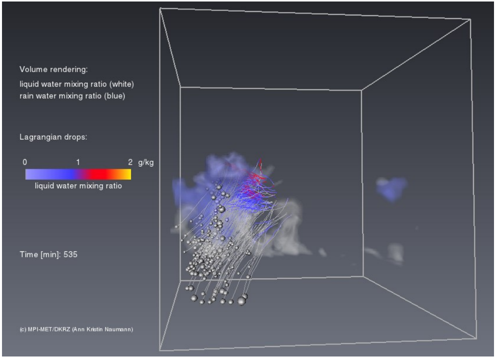
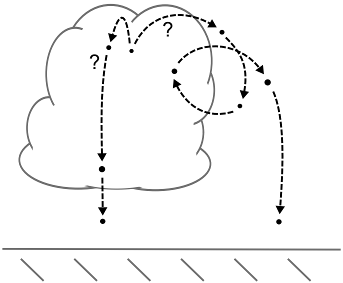
A Lagrangian drop model to study warm rain microphysics

Ann Kristin Naumann and Axel Seifert



Introduction

- Lagrangian drop (LD) model:
  - for the raindrop phase
  - one-way coupled (similar to piggybacking method, Grabowski 2014)
- possible applications:
  - comparison to bulk microphysics, e.g., evaluation of closure equations
  - growth histories and recirculation of raindrops
  - role of “lucky raindrops” (Magaritz et al. 2009) and the subsiding shell (Heus and Jonker 2008)



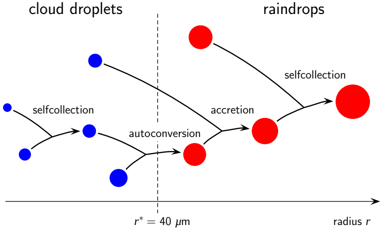
LDs in LES: Model description

- cloud and rain bulk microphysics from Seifert and Beheng (2001)
- initialisation proportional to bulk autoconversion rate
- one LD represents a multiplicity of real raindrops of the same size (here: $\xi = 5 \cdot 10^8$)
- growth and shrinking:
  - accretion
  - selfcollection
  - evaporation
  - no drop breakup
- momentum equation:

$$\frac{d\vec{v}_d}{dt} = \frac{1}{\tau_d}(\vec{v}_a - \vec{v}_d) - (1 - \frac{\rho_a}{\rho_w})g\vec{e}_3$$

$$\vec{v}_a = \vec{v}_{\text{res}} + \vec{v}_{\text{sgs}}$$

  - sgs model from Weil et al. 2004



(courtesy of Axel)

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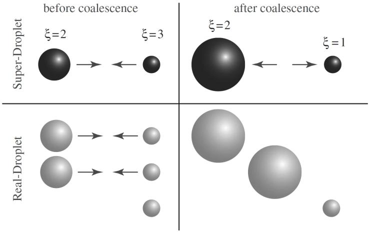
selfcollection:

1) how:



(Shima et al. 2009)

2) P_{jk} for each LD pair in a column:

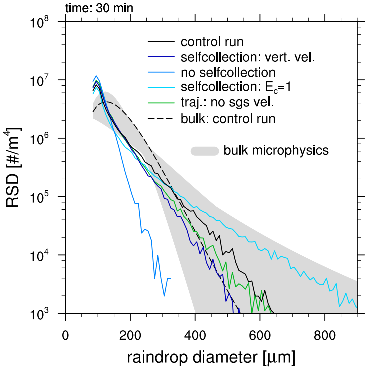
if $0 < \frac{z_j - z_k}{w_{d,k} - w_{d,j}} \leq \Delta t$,

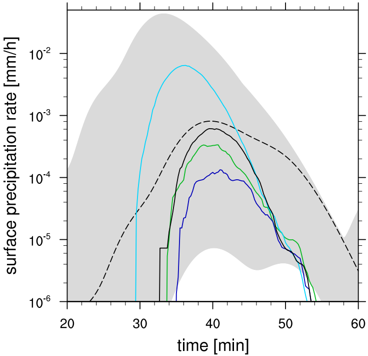
$$P_{jk} = \frac{max(\xi_j, \xi_k)}{\Delta x \Delta y} E_c \pi (r_j + r_k)^2 \frac{|\Delta \vec{v}_d|}{|\Delta w_d|}$$

LDs in a shallow cumulus cloud

- RICO: $(3.2\ \text{km})^2$ domain, $\Delta x = 25$ m, overall 150000 LDs
- movie: only those LDs that contribute to surface precipitation

Uncertanties in Lagrangian methods

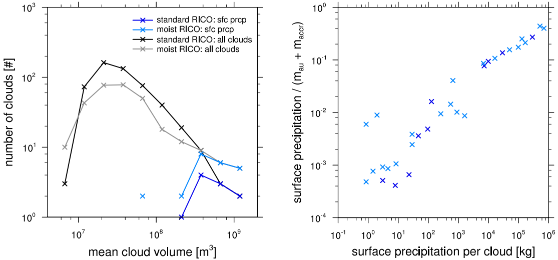




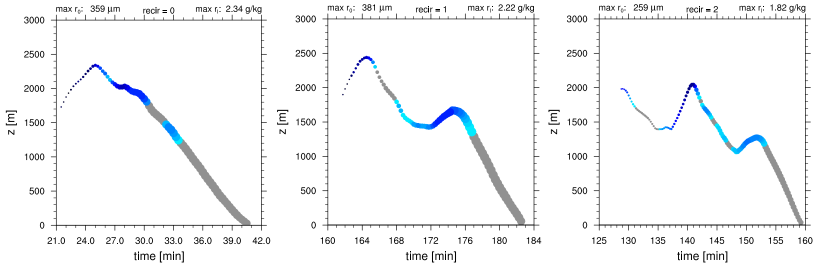
- horizontal velocity contribution
  - selfcollection for LD pairs in the same grid box column
  - $P_{jk} = \frac{max(\xi_j,\xi_k)}{\Delta x \Delta y} E_c \pi (r_j + r_k)^2 \frac{|\Delta \vec{v}_d|}{|\Delta w_d|}$
- velocity correlations of drops in close vicinity
  - $\vec{v}_a = \vec{v}_{res} + \vec{v}_{sgs}$
  - $\vec{v}_{sgs}$ from Weil et al. (2004) without drop correlations

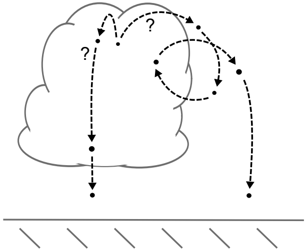
LDs in a field of shallow cumulus clouds

- Two RICO cases: standard and moist
  (van Zanten et al. 2011, and Stevens and Seifert 2008)
- each $(12.8\text{ km})^2$ domain, $\Delta x = 25$ m, $t = 4$ h
- 4 Mio LDs and 10 Mio LDs
- cloud tracking (Heus and Seifert, 2013)



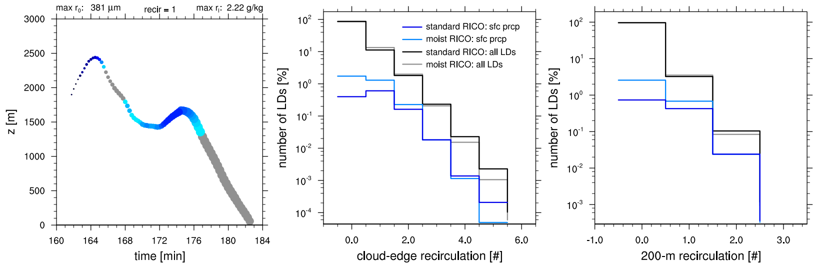
Recirculation: definitions

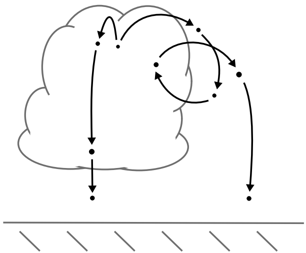




- **cloud-edge recirculation**: consecutive events in a LD's lifecycle of being outside the cloud, having a height maximum within the cloud and being outside the cloud again
- **200-m recirculation**: consecutive periods of descent and ascent of at least 200 m

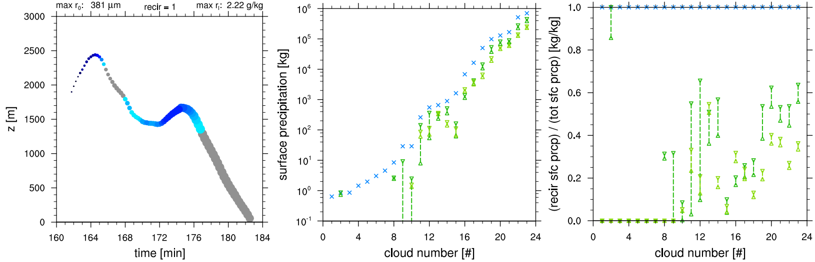
Recirculation: statistics

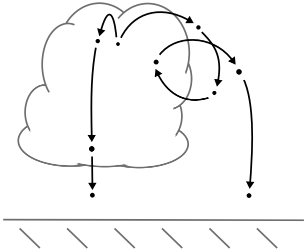




- recirculation of raindrops is common in shallow cumulus, especially for those raindrops that eventually contribute to surface precipitation

Recirculation: surface precipitation

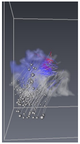




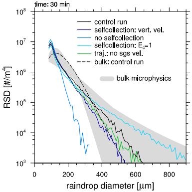
- contribution of recirculating raindrops to surface precipitation increases with increasing surface precipitation per cloud

Conclusions

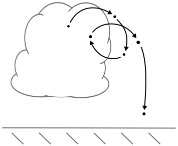
- We introduced a **Lagrangian drop** (LD) method to represent warm rain microphysics on a particle-based level.



- **Subgrid velocity** and **drop correlation** are an uncertainty in Lagrangian methods.
- Uncertainties in the Lagrangian model are much **smaller than in bulk microphysics**.



- **Recirculation of raindrops is common** in shallow cumulus, especially for those raindrops that contribute to surface precipitation.

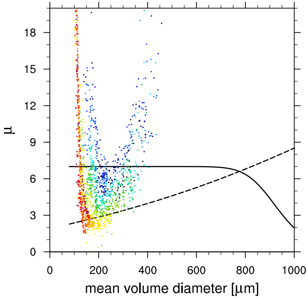


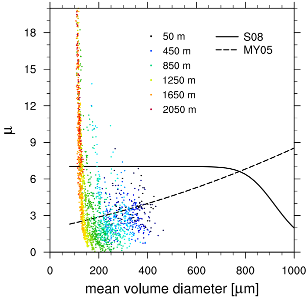
Appendix

Closure equation: μ-D relation

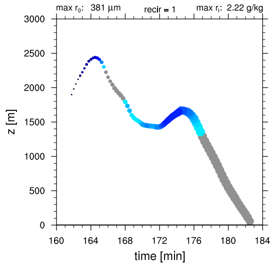
gamma distribution:
$n(D) = N_0 D^{\mu} e^{-\lambda D}$

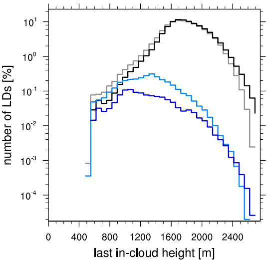
- μ-D relation differs among individual clouds
- existing closure equations not approriate for shallow cumulus

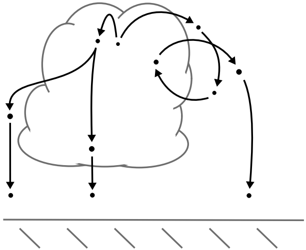




Last in-cloud height

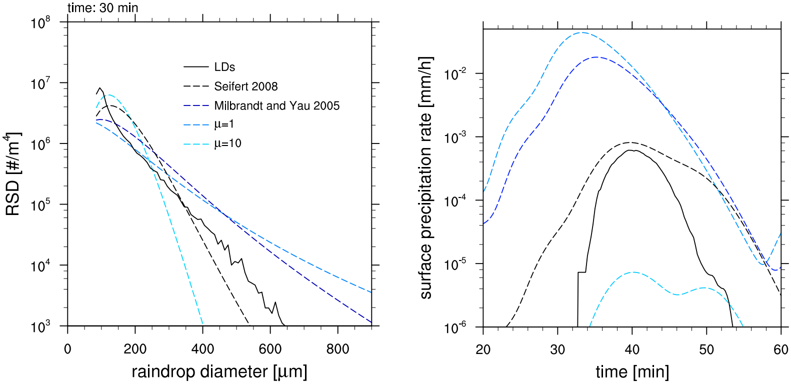






- raindrops mostly leave the cloud laterally, not through cloud base

Bulk microphysics: sensitivity to μ-D relation



- large sensitivity to μ-D assumption for an individual shallow cumulus cloud