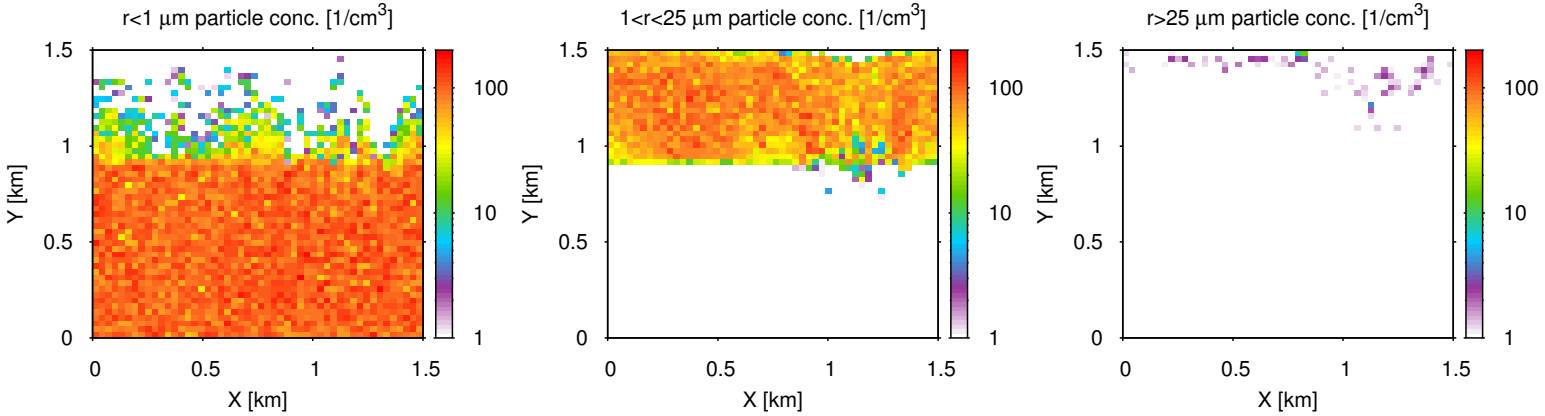

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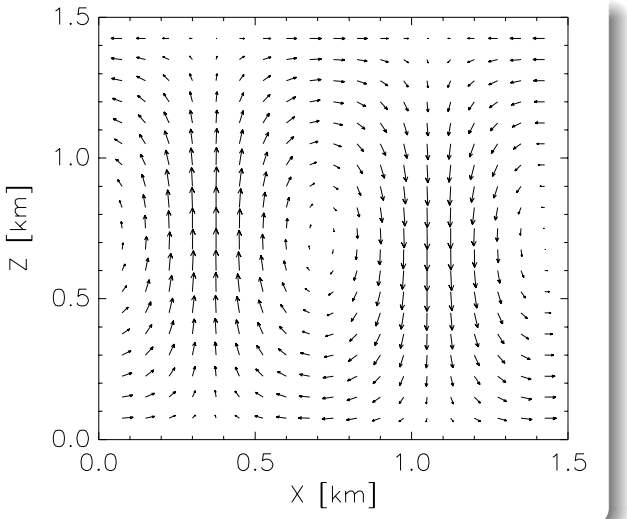

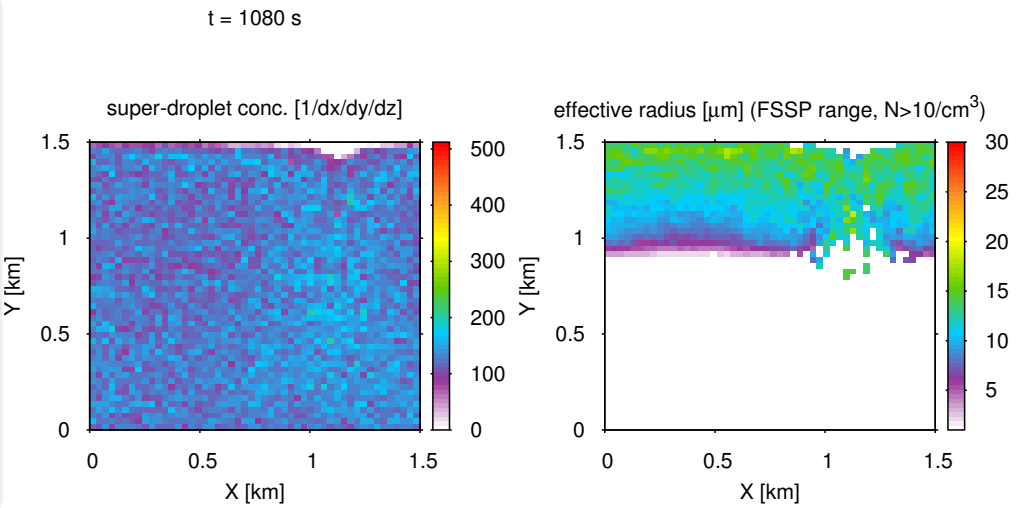

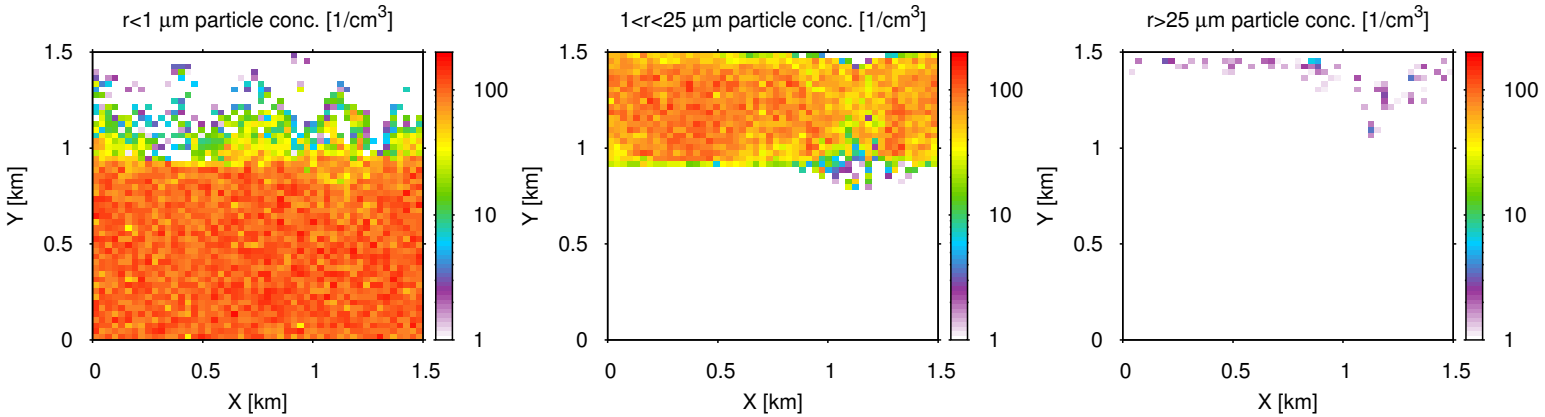

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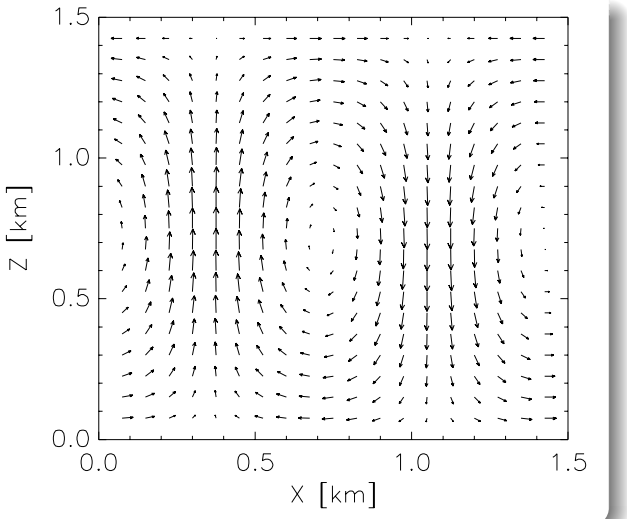

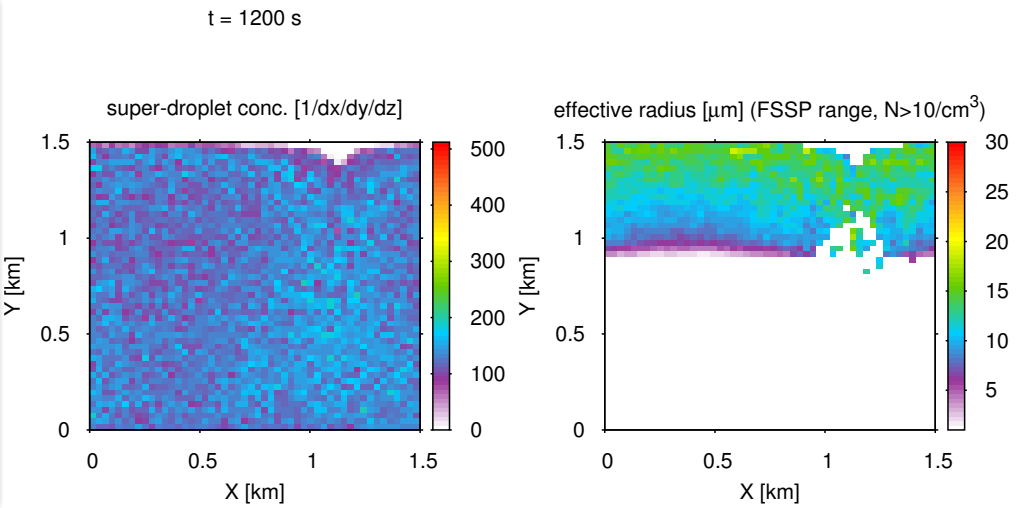

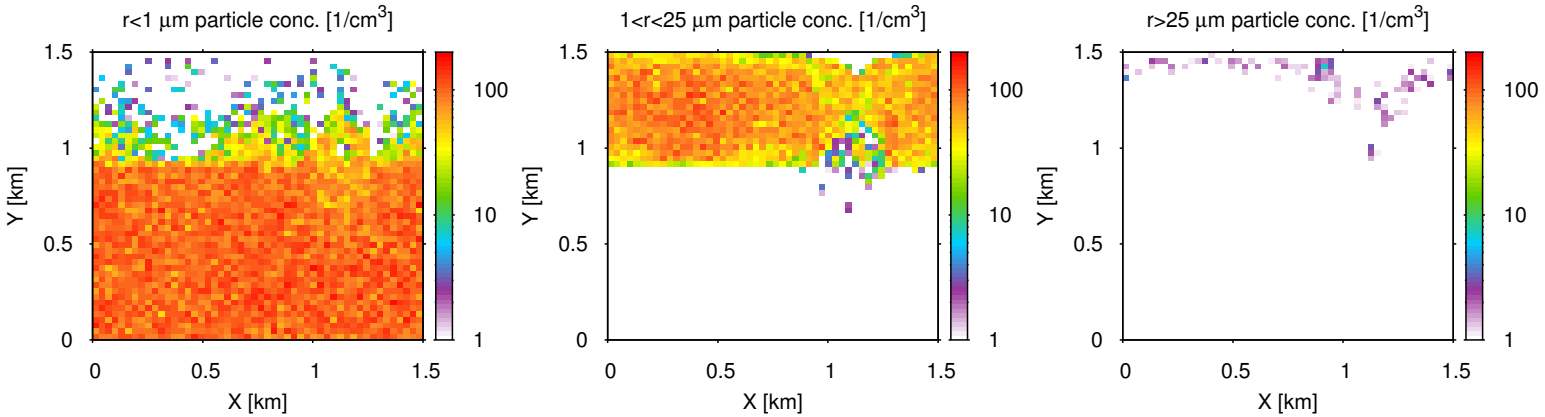

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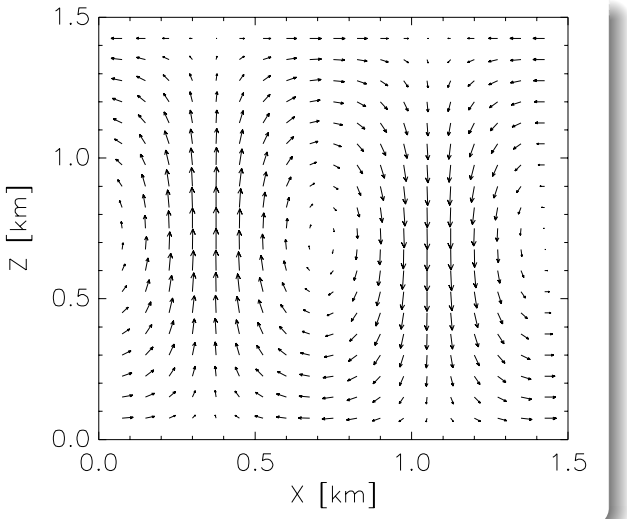

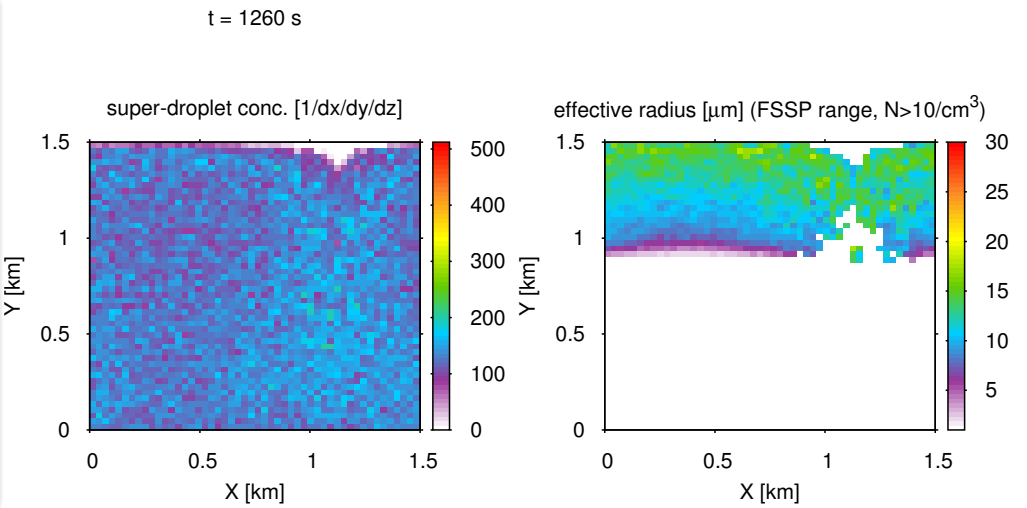

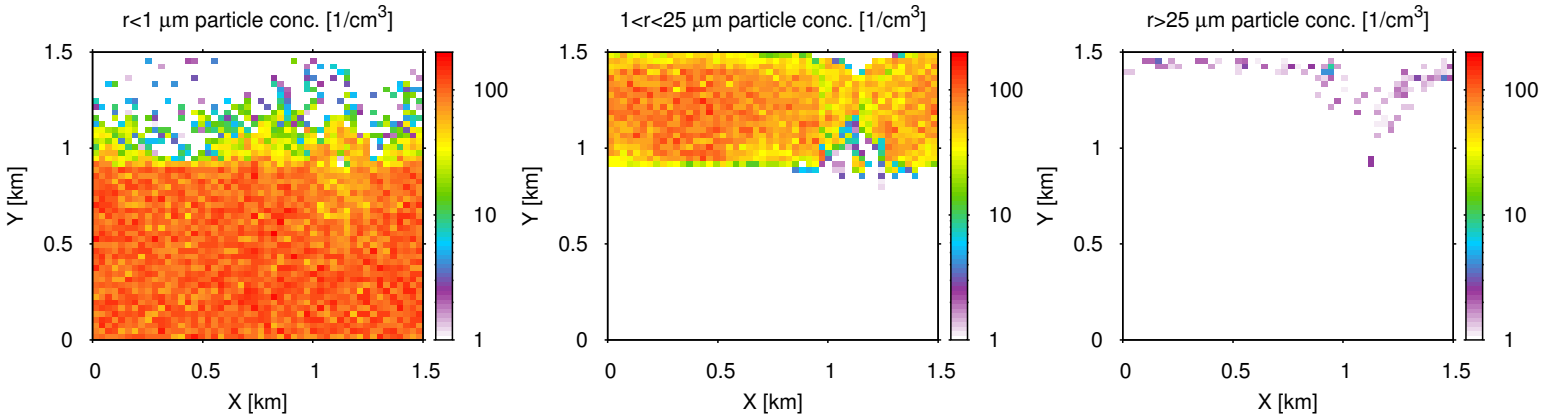

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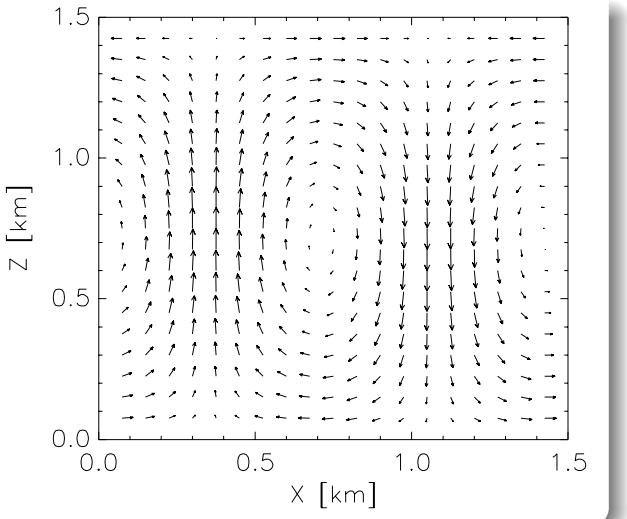
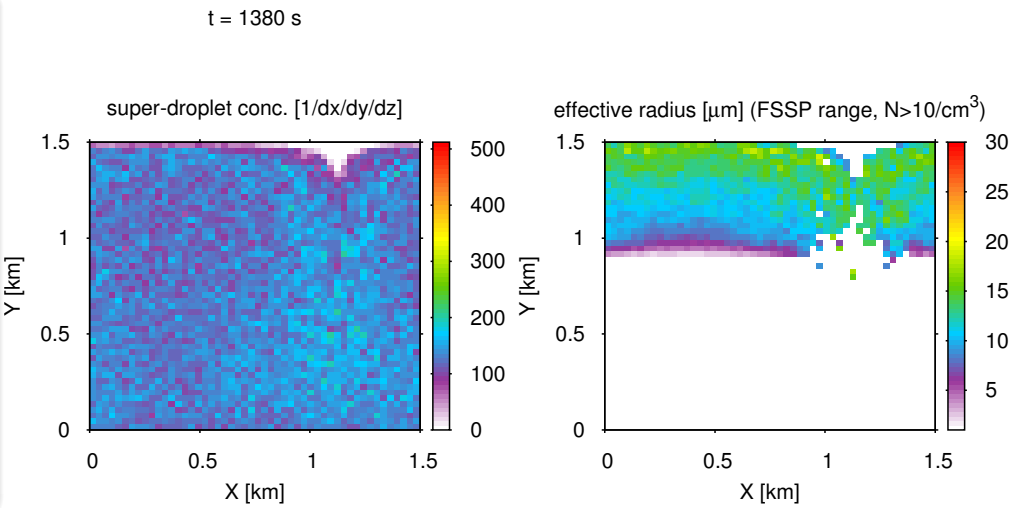
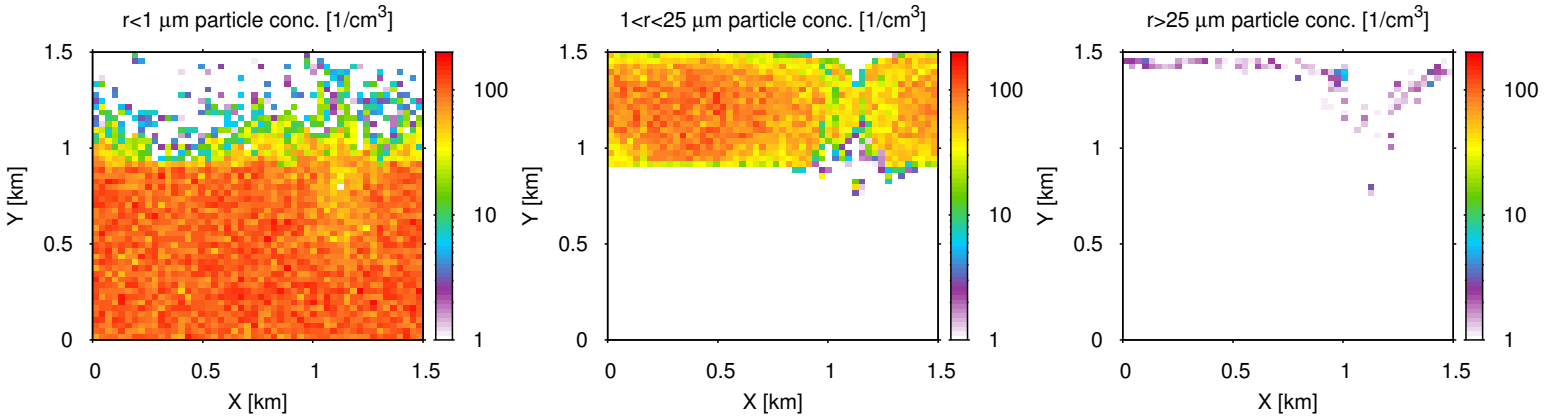
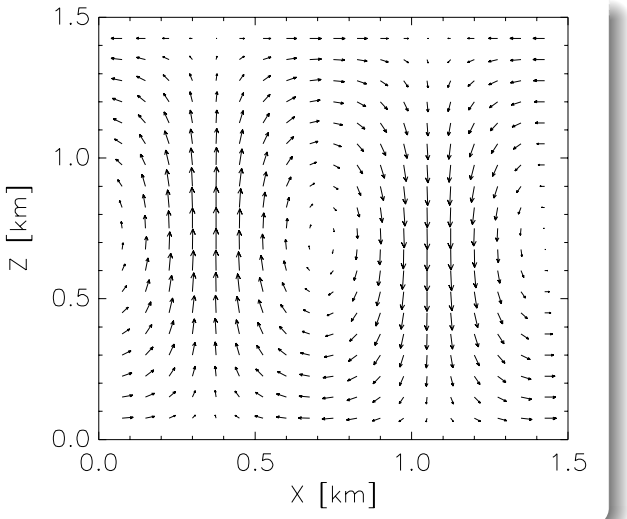
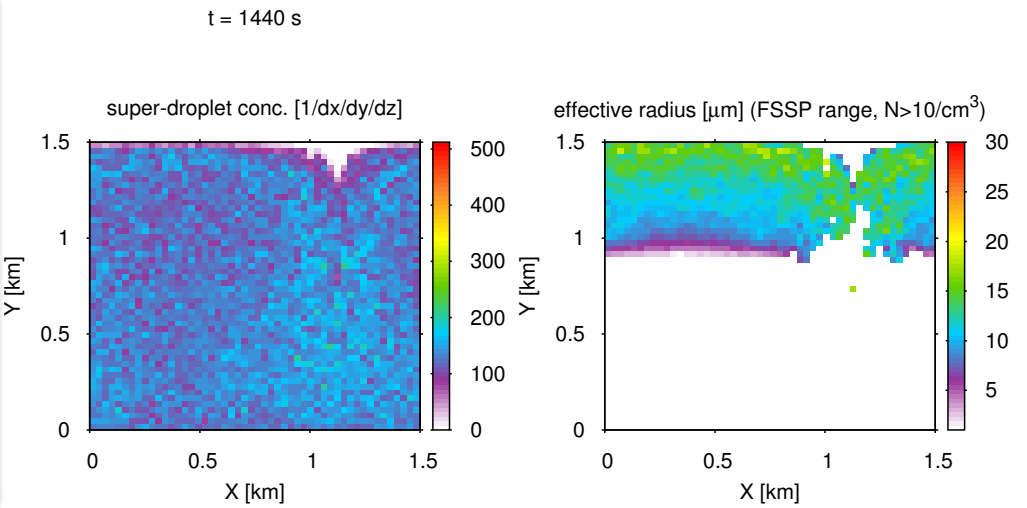


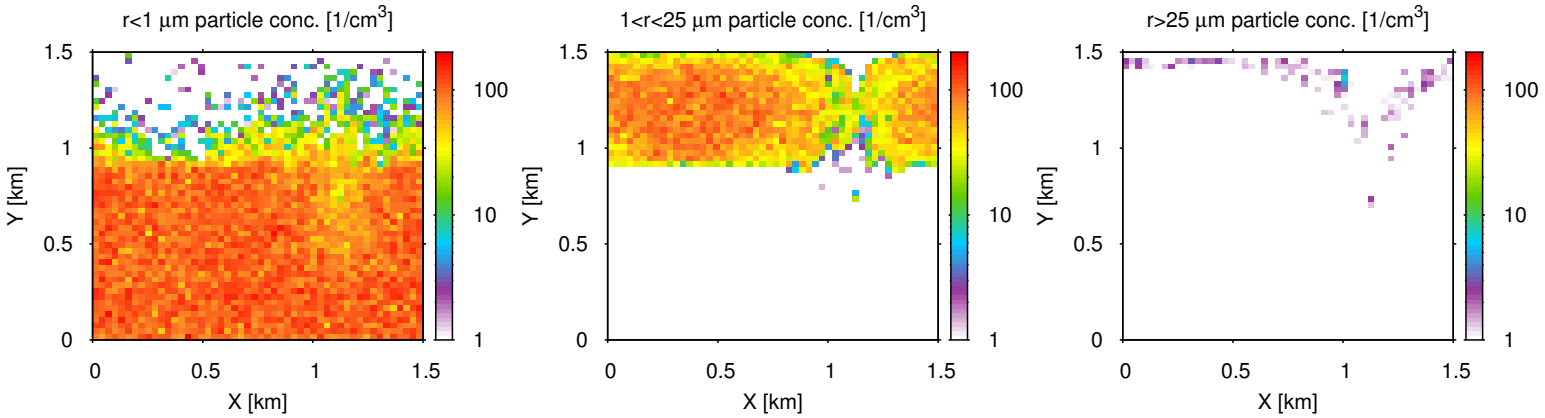




8th ICMW case 1 with Lagrangian/Monte-Carlo μ-physics







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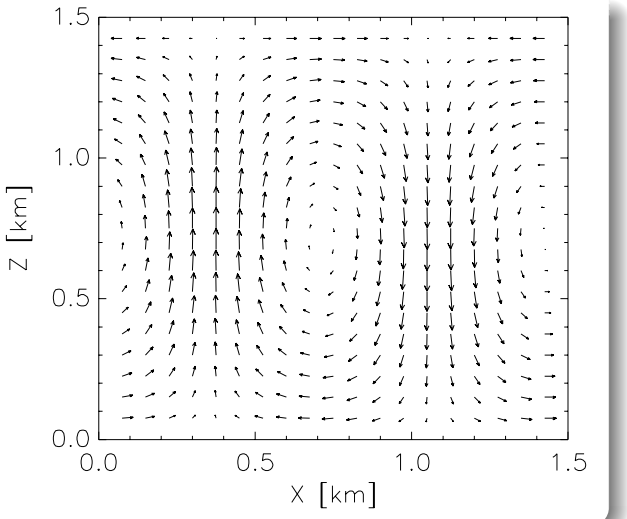

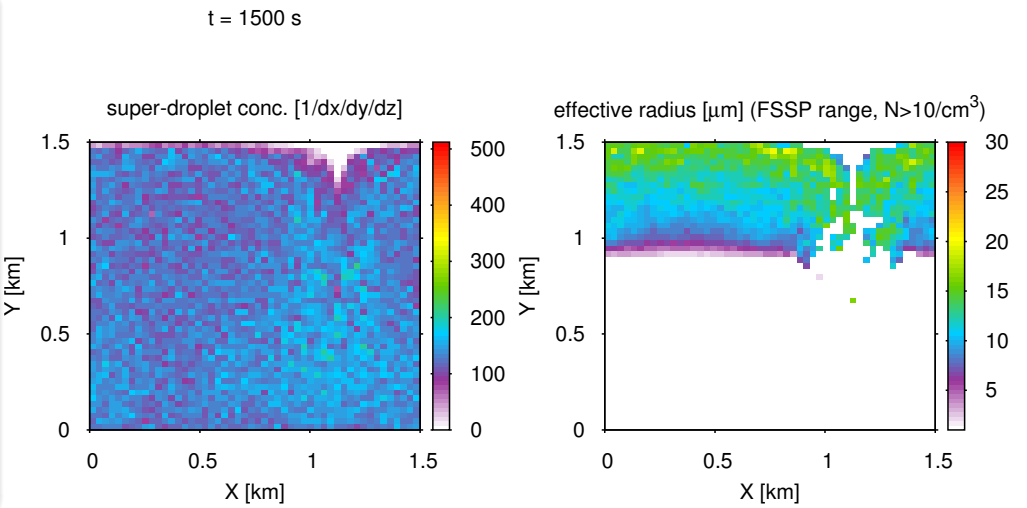

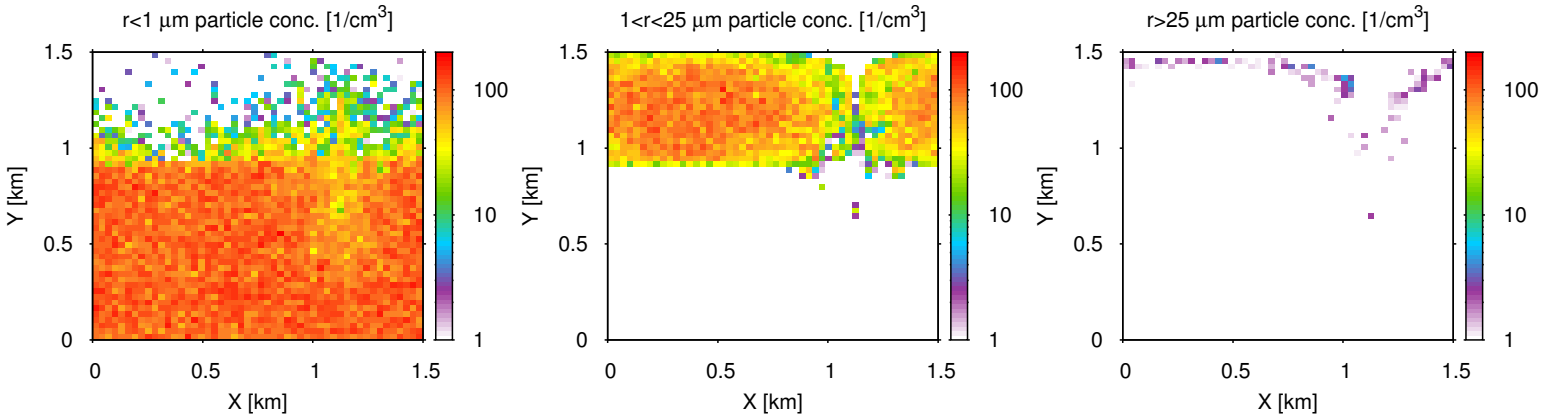

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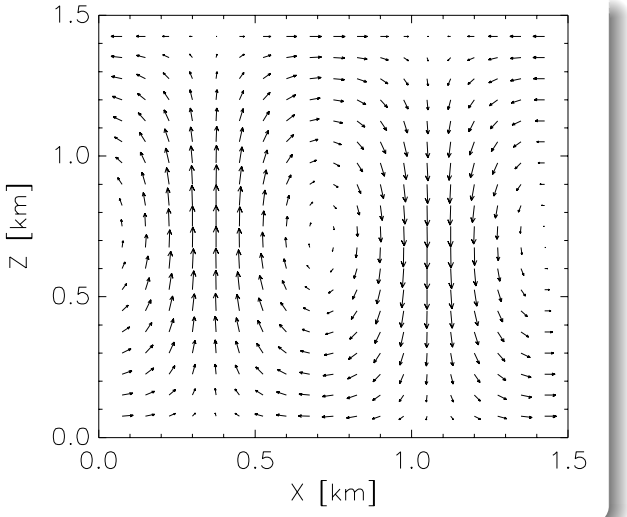

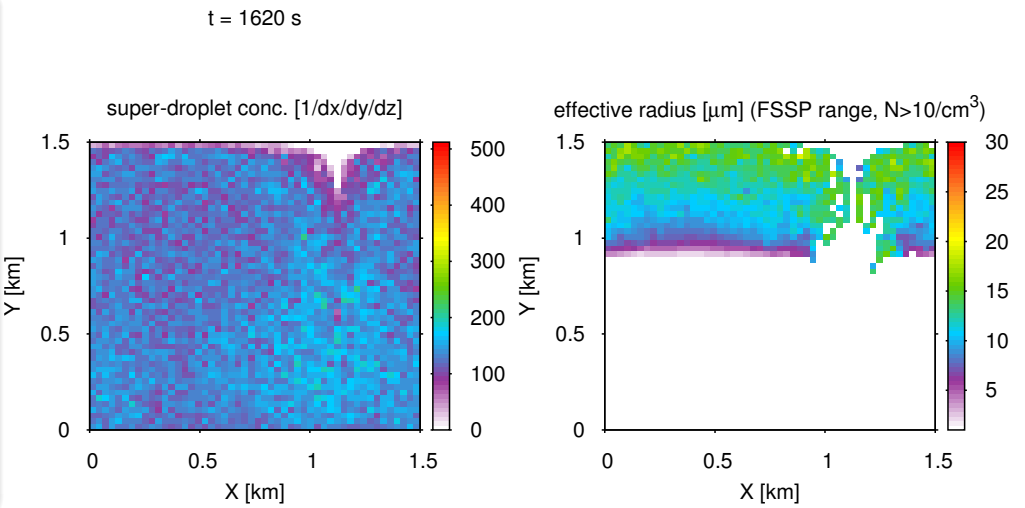

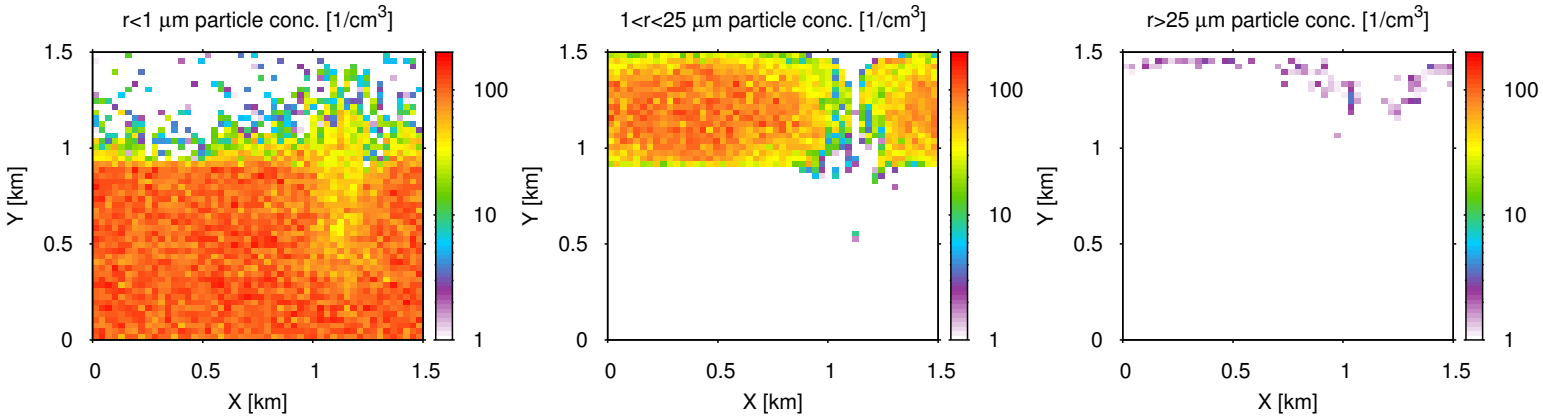

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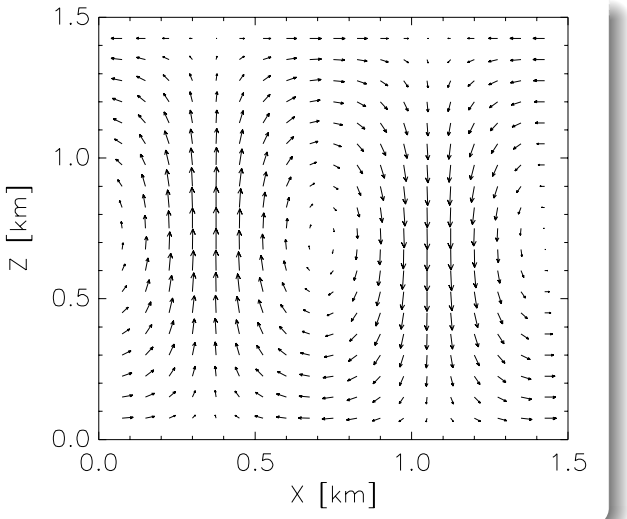

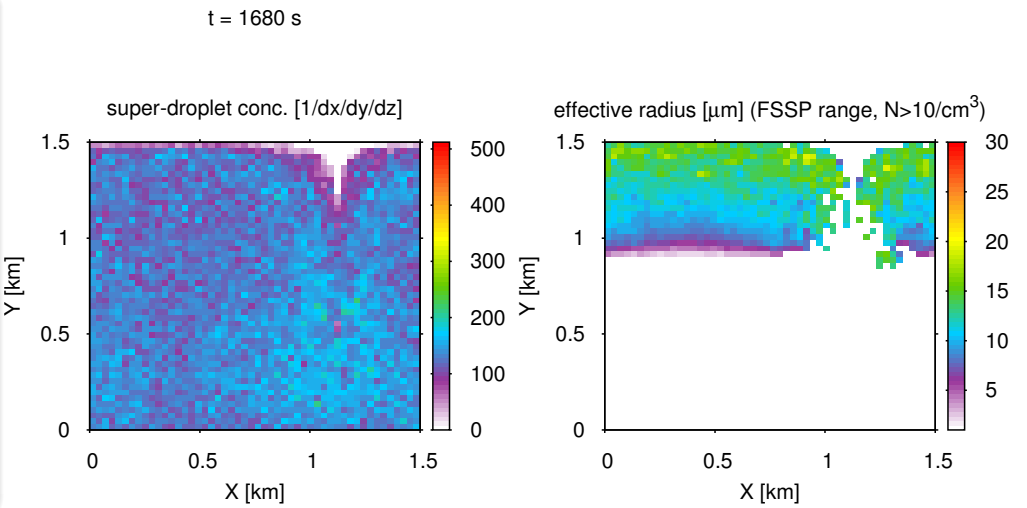

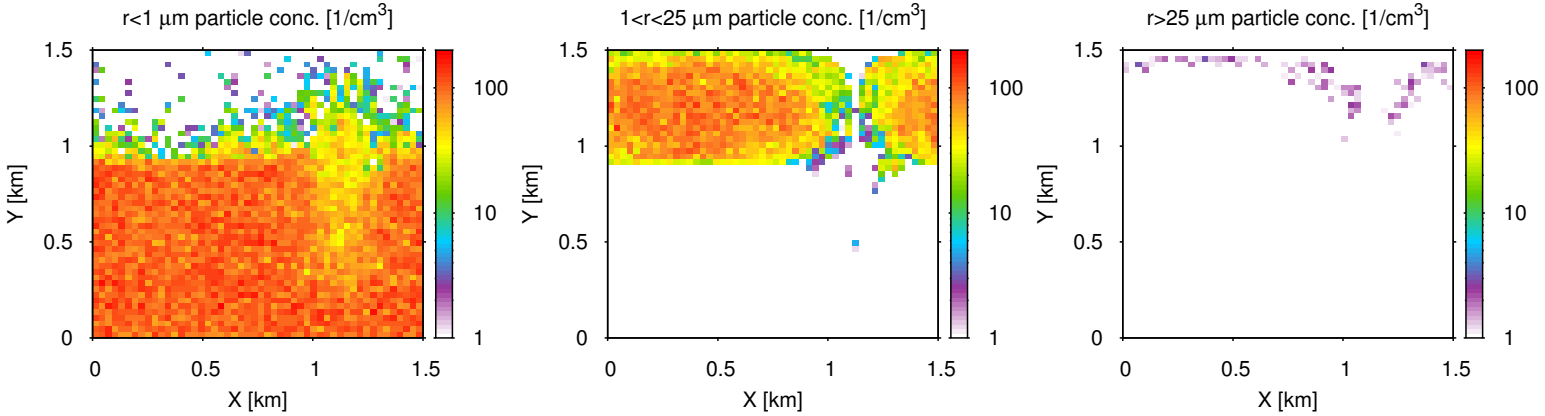

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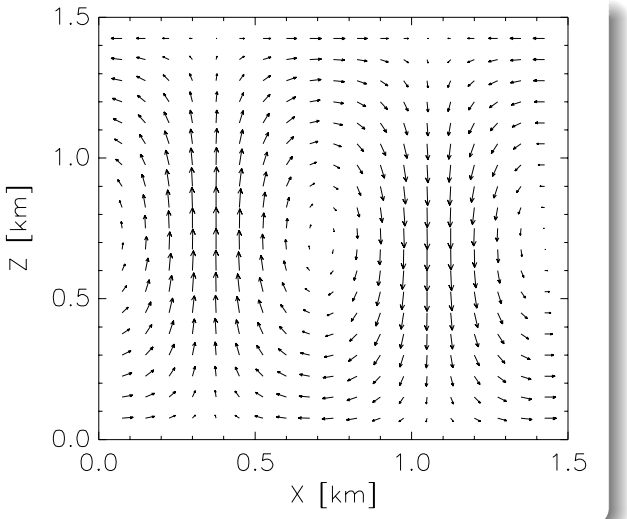

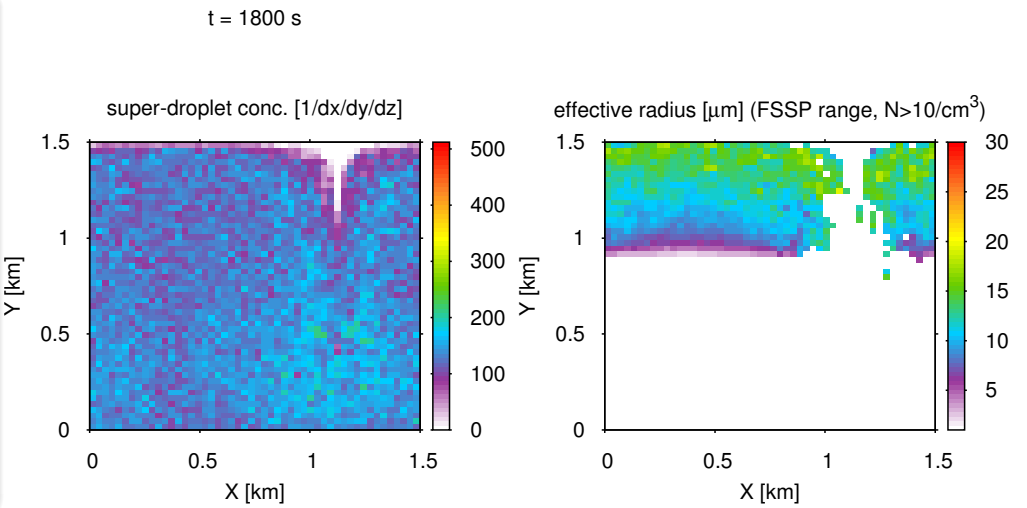

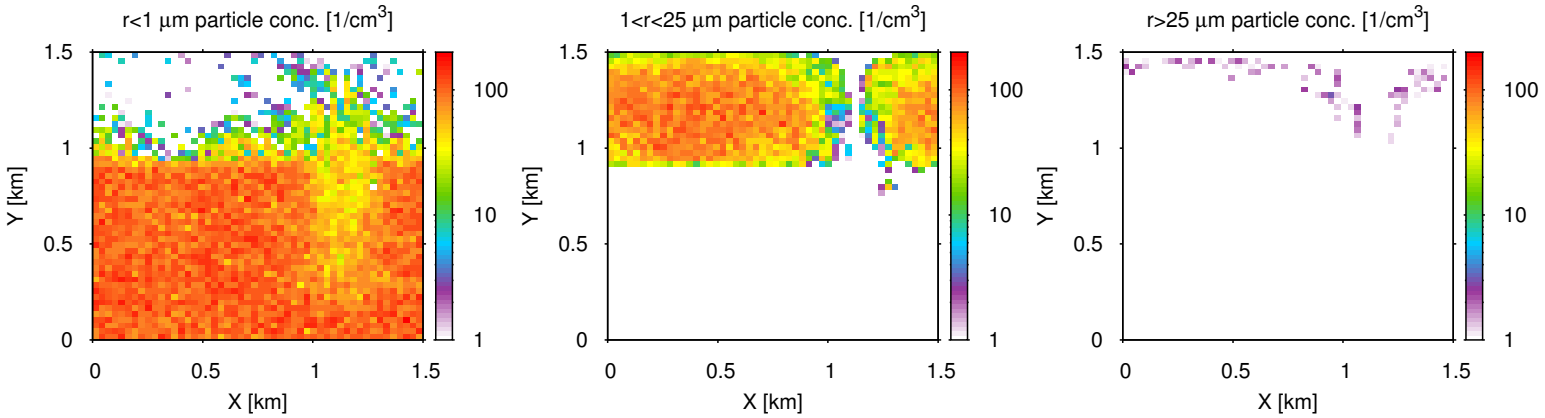

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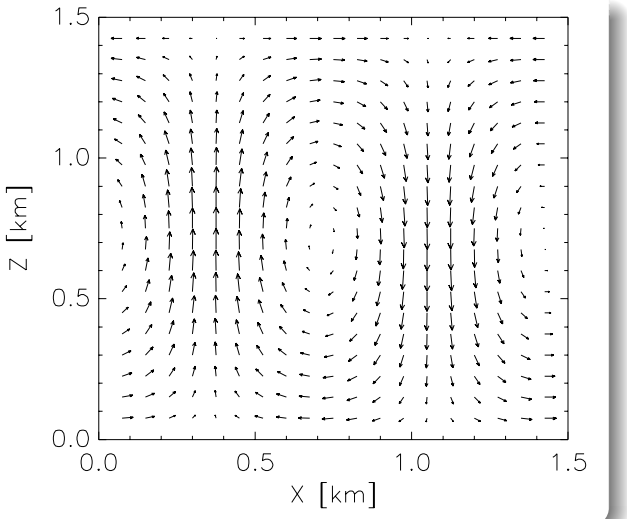

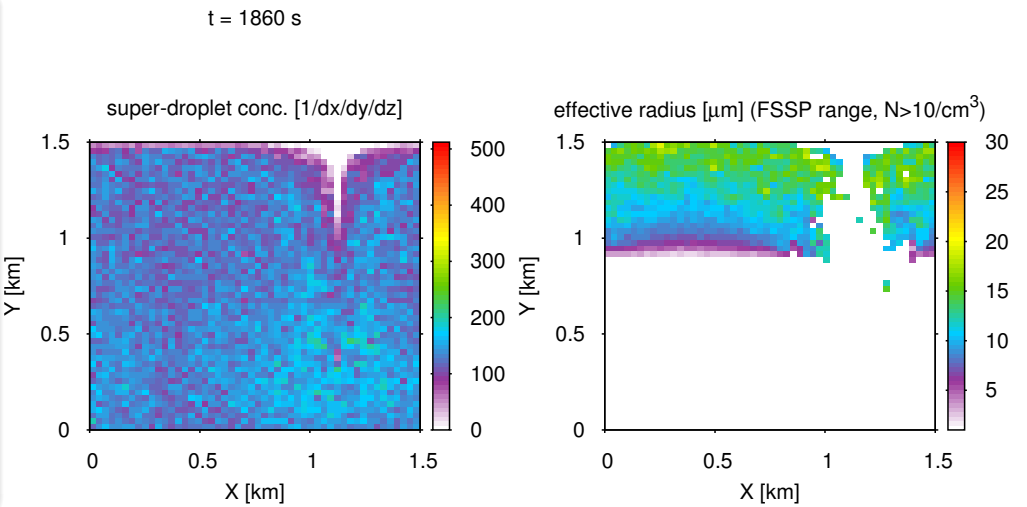

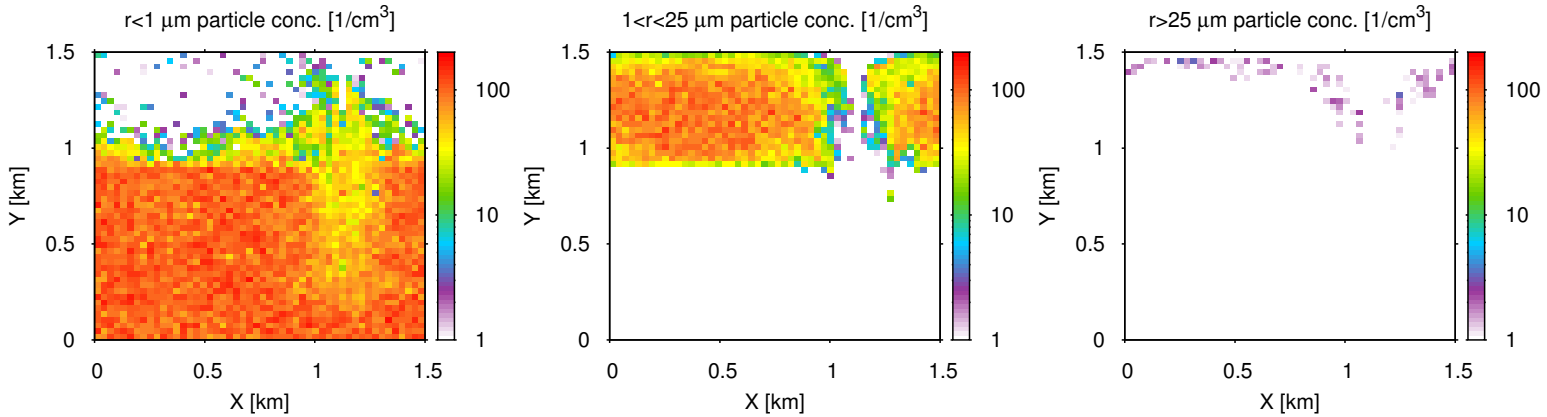

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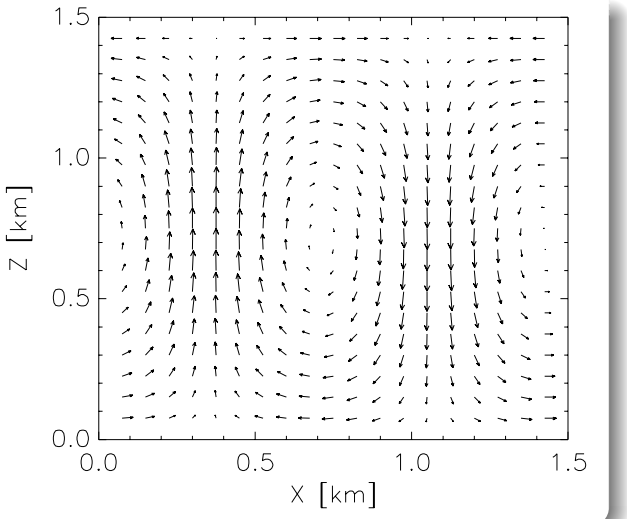

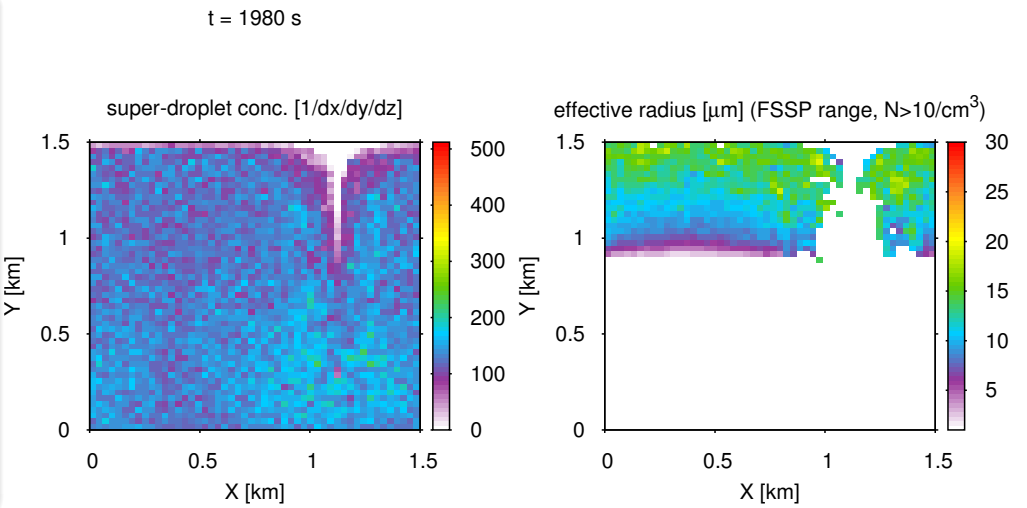

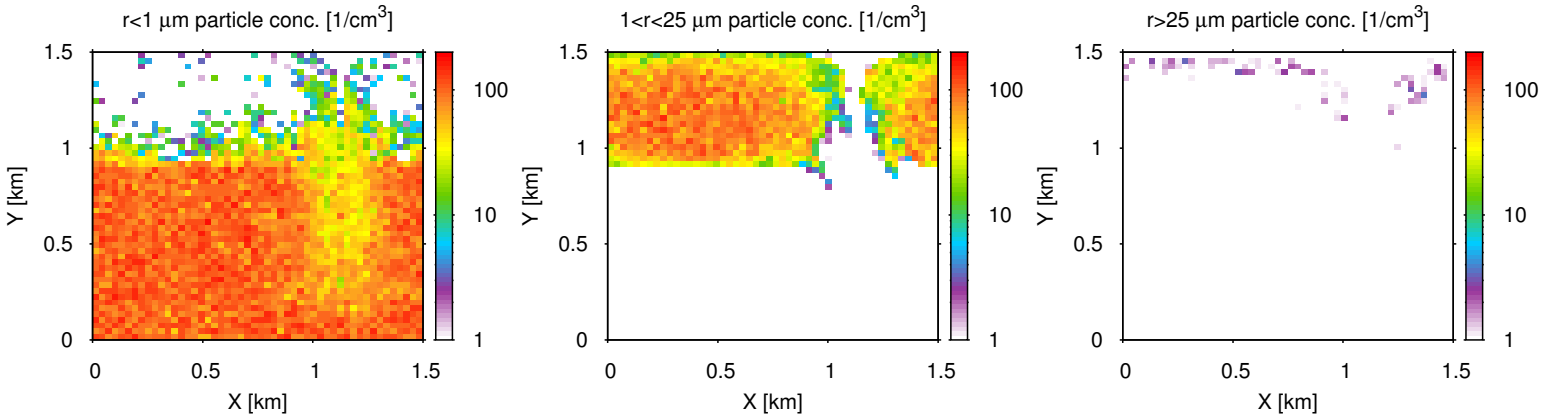

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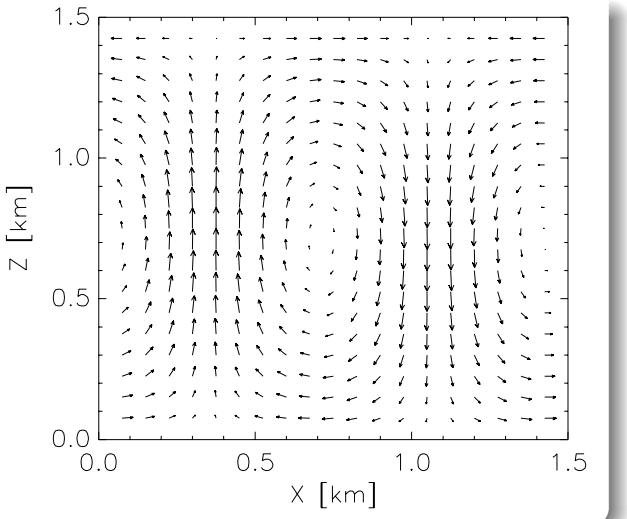

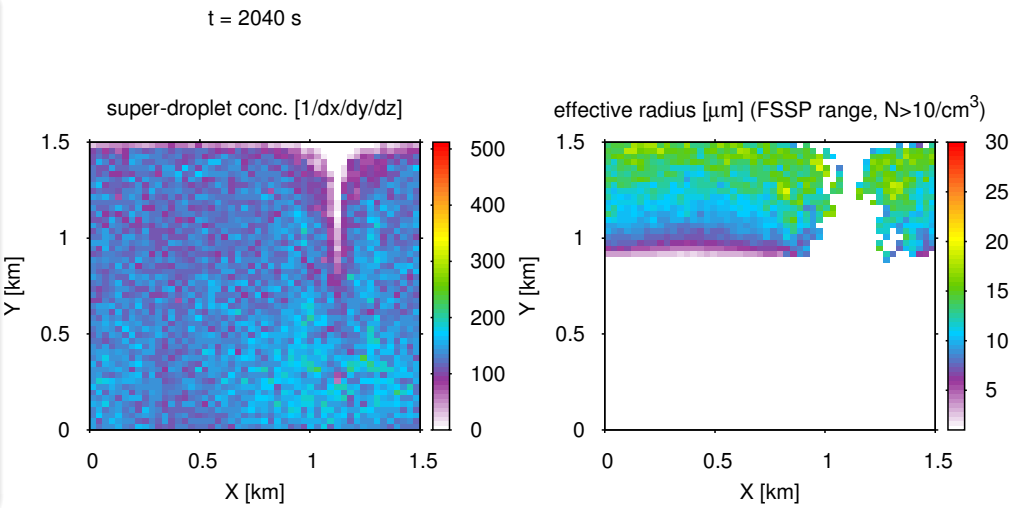

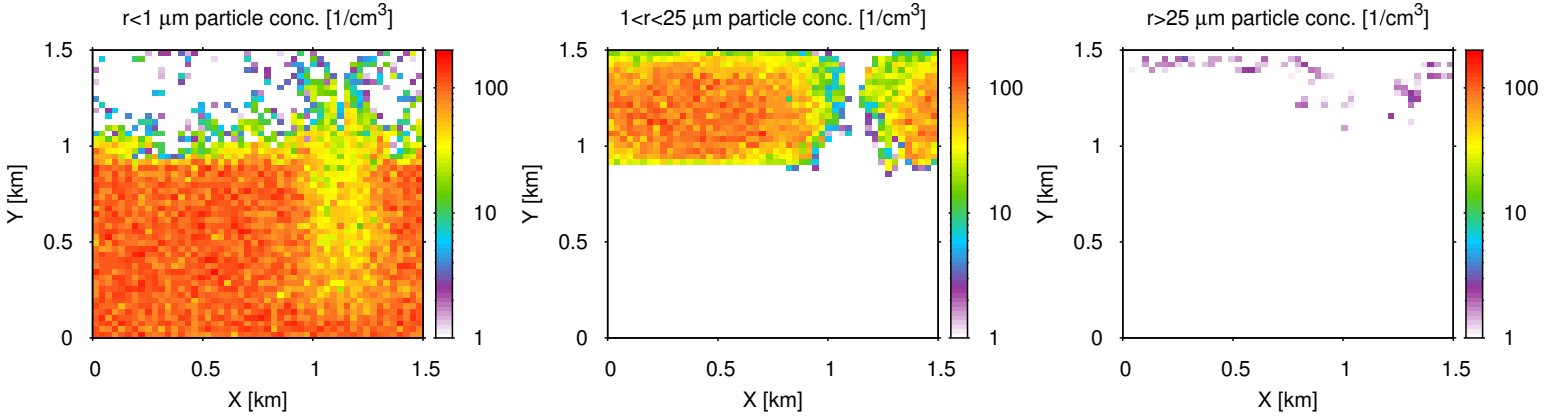

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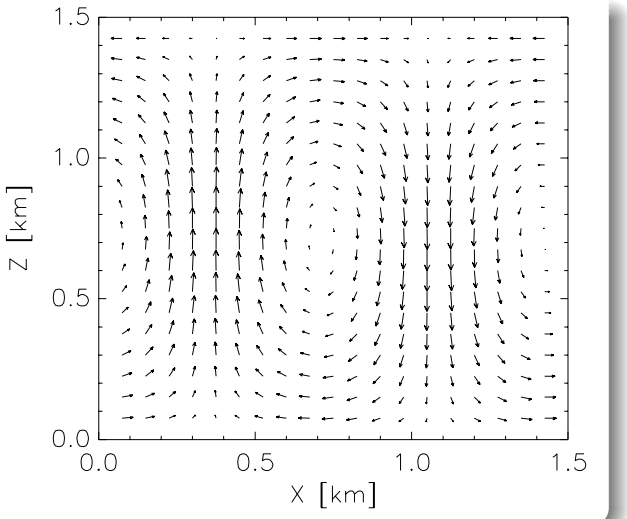

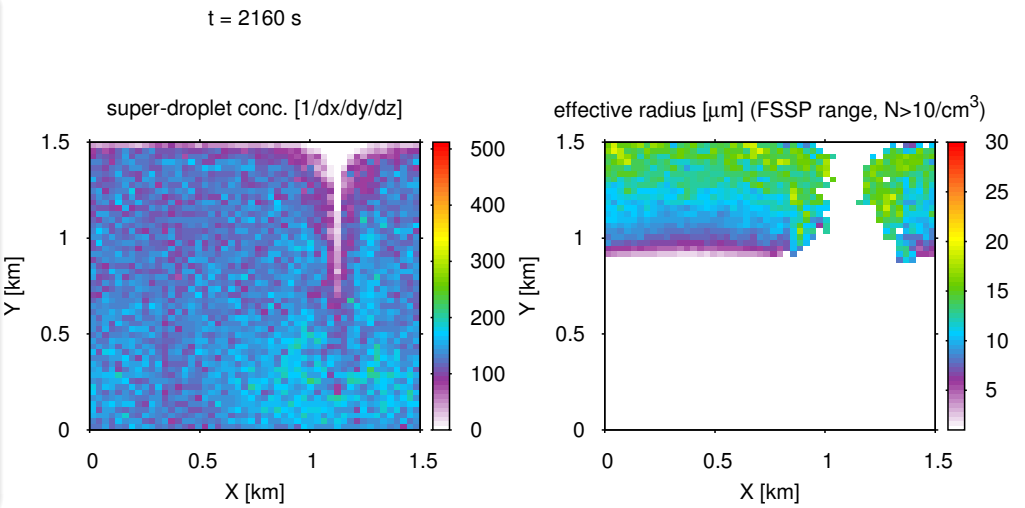

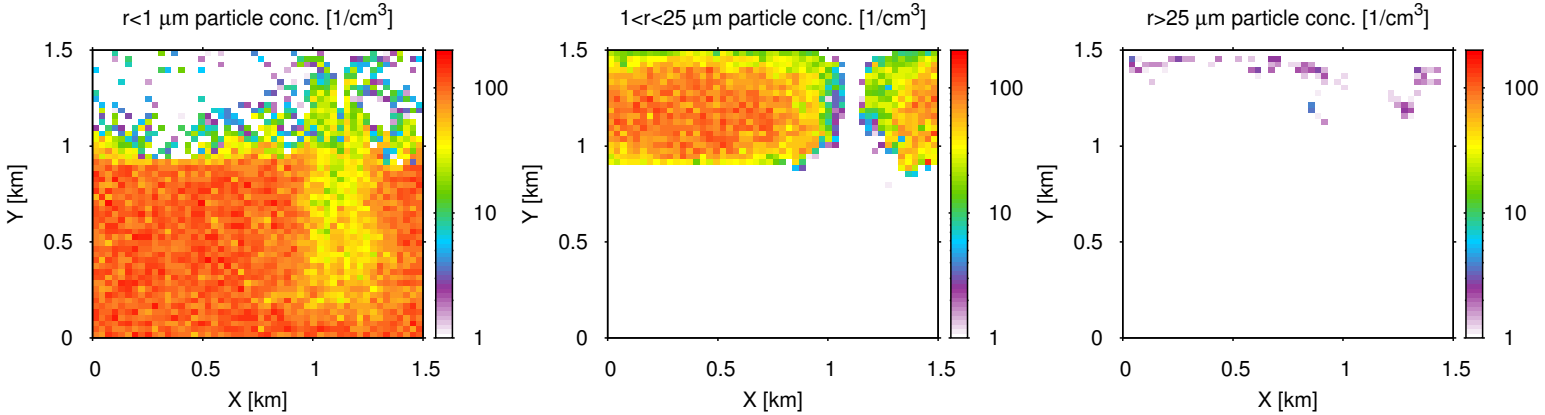

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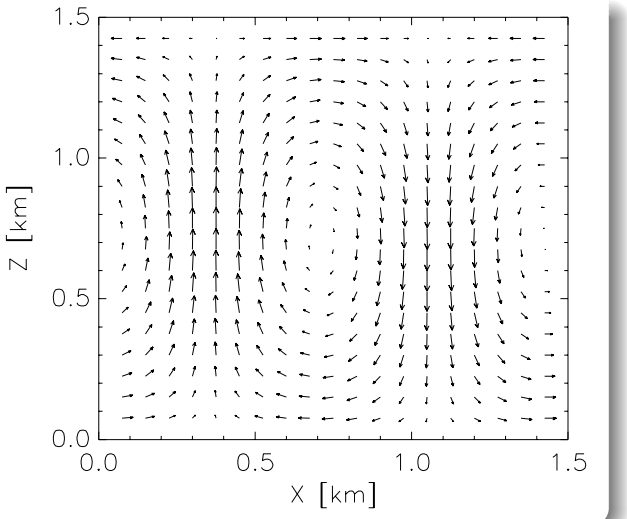

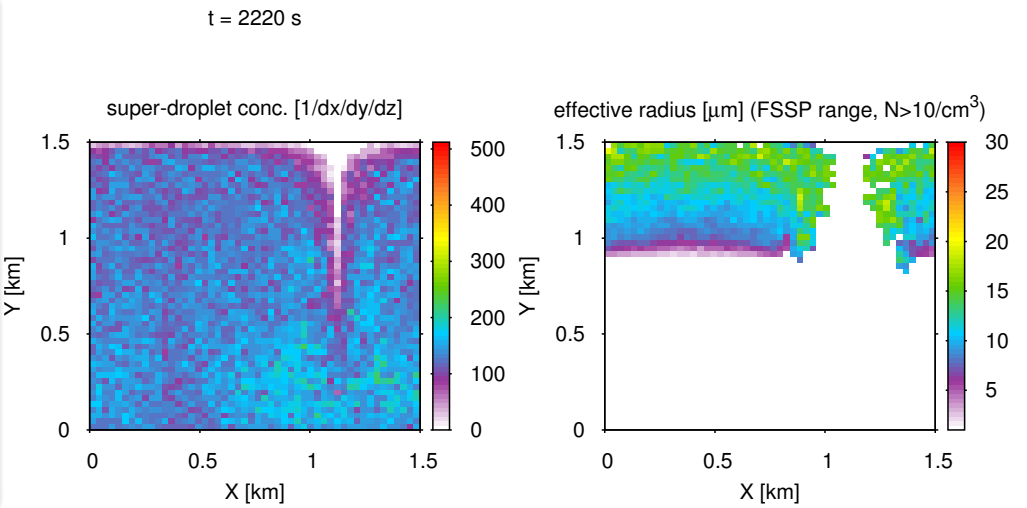

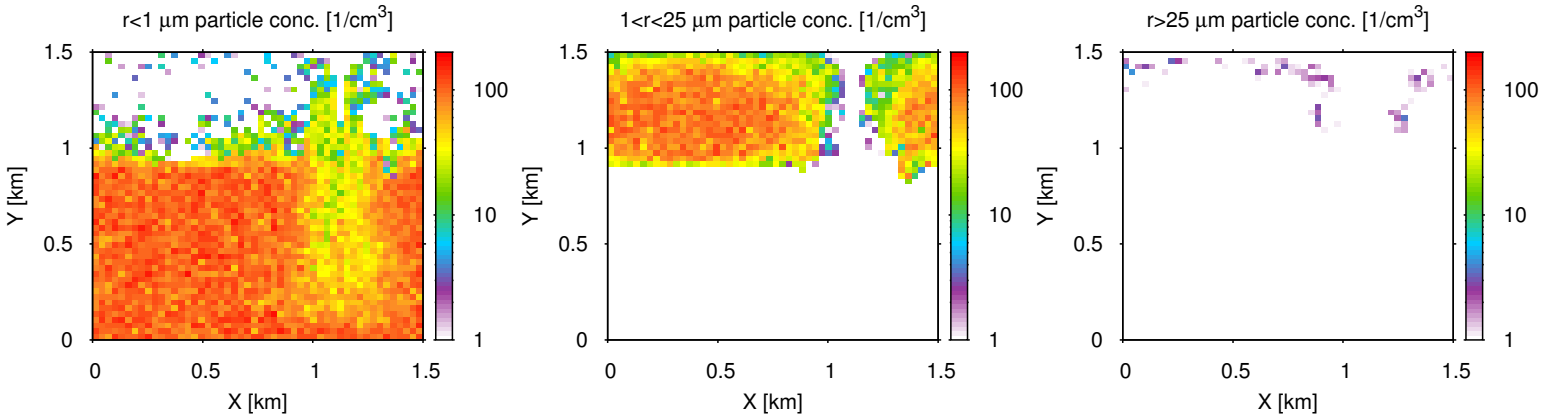

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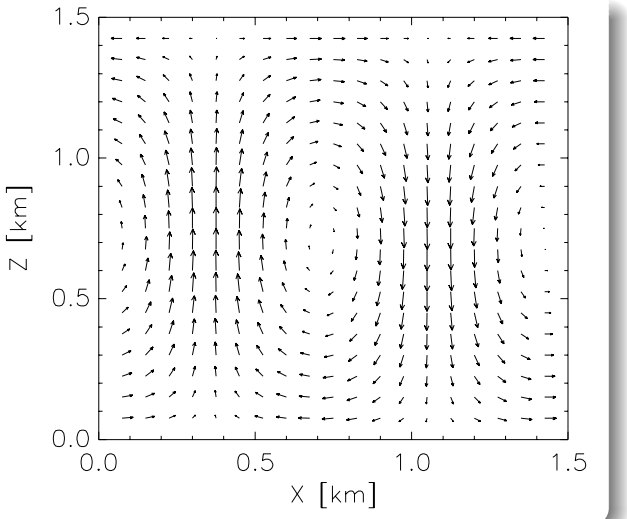

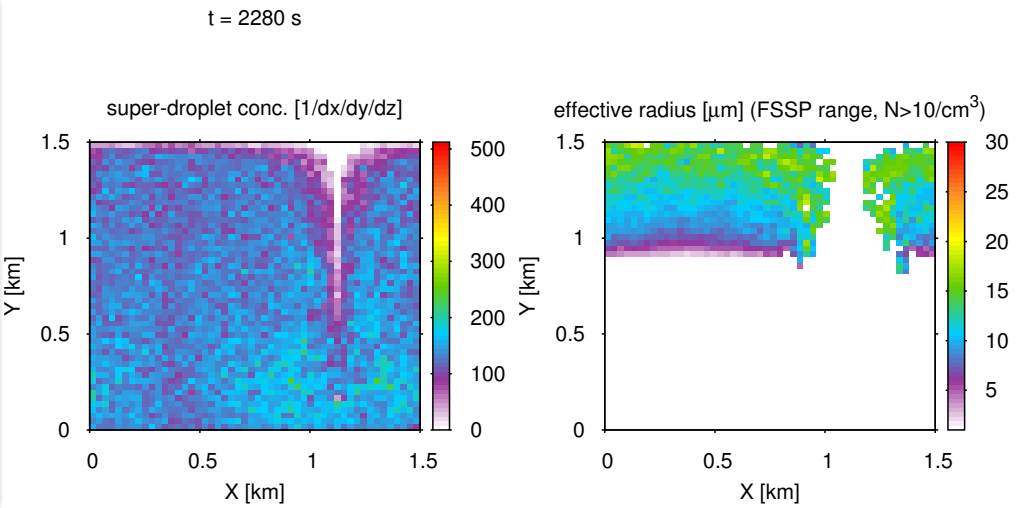

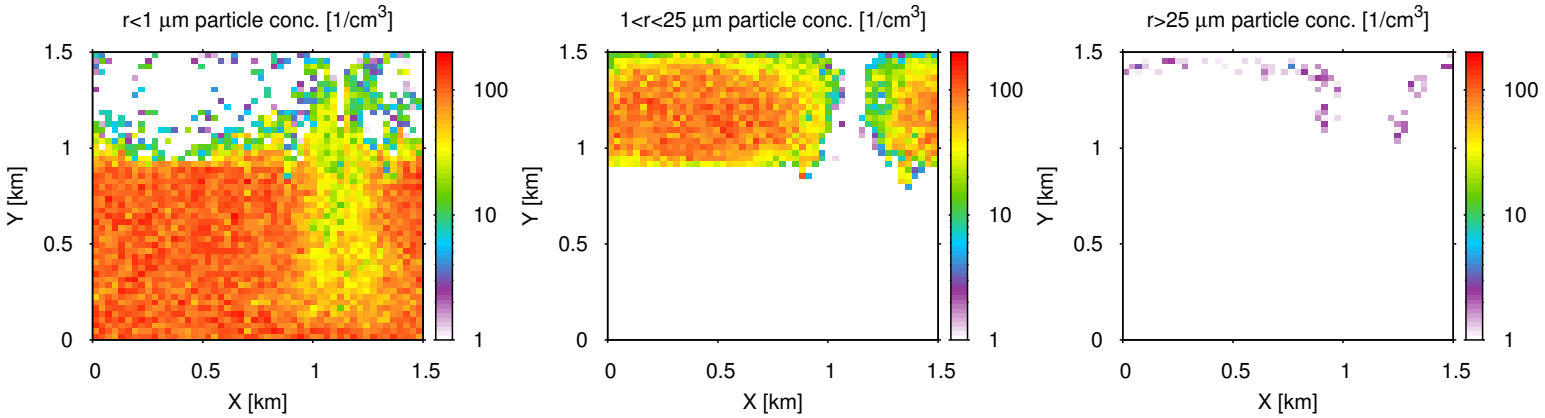

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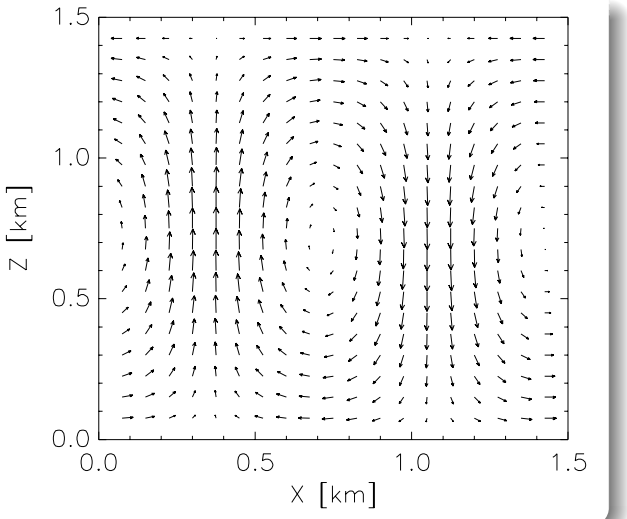

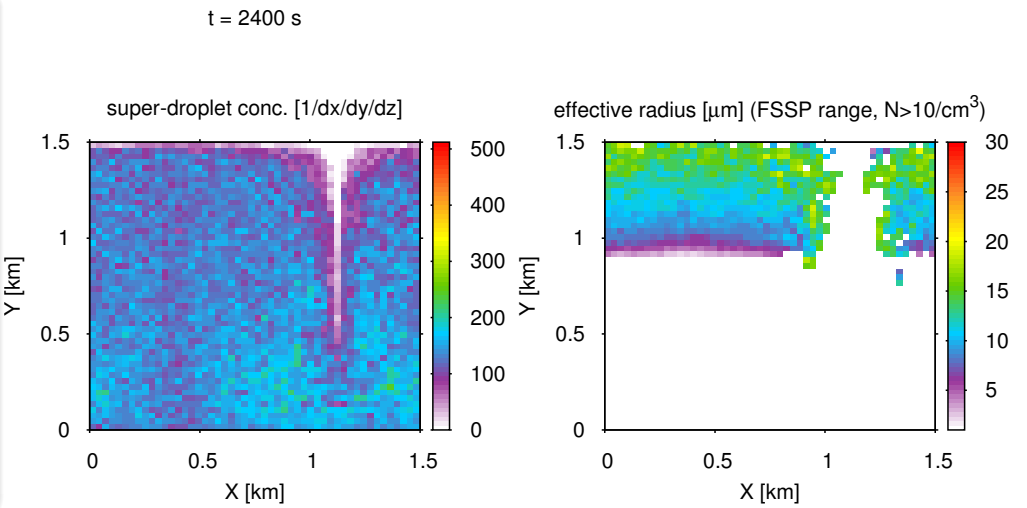

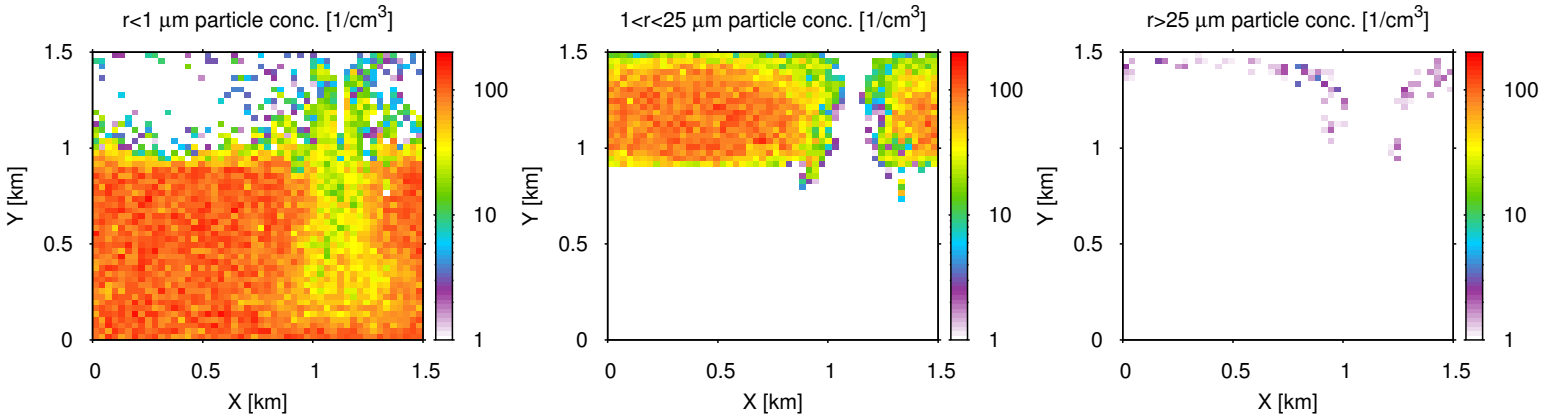

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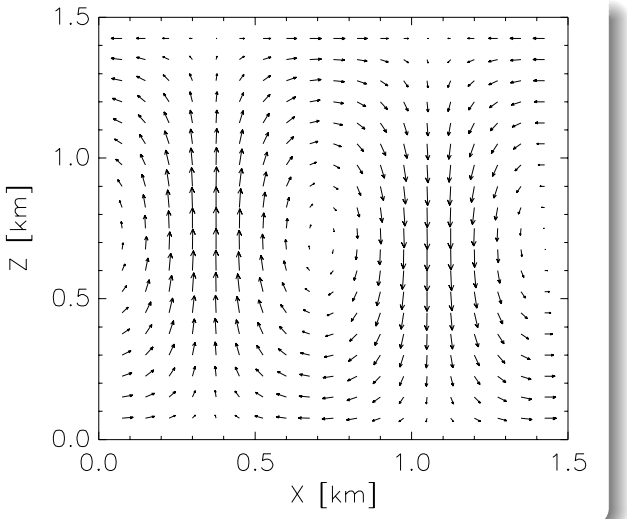

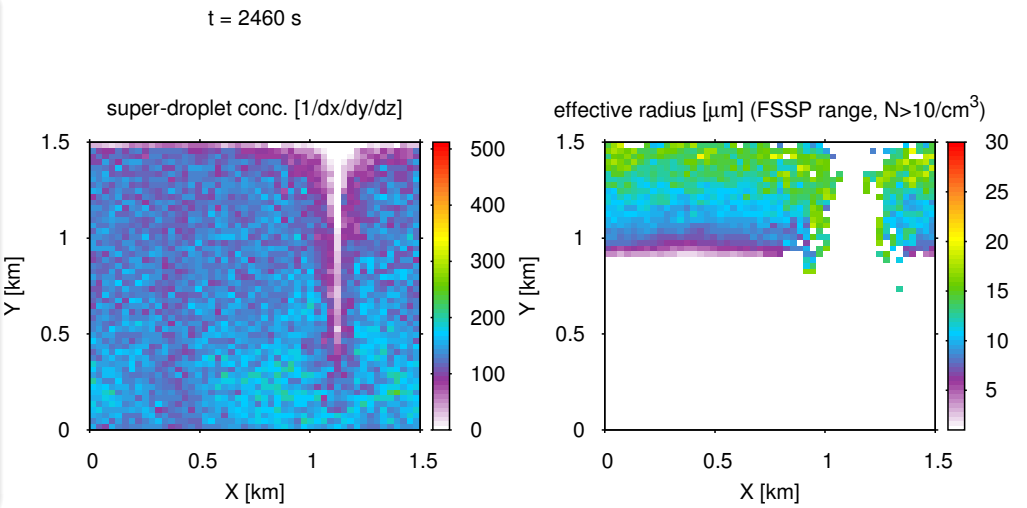

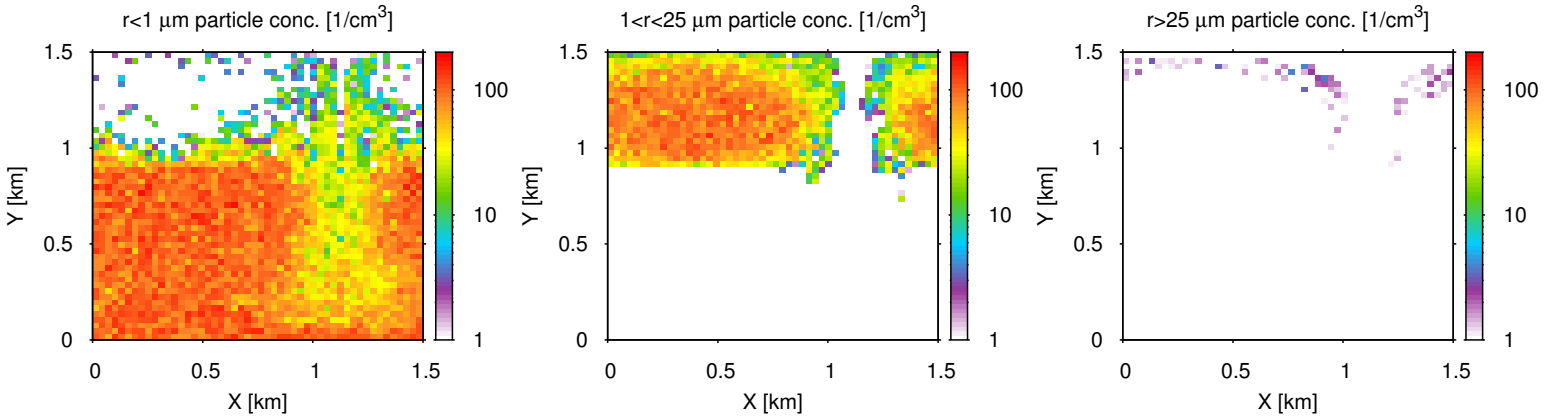

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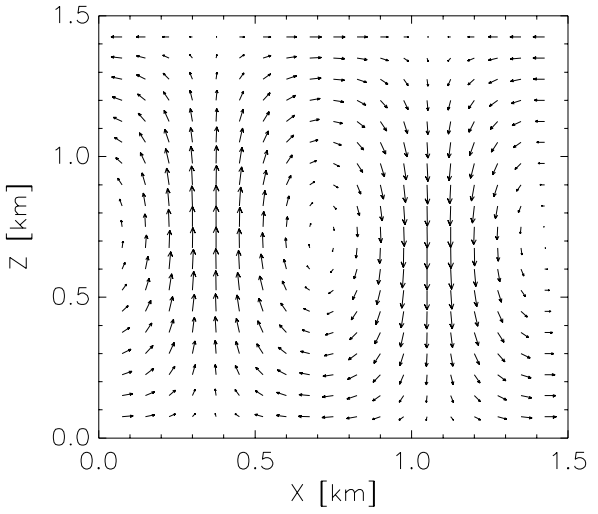

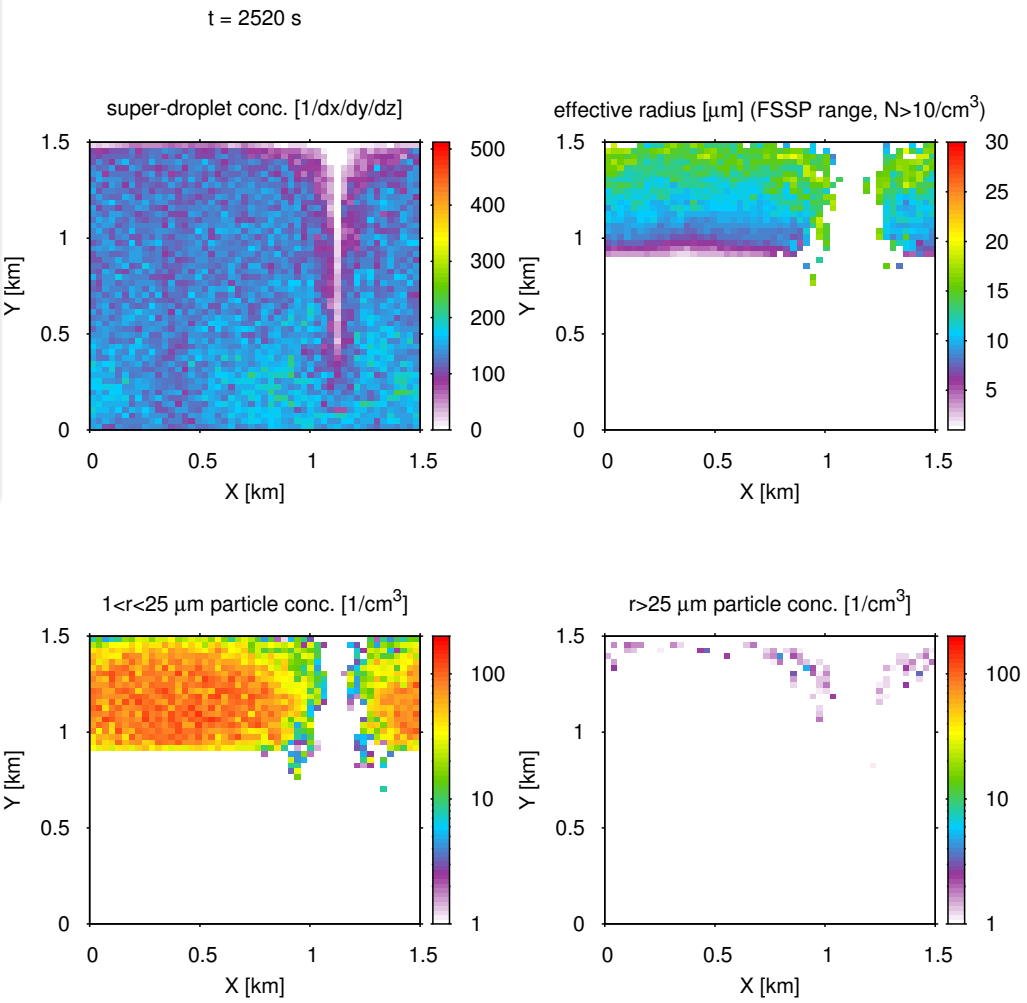

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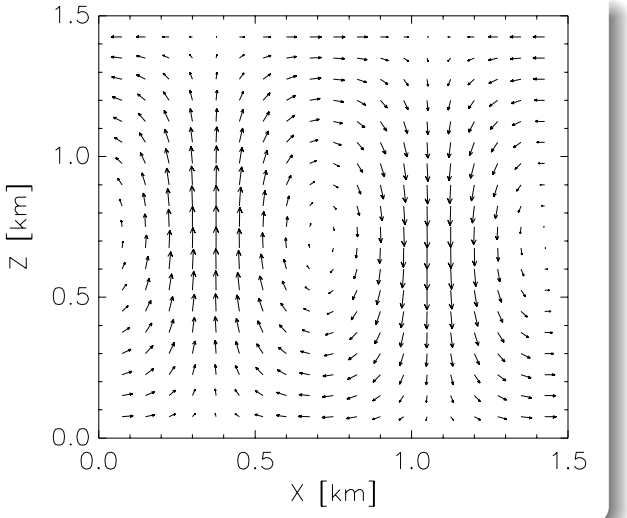

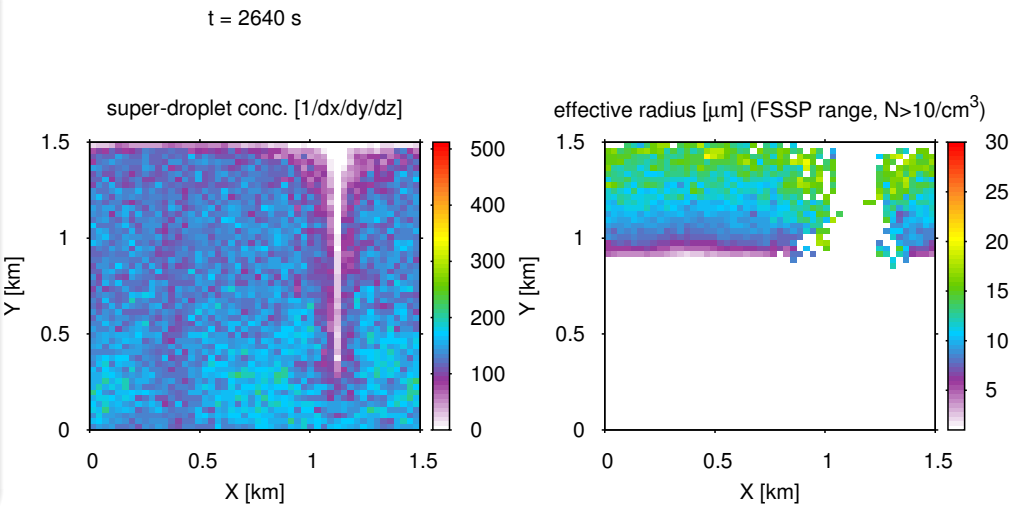

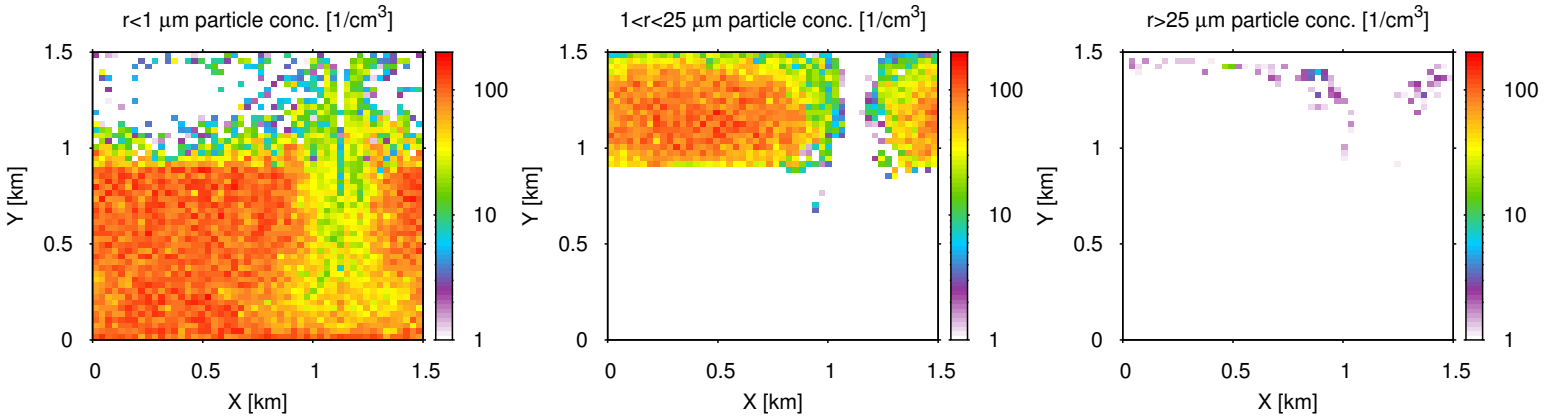

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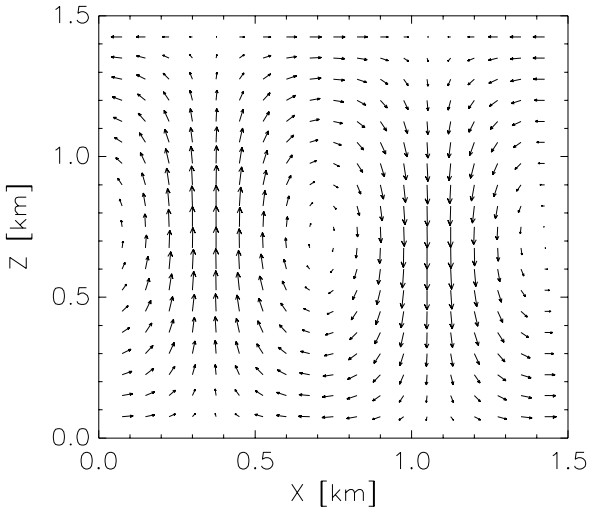

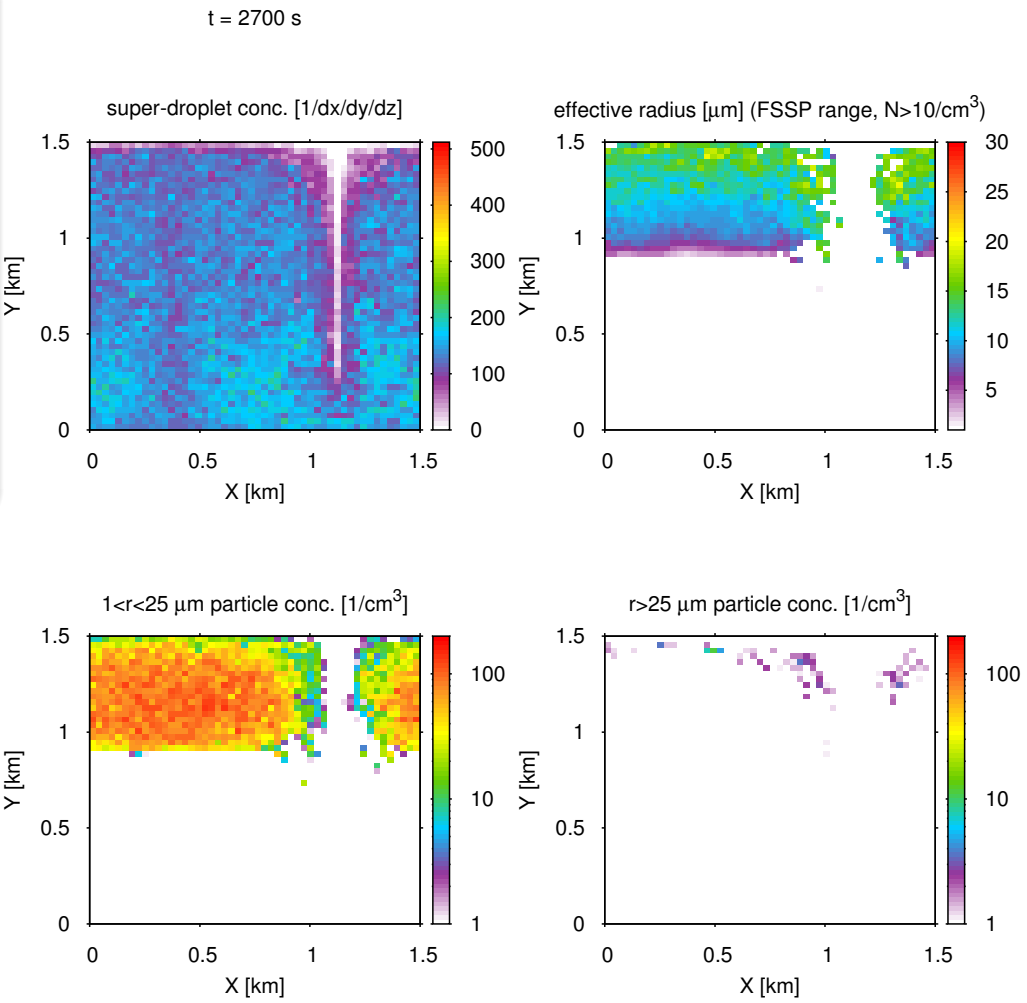

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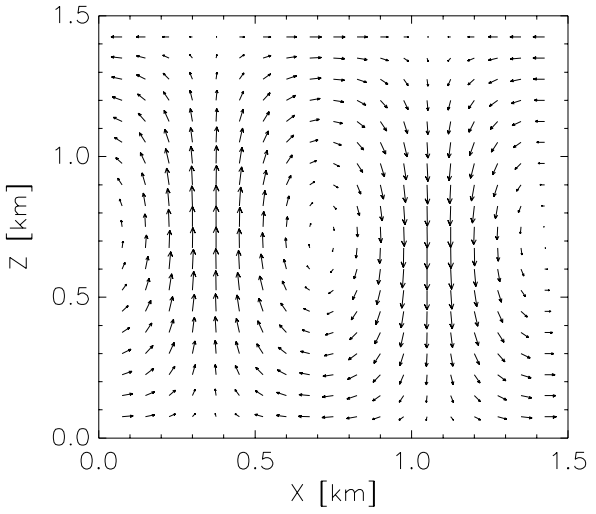

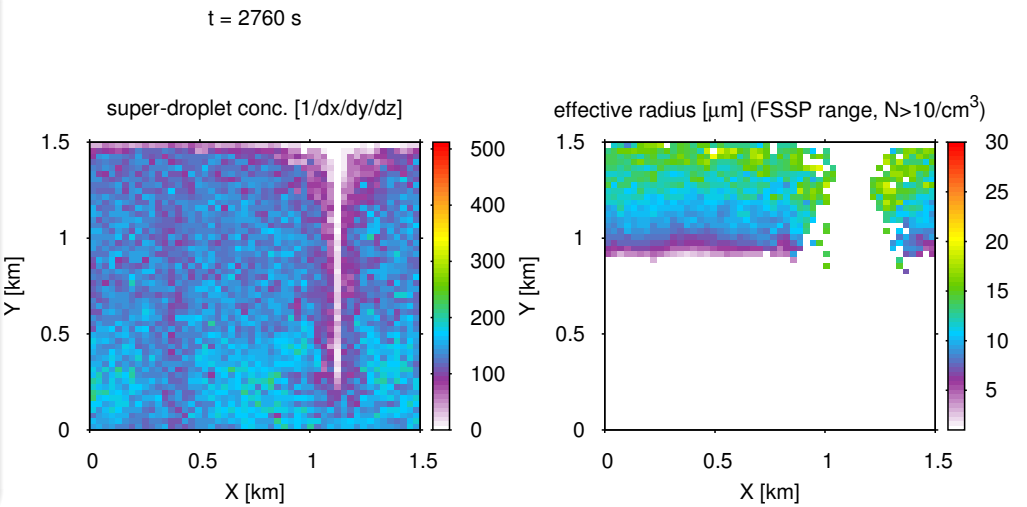

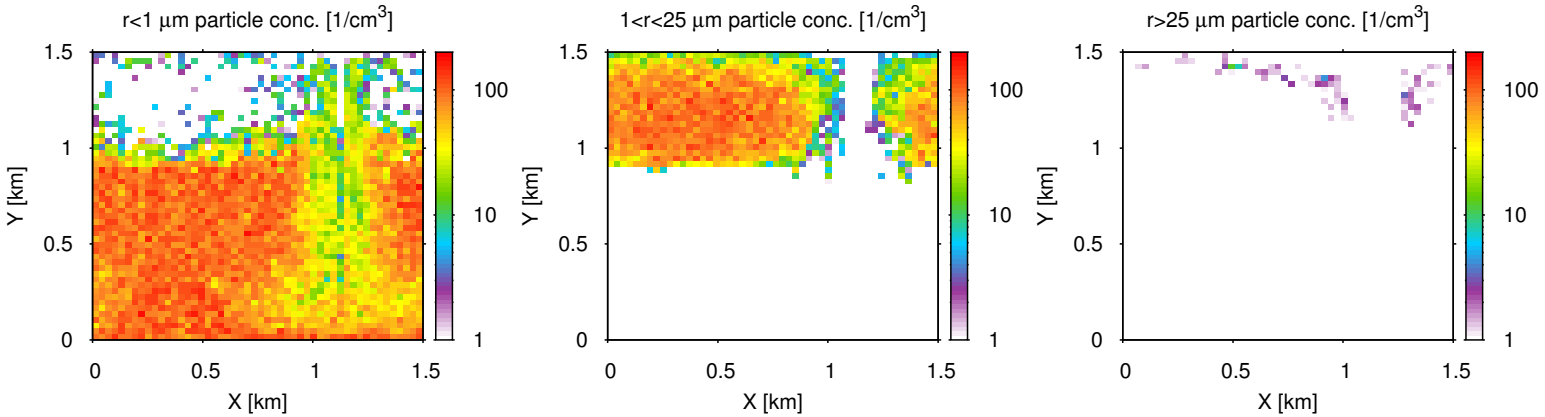

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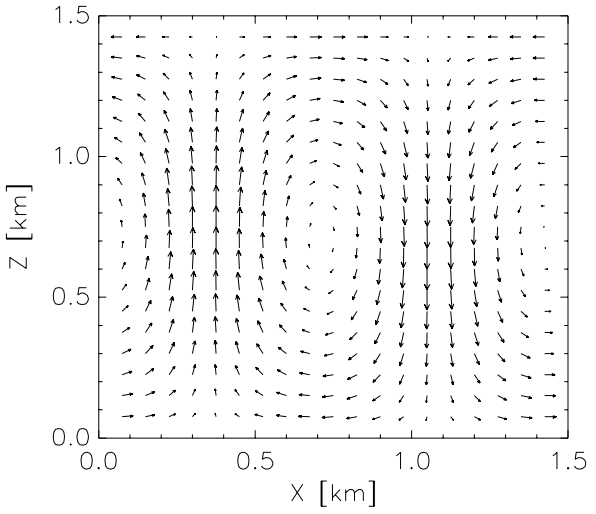

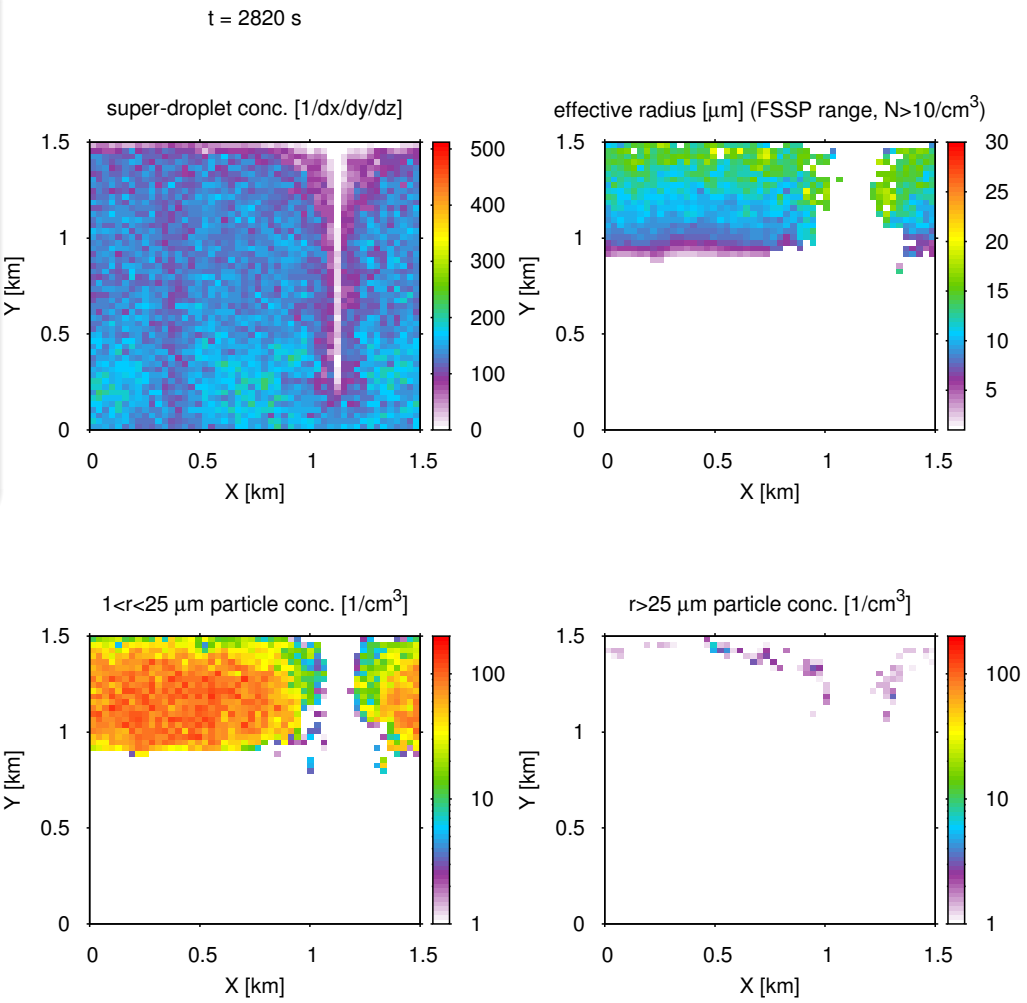

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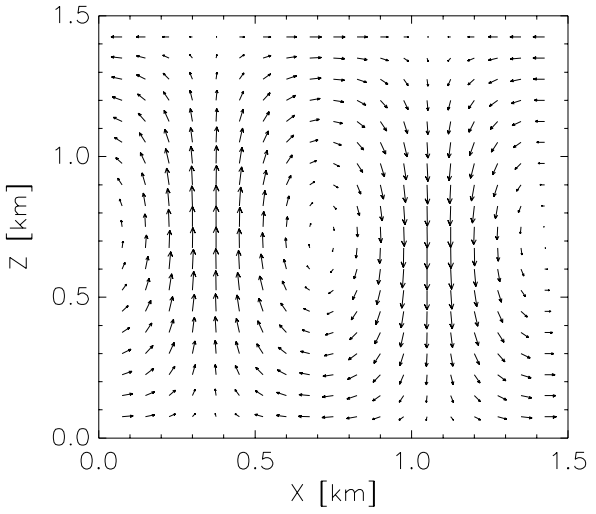

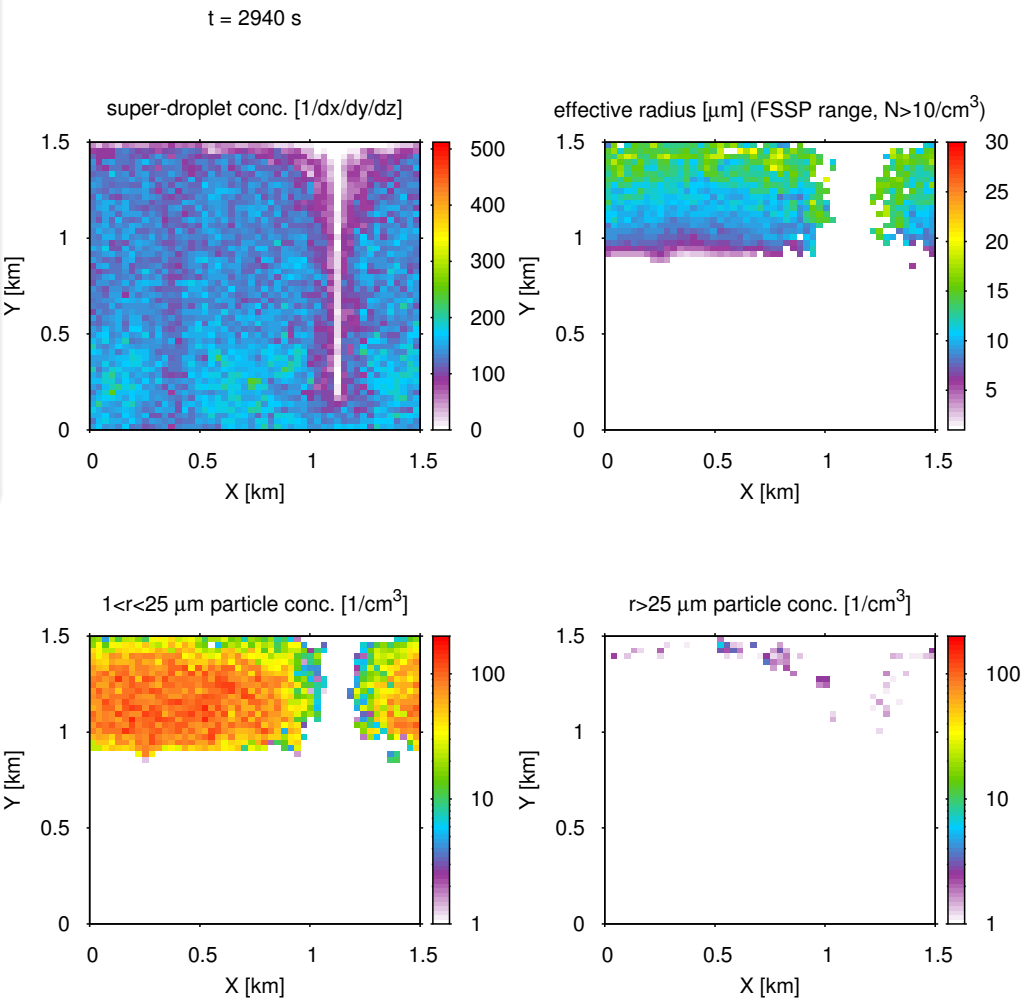

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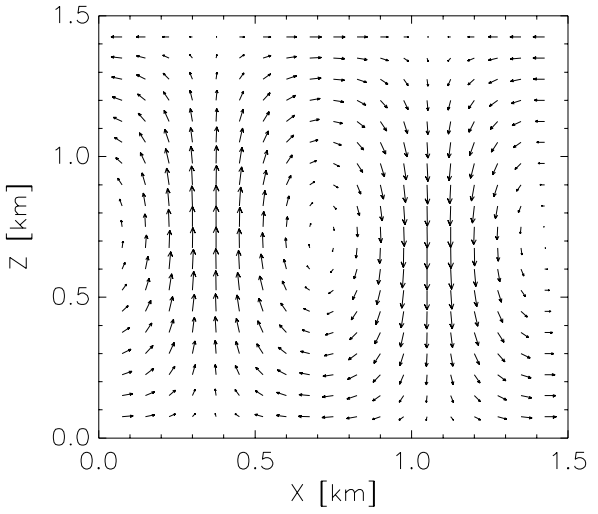
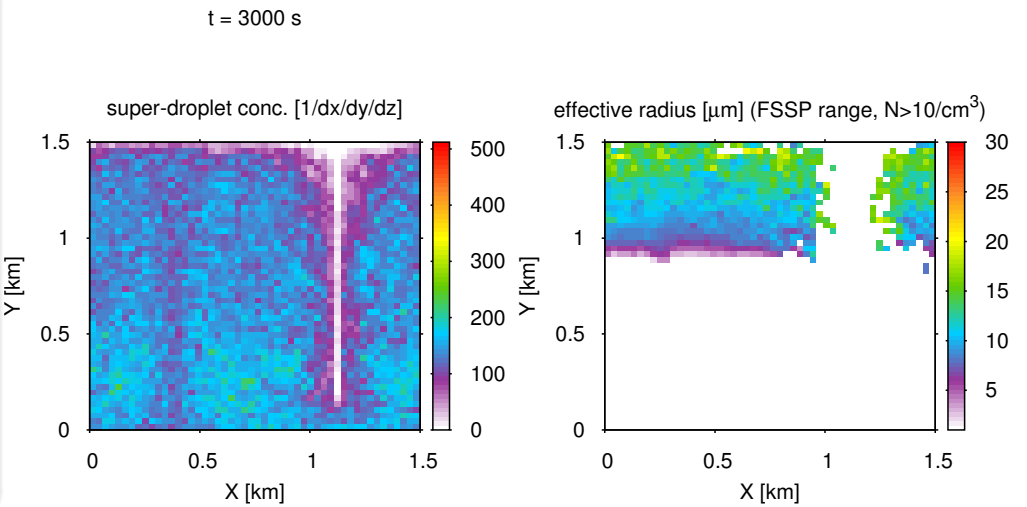
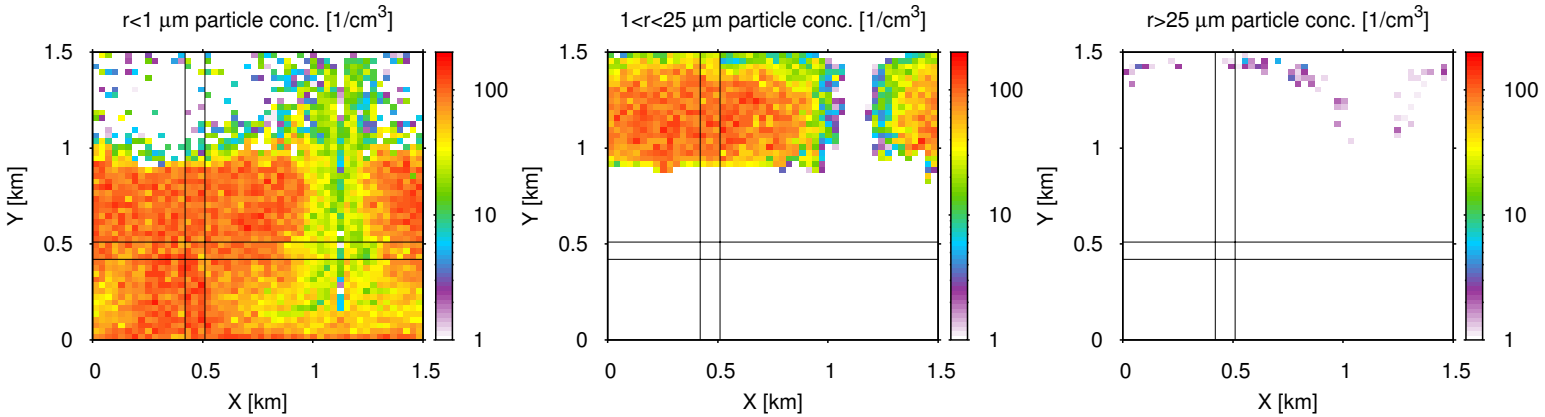
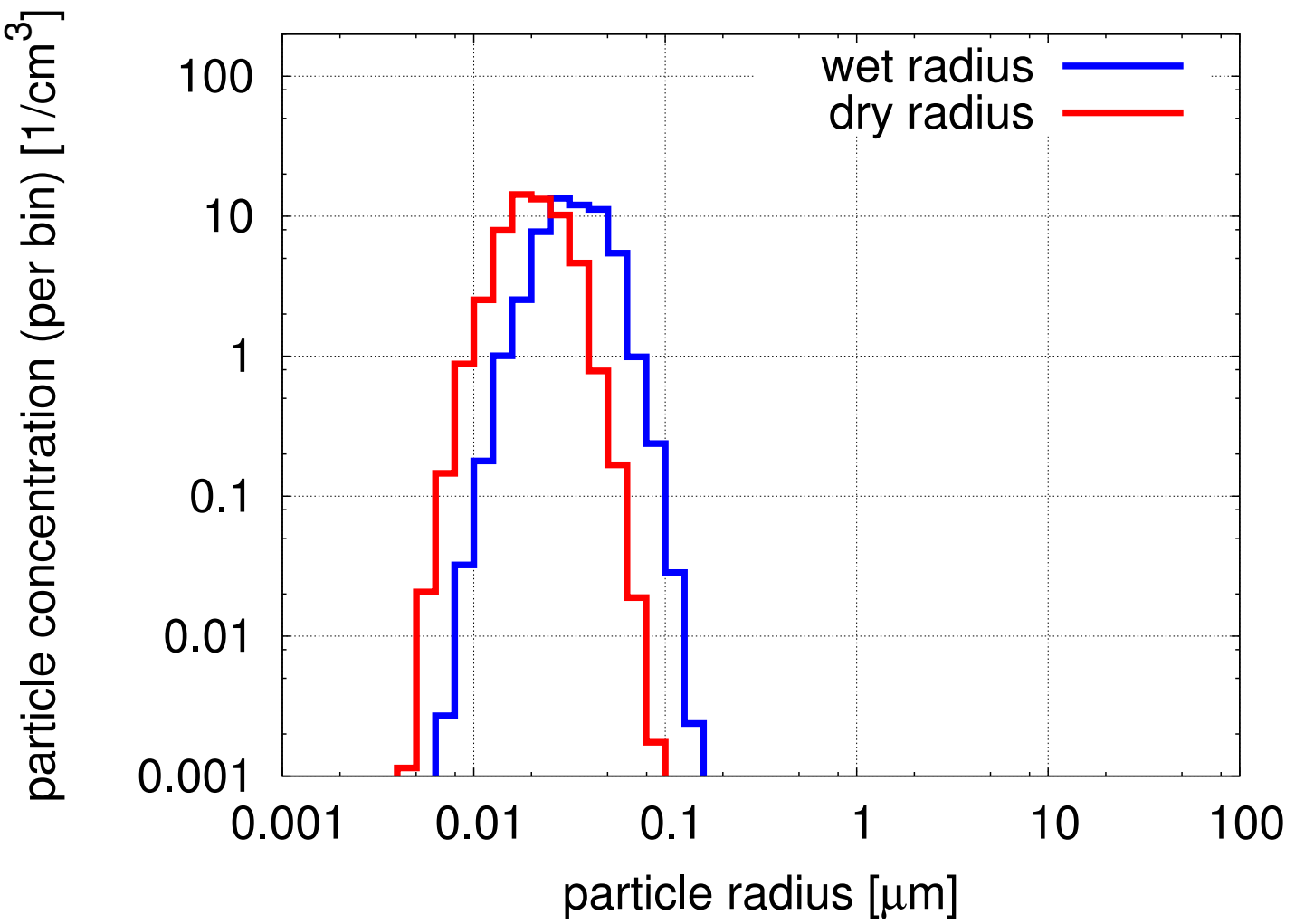






8th ICMW case 1 with Lagrangian/Monte-Carlo μ-physics



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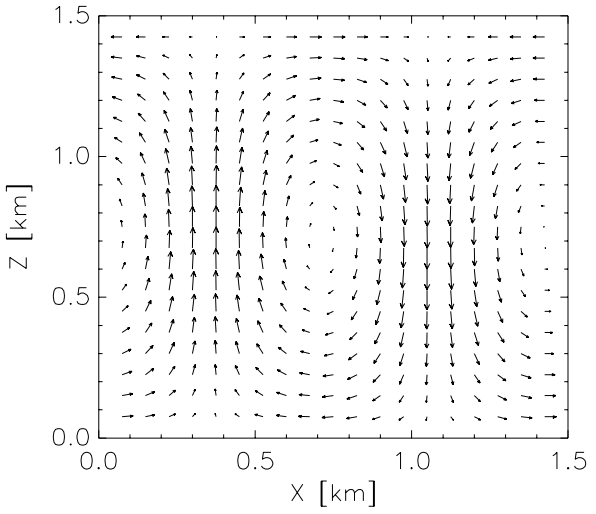

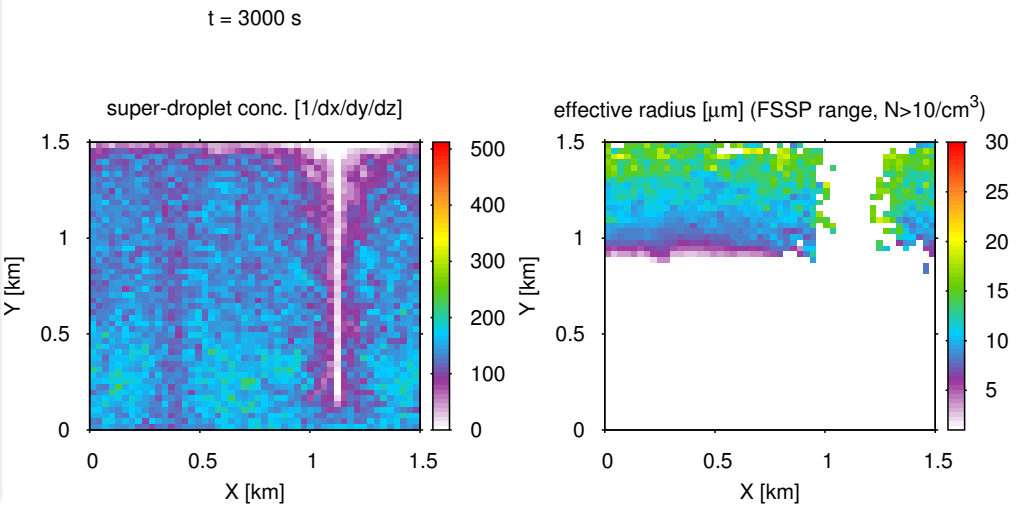

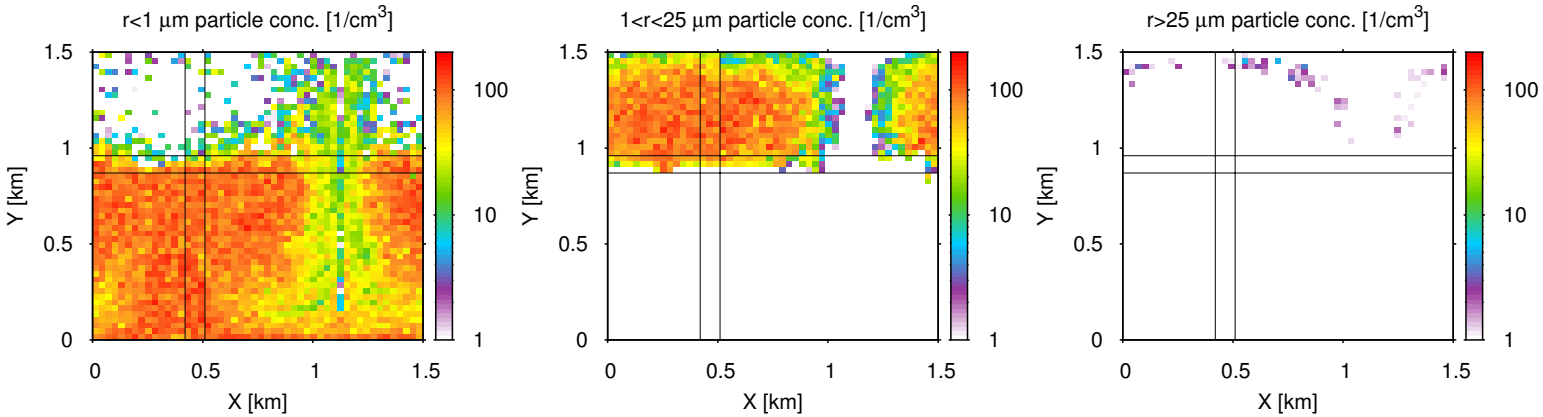

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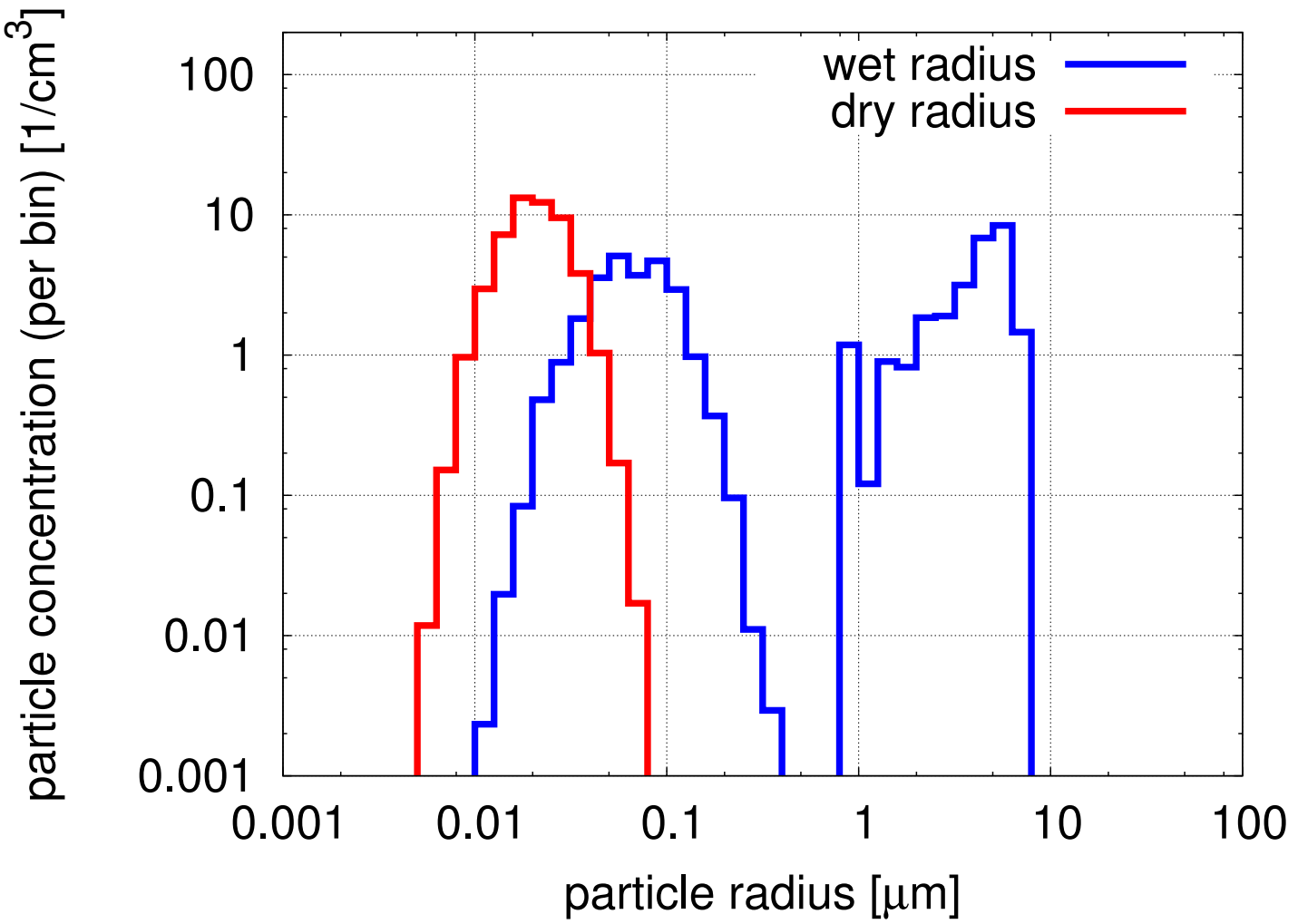
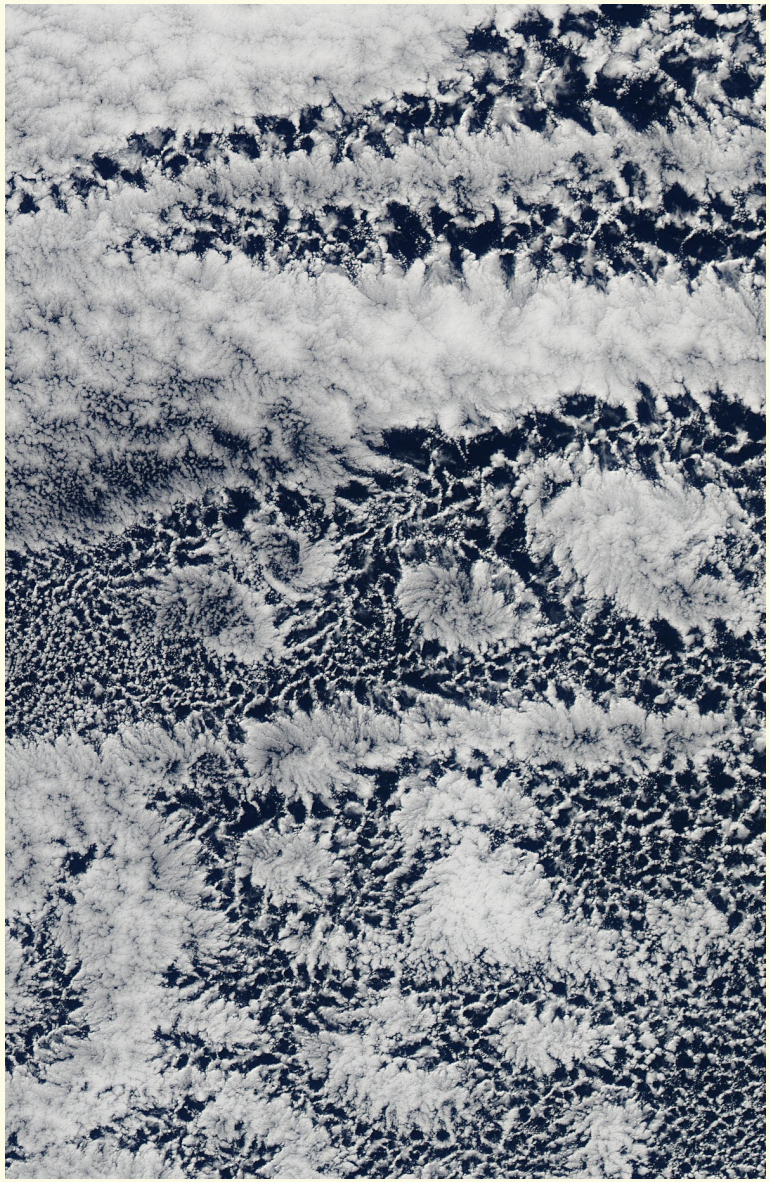


Summary

- Observations suggest that two-way aerosol-cloud interactions play an important role in such phenomena as the transition from closed to open cellural convection



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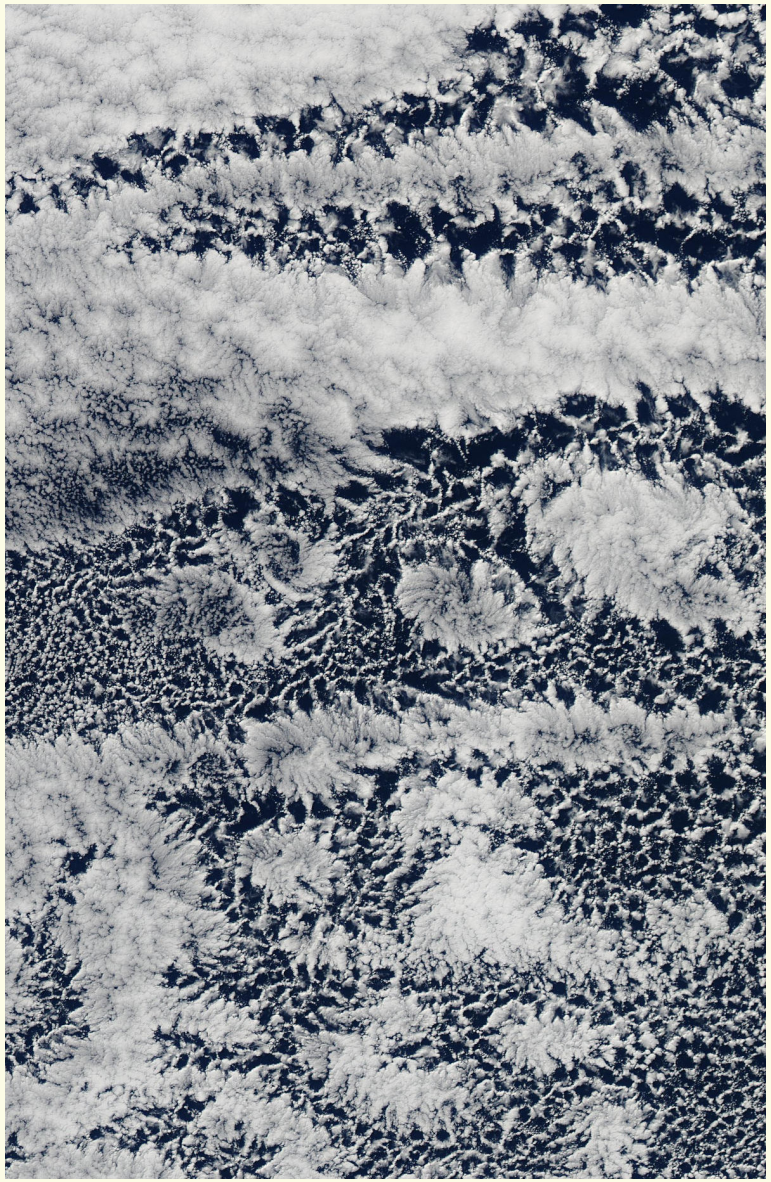
- Common cloud μ-physics representation approaches (bulk/multi-moment/bin) are incapable of representing these two-way interactions robustly



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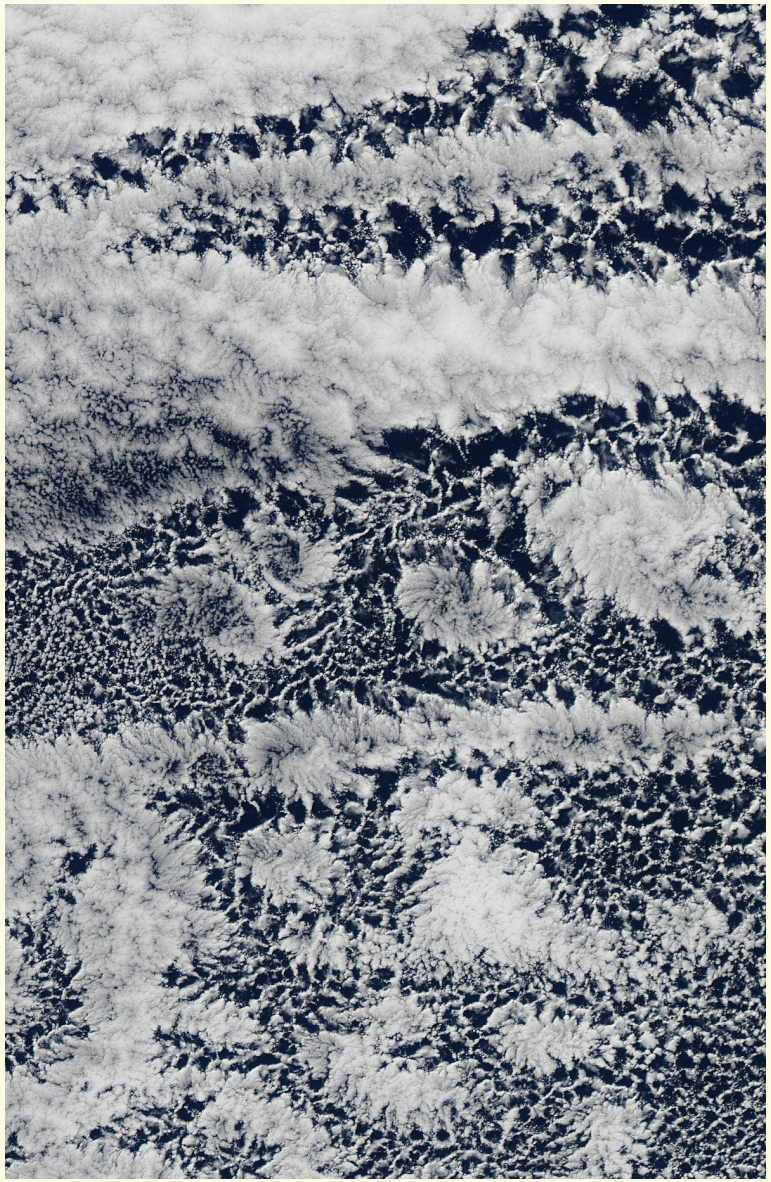

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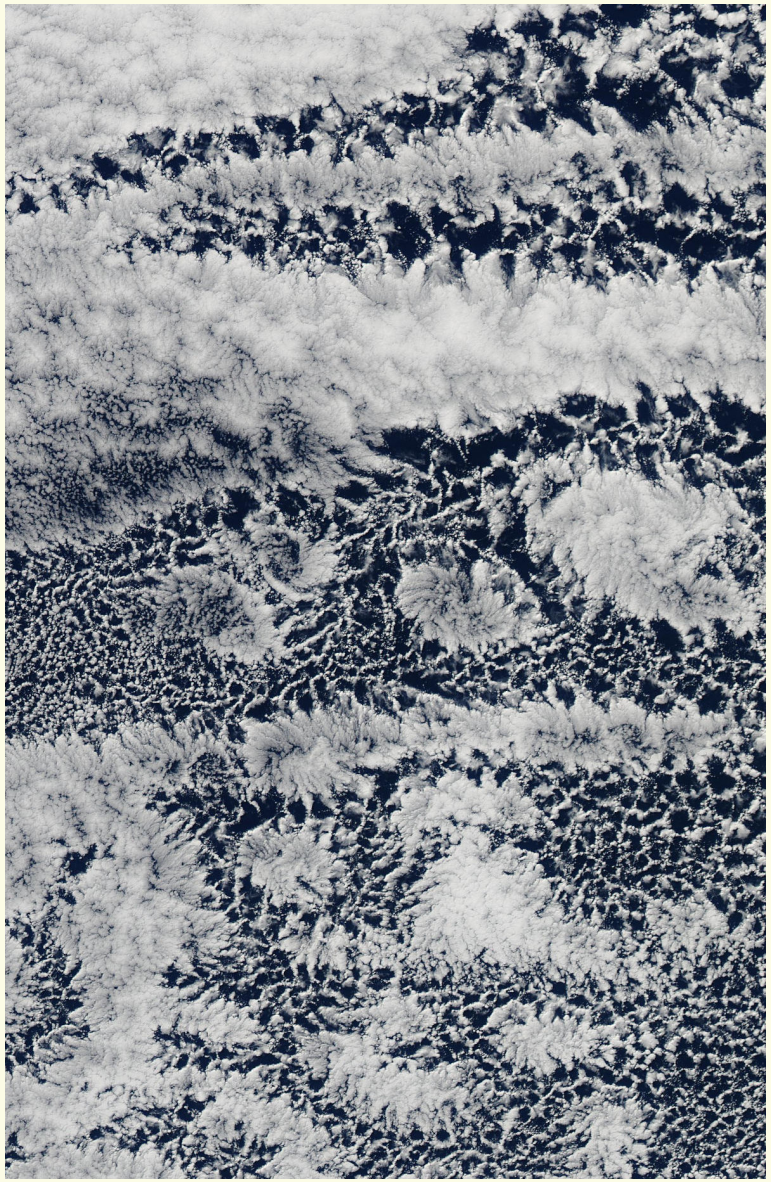
- Common cloud μ-physics representation approaches (bulk/multi-moment/bin) are incapable of representing these two-way interactions robustly
- New approaches include evolution of aerosol size and composition
- $\rightsquigarrow$ new challanges: initial condition, aerosol sources, numerics (new scales)



Thank you for your attention

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