Applying super-droplets as a compact representation of warm-rain microphysics for aerosol-cloud-aerosol interactions

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Clouds may influence aerosol characteristics of their environment. The relevant processes include wet deposition (rainout or washout) and cloud condensation nuclei (CCN) recycling through evaporation of cloud droplets and drizzle drops. Recycled CCN physicochemical properties may be altered if the evaporated droplets go through collisional growth or irreversible chemical reactions.

The key challenge of representing these processes in a numerical cloud model stems from the need to track properties of activated CCN throughout the cloud lifecycle. Lack of such "memory"characterises the so-called bulk, multi-moment as well as bin representations of cloud microphysics.

In this study we apply the particle-based scheme of Shima et al. 2009. Each modelled particle (aka super-droplet) is a numerical proxy for a multiplicity of real-world CCN, cloud, drizzle or rain particles of the same size, nucleus type, and position. Tracking cloud nucleus properties is an inherent feature of the particle-based frameworks, making them suitable for studying aerosol-cloud-aerosol interactions. The super-droplet scheme is furthermore characterized by linear scalability in the number of computational particles, and no numerical diffusion in the condensational and in the Monte-Carlo type collisional growth schemes.

Presented simulations are aimed at studying processing of aerosol by a drizzling stratocumulus deck. The simulations are carried out using a 2D kinematic framework and a VOCALS experiment-inspired set-up (see http://www.rap.ucar.edu/~gthompsn/workshop2012/).

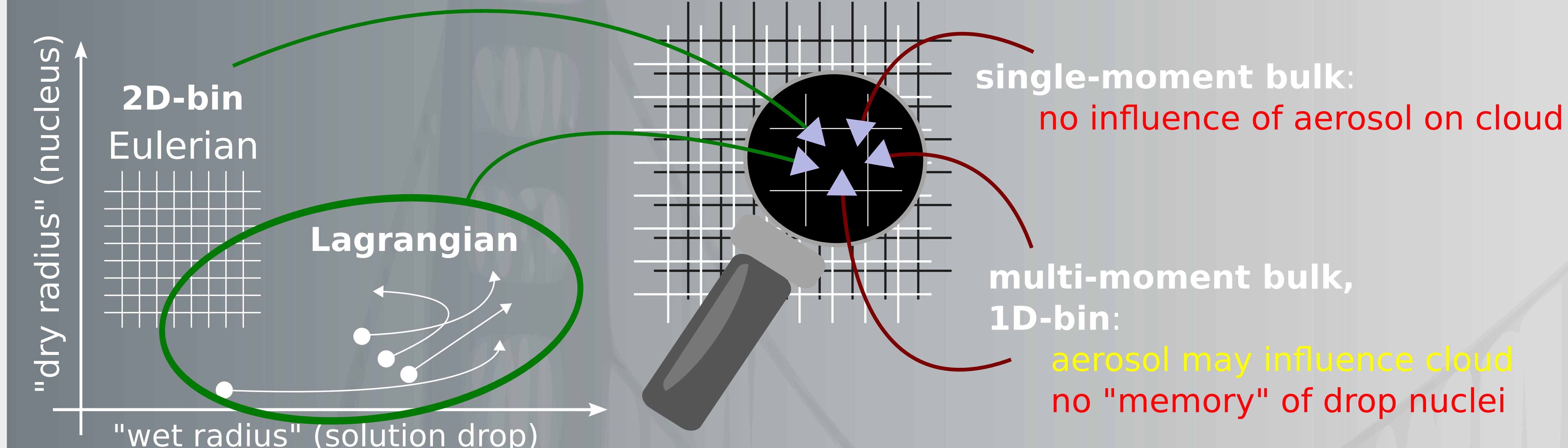
Simulation set-up (VOCALS inspired)

- based on "case 1" drizzling-Sc set-up from the 8-th Intl Cloud Modelling Workshop (Grabowski, Lebo et al. in preparation)
- 2D prescribed-flow flow field (single eddy)
- bi-modal initial dry aerosol spectrum (based on VOCALS campaign observations)
- constant-with-height initial water vapour and potential temperature profiles (supersaturation in the upper 1/3 of the domain)

Model implementation:

- MPDATA Eulerian advection solver (e.g. Smolarkiewicz 2006)
- Lagrangian particle tracking framework (parallelisation using Nvidia's Thrust library)
- open-source, implemented in C++, code repository at: http://icicle.igf.fuw.edu.pl/

The super-droplet microphysics (Shima et al. 2009)

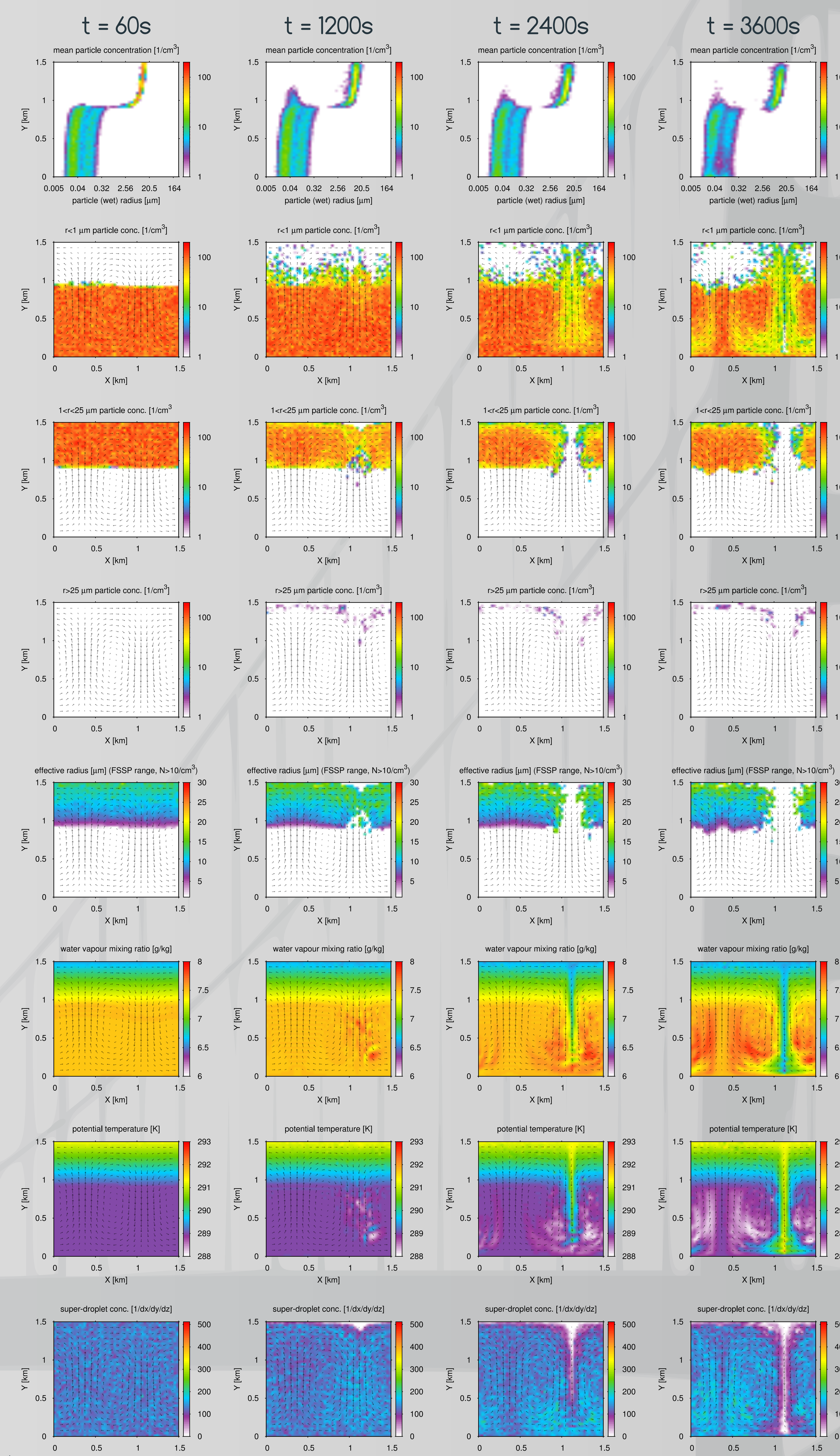


Lagrangian (in particle size) approach:

- diffusive error-free particle growth schemes both for condensational and collisional growth (aka "moving sectional", "method of lines")
- O(n) scaling with number of particle attributes
- extendable to Lagrangian-in-space → particle-based simulation

The super-droplet method:

- each super-droplet represents a multiplicity of solution droplets (aerosol, cloud or precipitation particles) of same size and composition
- particle attributes: multiplicity, dry and wet radii, nucleus type and size
- all particles are subject to: transport by the flow, sedimentation, condensational growth/evaporation, collisional growth (Monte-Carlo)
- coupling with Eulerian moisture and heat advection framework via rhs terms evaluated by summing over particles within a grid cell



Example simulation with geometric collisions:

- all aerosol activated at t=0 (unrealistic initial condition)
- newly formed cloudy air contains interstitial (unactivated) aerosol
- drizzle forming through coalescence in the upper part of the cloud does not reach bottom of the domain
- evaporation of cloud and drizzle drops on the downdraft edges (higher vapour mixing ratios, lower potential temperature)
- advection of drier air from above the cloud by the downdraft
- formation of a "cloud hole" with lowered aerosol concentration in the downdraft (aerosol formed by evaporation of collisionally-grown drops, particle-free air advected from above the cloud field)

Work in progress! Plans:

- more realistic collision kernel[s]
- simulations with different aerosol loading and composition
- inclusion of aqueous-phase irreversible chemical reactions

References:
- Shima et al. 2009: Q. J. R. Meteorol. Soc. 135
- Smolarkiewicz 2006: Int. J. Numer. Meth. Fluids 50

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