Aerosol processing by drizzling stratocumulus: a modelling study using a novel particle-based approach

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aerosol processing: concepts

- interactions: aerosol —▷ cloud & precipitation —▷ aerosol

- processed CCN formed by evaporation of
  - collisionally grown drops
  - drops within which irreversible oxidation occurred
- CCN spectrum modification by wet deposition
- adequate cloud μ-physics representations?

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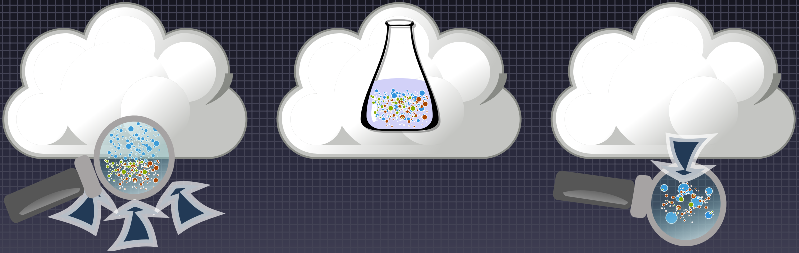

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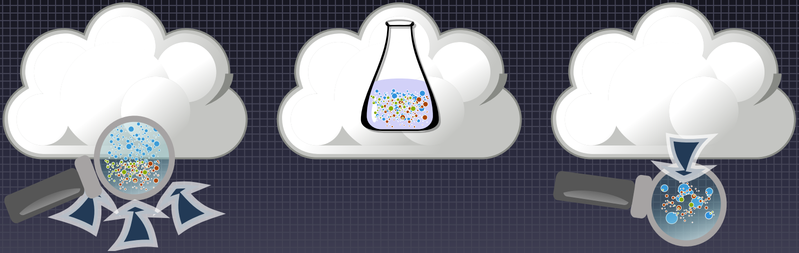

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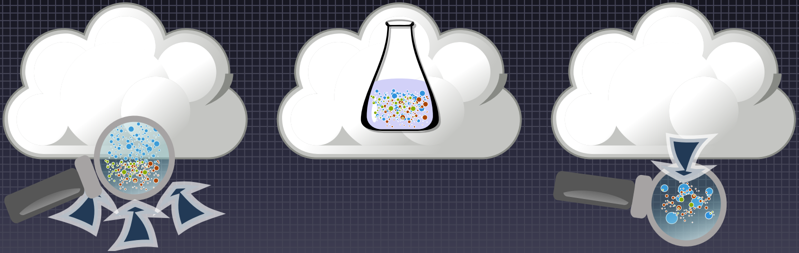

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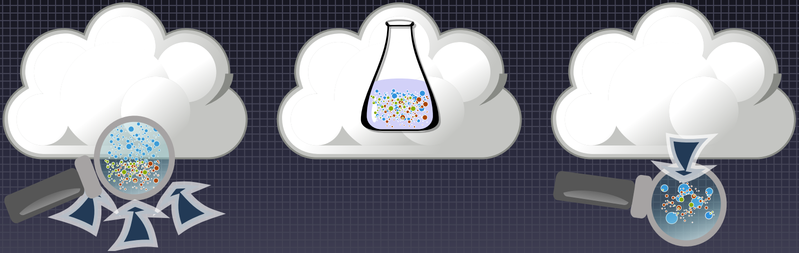

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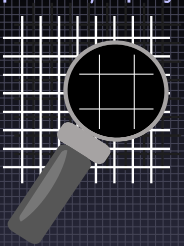

key features of the Lagrangian (in size) approach:

- diffusive-error-free particle growth schemes (aka "moving sectional")
- scales better than ND-bin with growing number of particle attributes
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coupled with Lagrangian-in-space $\rightsquigarrow$ super-droplet approach

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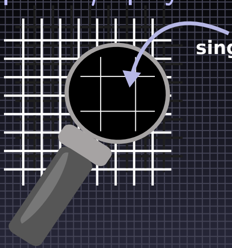

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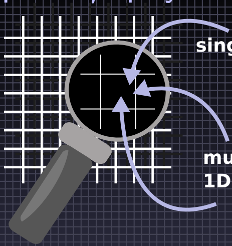

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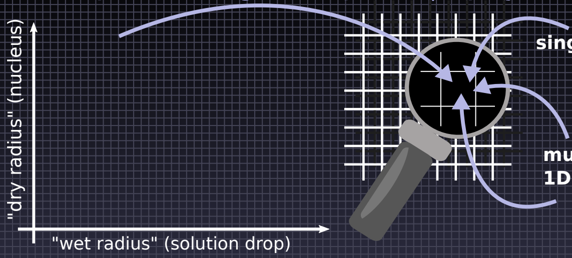

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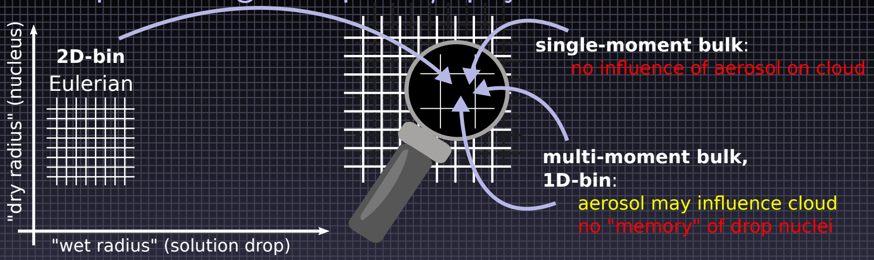

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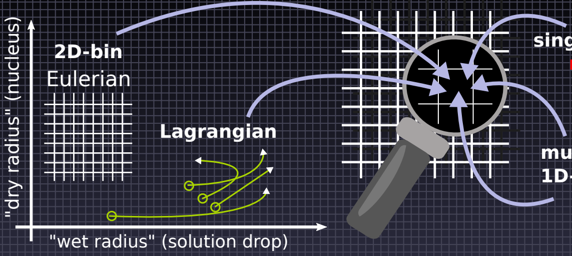

2D-bin
Eulerian

Lagrangian

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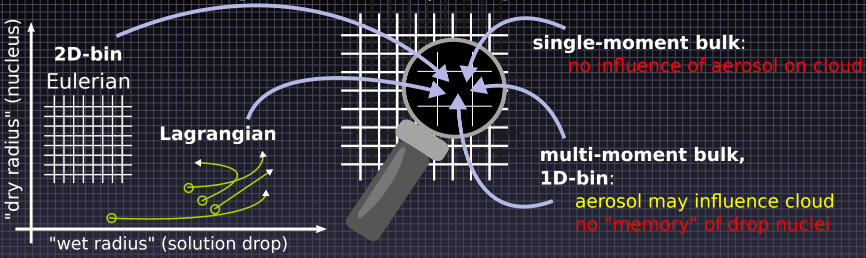

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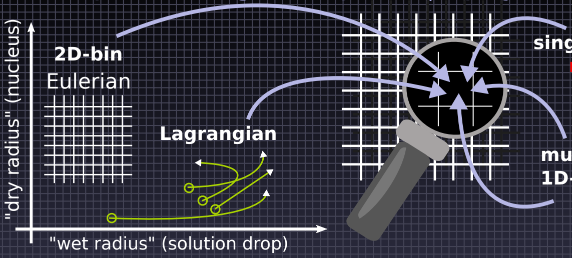

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Lagrangian μ-physics: key elements

- each particle (aka super-droplet) ⇝ many "similar" real-world particles
- attributes: multiplicity, dry radius, wet radius, nucleus type, ...
- aerosol, cloud, precip. particles not distinguished, subject to same processes

Eulerian / PDE	Lagrangian / ODE
advection of heat	particle transport by the flow
advection of moisture	condensational growth
	collisional growth
	sedimentation
$\partial_t(\rho_d r) + \nabla(\vec{v}\rho_d r) = \rho_d \dot{r}$	$\dot{r} = \sum_{\text{particles} \in \Delta V} \ldots$
$\partial_t(\rho_d \theta) + \nabla(\vec{v}\rho_d \theta) = \rho_d \dot{\theta}$	$\dot{\theta} = \sum_{\text{particles} \in \Delta V} \ldots$
advection of trace gases	in-particle aqueous chemistry
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  - Shima et al. 2009, QJ
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- 2D prescribed-flow (single eddy)
- bi-modal initial dry aerosol spectrum
- details:
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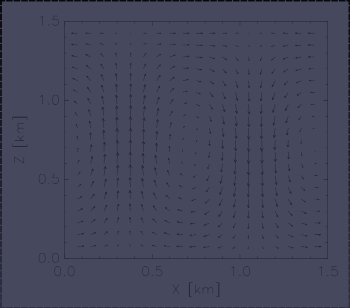

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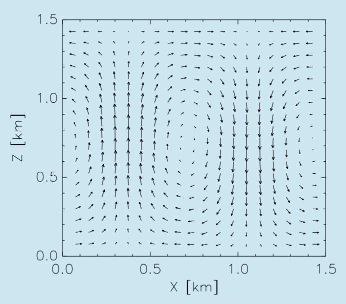

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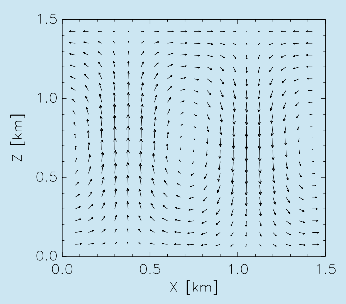

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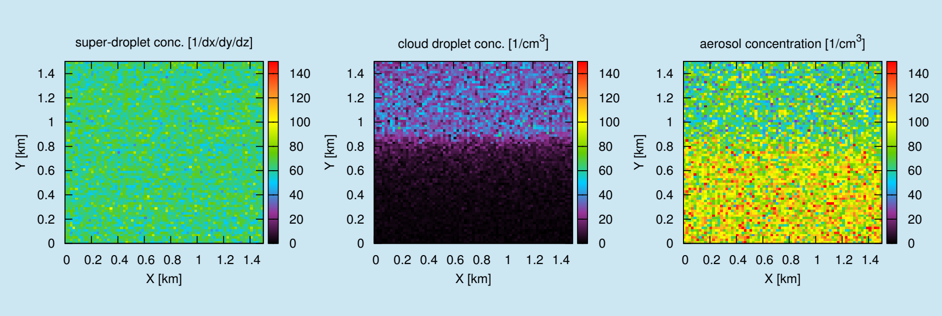

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Monte-Carlo coalescence scheme (Shima et al. 2009)

- for all n super-droplets in a grid box of volume ΔV in timestep Δt
- each representing ξ real particles (aerosol/cloud/drizzle/rain)
- the probability of coalescence of i-th and j-th super-droplets is:

$$P_{ij} = max(\xi_i, \xi_j) \cdot \underbrace{E(r_i, r_j) \cdot \pi (r_i + r_j)^2 \cdot |v_i - v_j|}_{\text{coalescence kernel}} \cdot \frac{\Delta t}{\Delta V} \cdot \frac{n \cdot (n-1)}{2} / \left[\frac{n}{2}\right]$$

  where r – drop radii, $E(r_i, r_j)$ – collection efficiency, v – drop velocities
- coalescence takes place once in a number of timesteps (def. by P_{ij})
- all min(ξ_i,ξ_j) droplets coalesce
  $\rightsquigarrow$ there's always a "bin" of the right size to store the collided particles
- collisions triggered by comparing a uniform random number with P_{ij}
- extensive parameters summed ($\leftrightsquigarrow$ conserved), intensive averaged
- [n/2] random non-overlapping (i,j) pairs examined instead of all (i,j) pairs
  cost: $O(n^2) \rightsquigarrow O(n)$, probability upscaled by $\frac{n \cdot (n-1)}{2} / \left[\frac{n}{2}\right]$

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- each representing ξ real particles (aerosol/cloud/drizzle/rain)
- the probability of coalescence of i-th and j-th super-droplets is:

$$P_{ij} = max(\xi_i, \xi_j) \cdot \underbrace{E(r_i, r_j) \cdot \pi (r_i + r_j)^2 \cdot |v_i - v_j|}_{\text{coalescence kernel}} \cdot \frac{\Delta t}{\Delta V} \cdot \frac{n \cdot (n-1)}{2} / \left\lfloor \frac{n}{2} \right\rfloor$$

  where r – drop radii, $E(r_i, r_j)$ – collection efficiency, v – drop velocities
- coalescence takes place once in a number of timesteps (def. by P_{ij})
- all min(ξ_i,ξ_j) droplets coalesce
  $\rightsquigarrow$ there's always a "bin" of the right size to store the collided particles
- collisions triggered by comparing a uniform random number with P_{ij}
- extensive parameters summed ($\rightsquigarrow$ conserved), intensive averaged
- $\lfloor n/2 \rfloor$ random non-overlapping (i,j) pairs examined instead of all (i,j) pairs
  cost: $O(n^2) \rightsquigarrow O(n)$, probability upscaled by $\frac{n \cdot (n-1)}{2} / \left\lfloor \frac{n}{2} \right\rfloor$

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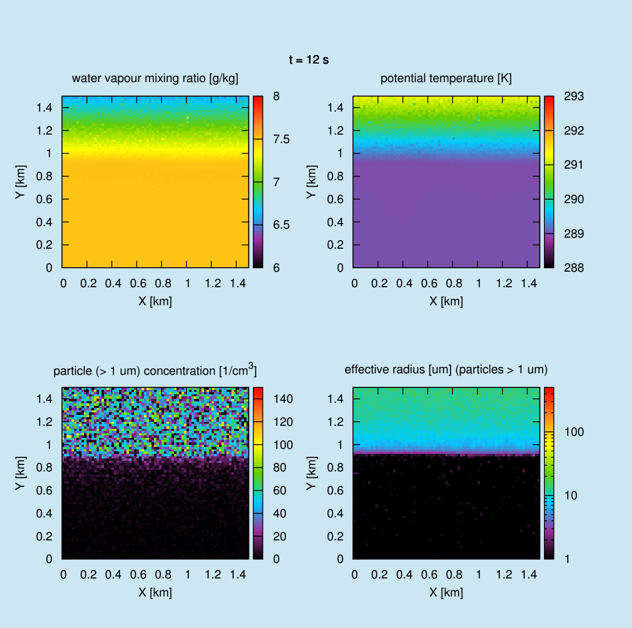

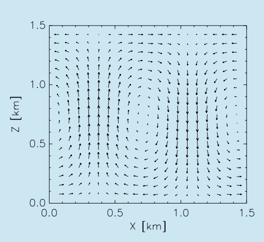

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$E(r_i, r_j) = 10$
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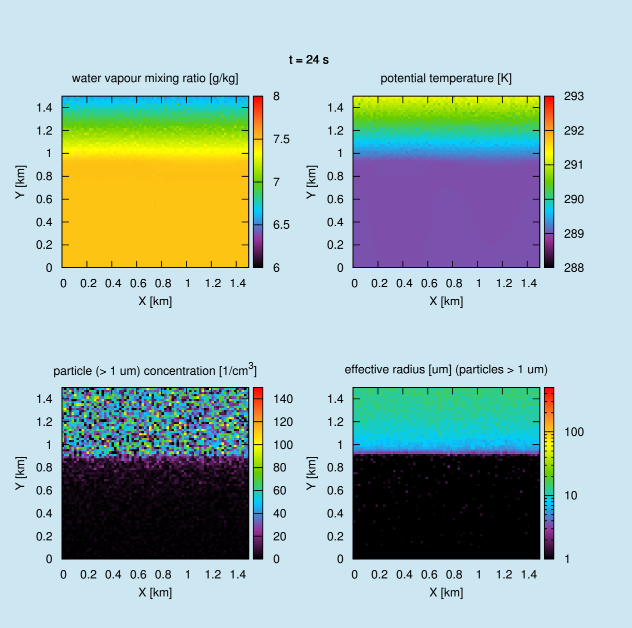

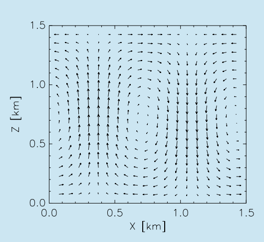

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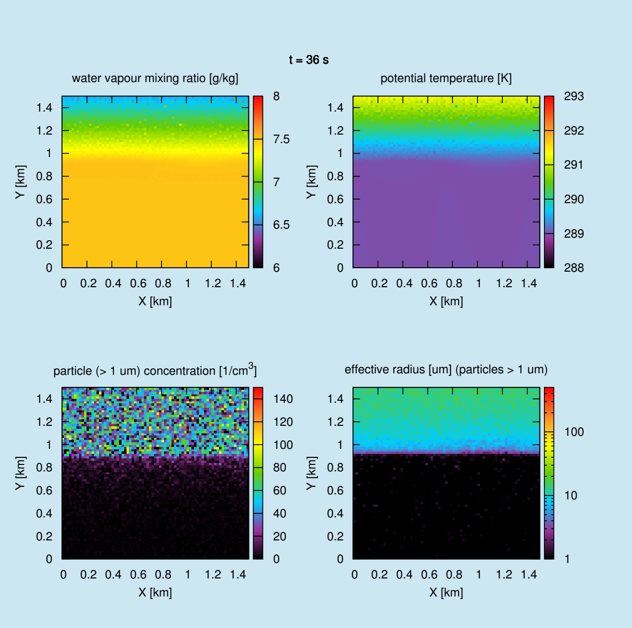

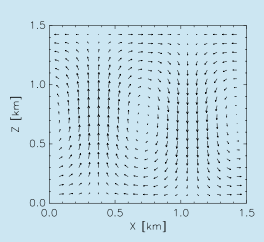

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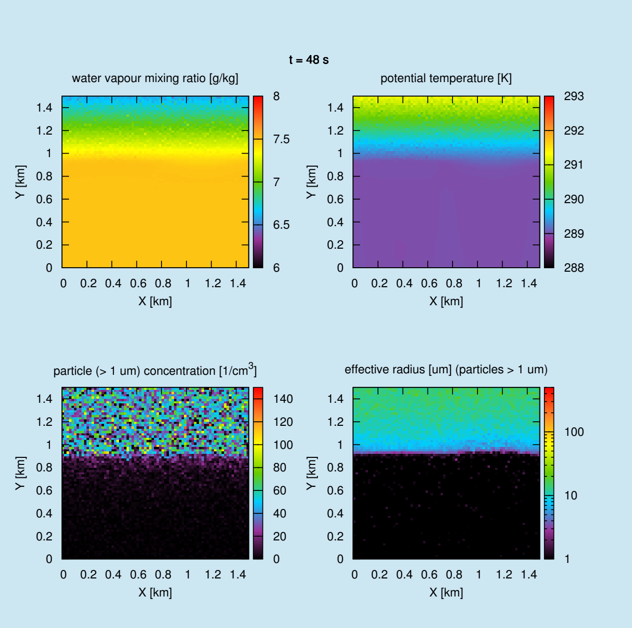

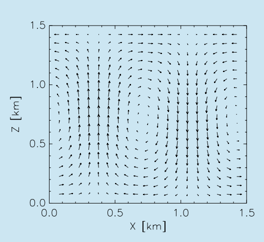

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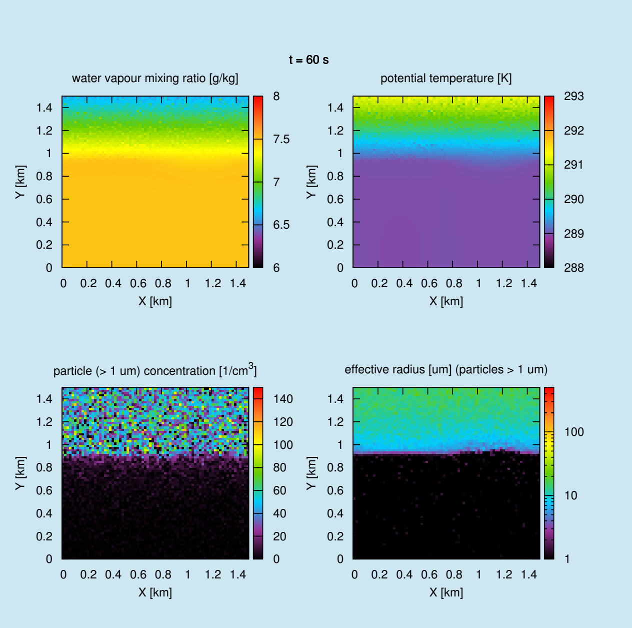

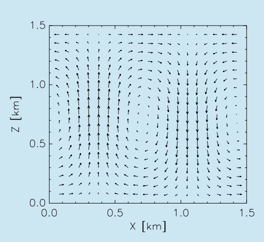

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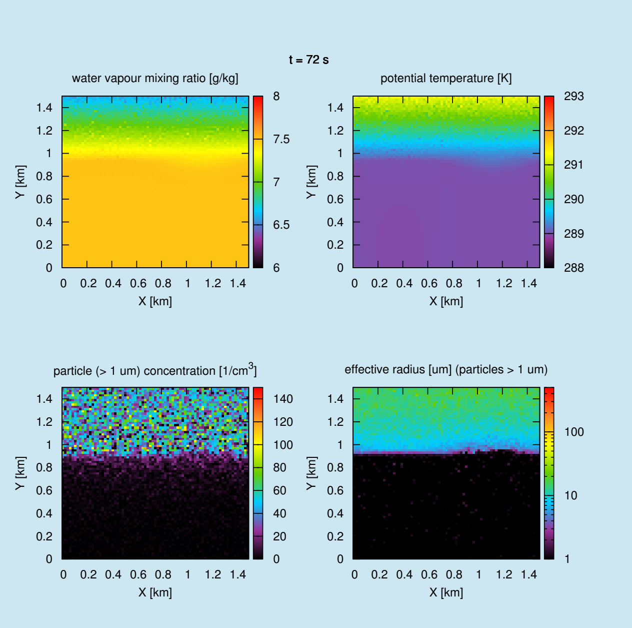

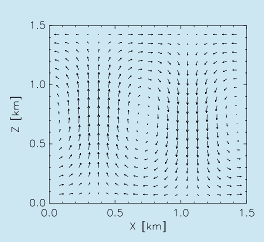

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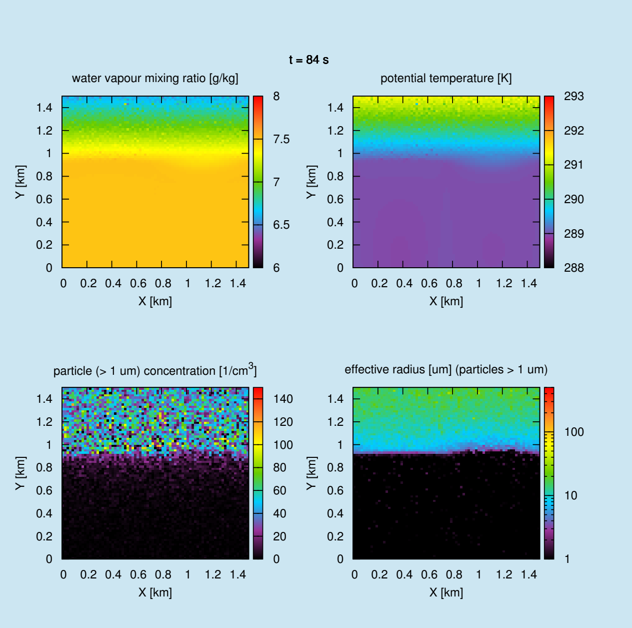

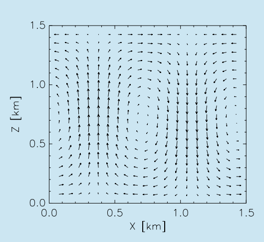

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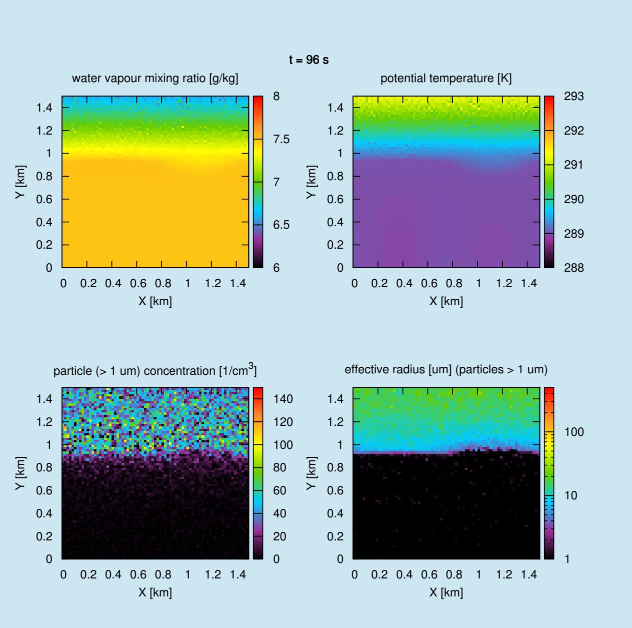

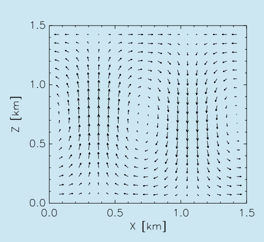

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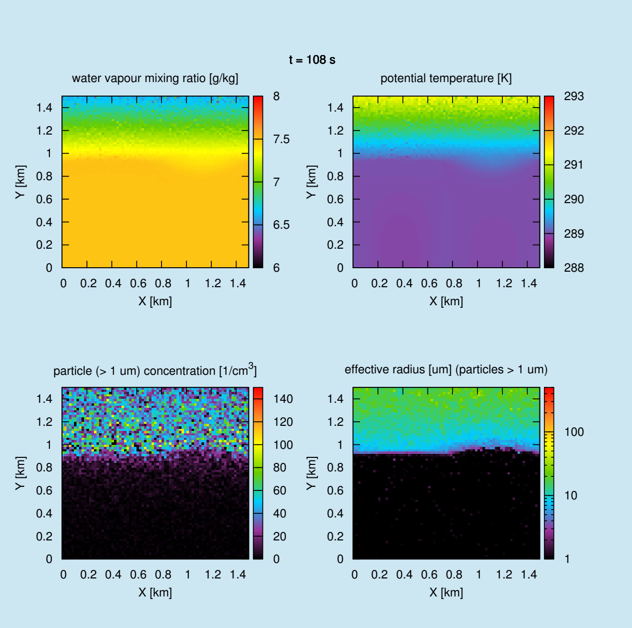

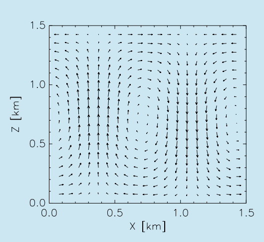

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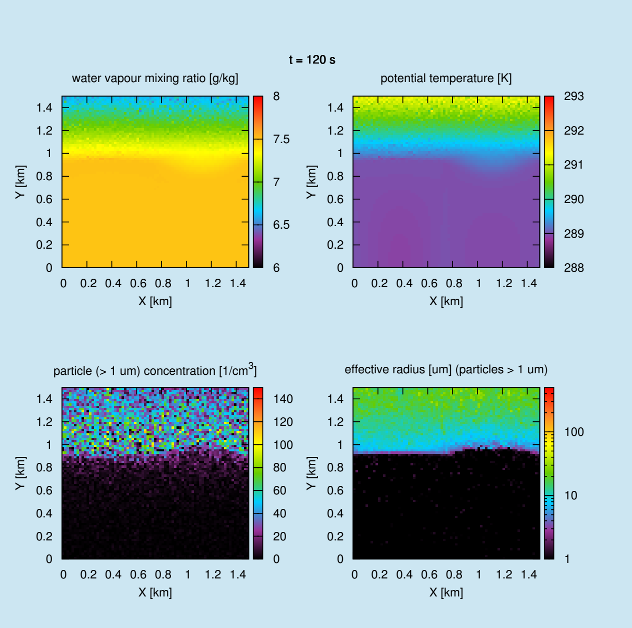

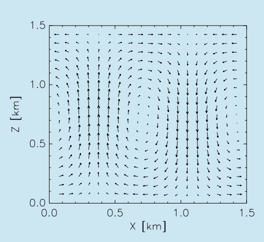

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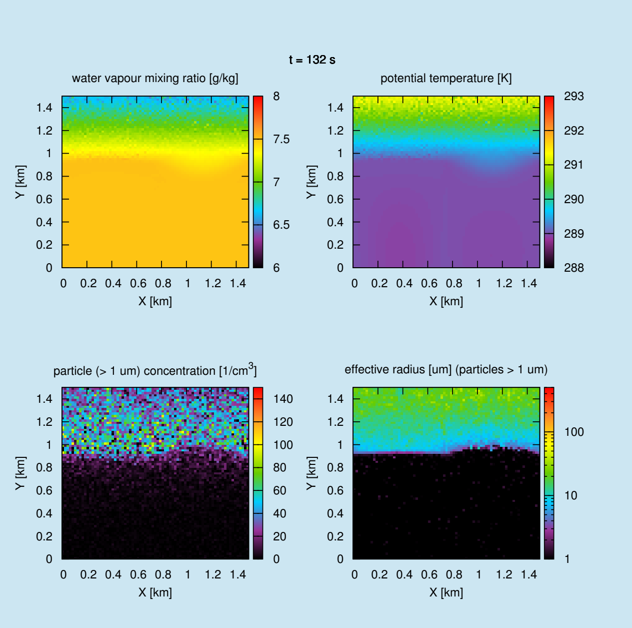

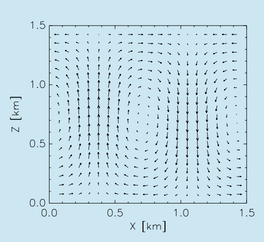

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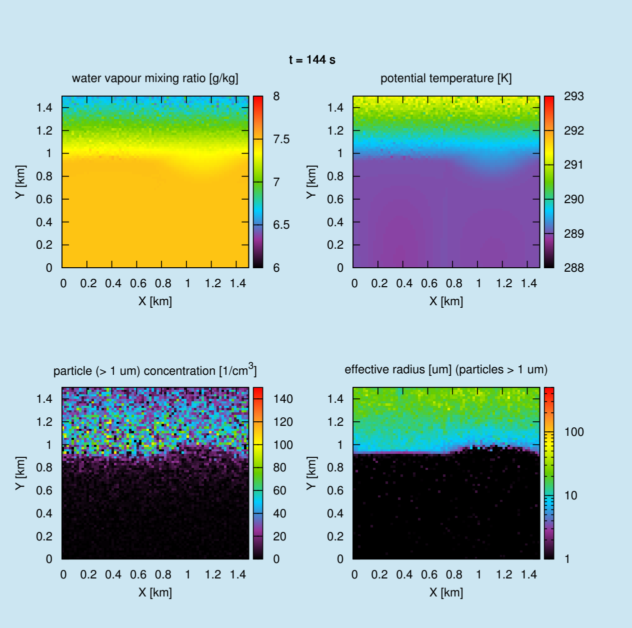

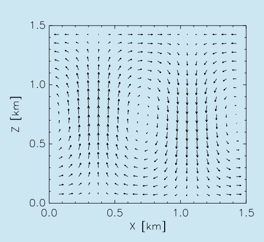

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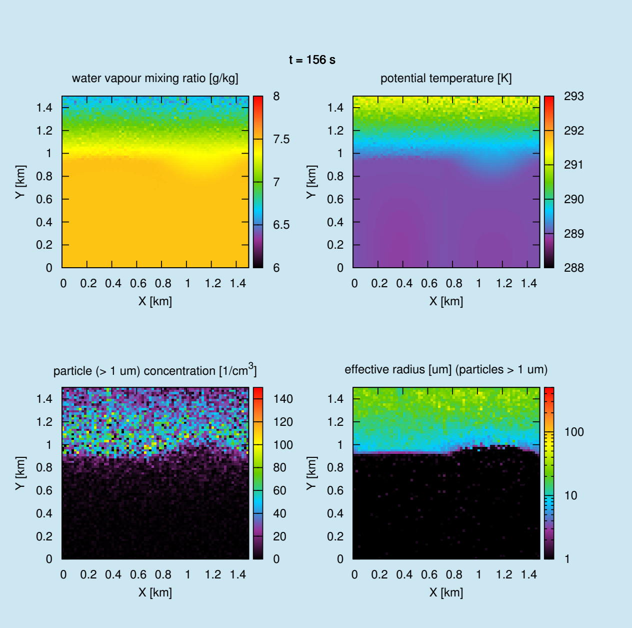

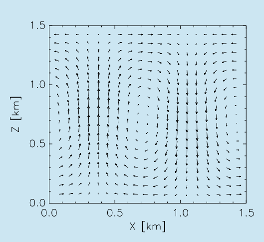

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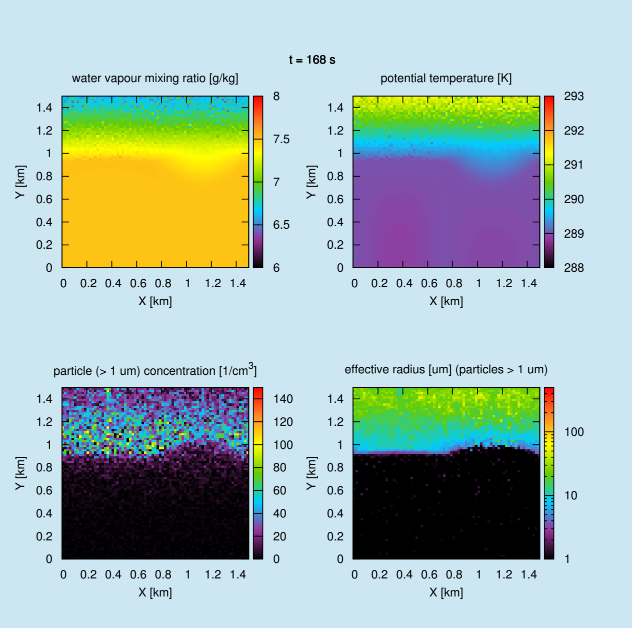

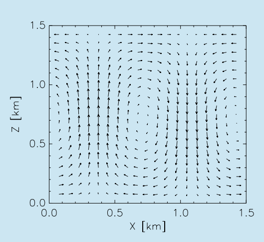

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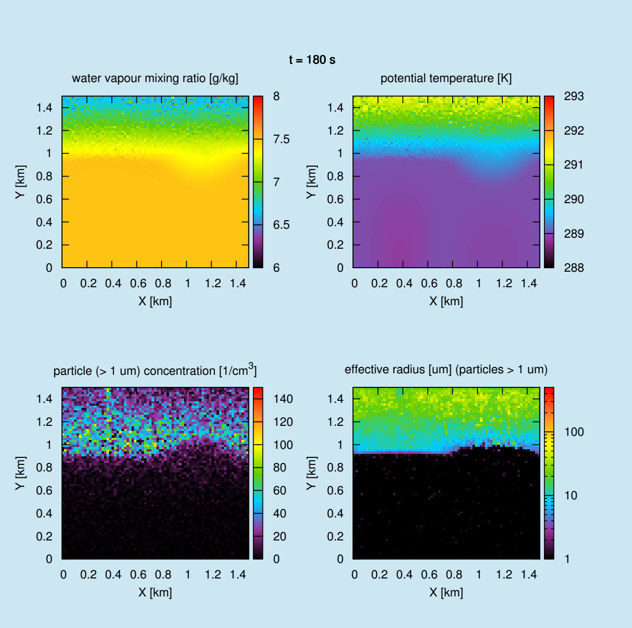

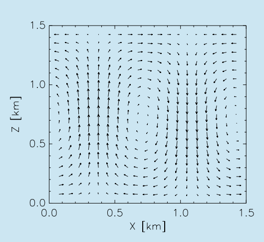

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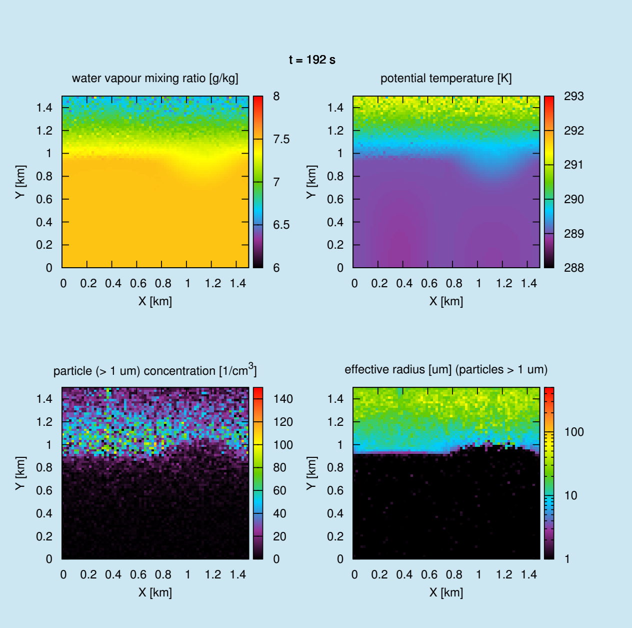

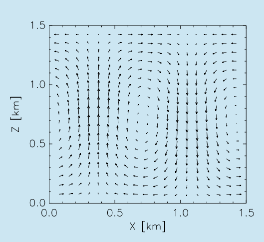

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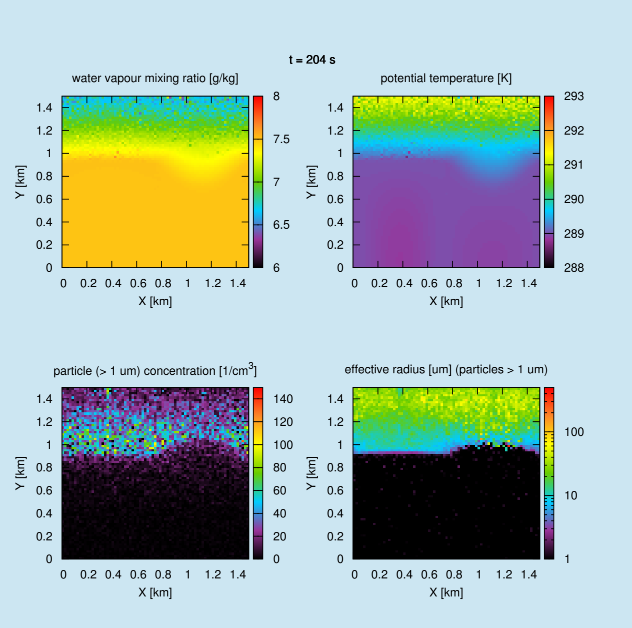

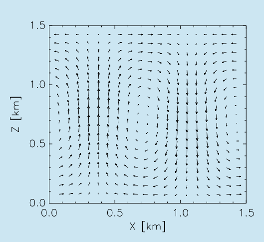

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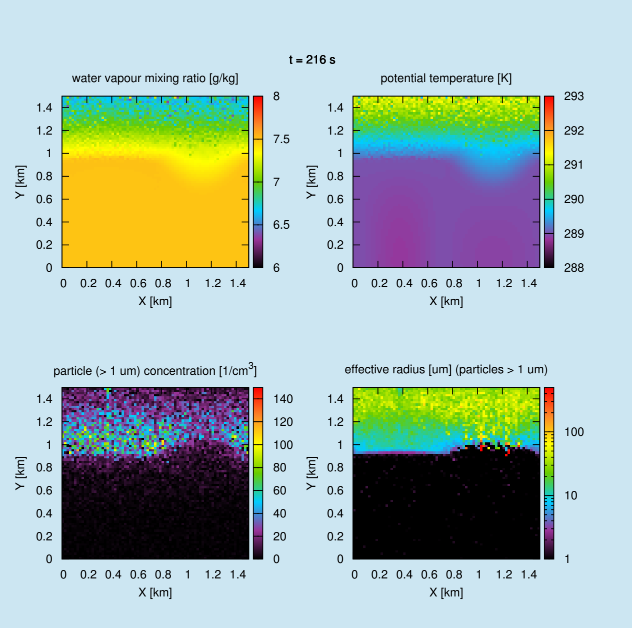

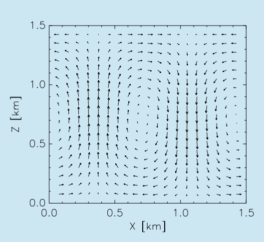

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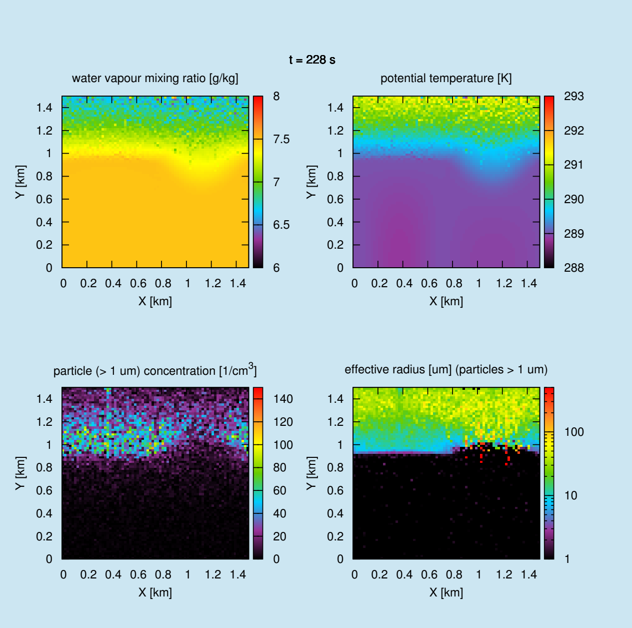

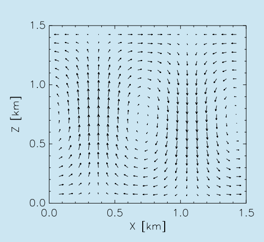

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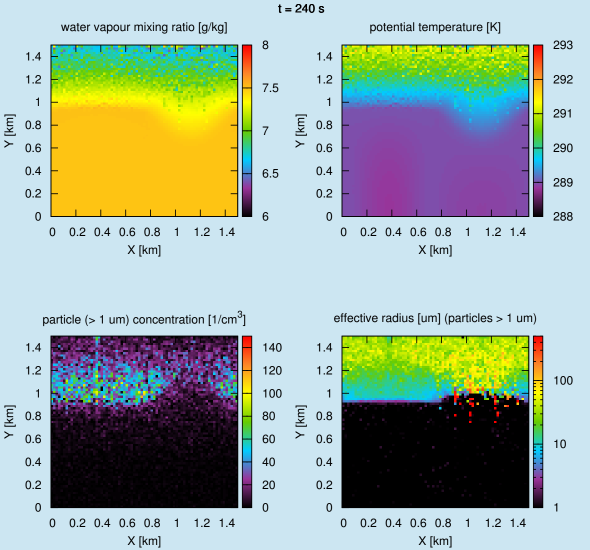

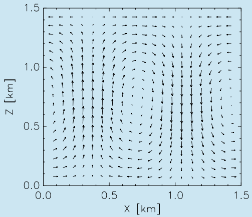

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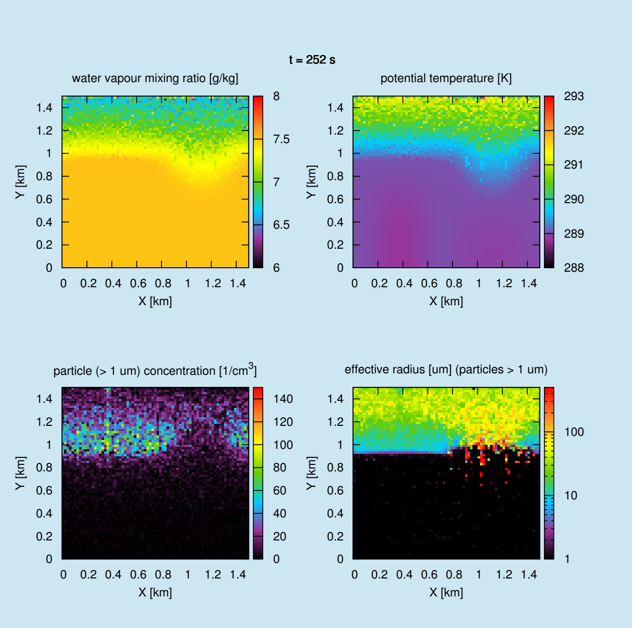

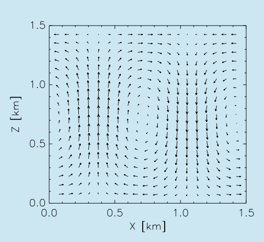

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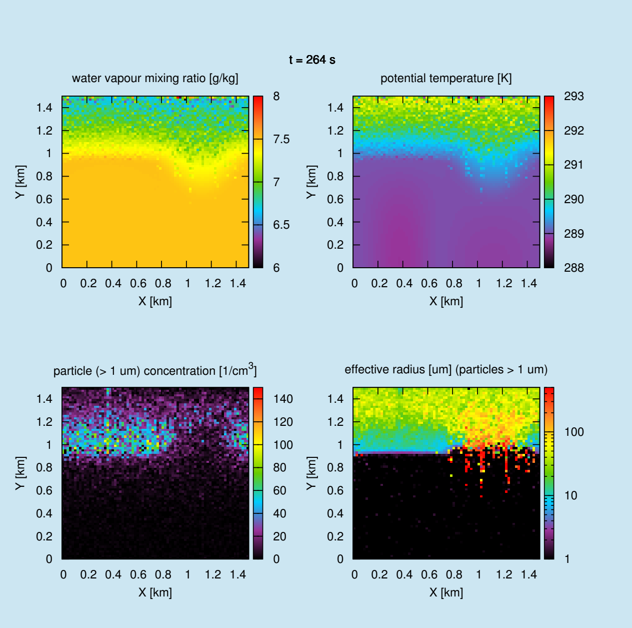

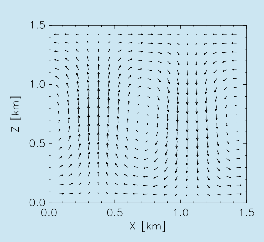

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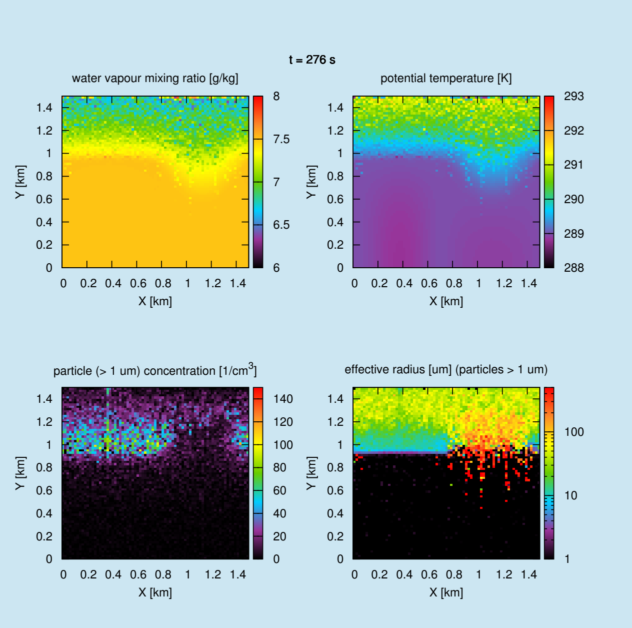

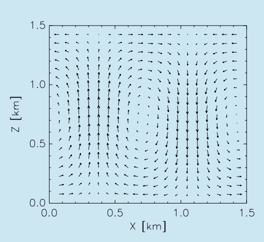

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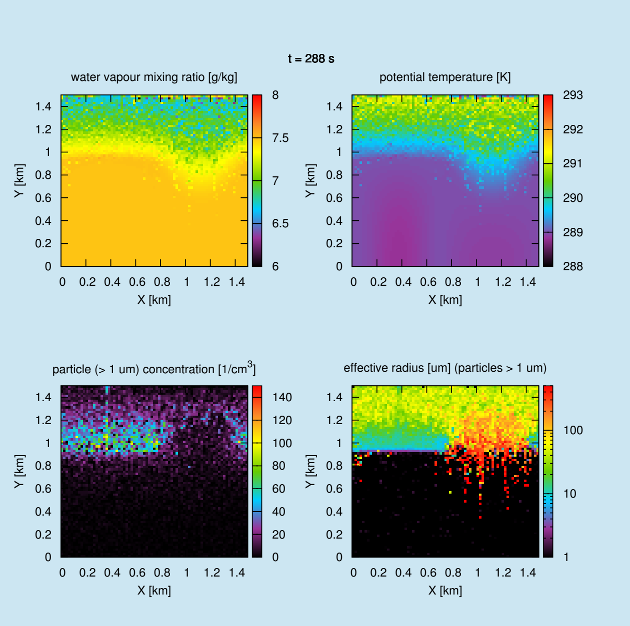

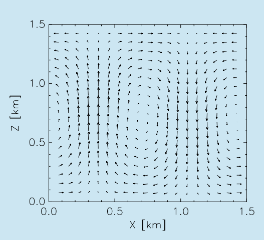

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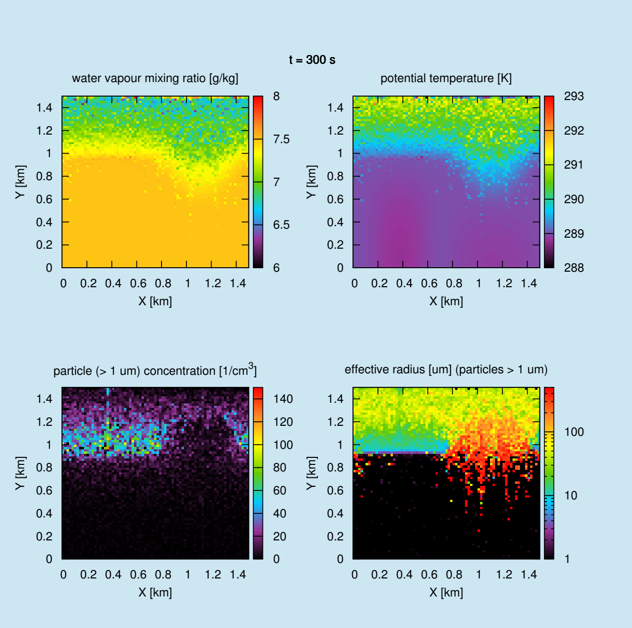

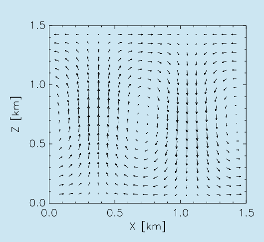

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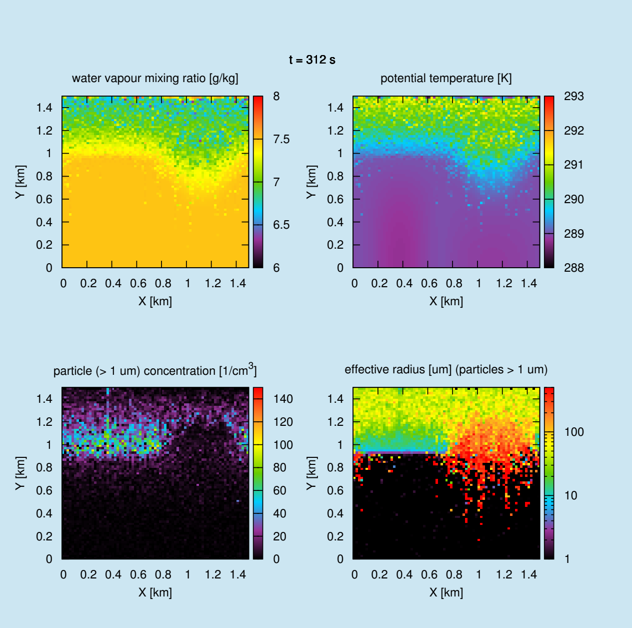

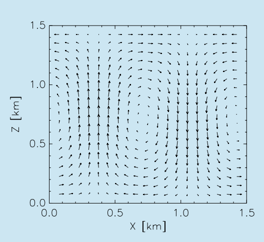

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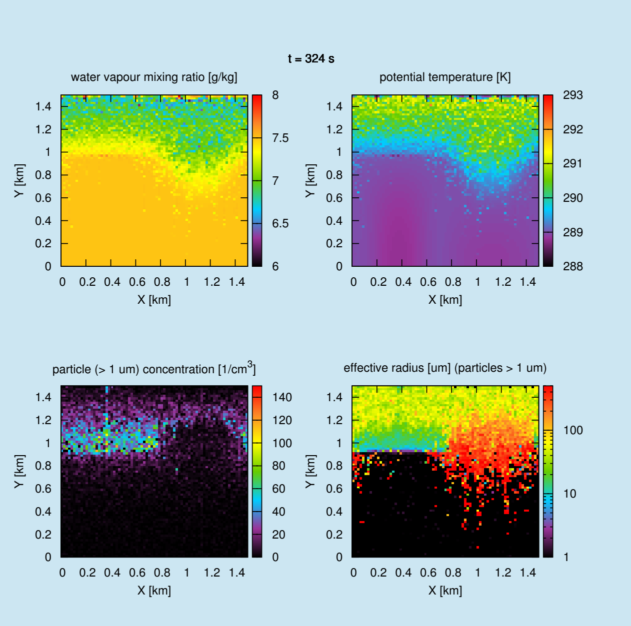

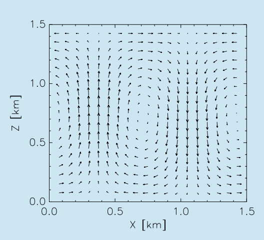

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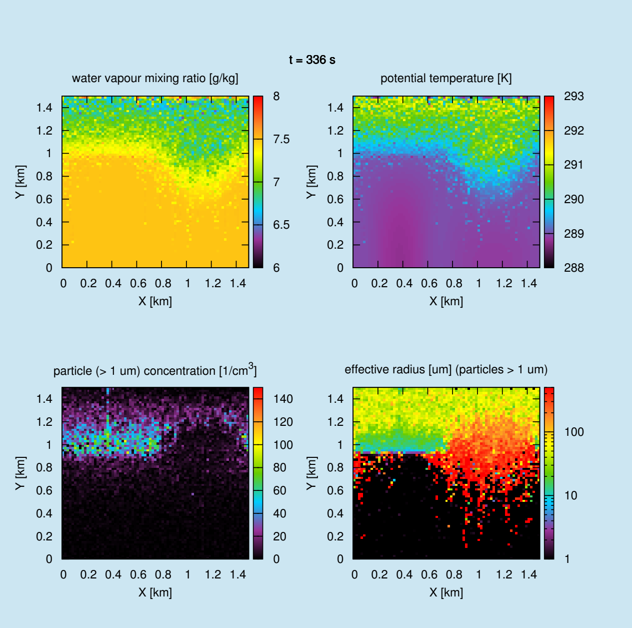
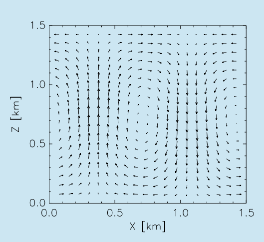
$E(r_i, r_j) = 10$
($\rightsquigarrow$ unphysical!)

proof-of-concept simulation with super-droplets using icicle



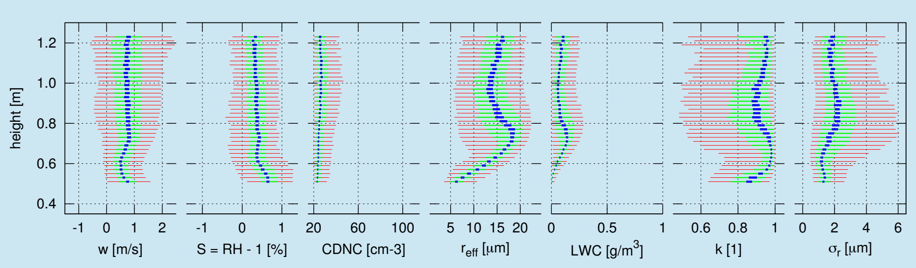


64 SD / grid cell
($\rightsquigarrow$ low res!)

$E(r_i, r_j) = 10$
($\rightsquigarrow$ unphysical!)

3D LES with super-droplets (Arabas & Shima 2012)

- 24h LES using the "RICO" set-up (van Zanten et al. 2011)
- Nagoya Univ. CReSS model (Tsuboki 2008)
- comparison with aircraft measurements (OAP-2DS, Fast-FSSP)



More:

- ICCP poster no. P.8.16
- arXiv:1205.3313

Thanks for your attention!

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Piotr Smolarkiewicz & Wojciech Grabowski (NCAR)

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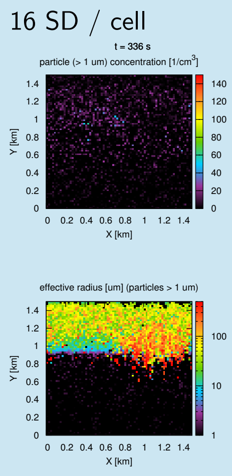
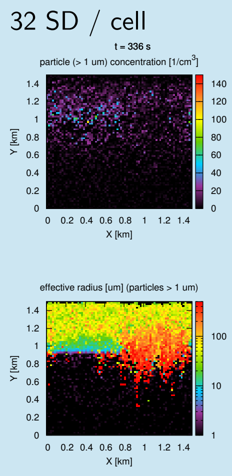
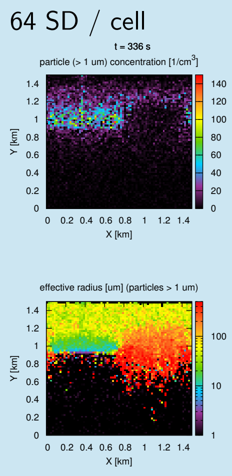
Thanks are due authors of open-source software used in icicle, incl.:
Blitz++, Thrust, Boost.units, gnuplot-iostream, . . .

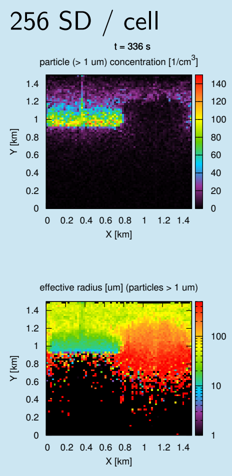
Super-Droplet concentration

- ⇝ number of ”bins” (exchanged among ”parcels”)
- ⇝ number of ”parcels” (each carrying a single ”bin”)



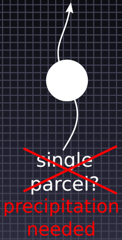






”multiple collisions” needed for low SD conc. (cf. Shima et al. 2009)
not implemented yet in icicle!

aerosol processing: minimal modelling framework


~~single parcel?~~

precipitation needed

- kinematic (prescribed-flow)
  $\rightsquigarrow$ perhaps still enough? (focus on μ-physics)
- decoupled from cloud dynamics
  $\rightsquigarrow$ computationally cheap

aerosol processing: minimal modelling framework

~~single parcel?~~

precipitation needed

~~single column?~~

up- & downdraft needed

- kinematic (prescribed-flow)
  ⇝ perhaps still enough? (focus on μ-physics)
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aerosol processing: minimal modelling framework

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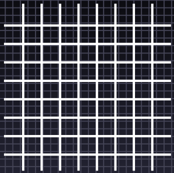
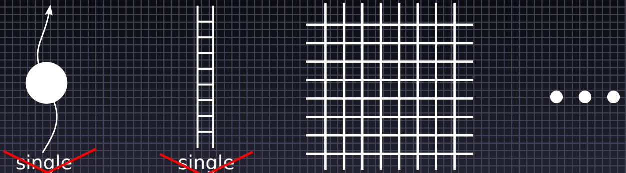


2D

enough?

- kinematic (prescribed-flow) $\rightsquigarrow$ perhaps still enough? (focus on μ-physics)
- decoupled from cloud dynamics $\rightsquigarrow$ computationally cheap

aerosol processing: minimal modelling framework



~~single parcel?~~
precipitation needed

~~single column?~~
up- & downdraft needed

2D
enough?

other...

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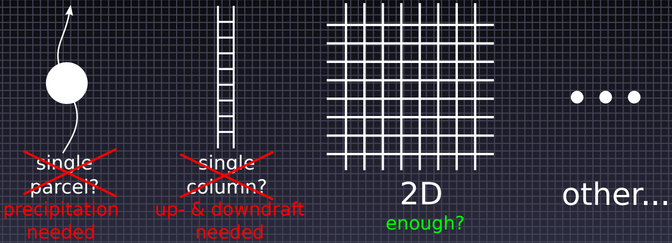
aerosol processing: minimal modelling framework



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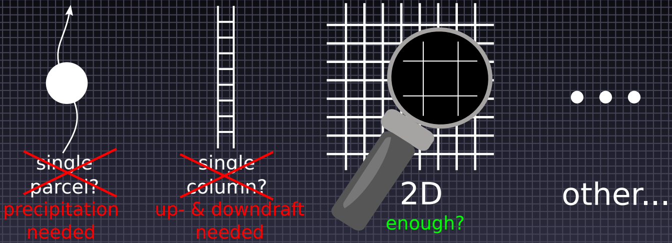

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