libcloudph++
a new library of Eulerian and Lagrangian warm-rain cloud microphysics schemes

Sylwester Arabas[1], Dorota Jarecka[2,1]

1: Faculty of Physics, University of Warsaw, Poland
2: National Center for Atmospheric Research, USA

Dept. of Atmospheric Science, University of Wyoming
Laramie, May 11th 2015

Plan of the talk

"cloud reactor" project: goals and the team

libcloudph++: design choices and their rationale

libcloudph++: Lagrangian "super-droplet" μ-physics

libcloudph++: access from Python and Fortran
(presented by Dorota Jarecka, NCAR)

"cloud reactor" project: architects, goals & funding

Hanna Pawłowska, Piotr Smolarkiewicz & Wojtek Grabowski

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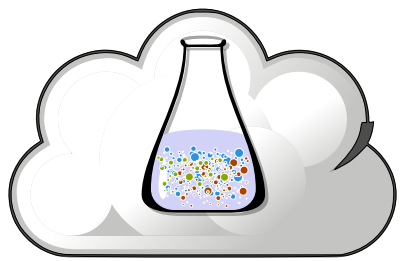

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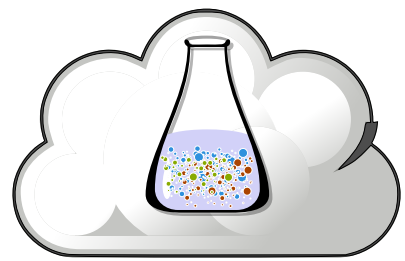

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POLAND

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why not to develop everything from scratch:

- have to wait 3 years before tackling scientific problems

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libmpdata++ & libcloudph++

project target

LES-type tool featuring:

- robust numerics (MPDATA)
- particle-based aerosol/warm-rain μ-physics (super-droplet)

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current "products" – C++ libraries

libmpdata++ parallel solvers for systems of transport equations

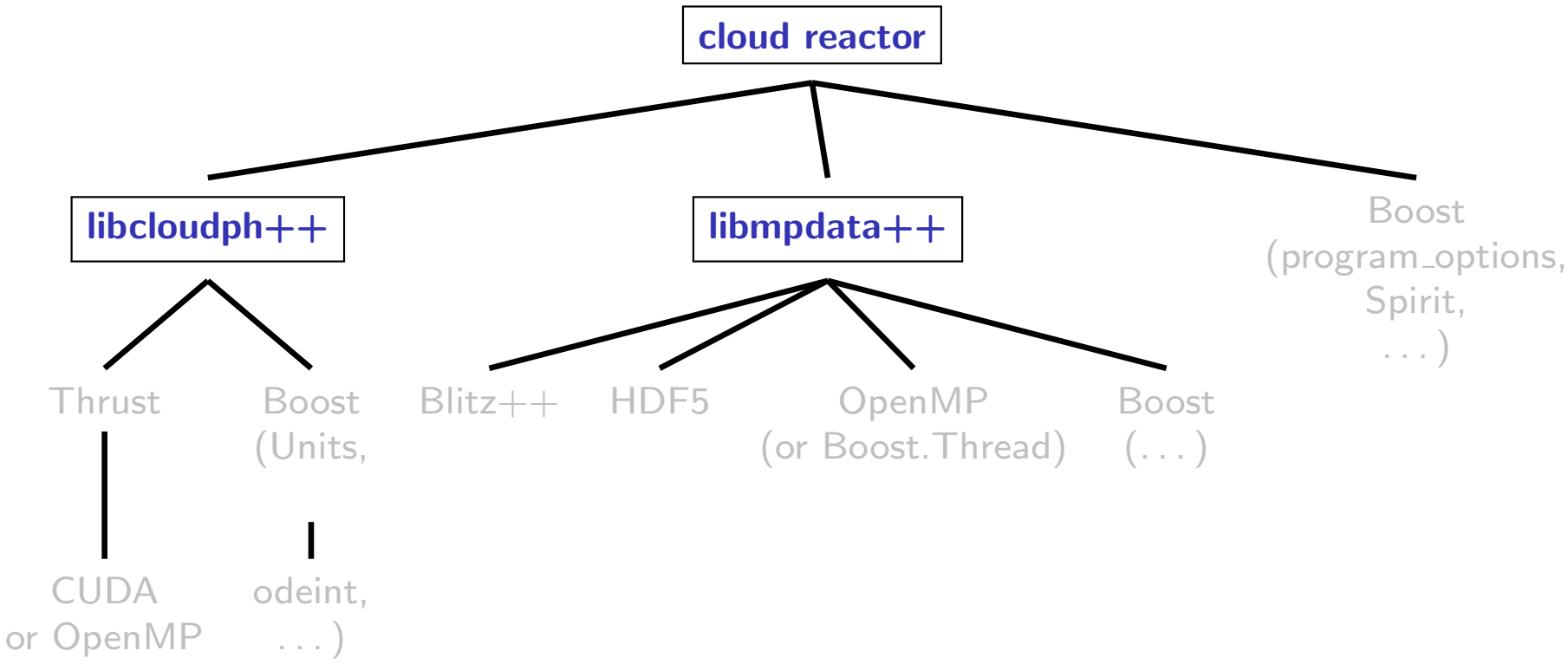
- `http://libmpdataxx.igf.fuw.edu.pl/`
- GMD paper doi:doi:10.5194/gmd-8-1005-2015

libcloudph++ aerosol/cloud μ-physics algorithm collection

- `http://libcloudphxx.igf.fuw.edu.pl/`
- GMDD paper doi:10.5194/gmdd-7-8275-2014

a few words on first design choices

- structure the code into "standalone" libraries



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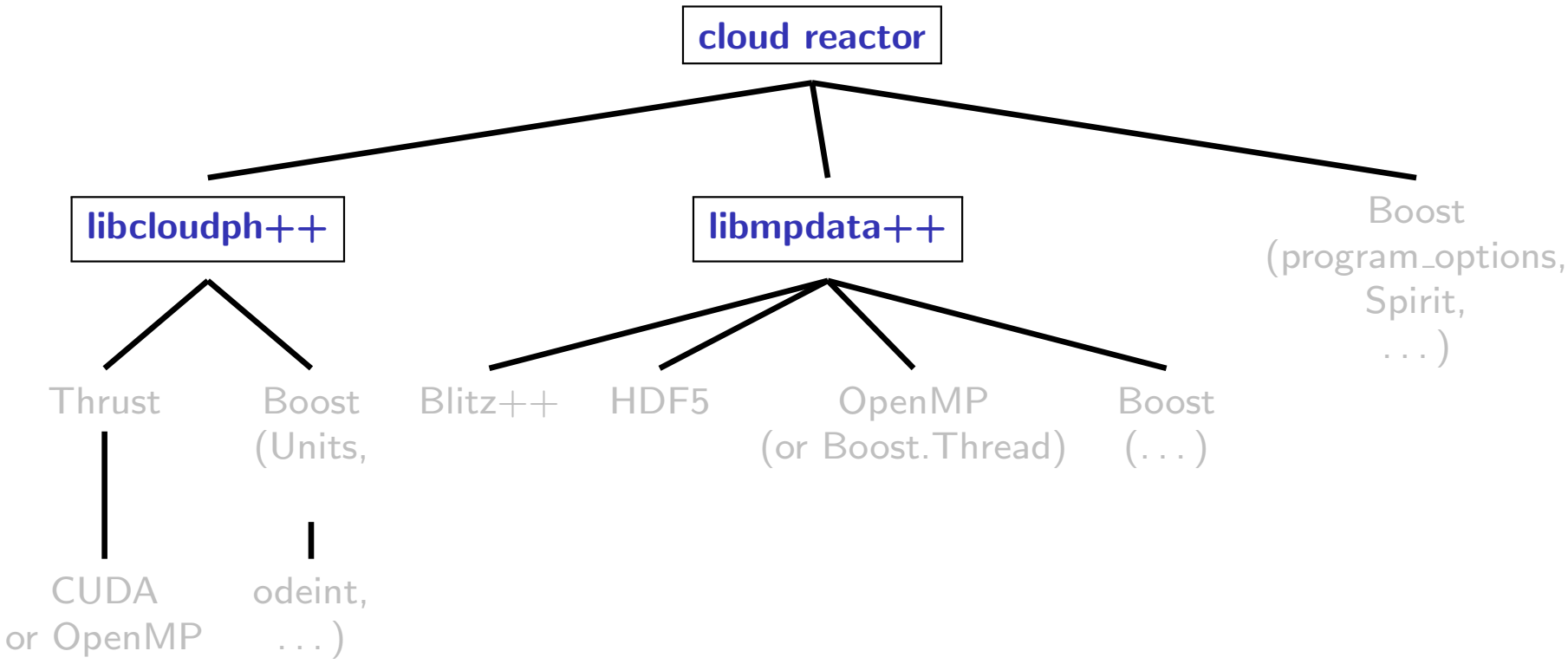

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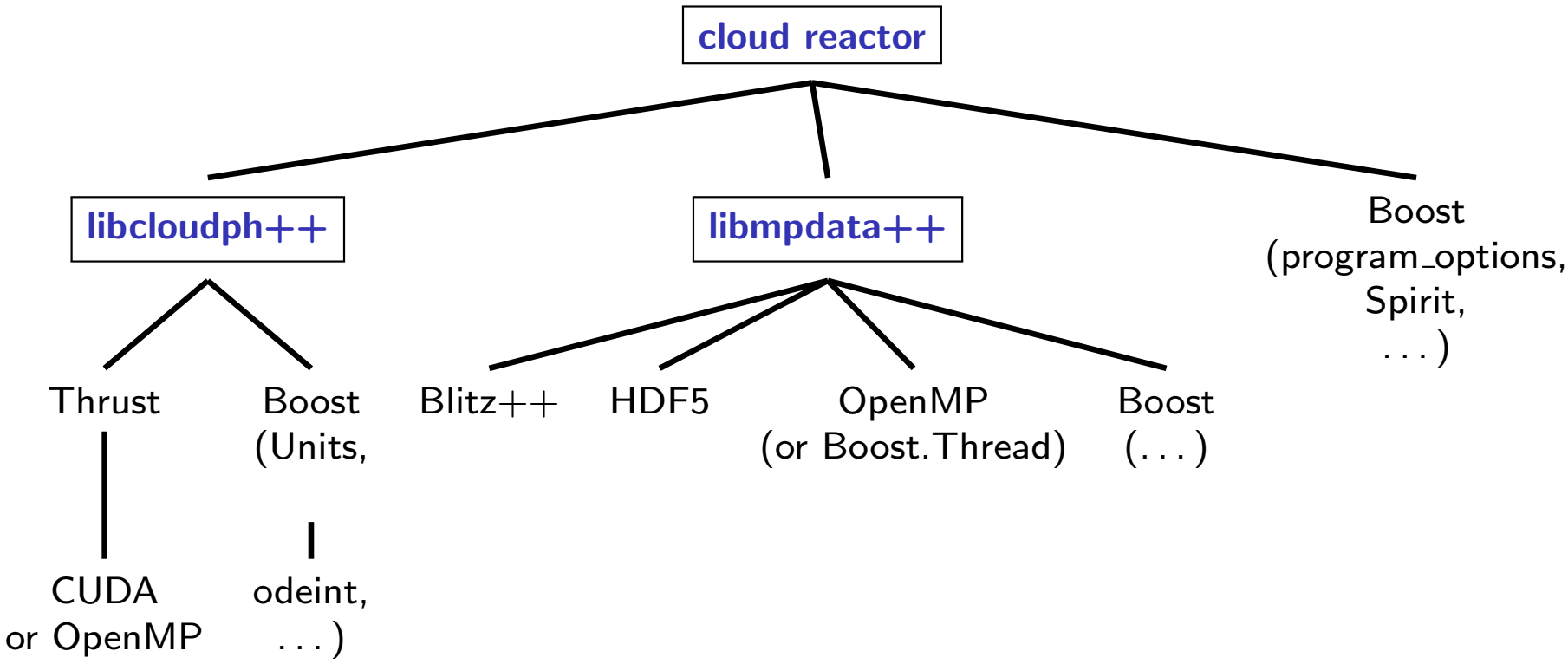

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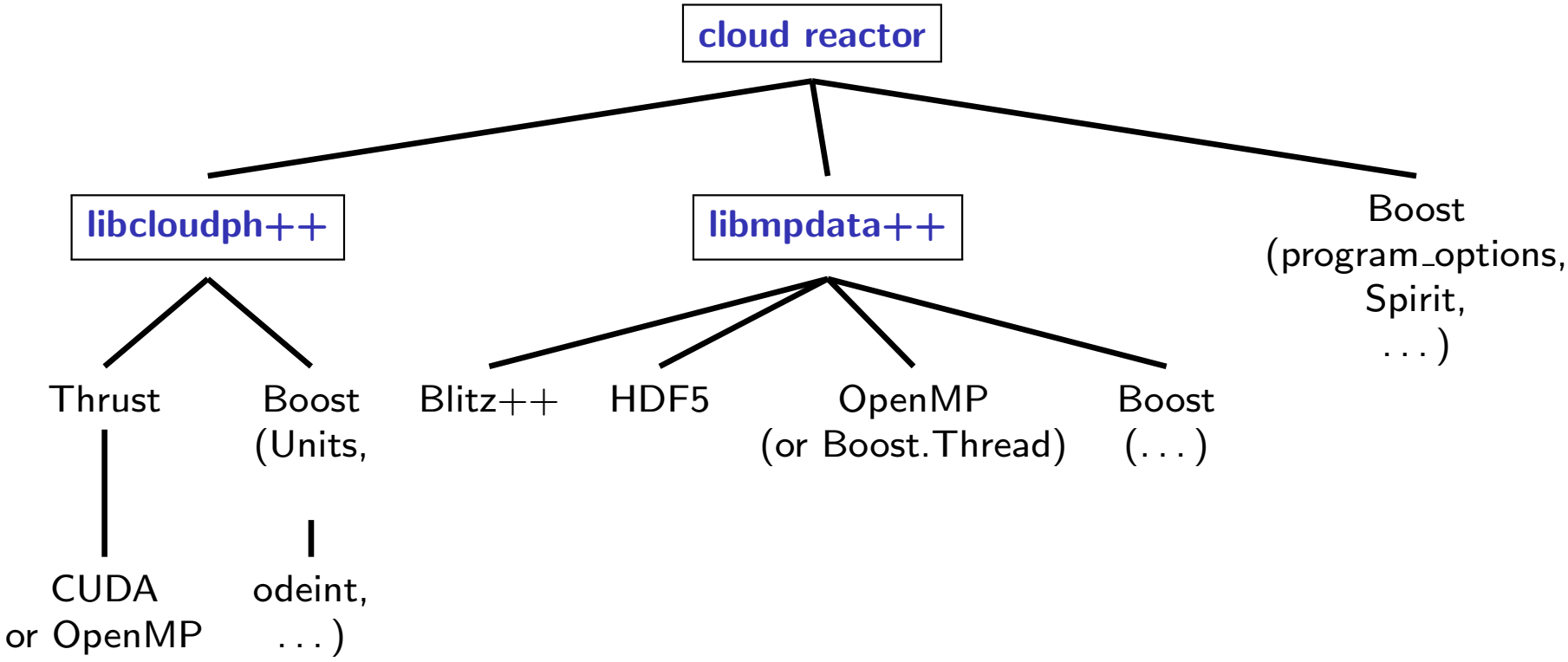
- leverage existing **reusable** software
  - ⇝ save time, benefit from state-of-the-art components



libcloudph++ components

- single-moment bulk saturation-adjustment scheme with Kessler's coalescence
- double-moment bulk scheme with predicted supersaturation (Morrison & Grabowski 2007)
- particle-based scheme with Monte-Carlo coalescence (super-droplet method of Shima et al. 2009)
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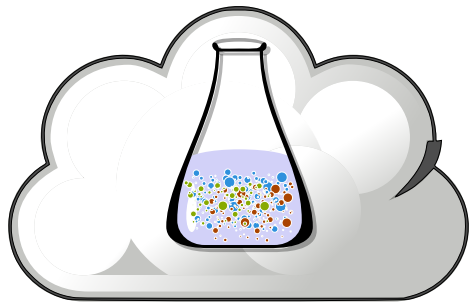

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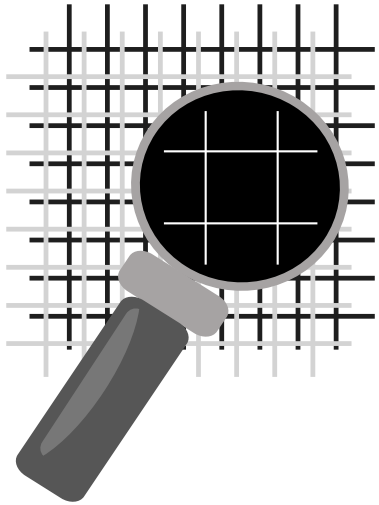
Eulerian vs. Lagrangian μ-physics



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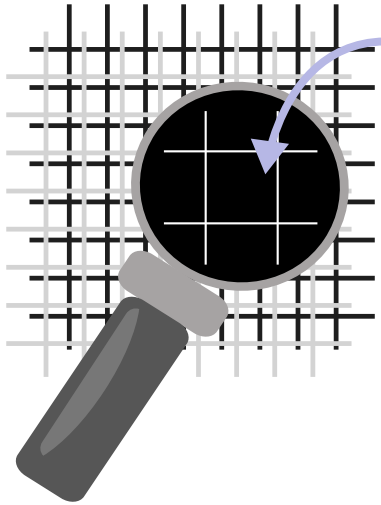

single-moment bulk

no influence of aerosol on cloud

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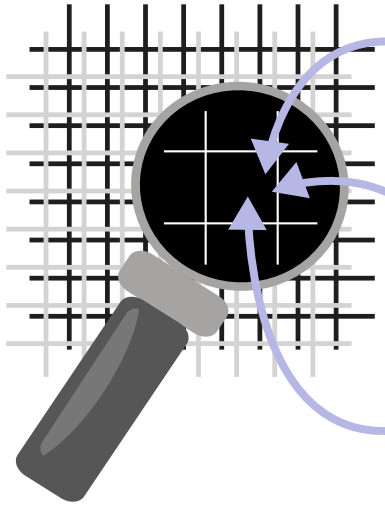

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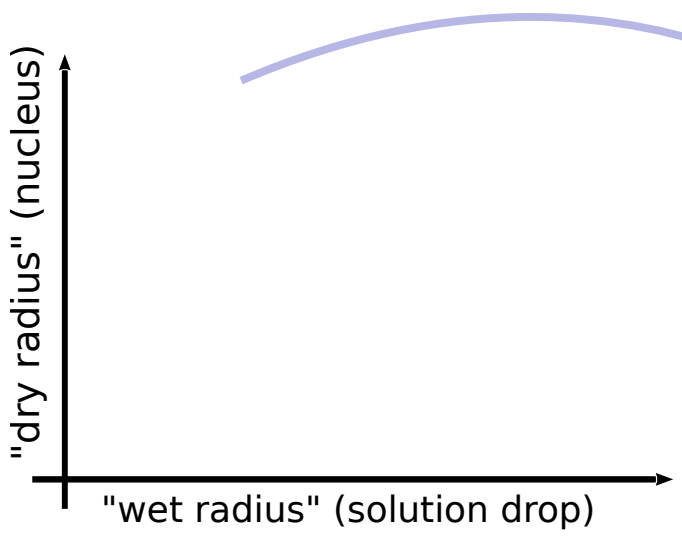

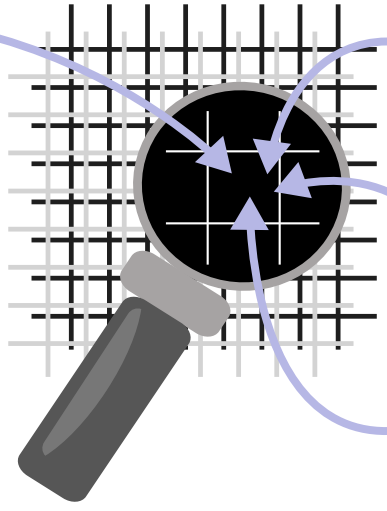

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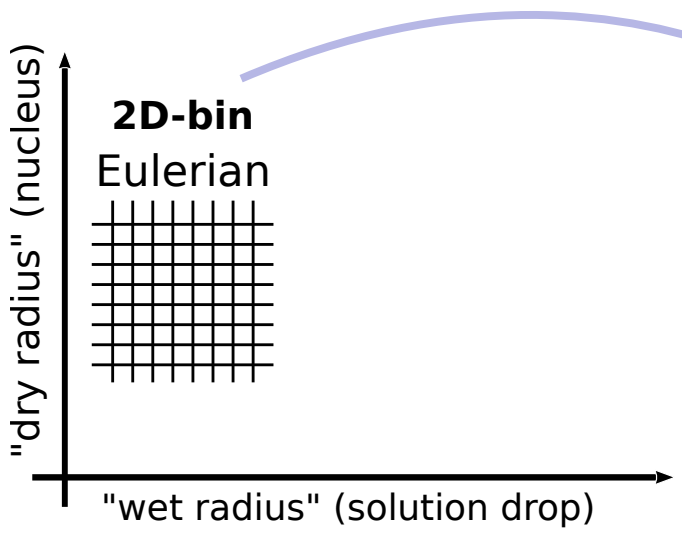

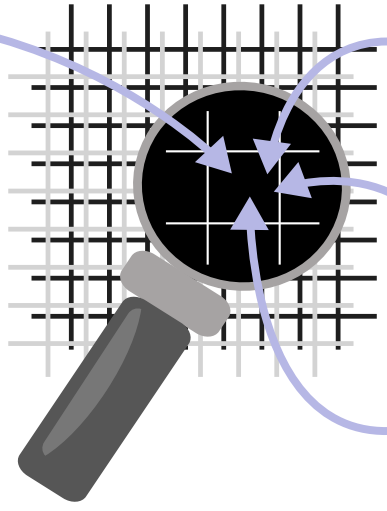

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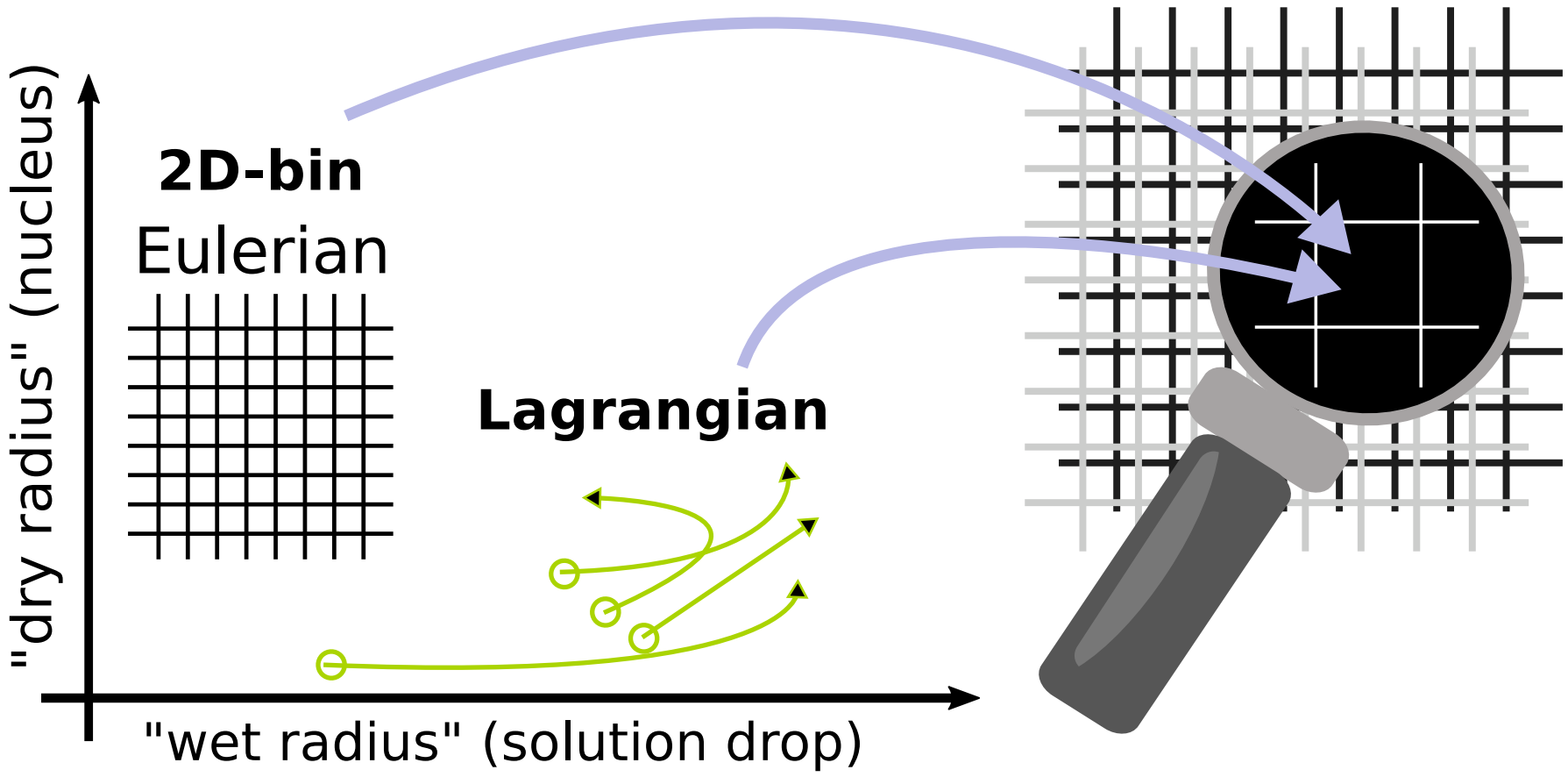

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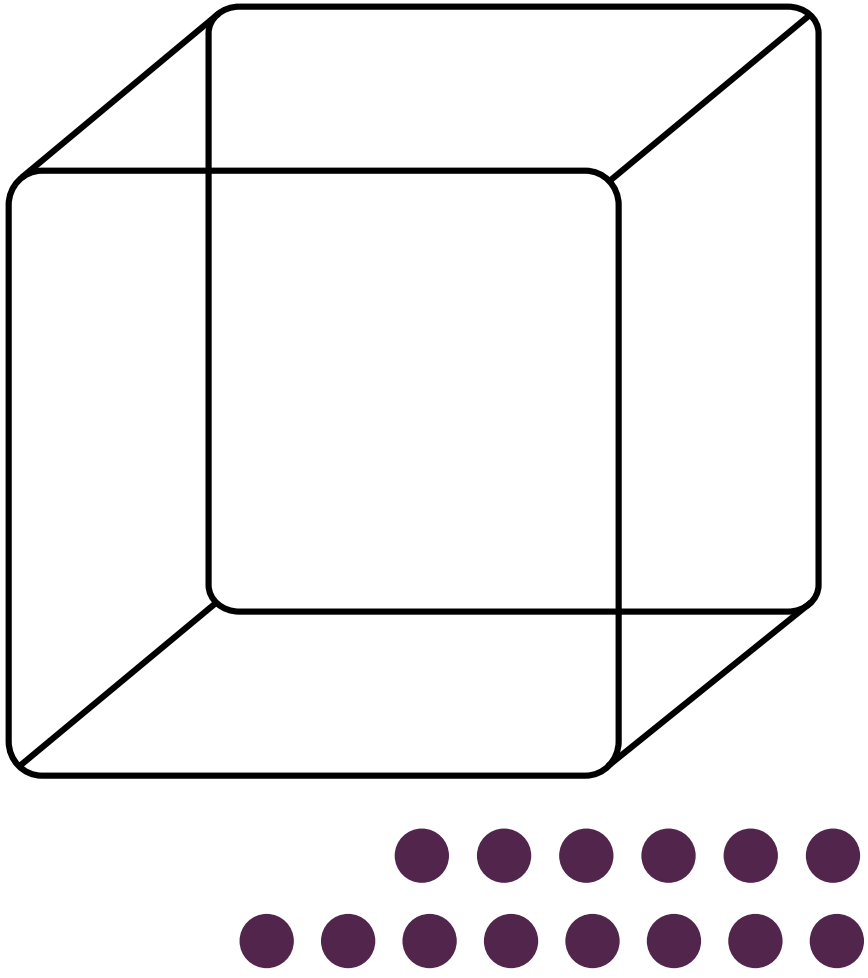

The domain is populated with "information carriers" (alias computational particles, super droplets)

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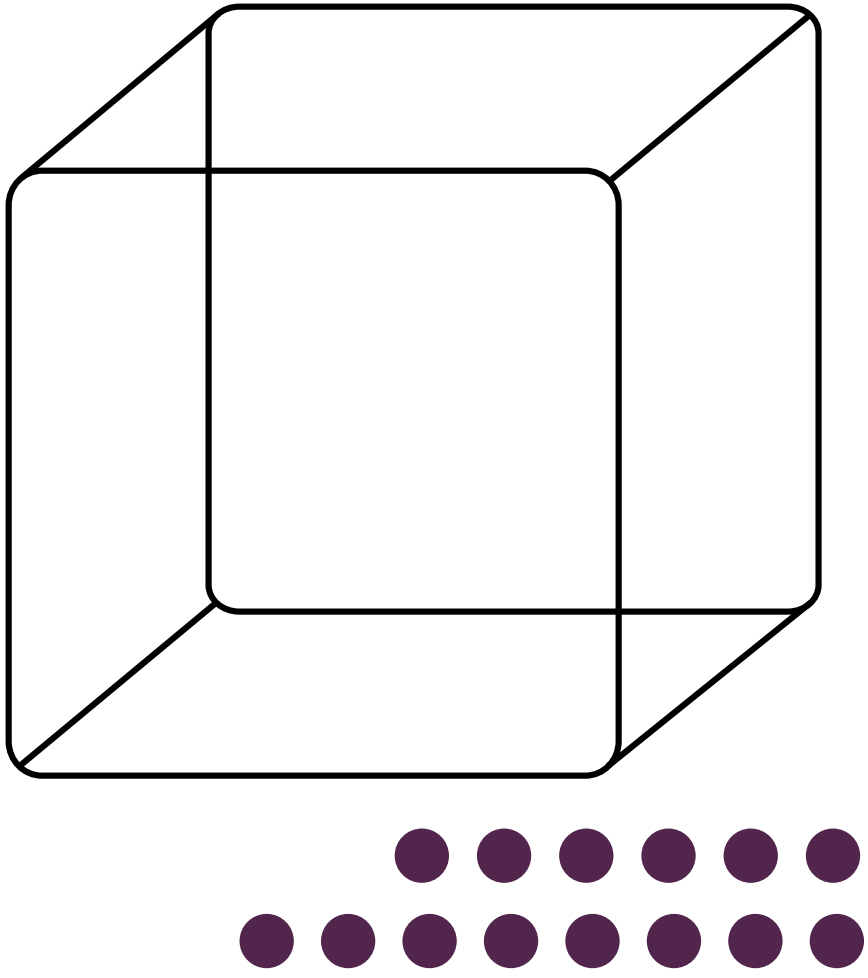

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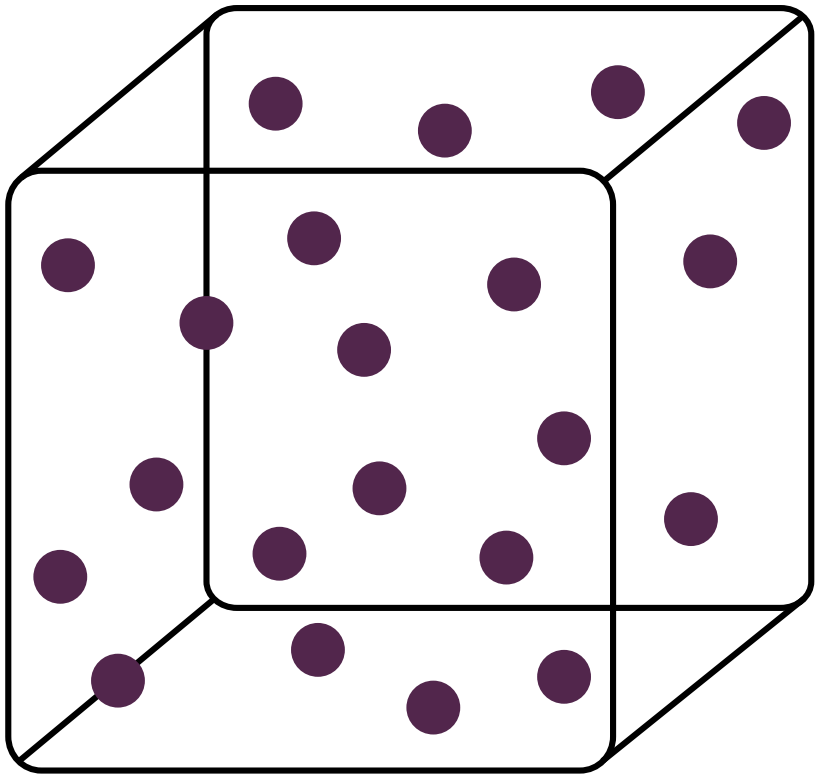

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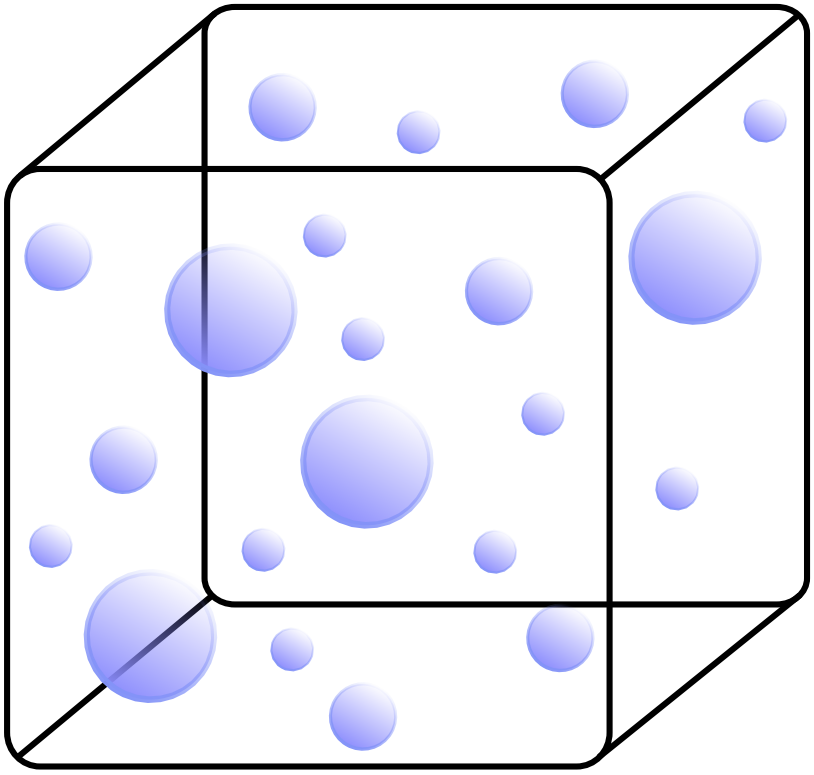

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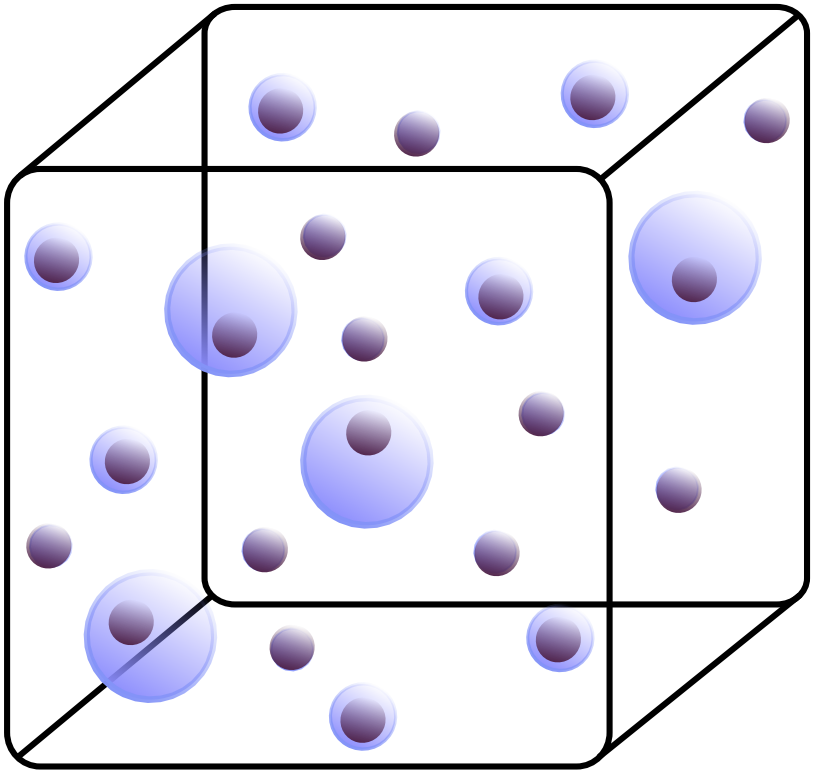

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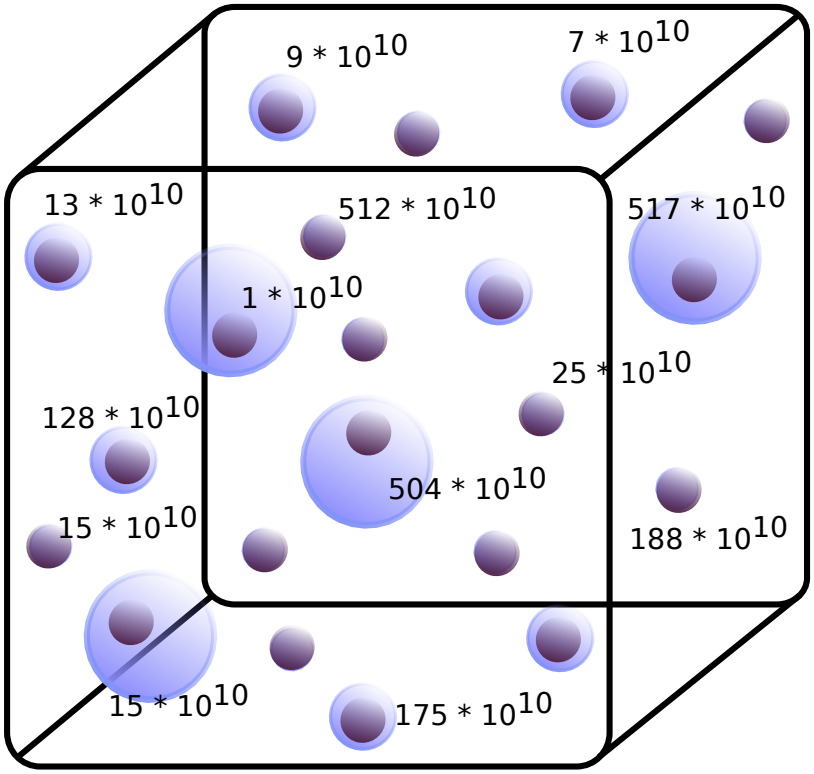

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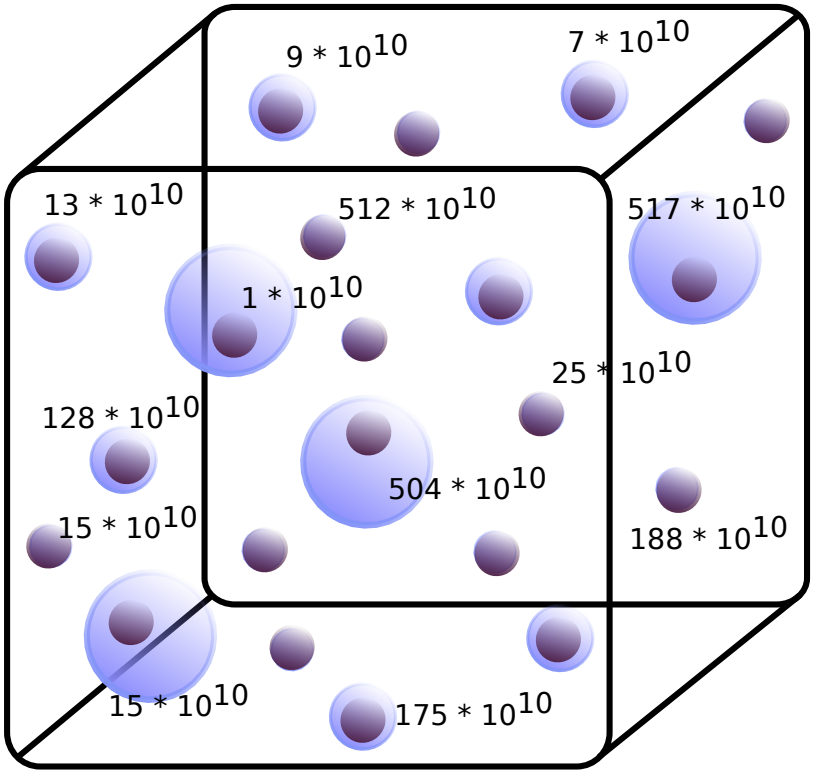

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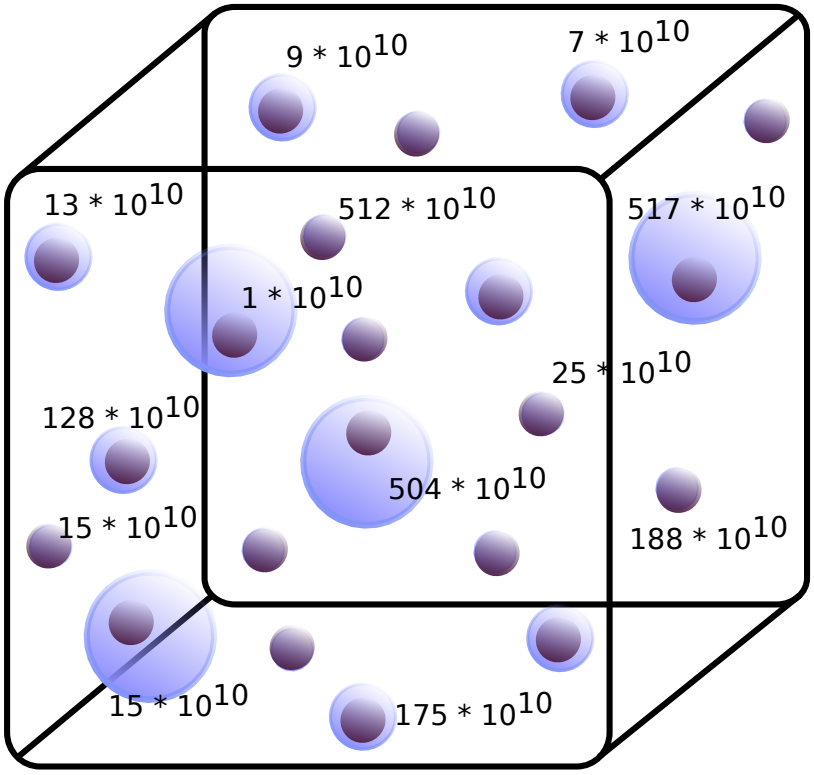

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transport does not incur numerical diffusion!

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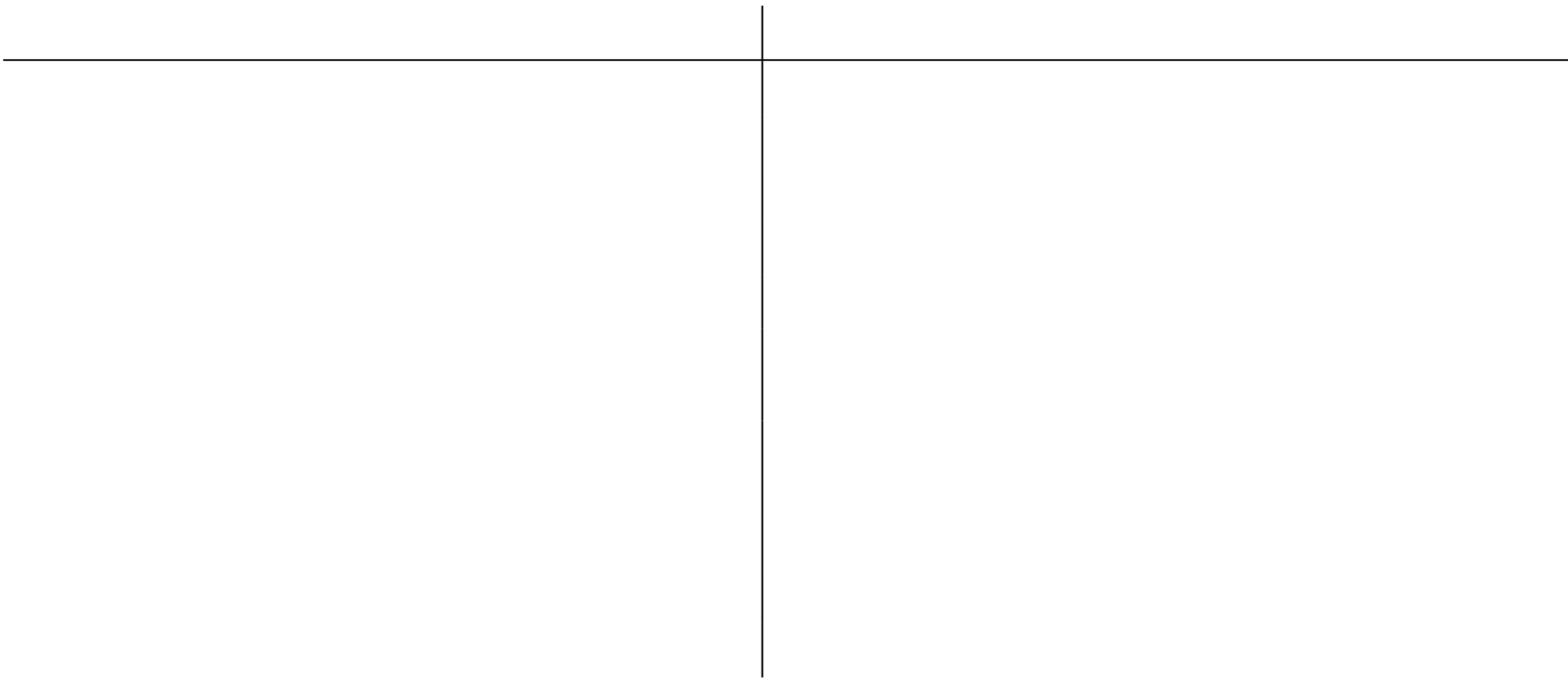

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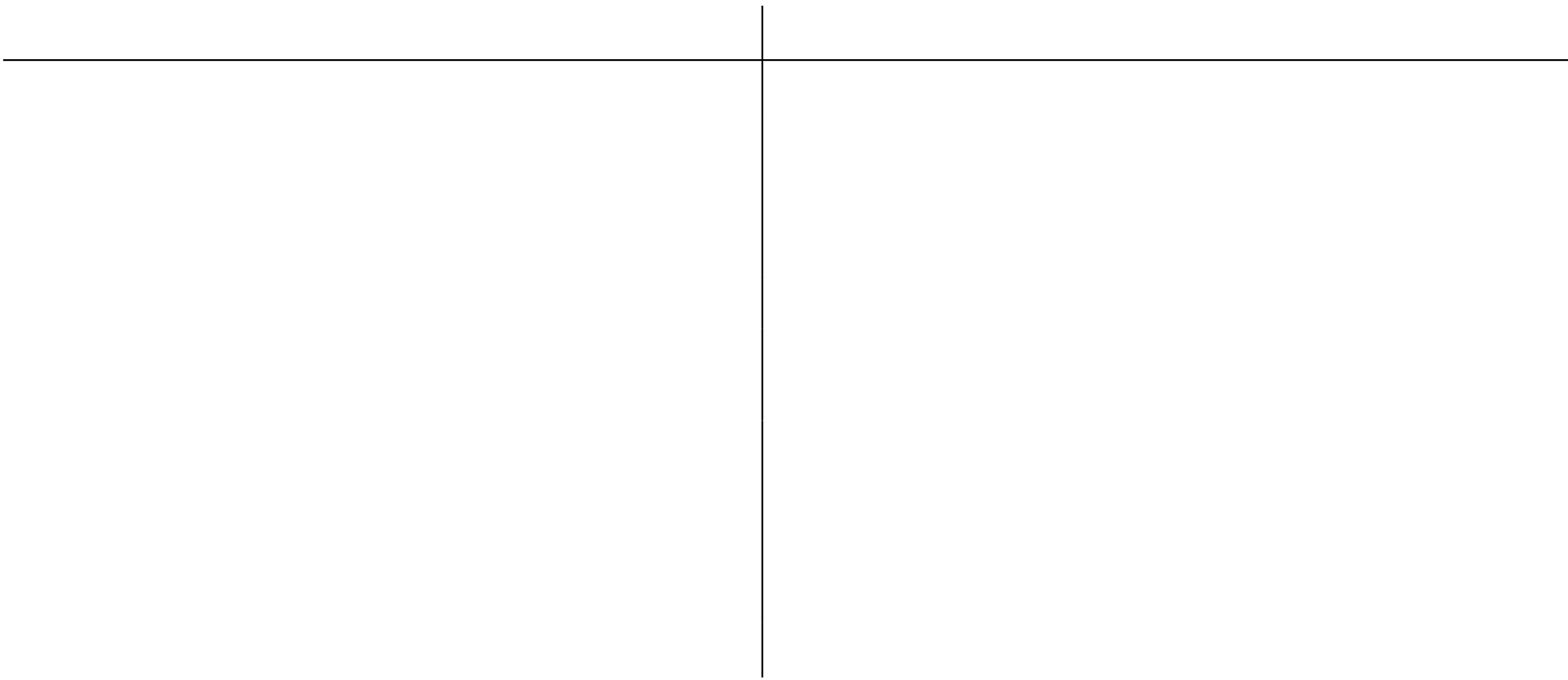

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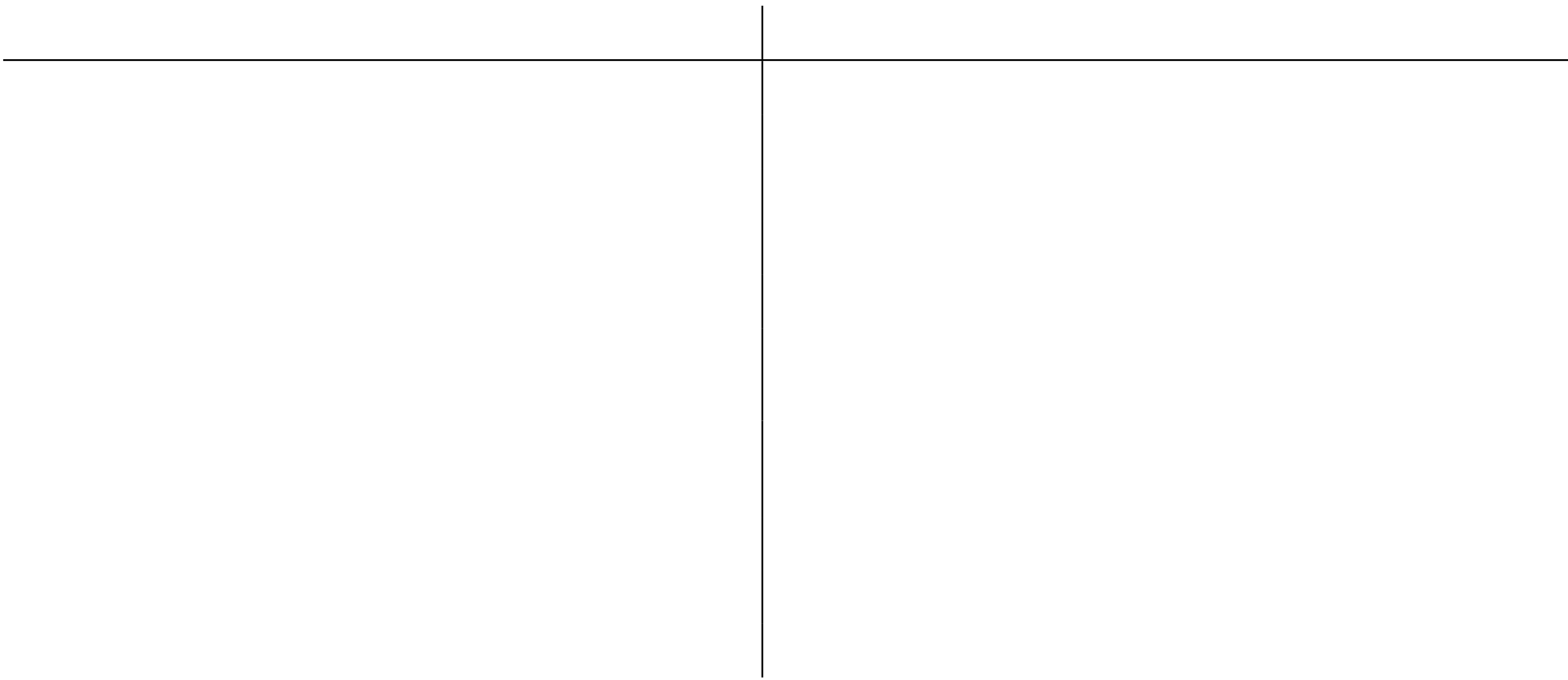

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Eulerian / PDE	Lagrangian / ODE
advection of heat	particle transport by the flow
advection of moisture	condensational growth
	collisional growth
	sedimentation

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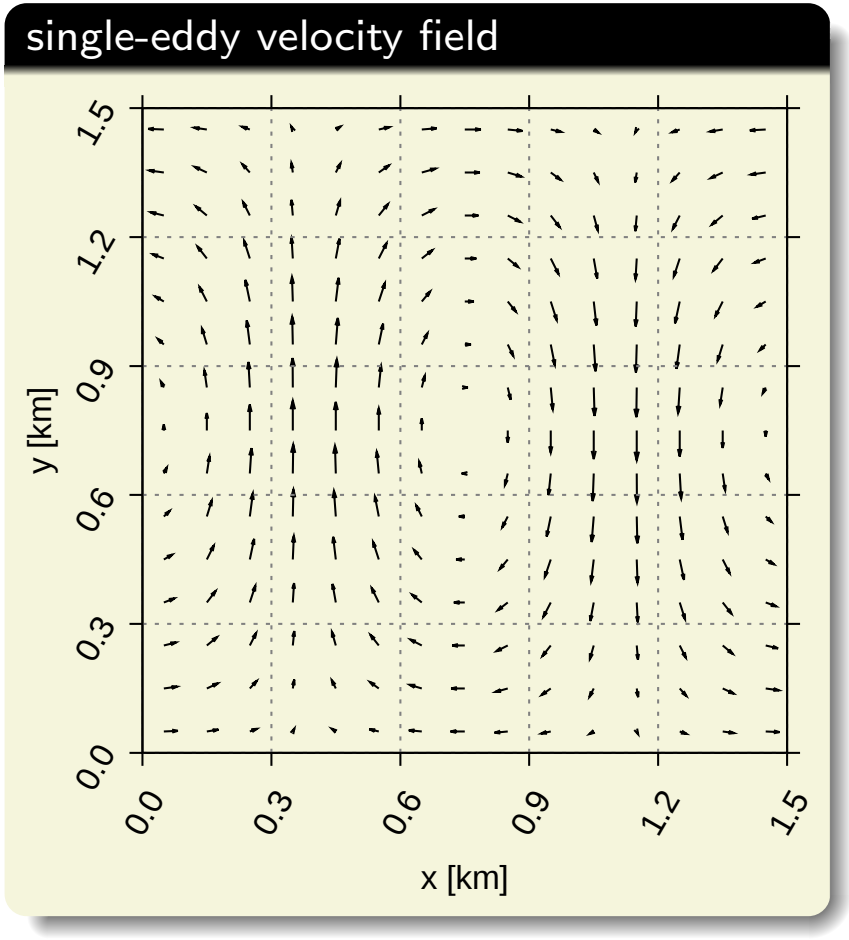
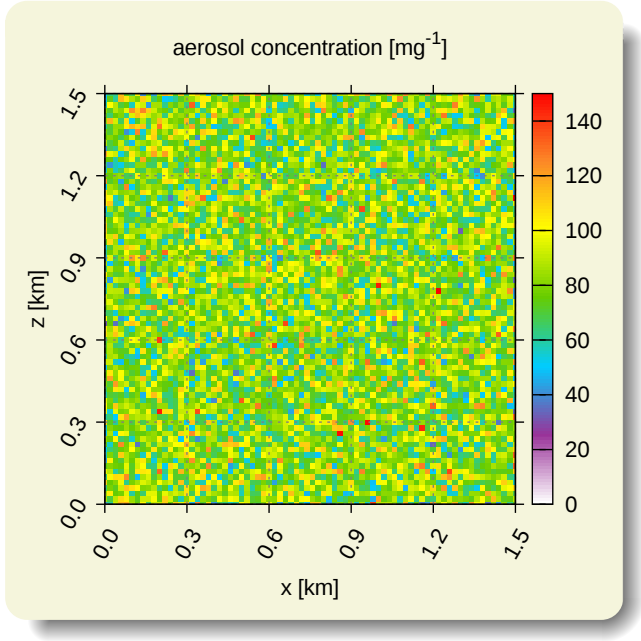
- recent examples in context of precipitating clouds:
  - Shima et al. 2009, QJ
  - Andrejczuk et al. 2010, JGR
  - Riechelmann et al. 2012, NJP

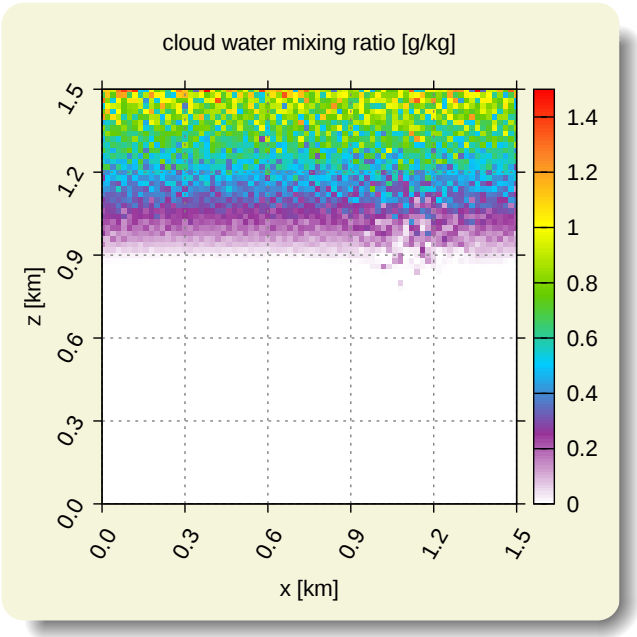
libcloudph++: VOCALS-inspired aerosol processing set-up

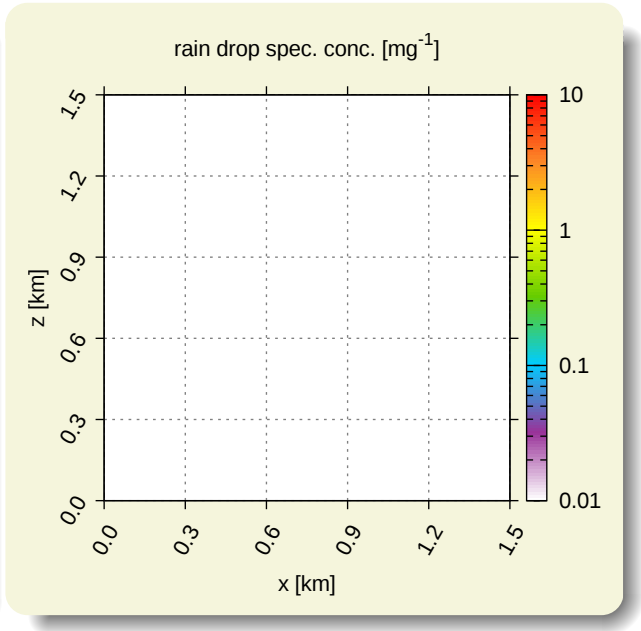


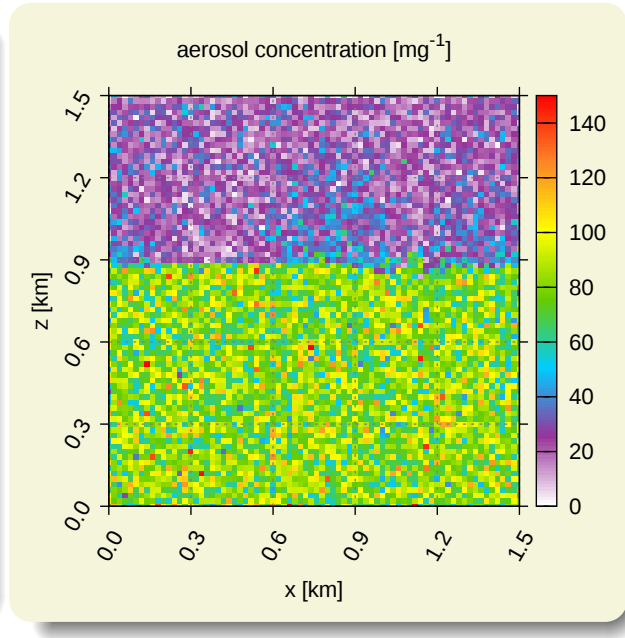


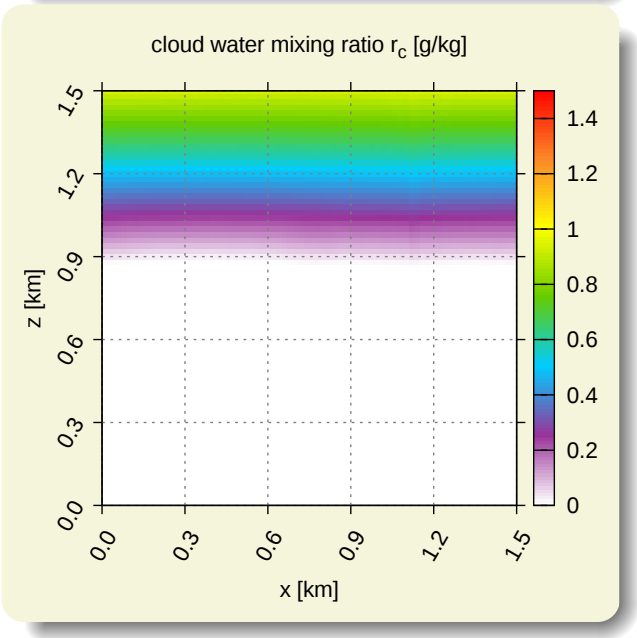
- set-up: Grabowski & Lebo (ICMW 2012)
- 2D prescribed flow
- advection: libmpdata++ (2-pass FCT)
- μ-physics: libcloudph++

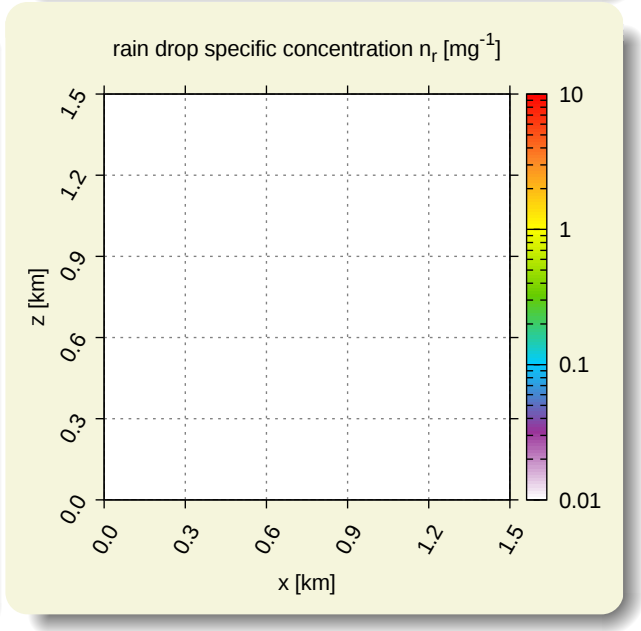
libcloudph++: VOCALS-inspired aerosol processing set-up











Lagrangian/Monte-Carlo scheme
(Shima et al. 2009)

2-moment bulk scheme
(Morrison & Grabowski 2007)

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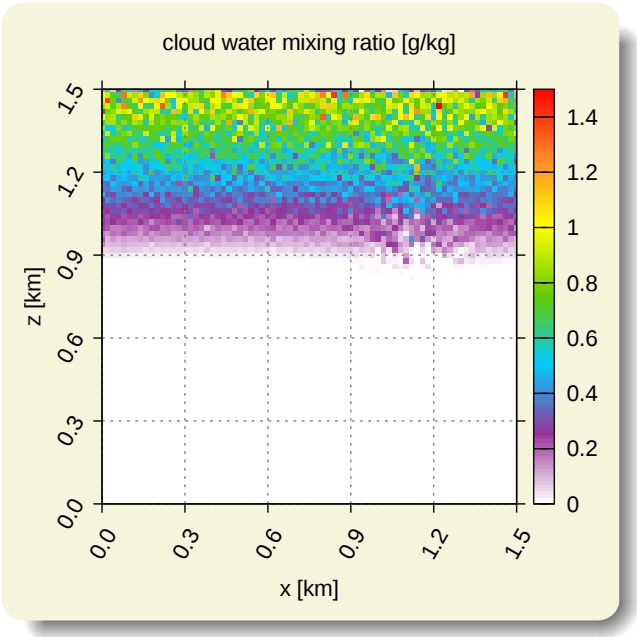

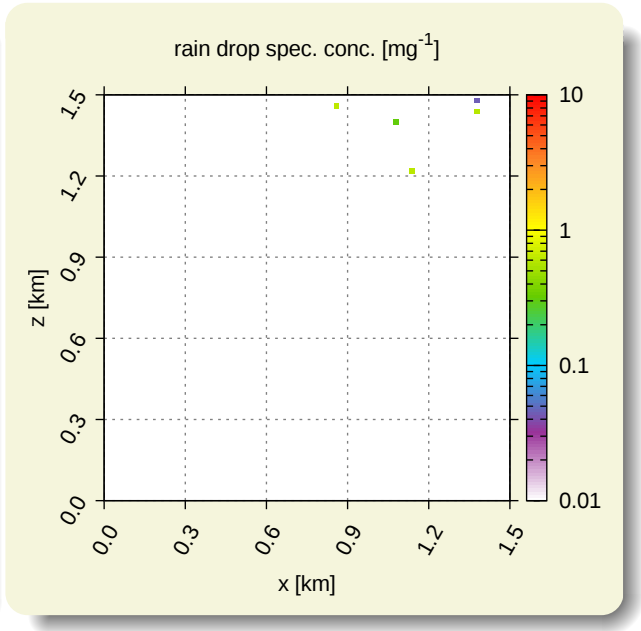

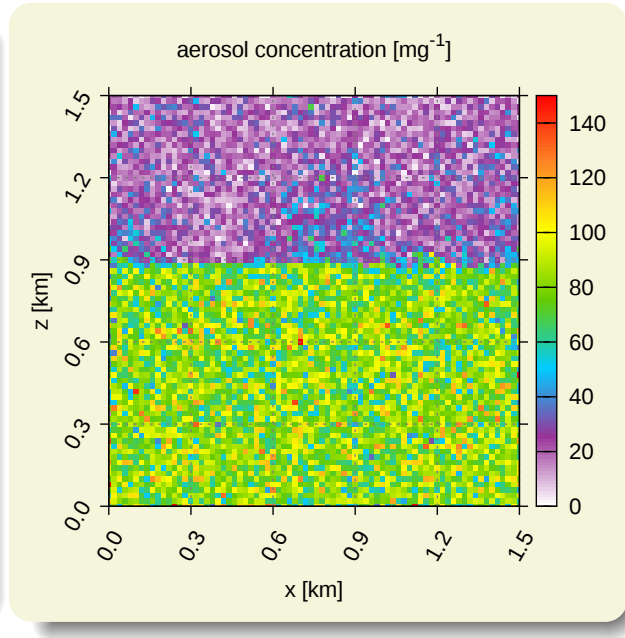

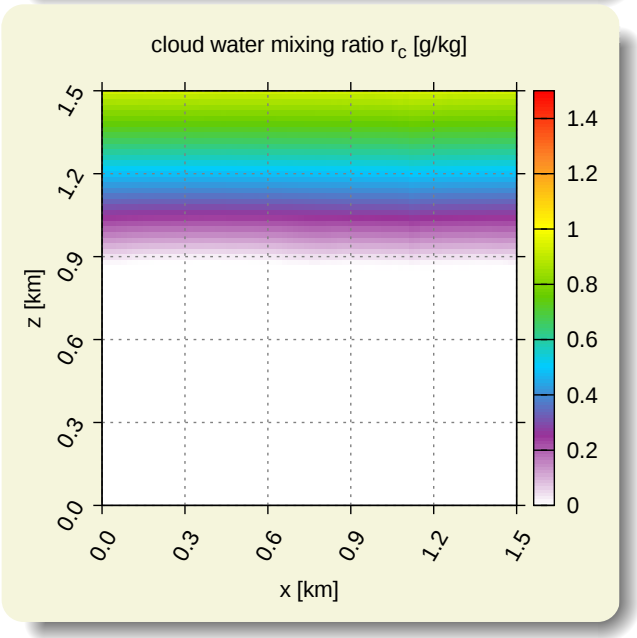

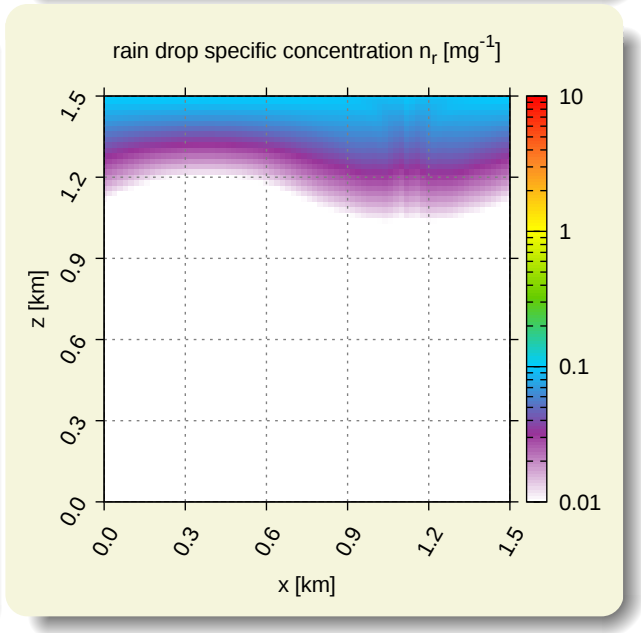

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2-moment bulk scheme
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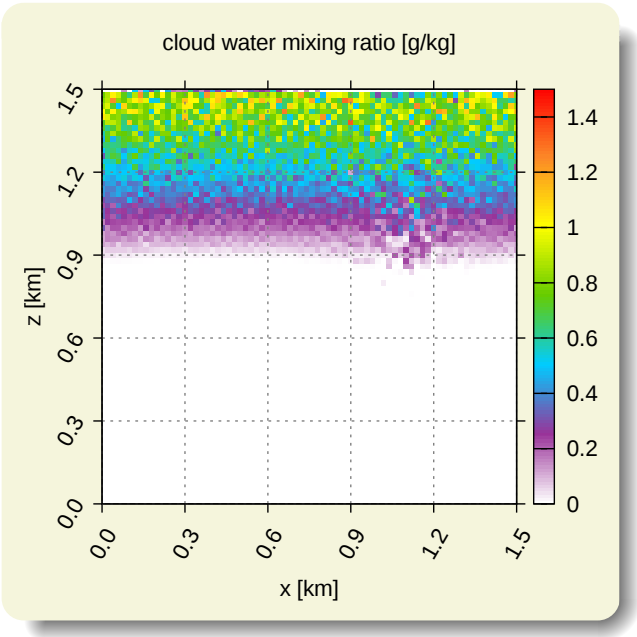
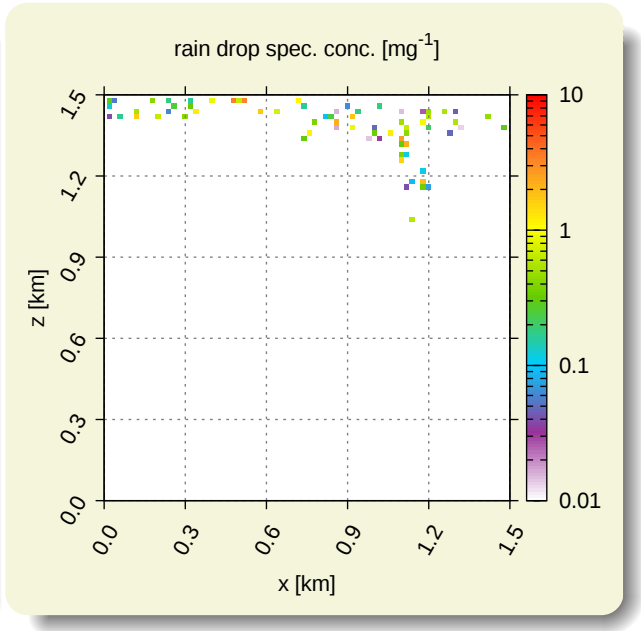
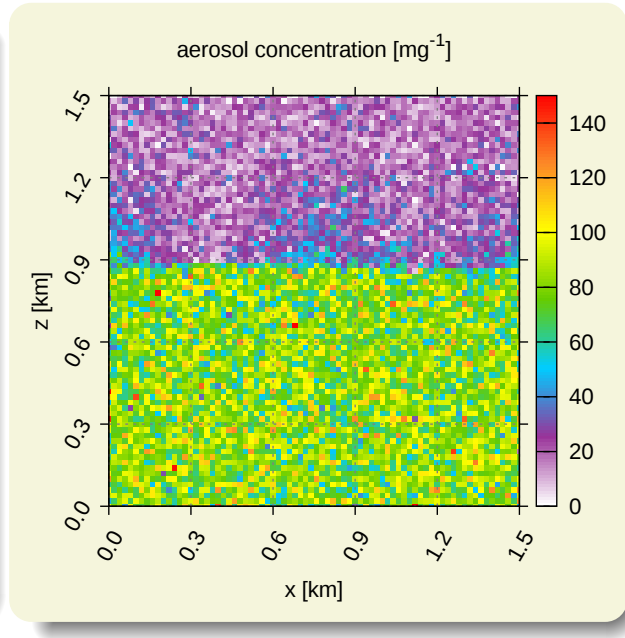
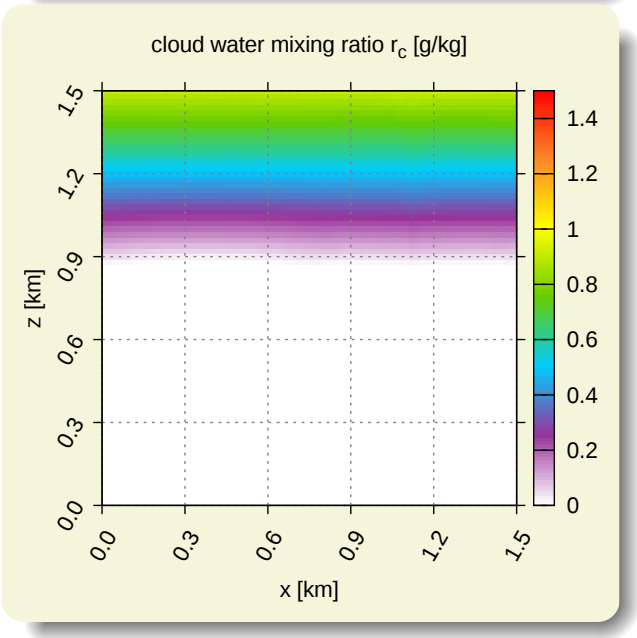
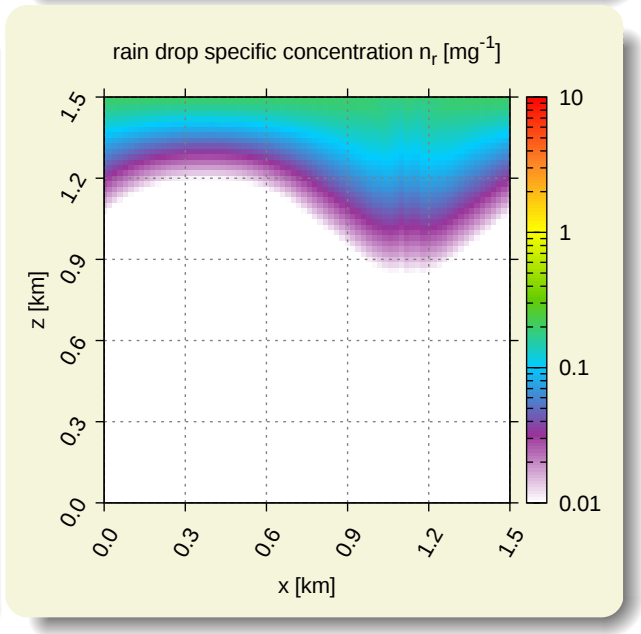
libcloudph++: VOCALS-inspired aerosol processing set-up











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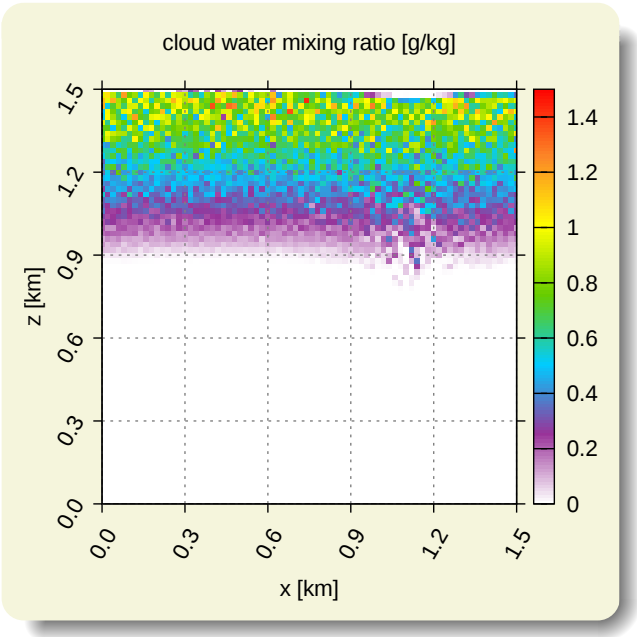
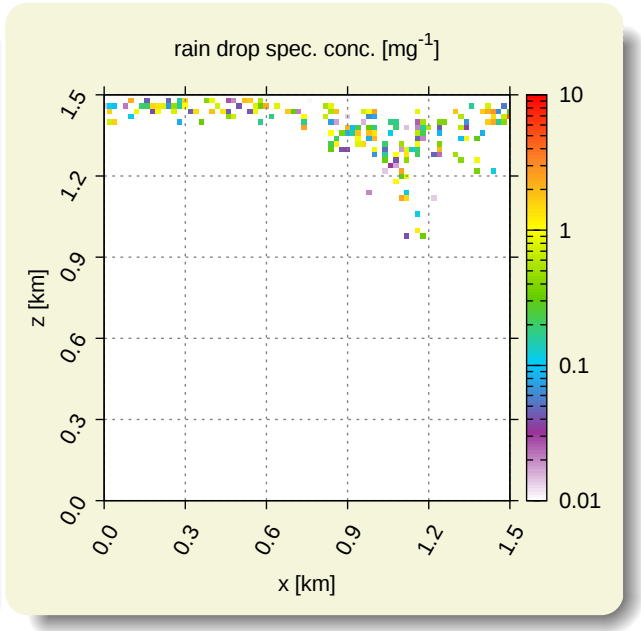
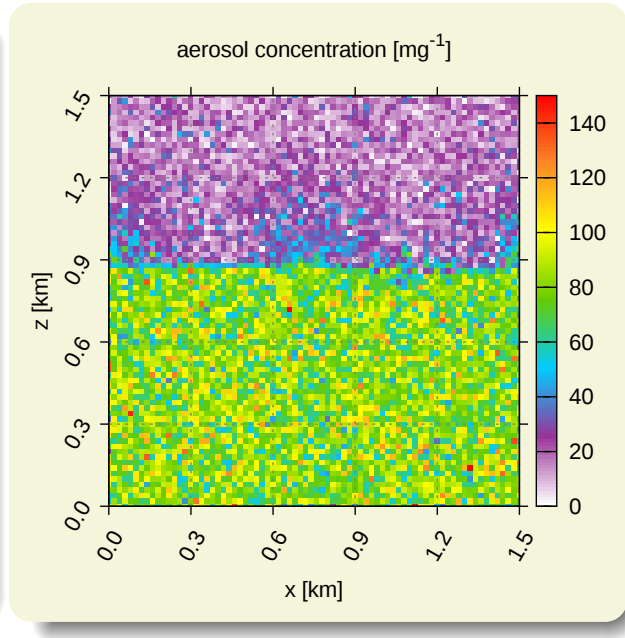
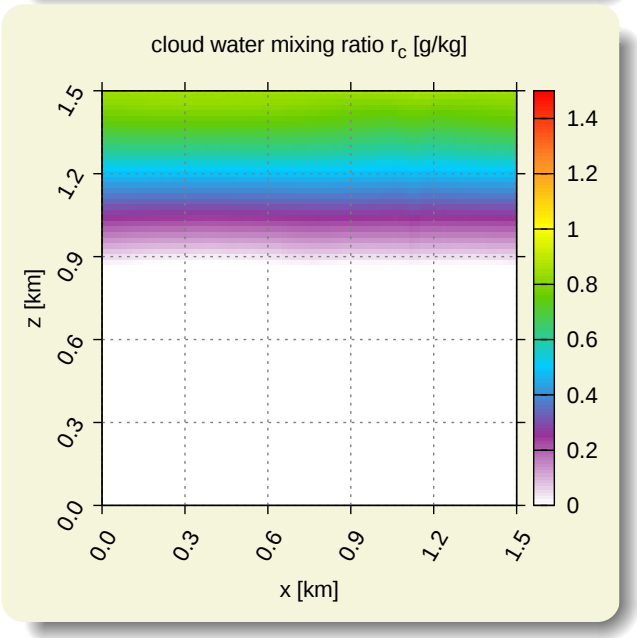
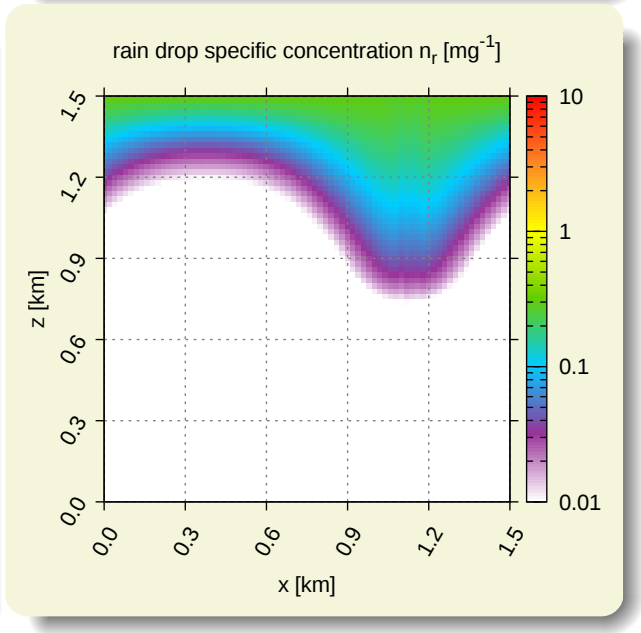
libcloudph++: VOCALS-inspired aerosol processing set-up











Lagrangian/Monte-Carlo scheme
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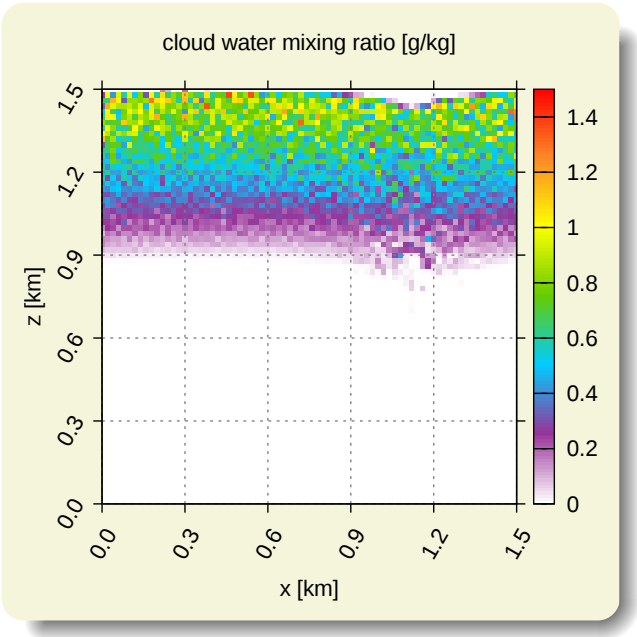
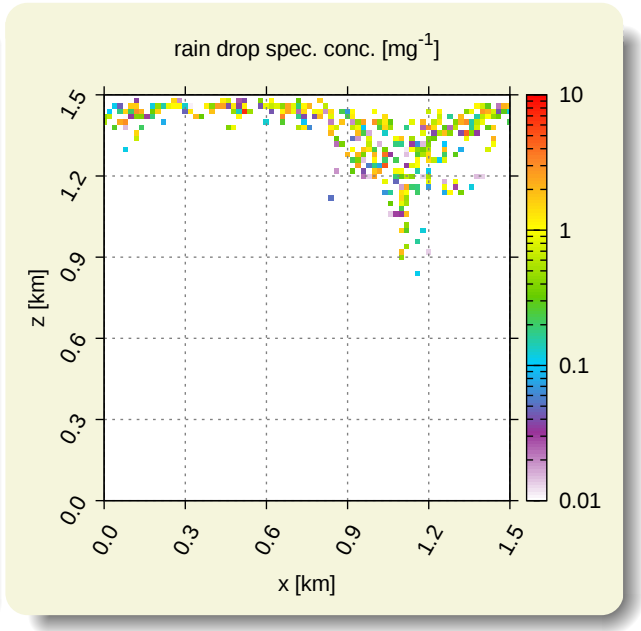
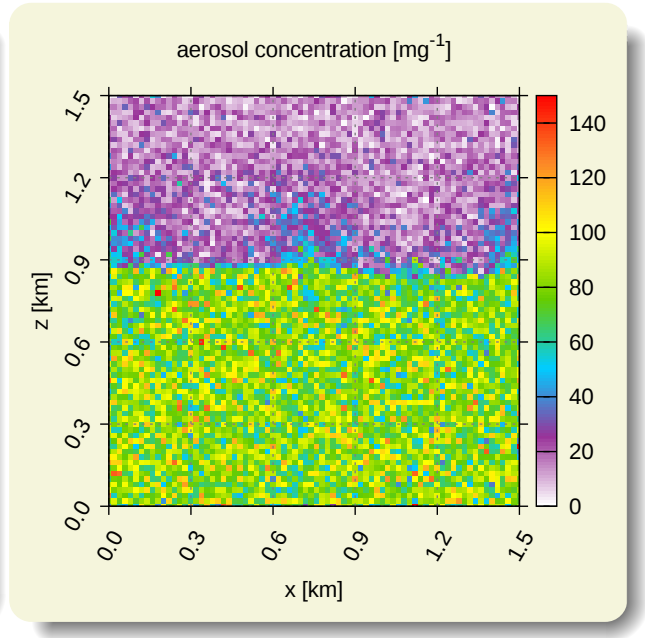
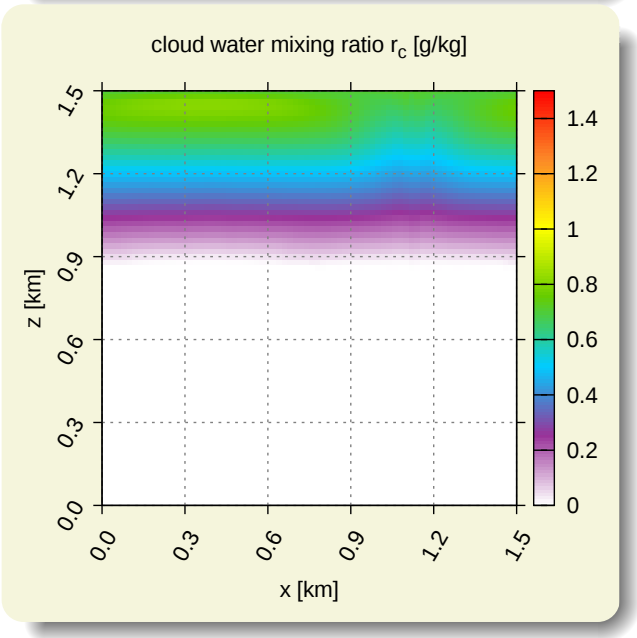
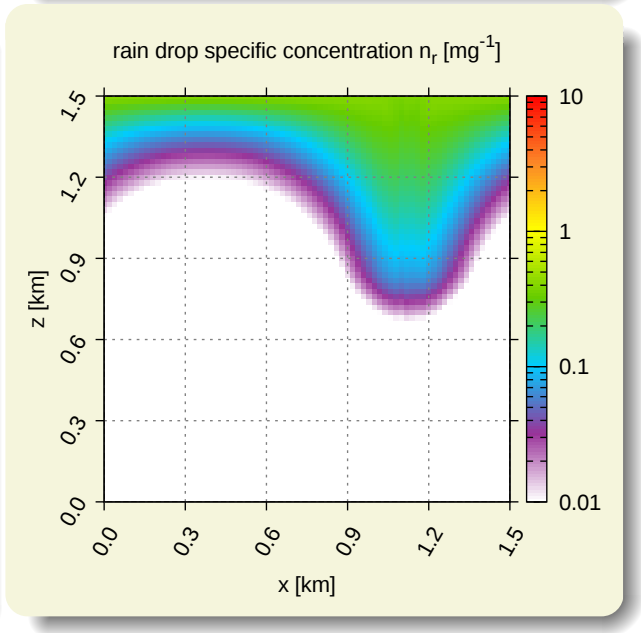
libcloudph++: VOCALS-inspired aerosol processing set-up











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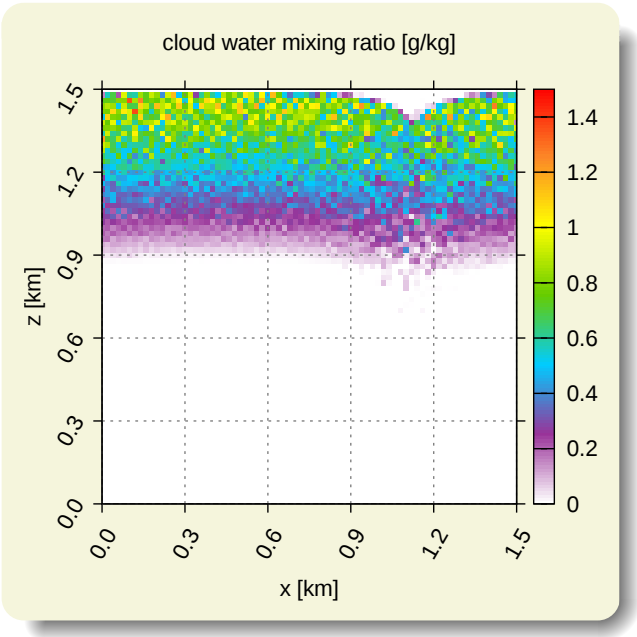
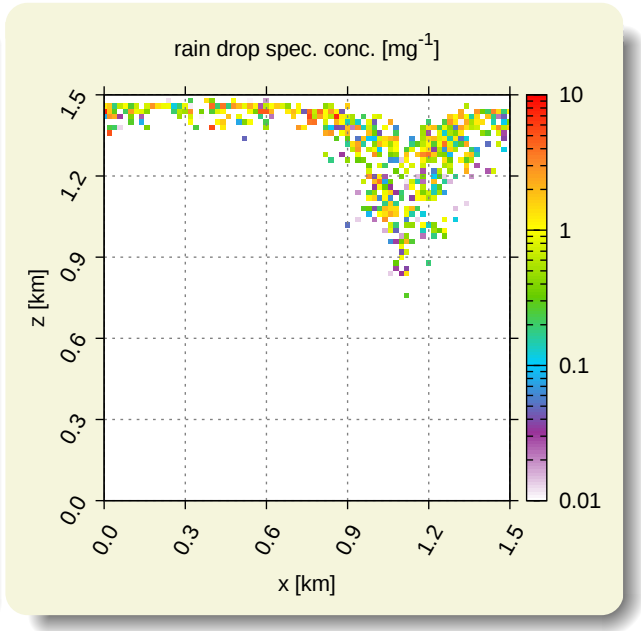
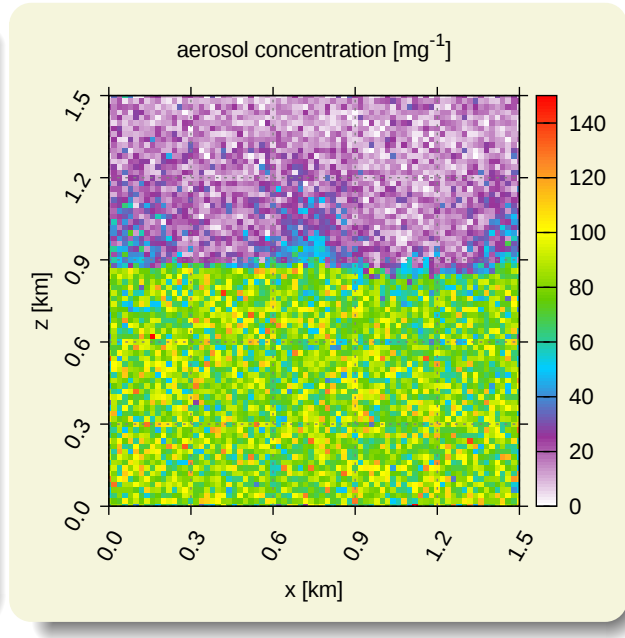
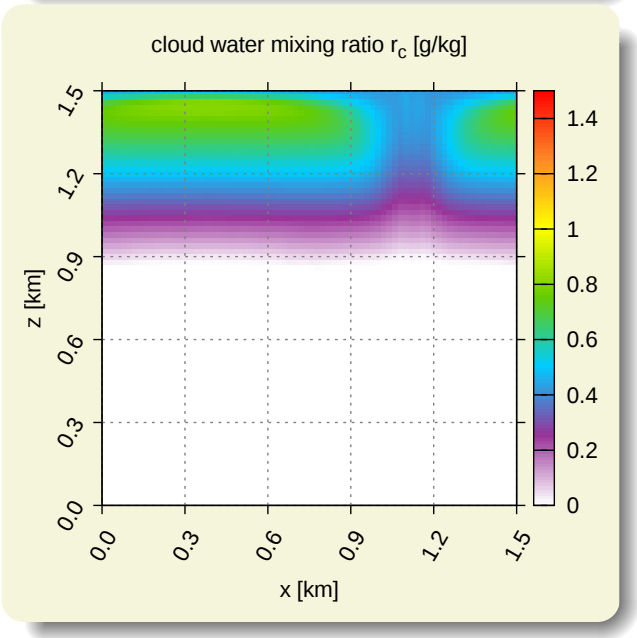
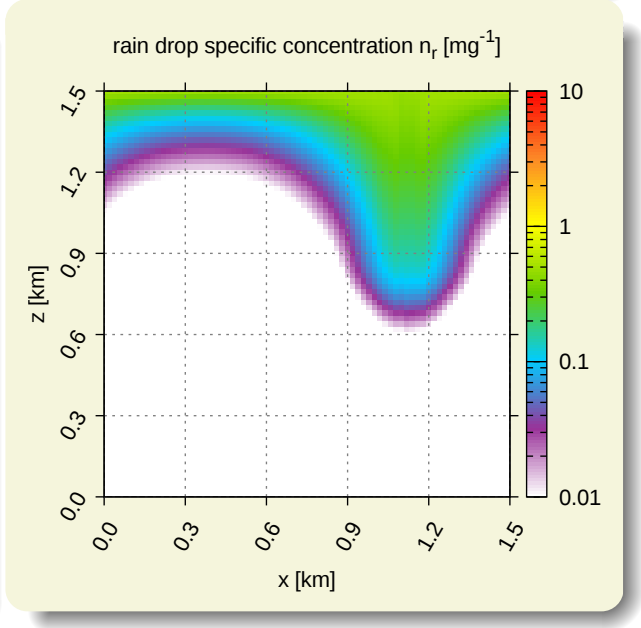
libcloudph++: VOCALS-inspired aerosol processing set-up











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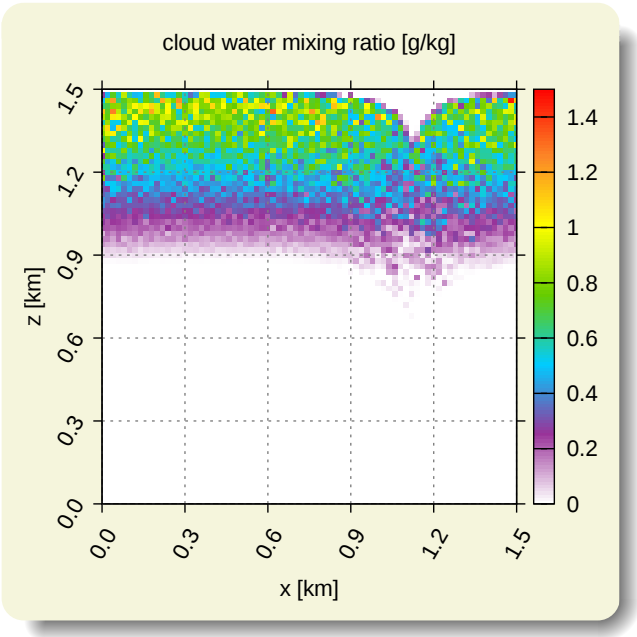

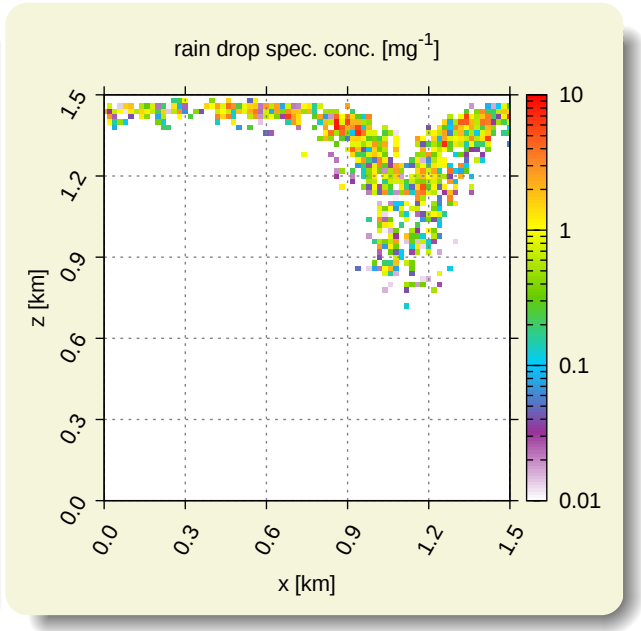

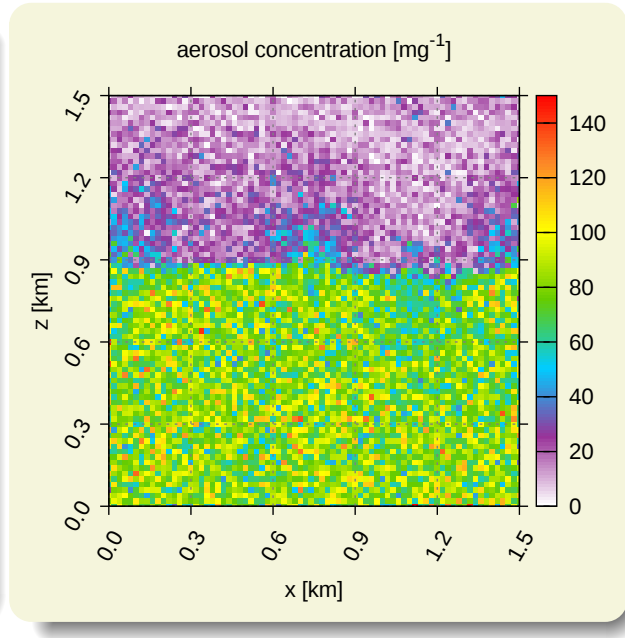

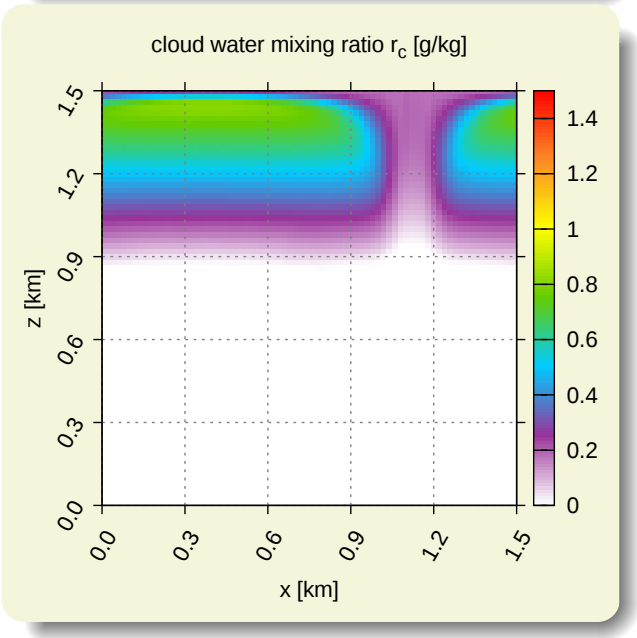

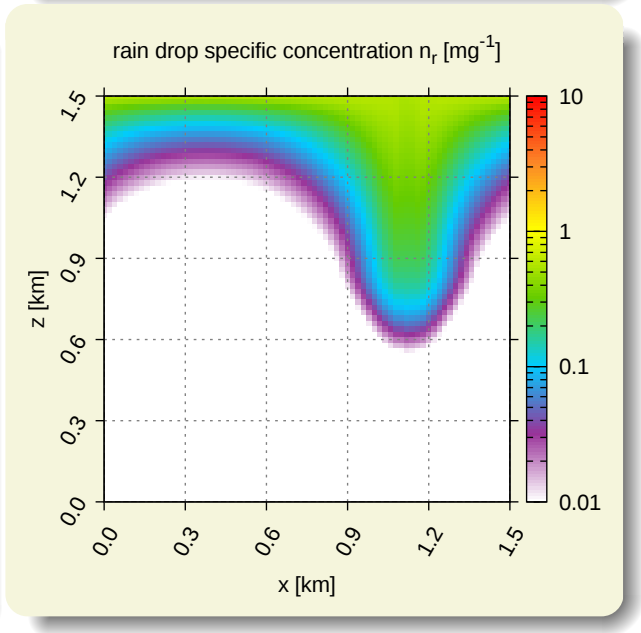

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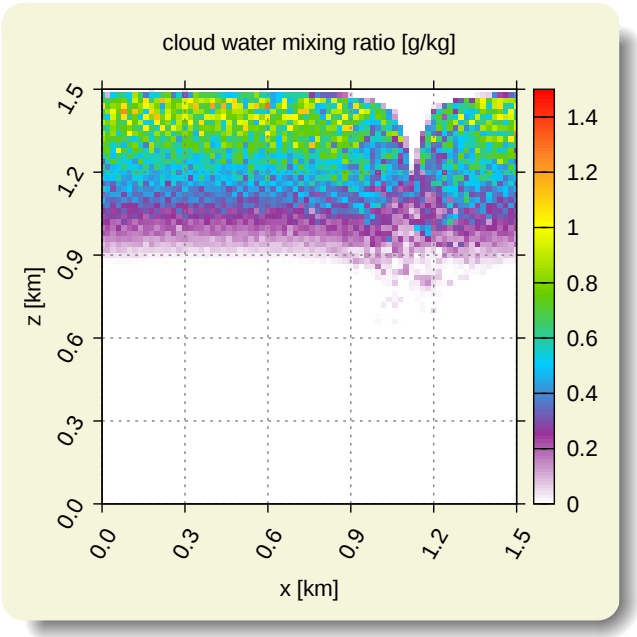

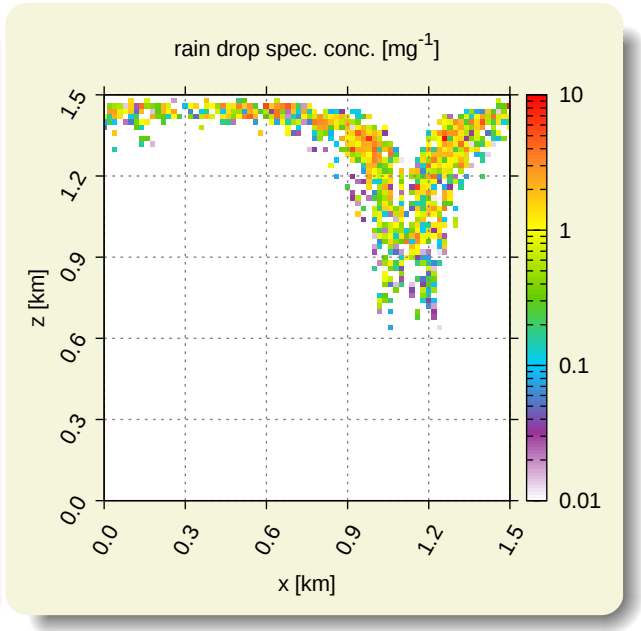

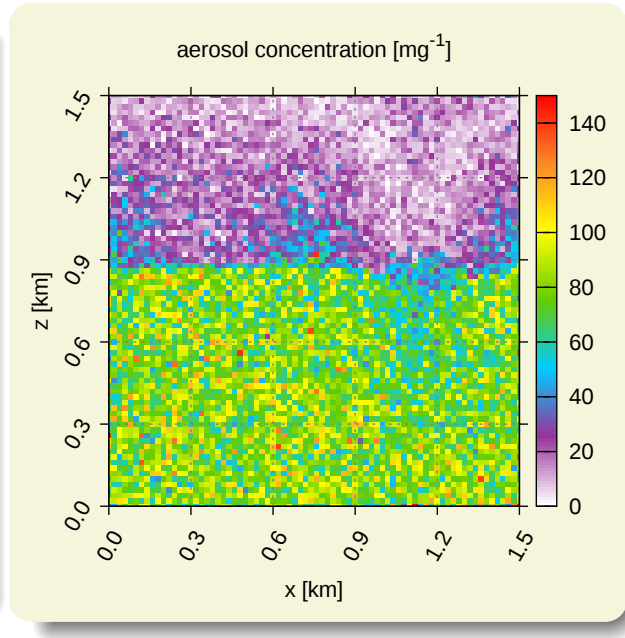

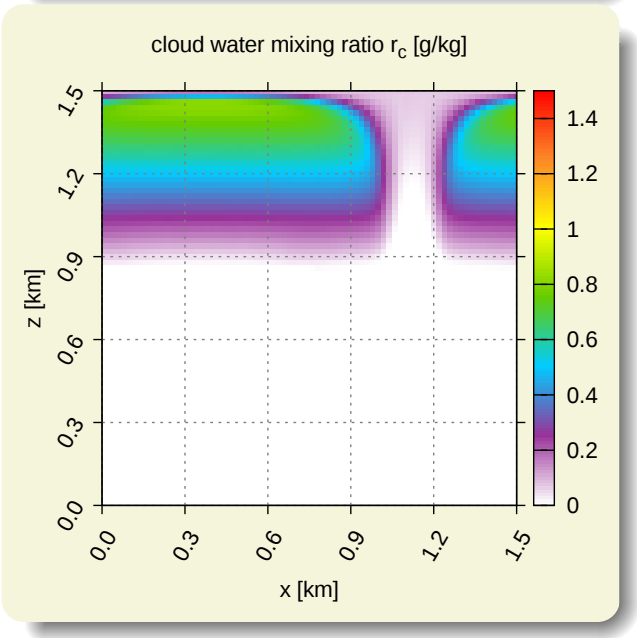

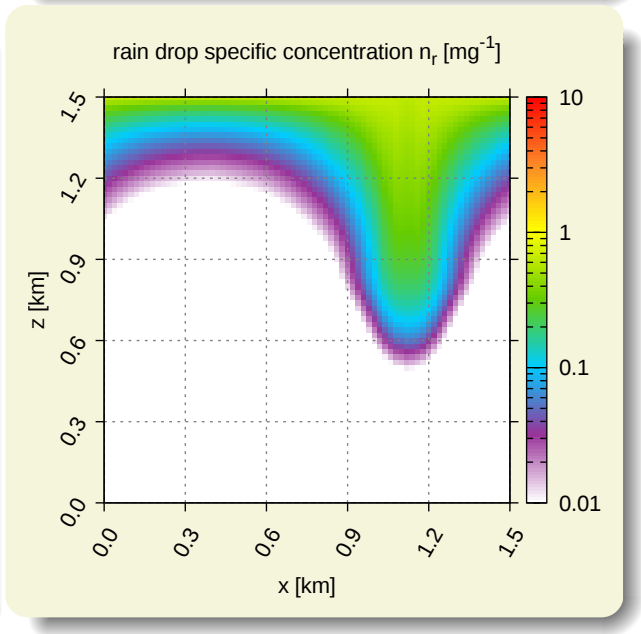

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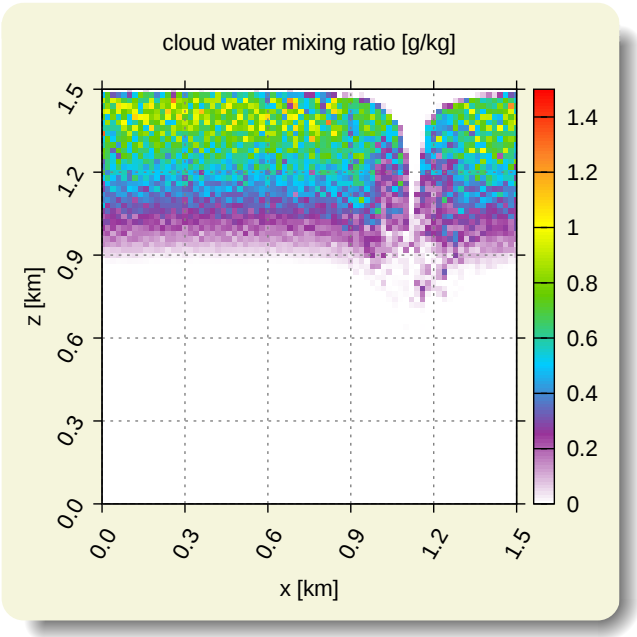

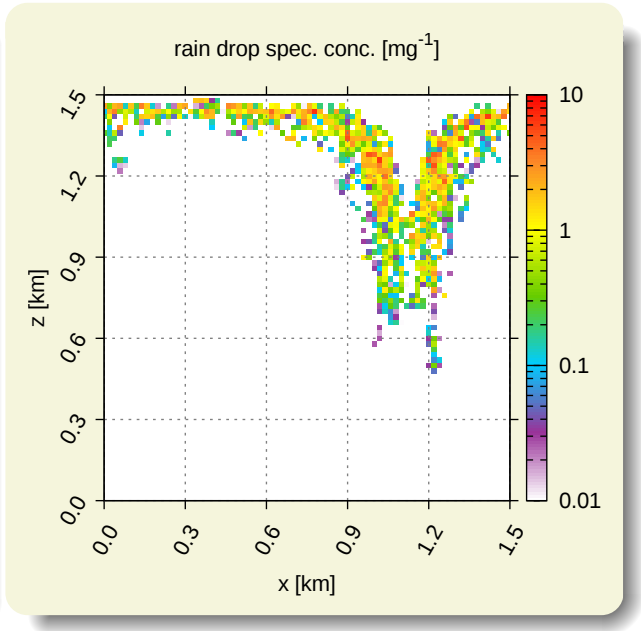

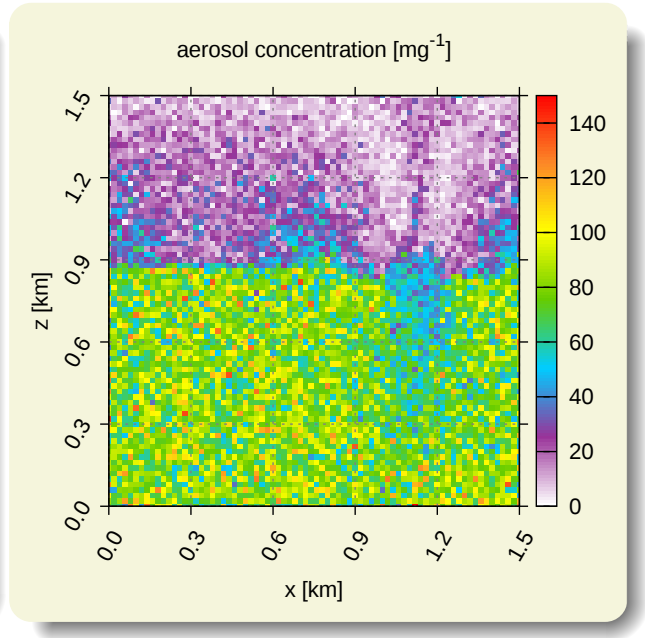

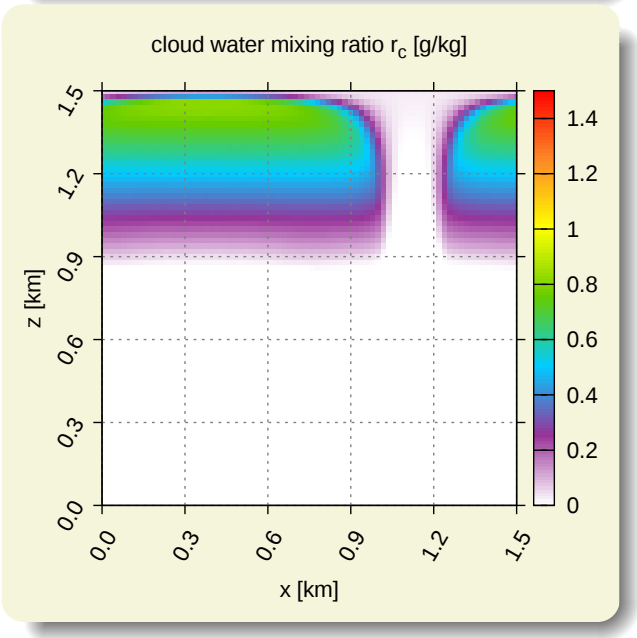

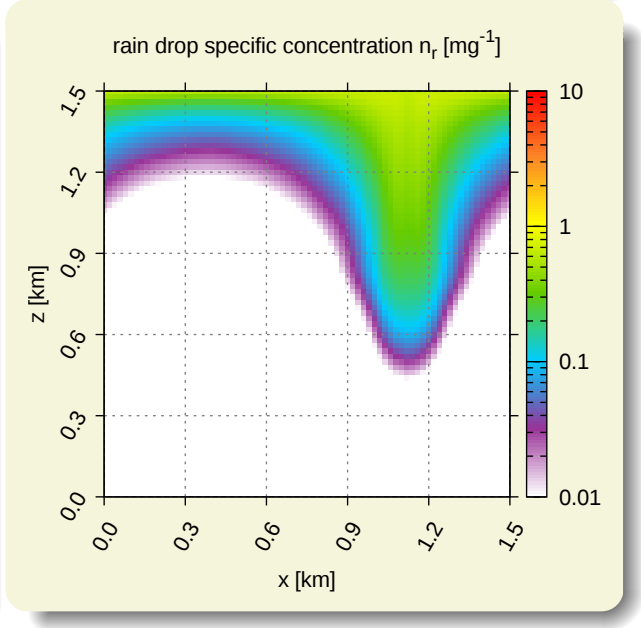

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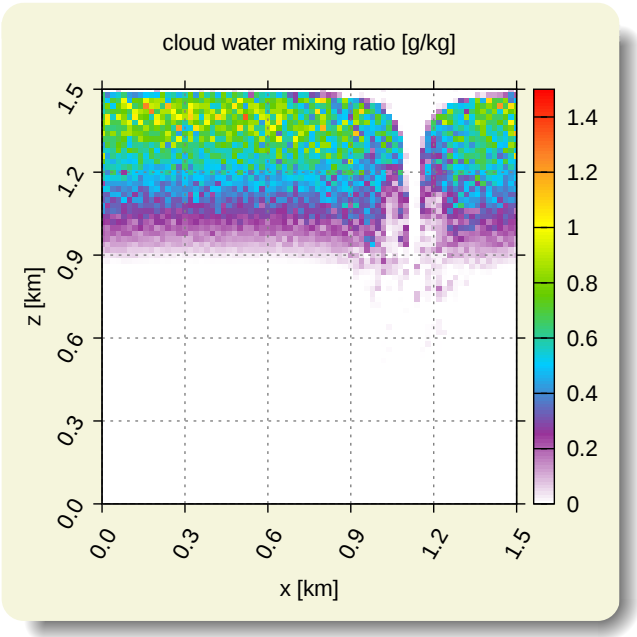

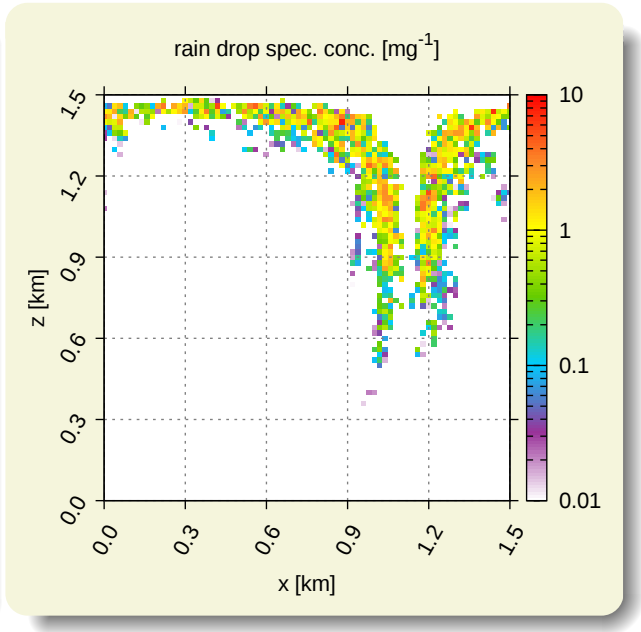

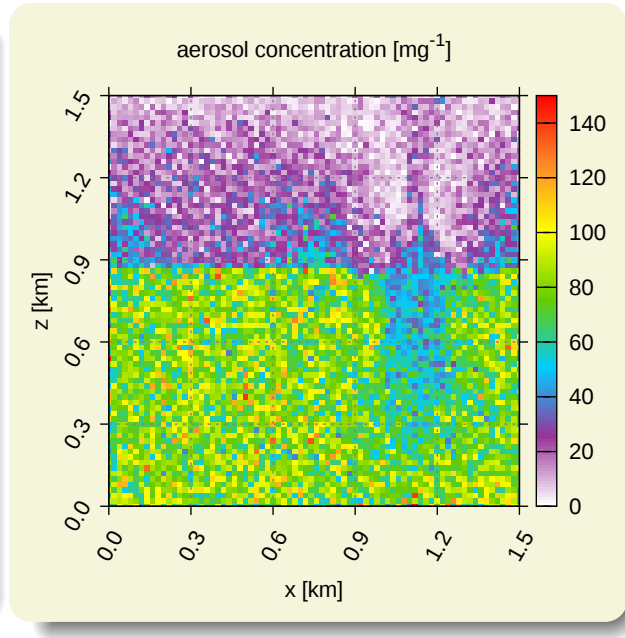

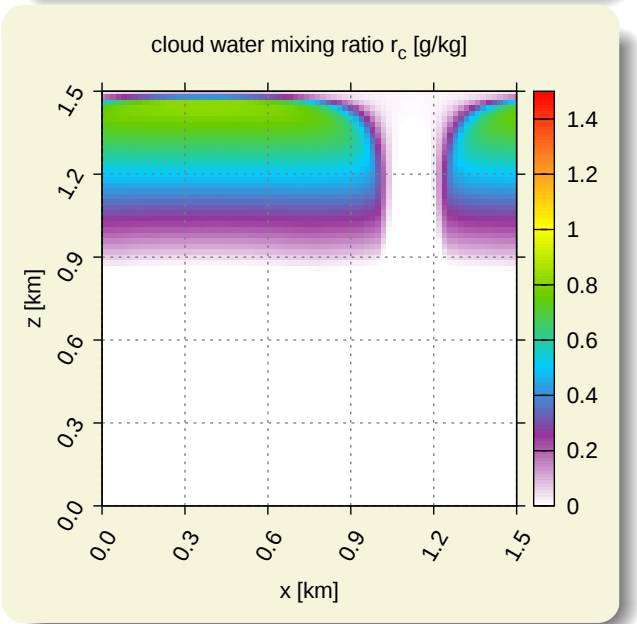

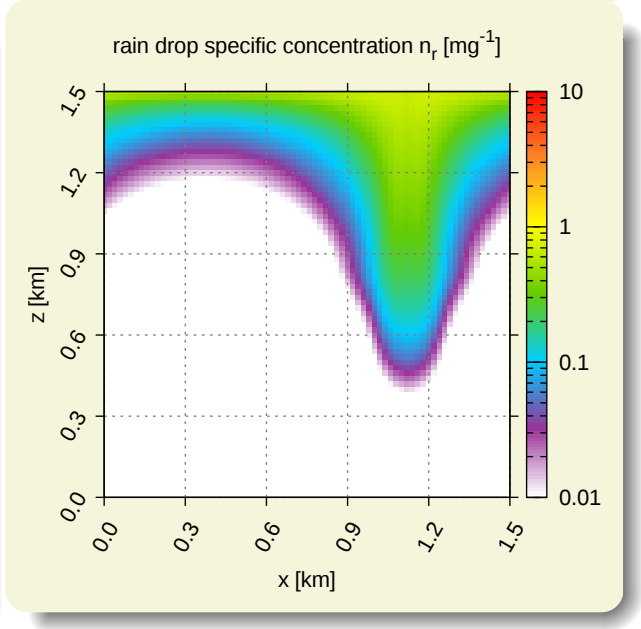

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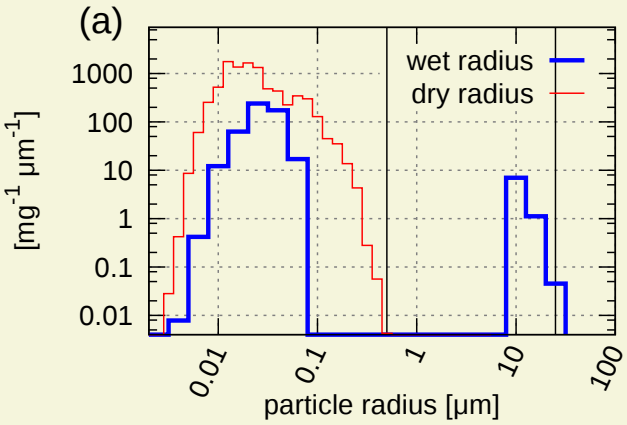
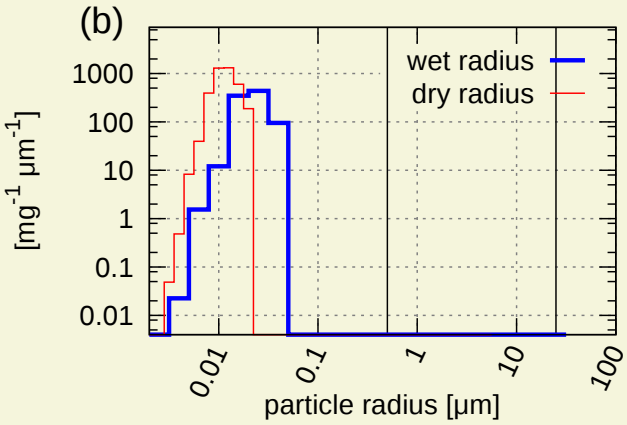
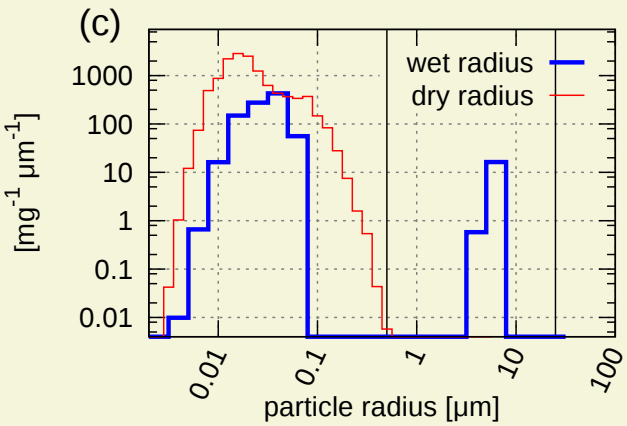
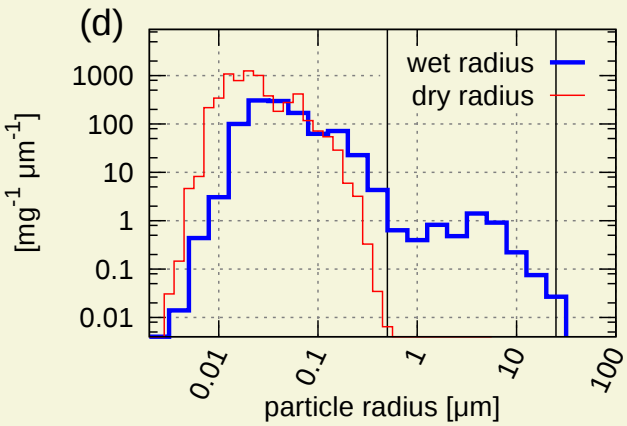
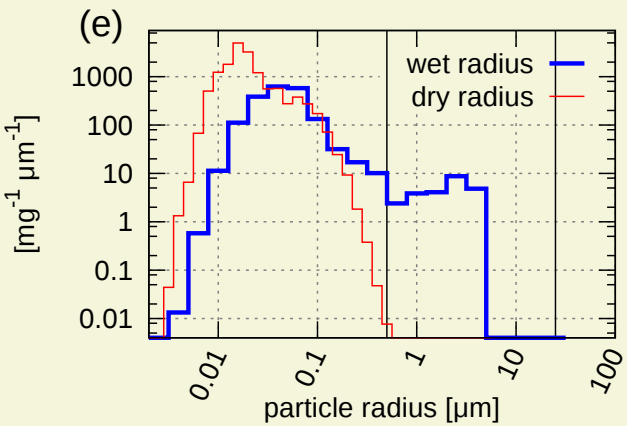
2×2 cell particle-derived spectra

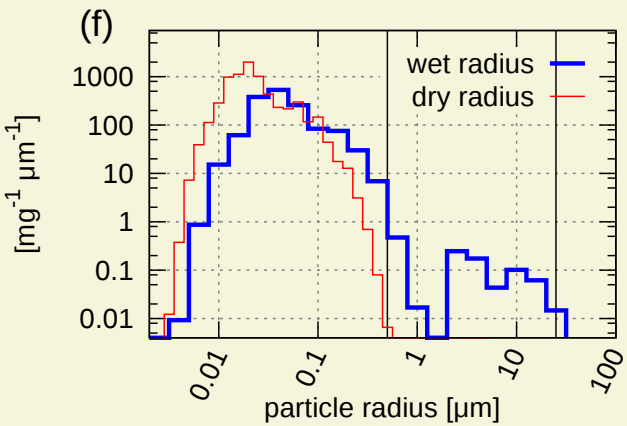


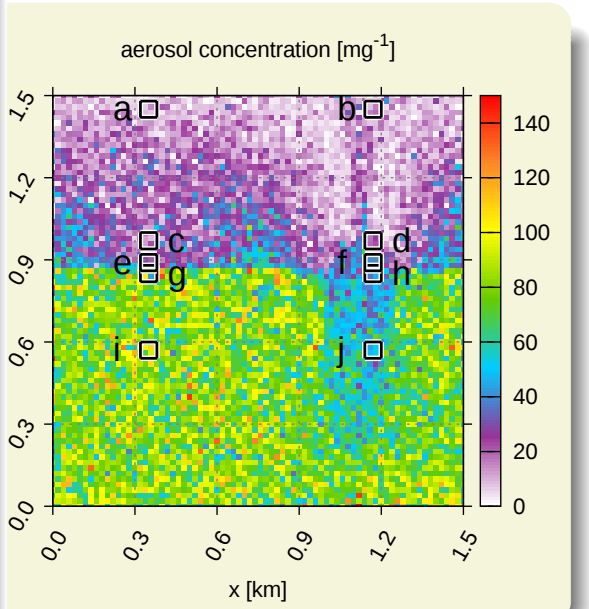












libcloudph++: summary & some technicalities

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- written using Boost.units – compile-time dimensional analysis
- reusable:
  - design: no assumptions on dimensionality or dyn-core type
  - documentation: API described in the paper/manual
  - legal/practical matters: open source, GPL, hosted on github

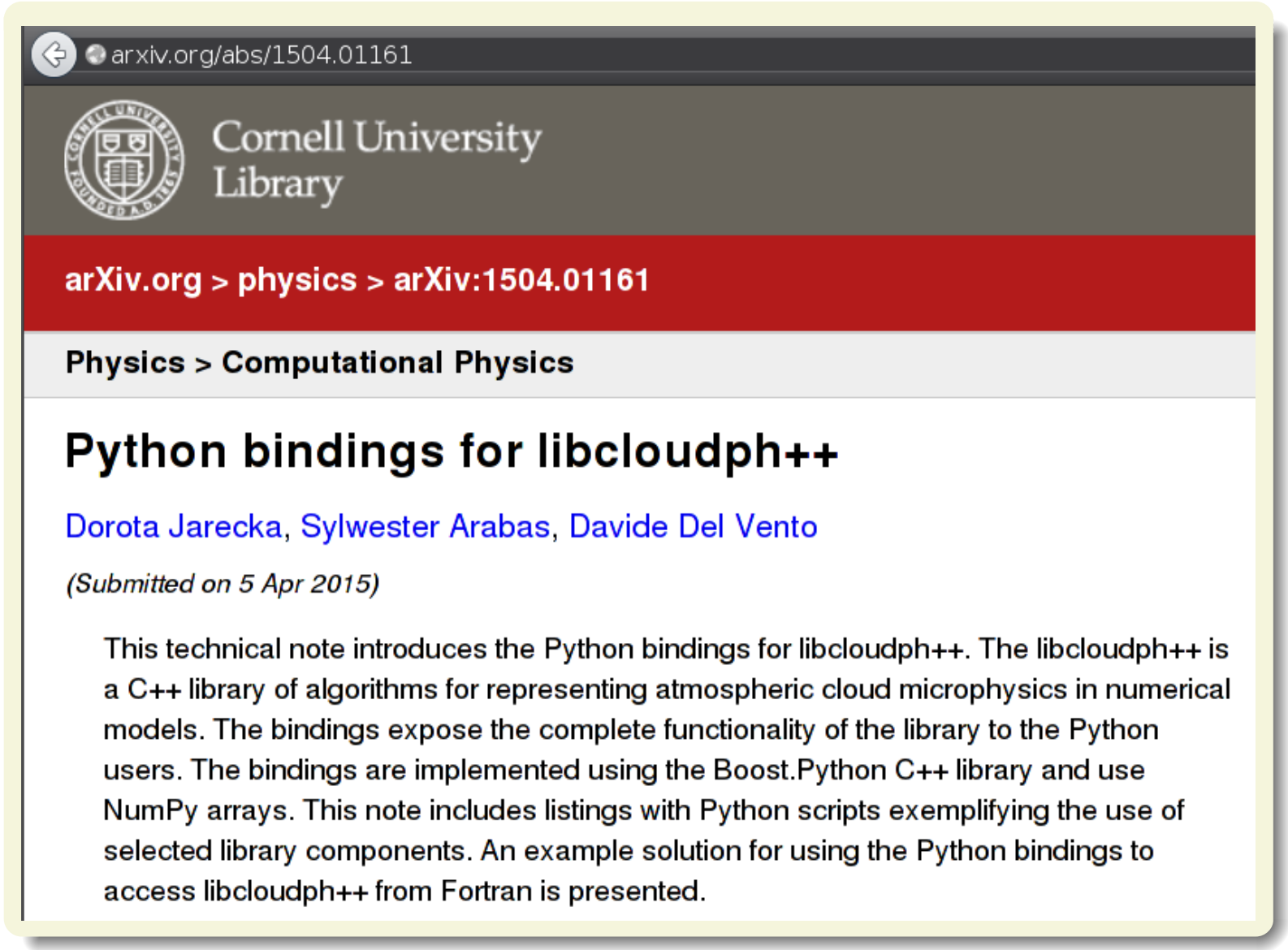
Plan of the talk

"cloud reactor" project: goals and the team

libcloudph++: design choices and their rationale

libcloudph++: Lagrangian "super-droplet" μ-physics

libcloudph++: access from Python and Fortran
(presented by Dorota Jarecka, NCAR)



http://arxiv.org/abs/1504.01161

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$\rightsquigarrow$ Python is an efficient glue language!

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Python

- user interface
  (no need to interact with the native C++ interface)
- rapid-development
  of new features
- interfacing with other languages

libcloudph++ with Python: examples

libcloudph++ with Python: examples

calling saturation adjustment procedure

```
import numpy
import libcloudphxx as libcl

opts = libcl.blk_1m.opts_t()

rhod = numpy.array([1.   ])
th_d = numpy.array([305. ])
r_v  = numpy.array([0.01 ])
r_c  = numpy.array([0.001])
r_r  = numpy.array([0.001])
dt   = 1

libcl.blk_1m.adj_cellwise(opts,
        rhod,                   # array, read-only
        th_d, r_v, r_c, r_r,    # arrays, read-write
        dt)                     # scalar
```

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  - Dutch Atmospheric Large Eddy Simulation (DALES)

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  no modifications
- DALES:
  ca. 10 LoC changed;
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- coupling code:
  ca. 300 LoC in Python

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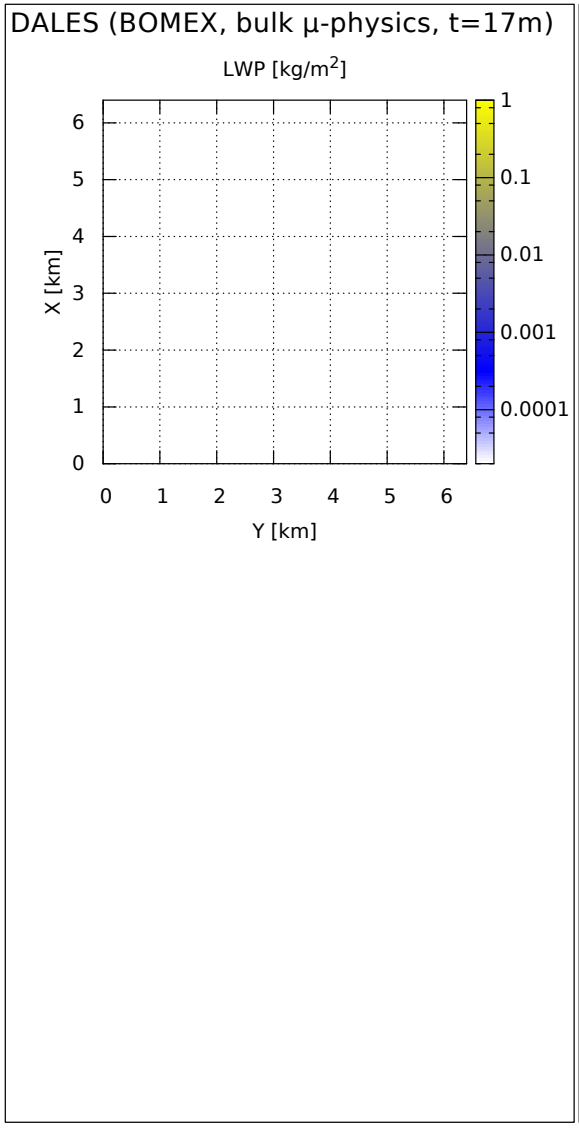

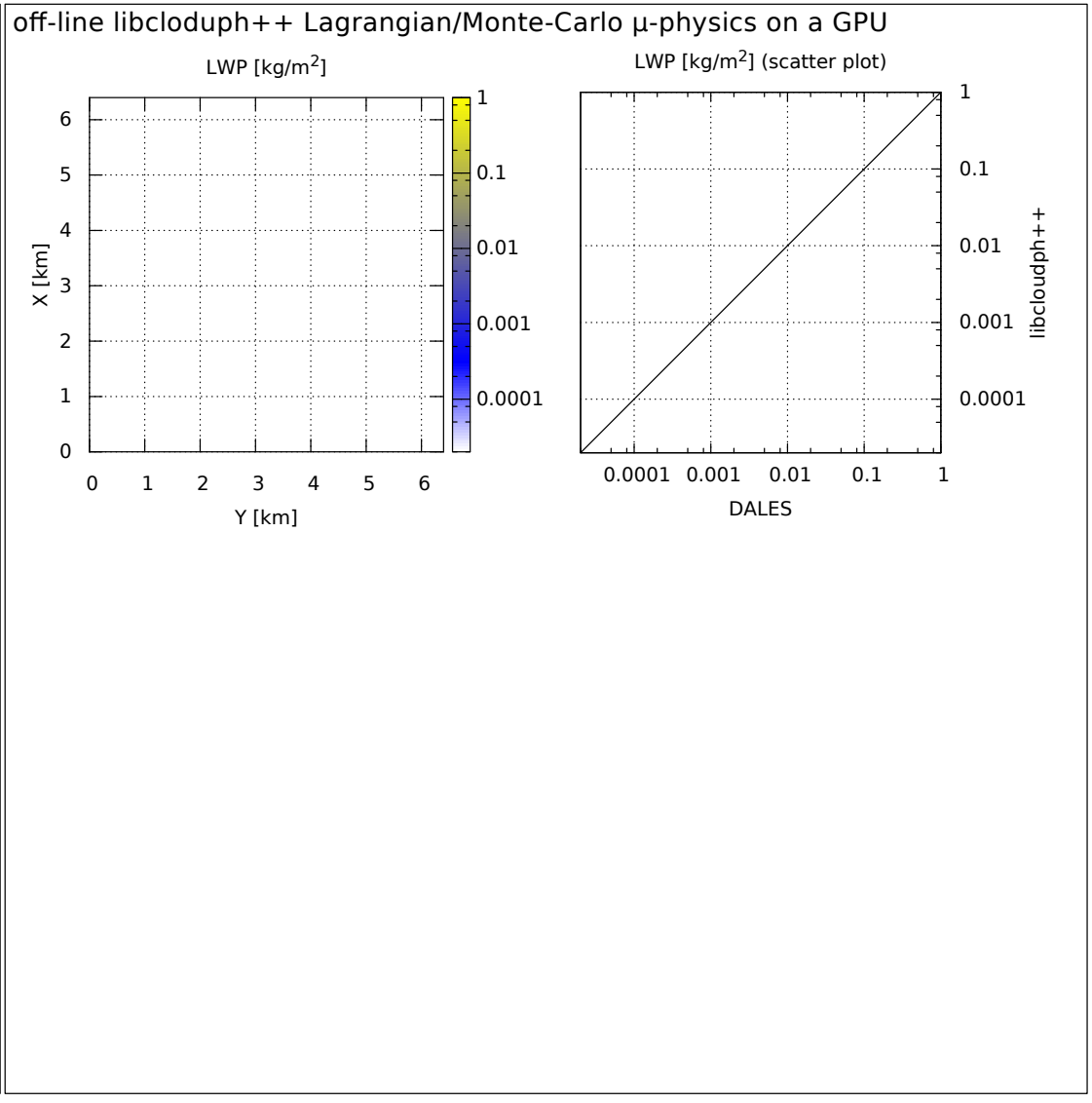

collaboration with Harm Jonker / TU Delft

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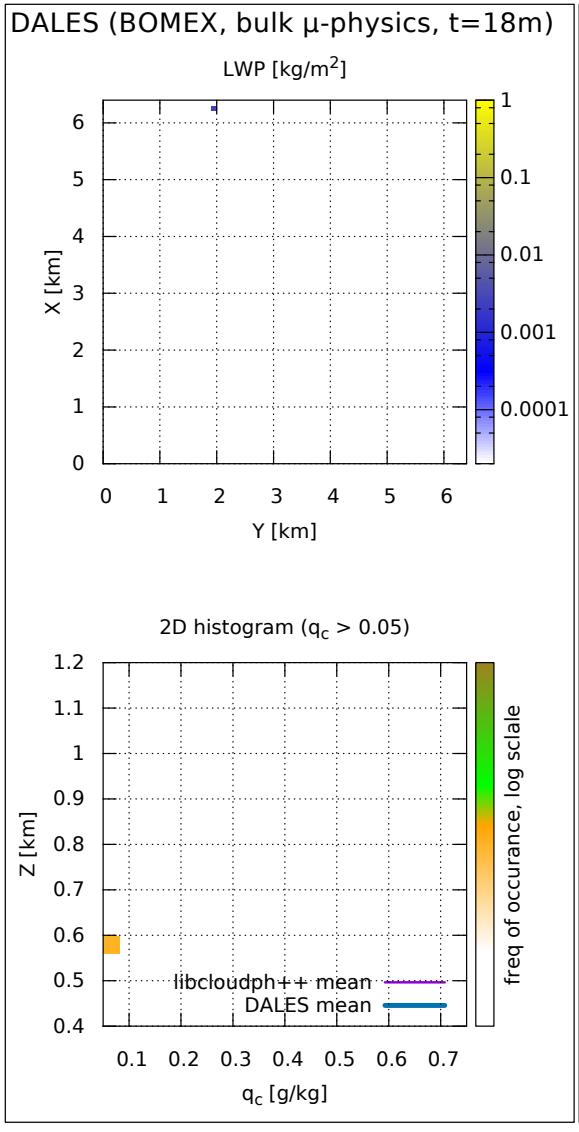

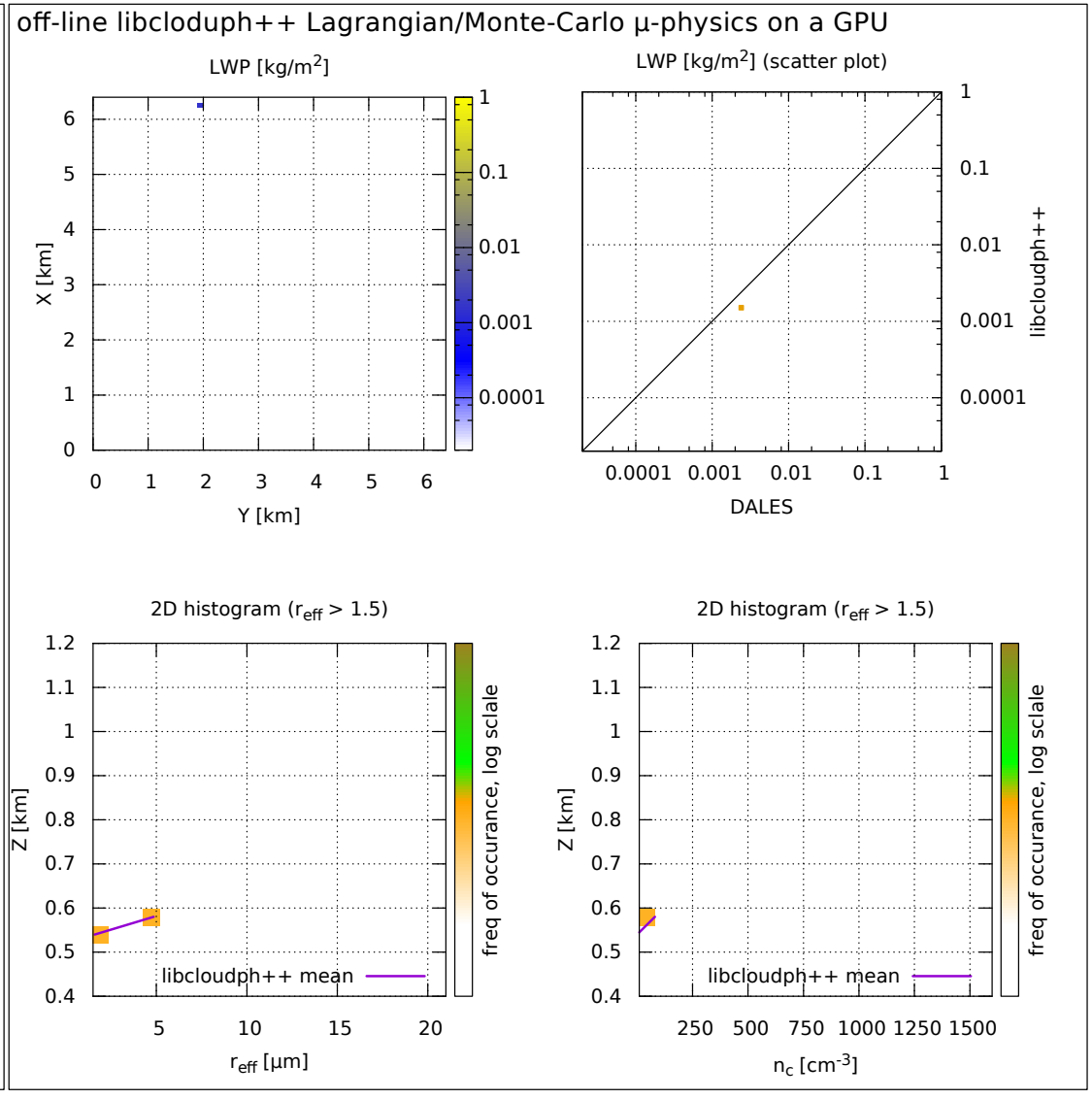

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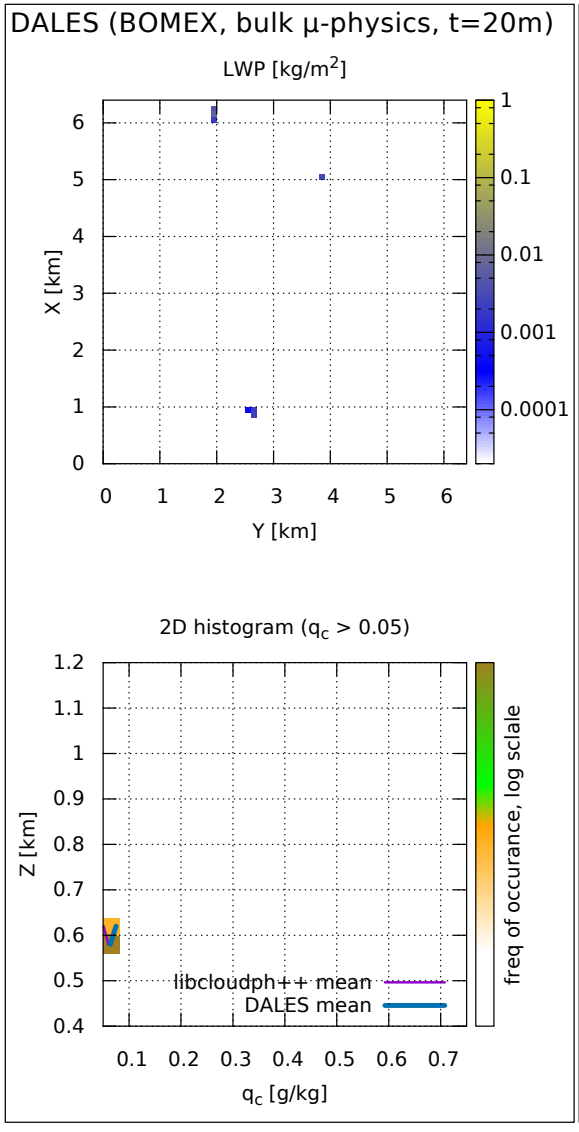

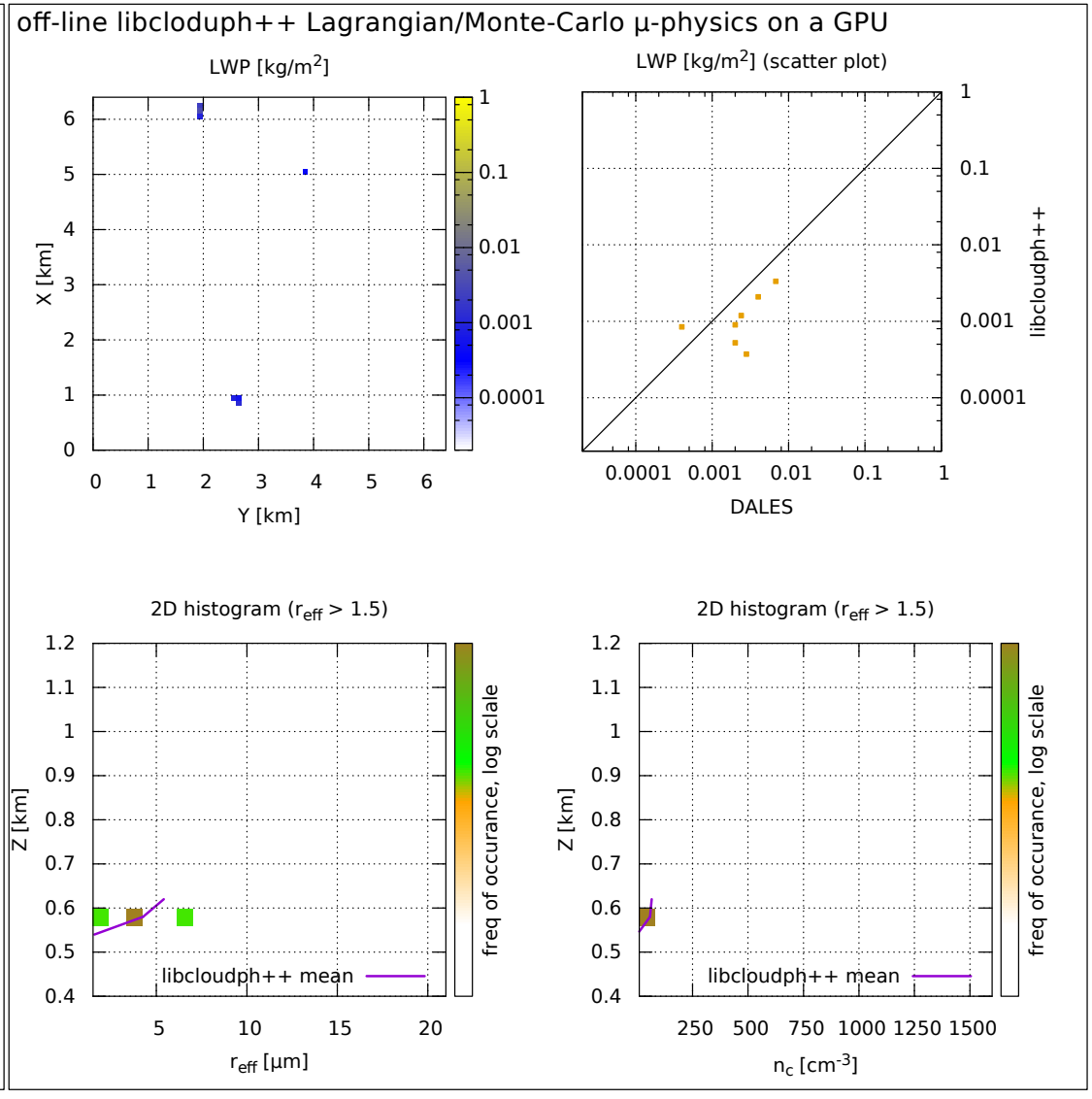

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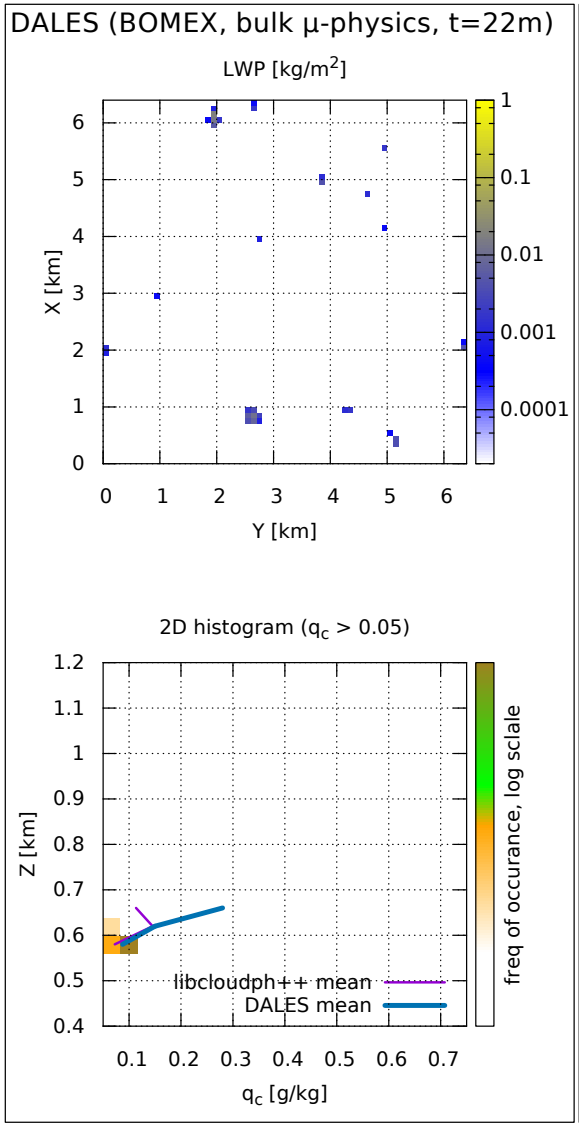

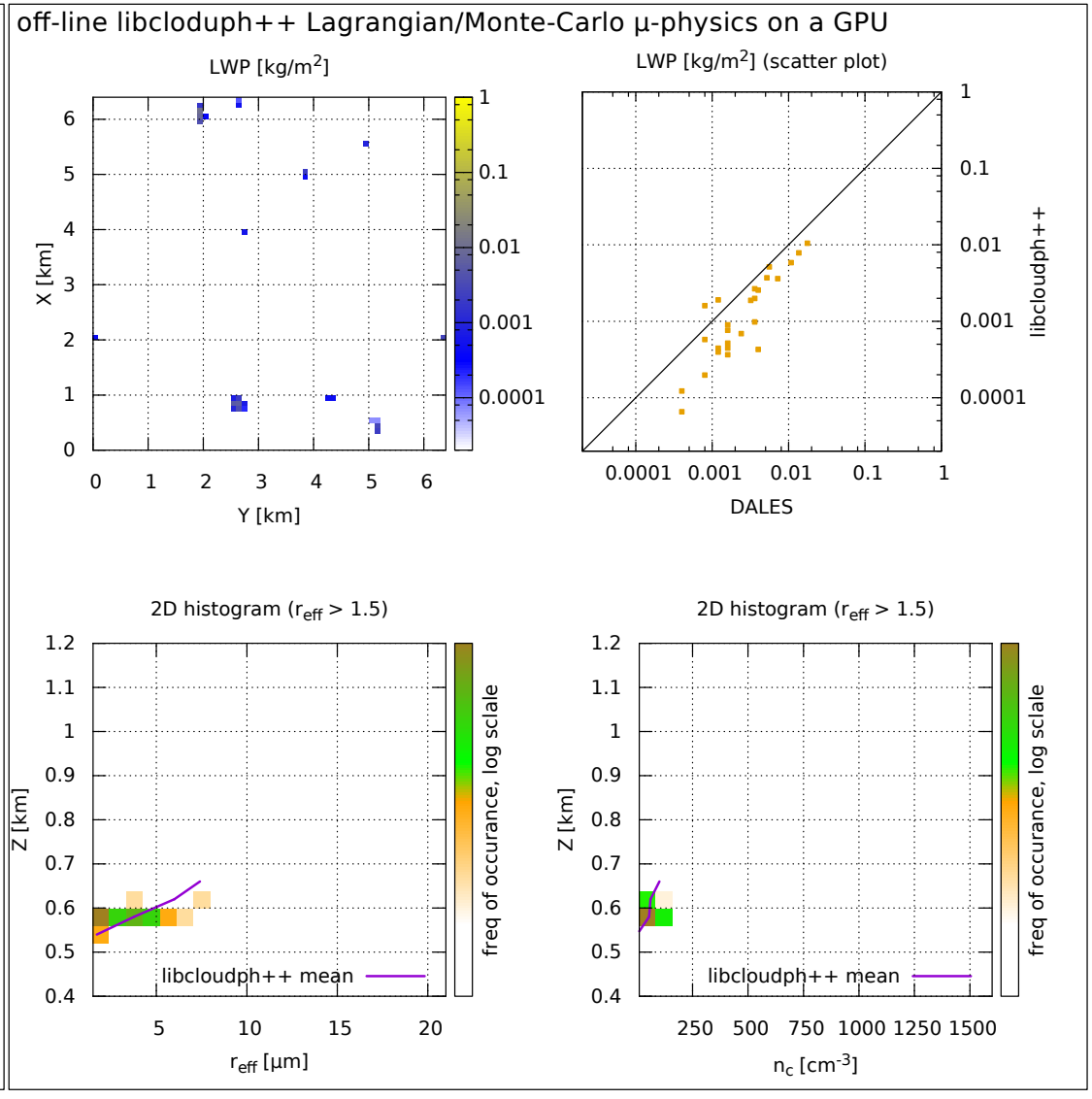

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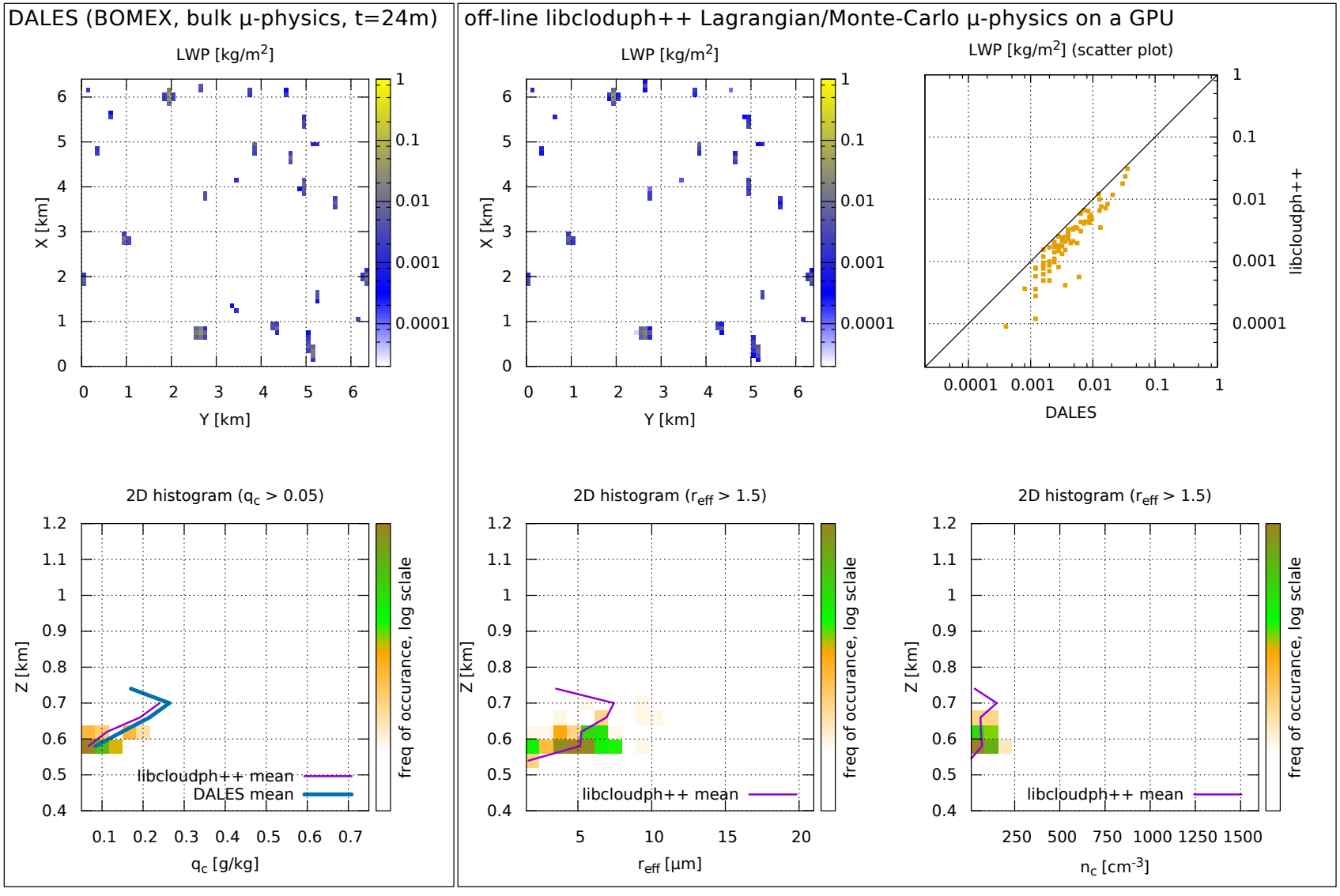

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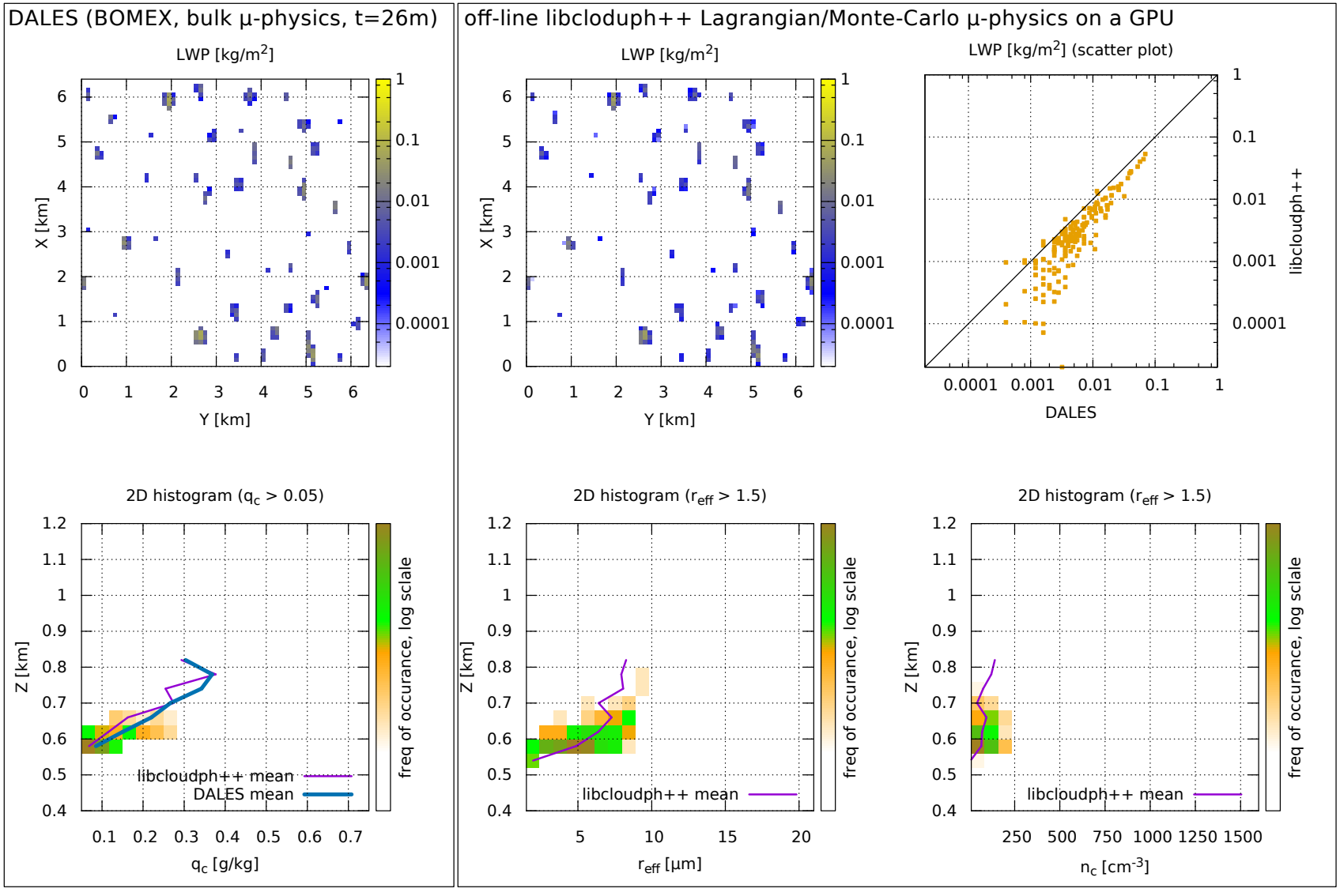

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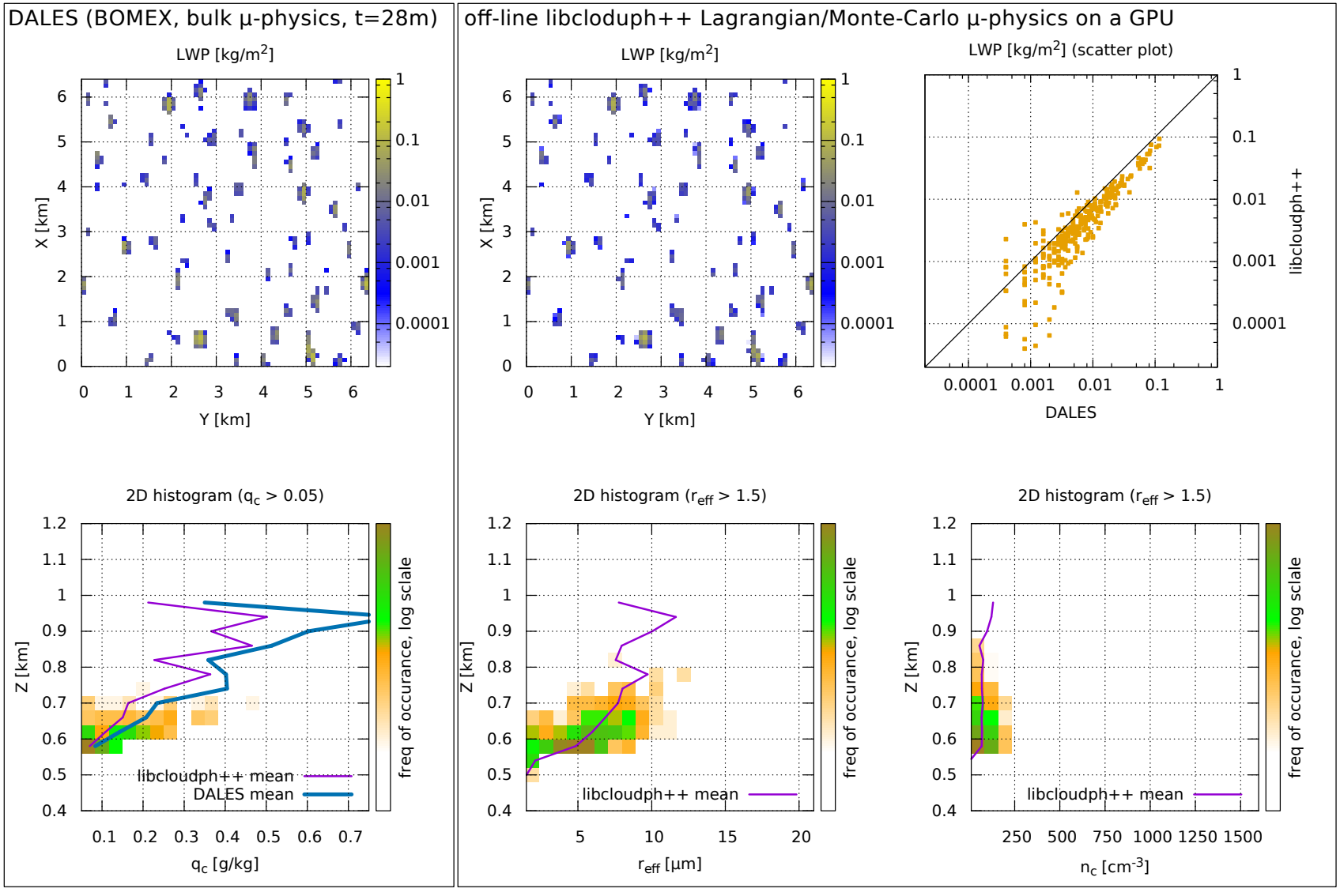

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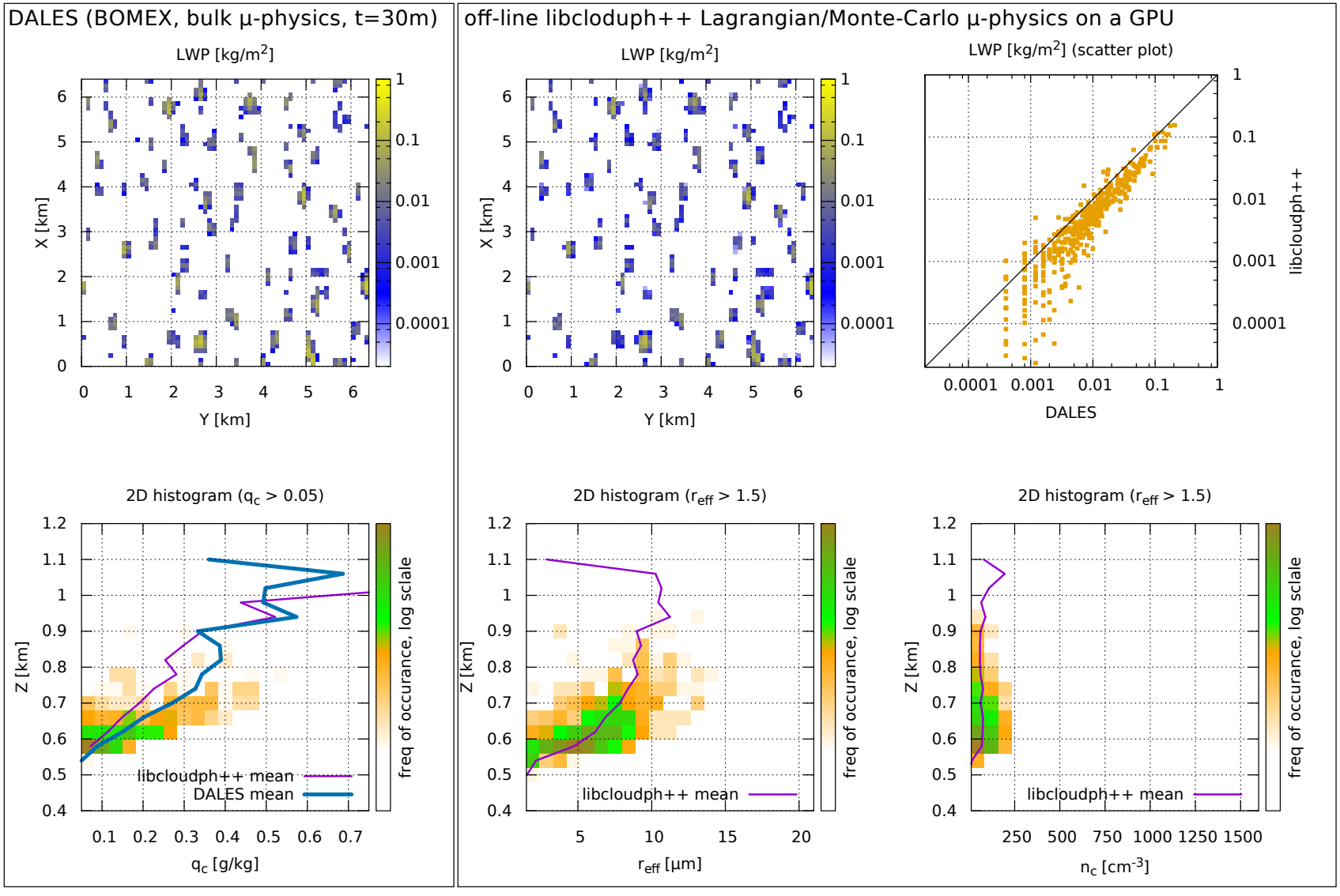

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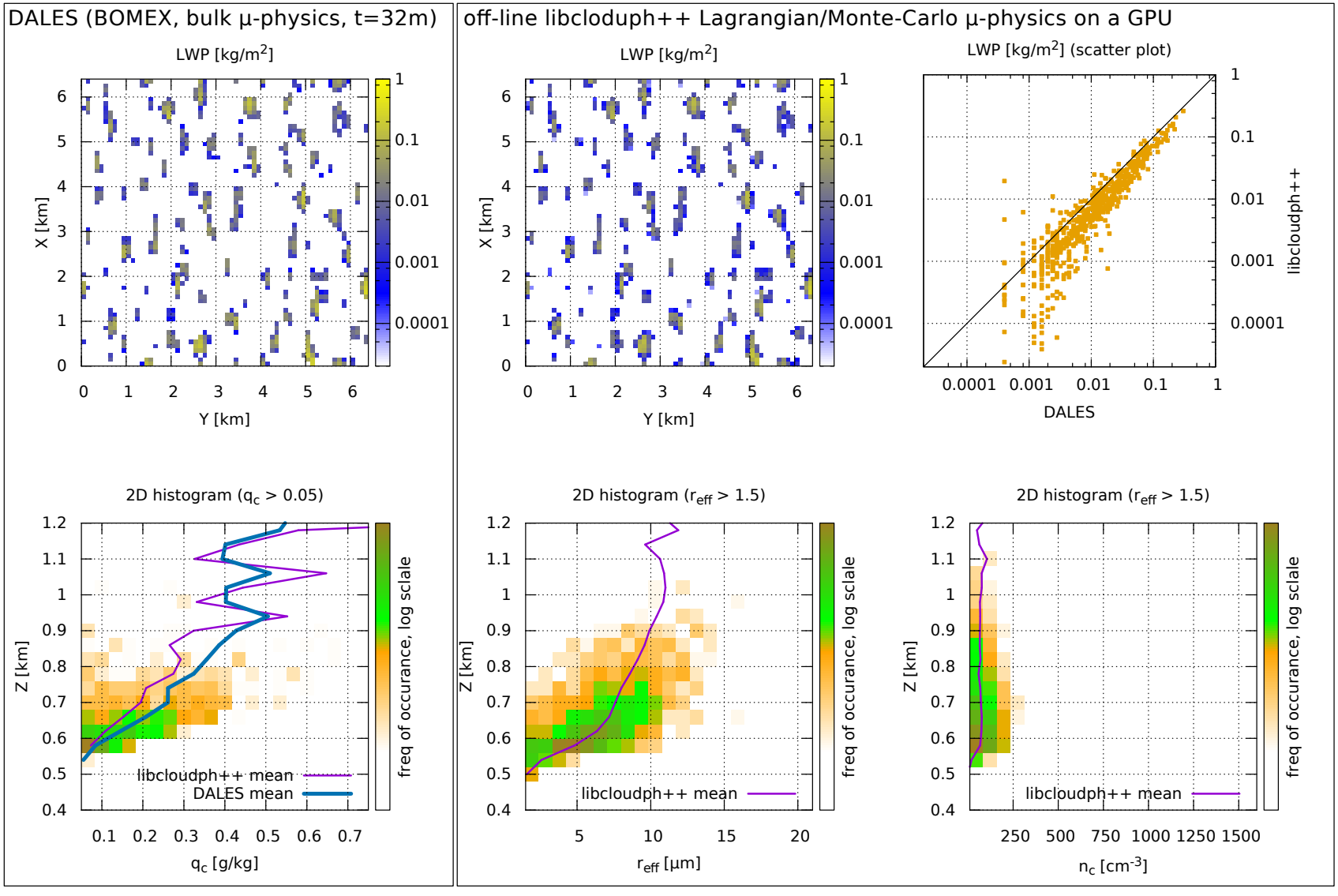

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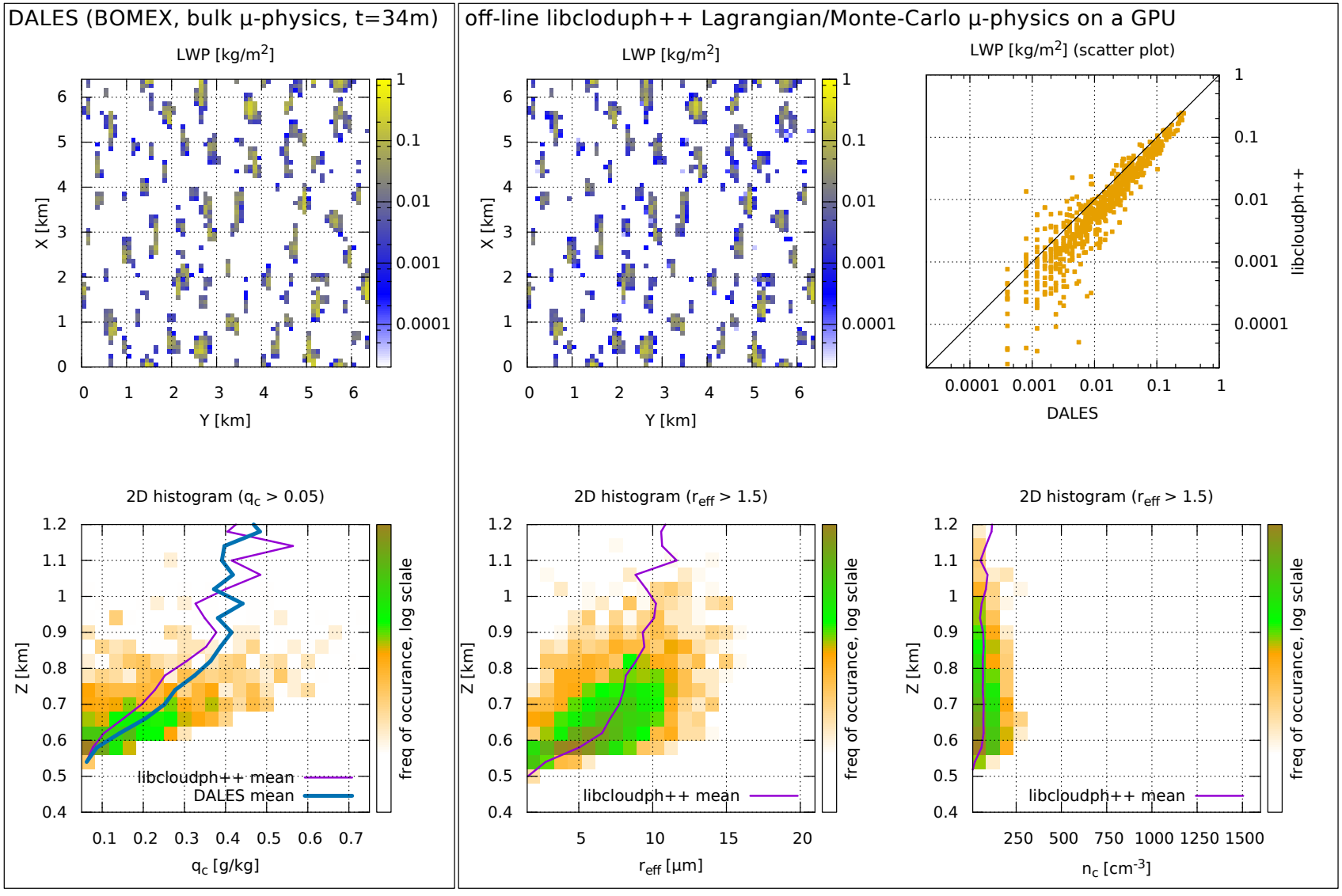

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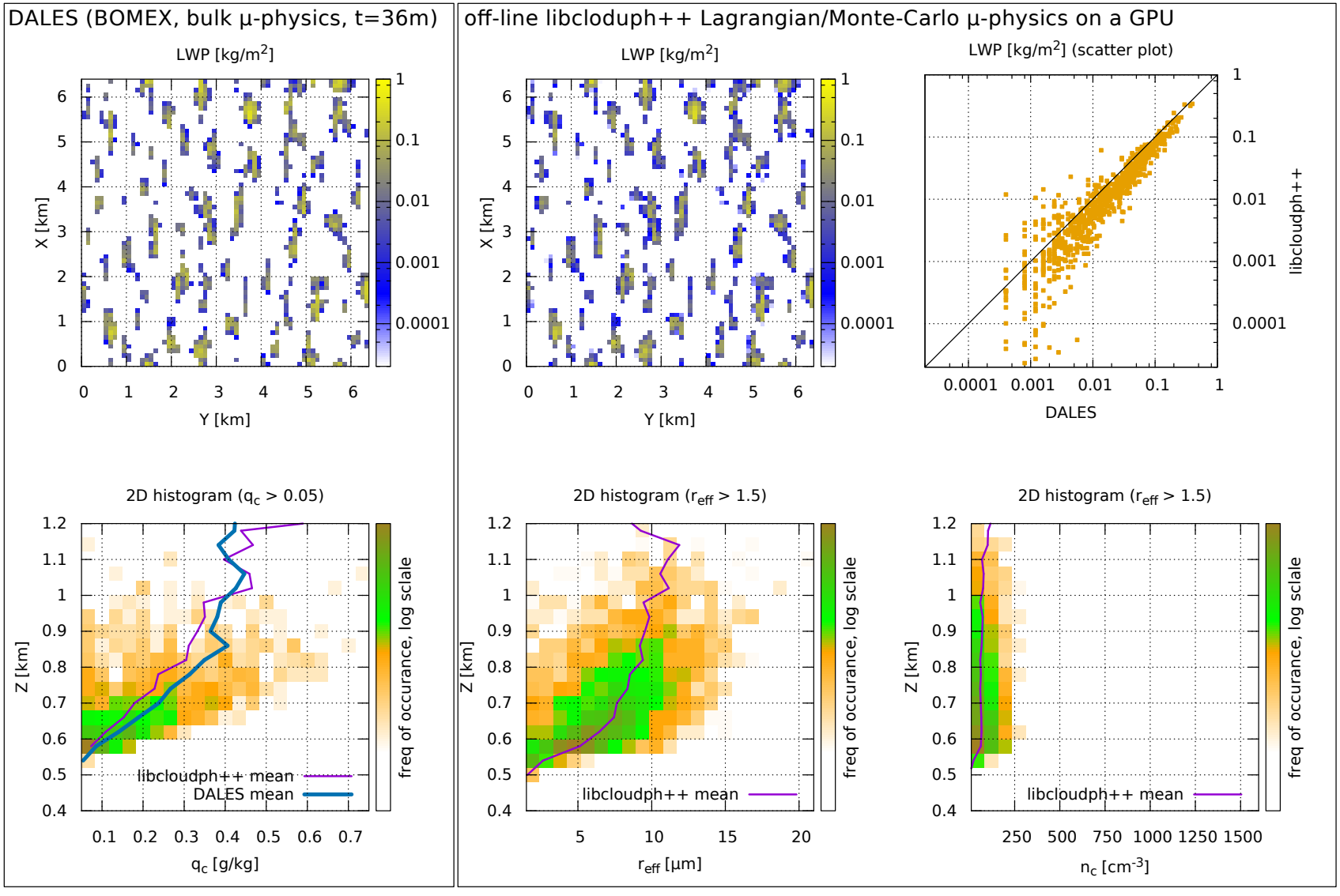

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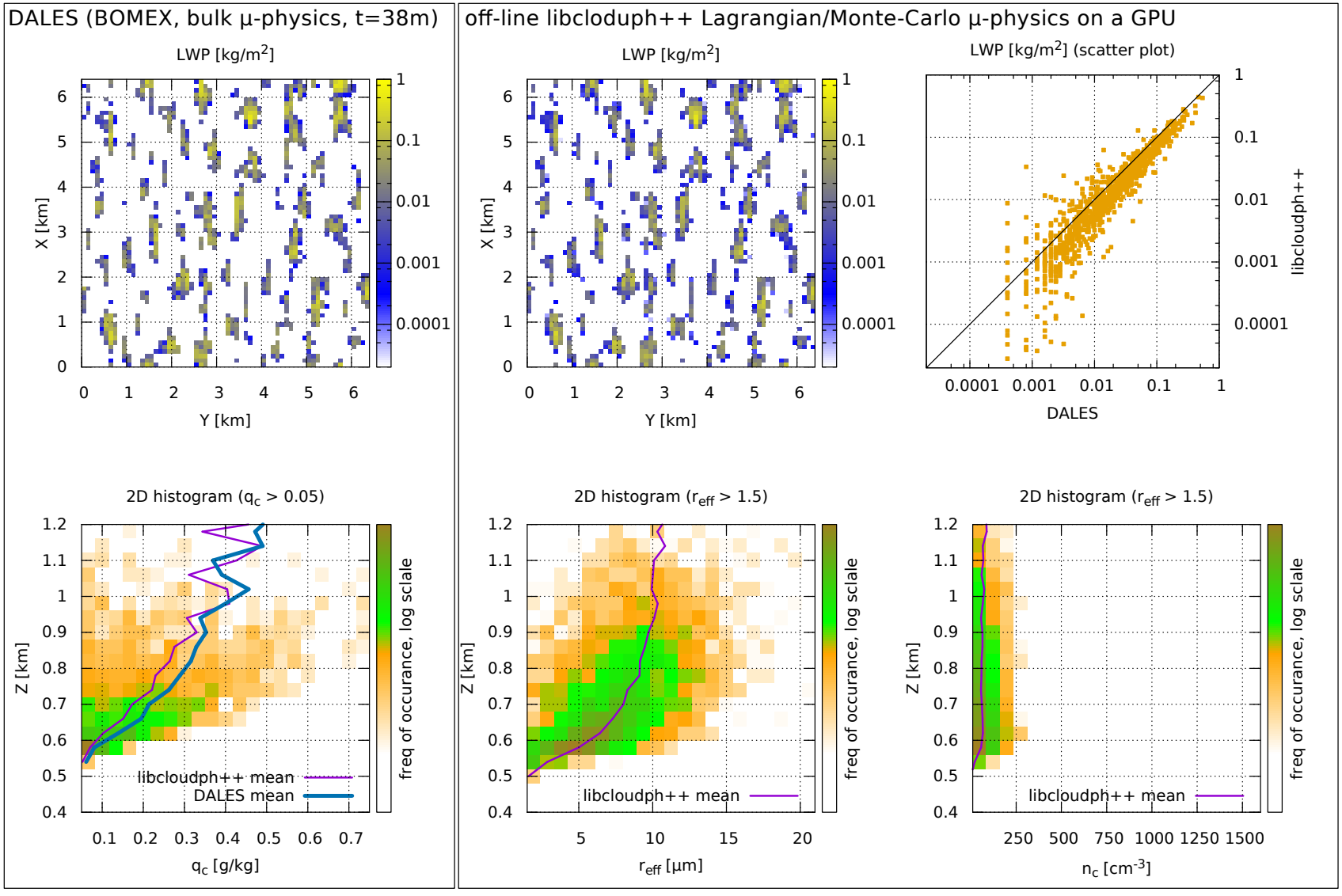

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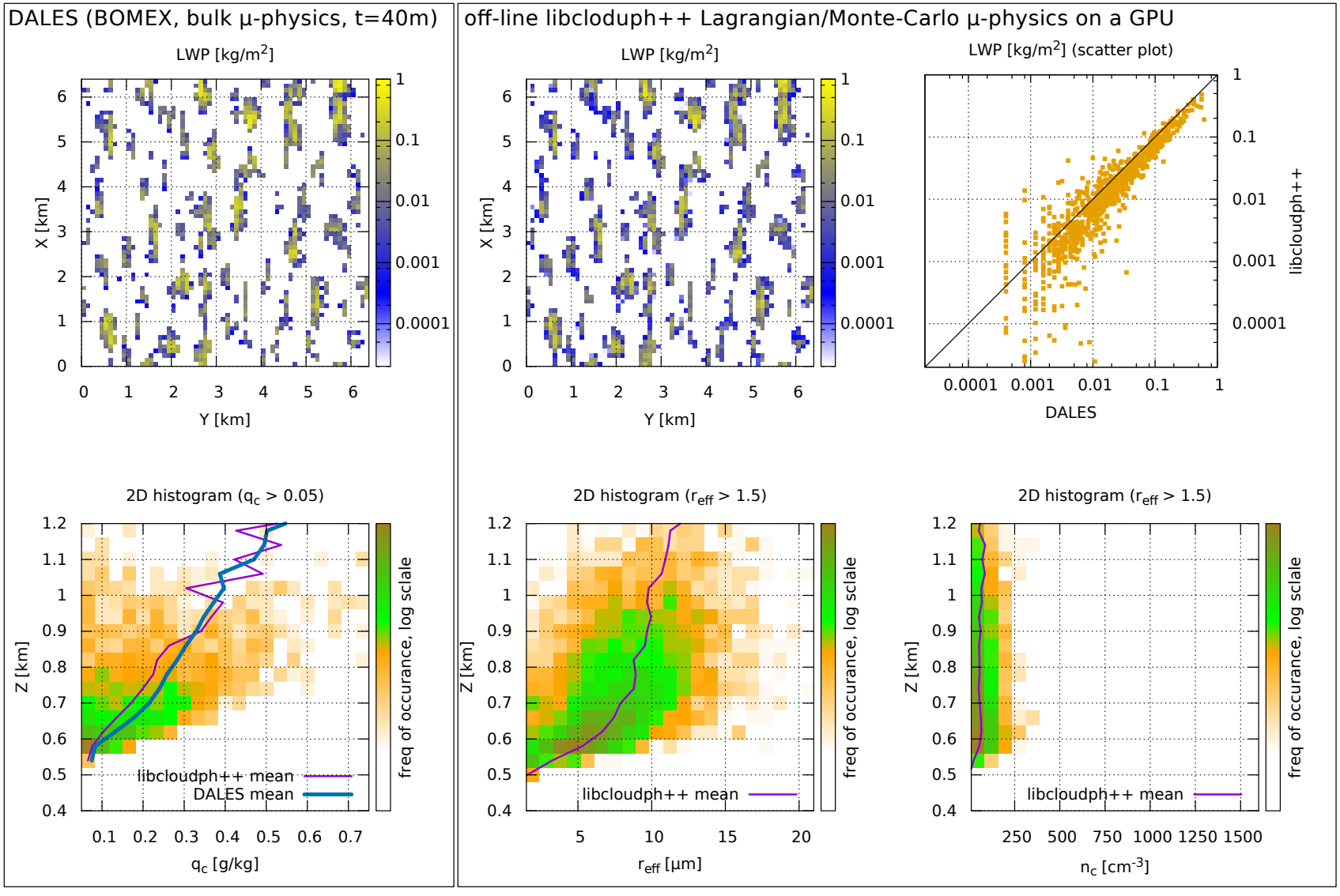

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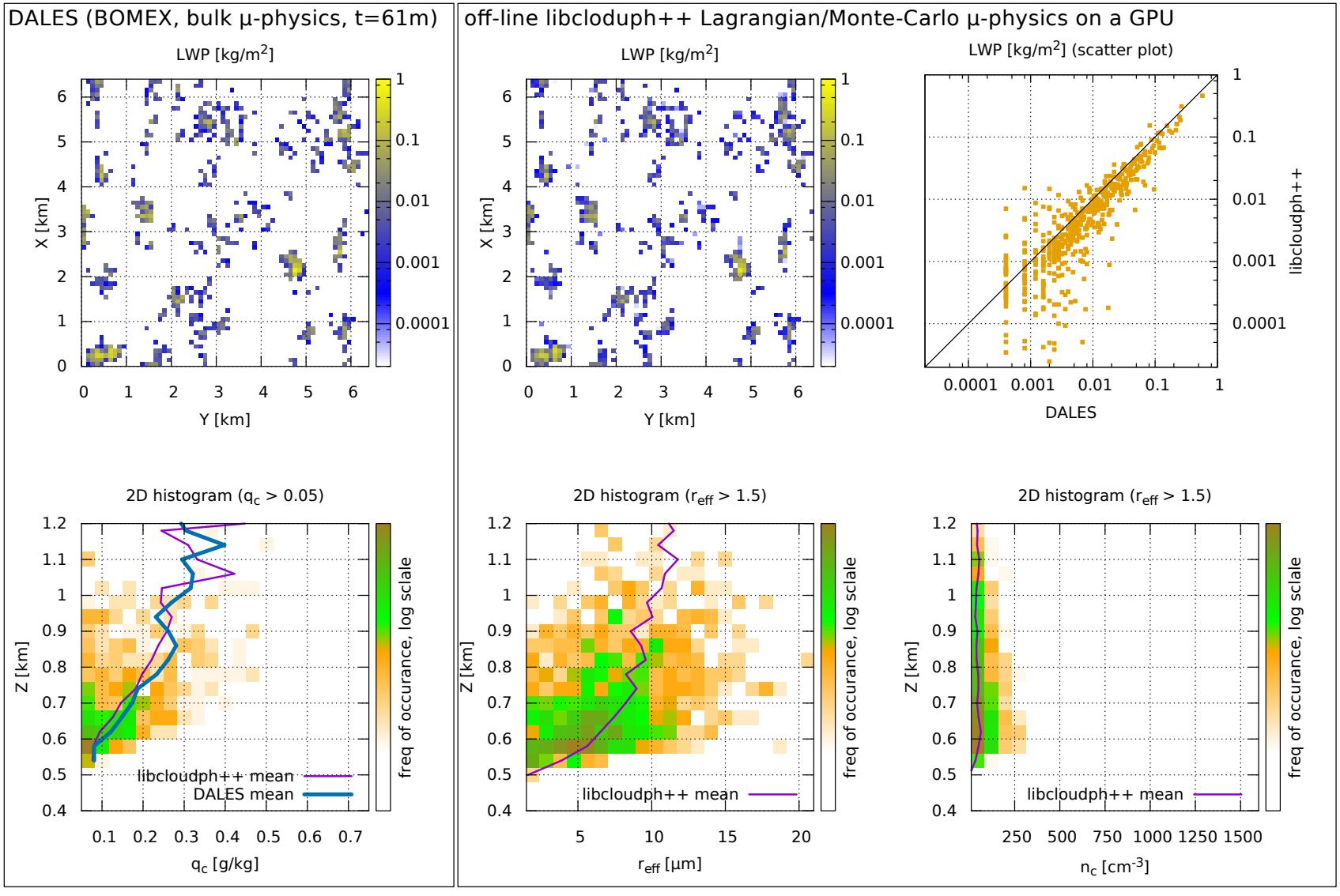

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