# Study of droplet-size distribution in turbulent clouds using stochastic microphysics at unresolved scales

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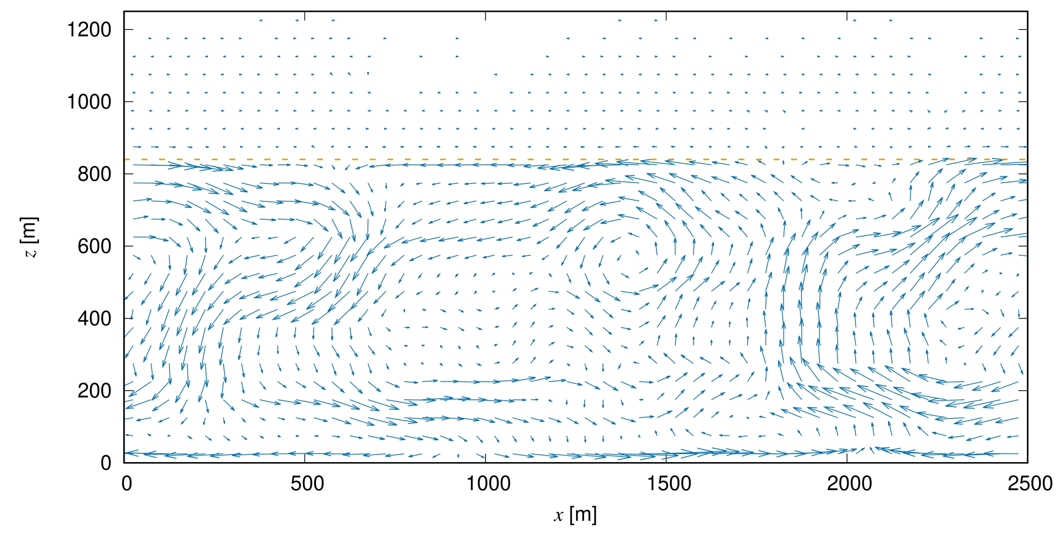
## Introduction

We study the droplet-size distribution under the influence of turbulence fluctuations at subgrid scales (SGS). Cloud droplets and unactivated cloud condensation nuclei (CCN) are described by Lagrangian particles (superdroplets). Processes occurring in the range of unresolved scales are modeled using a Monte Carlo scheme. Collisions and coalescence of droplets are not considered.

## Forcing the microphysics

- Turbulent-like synthetic flow

$$\mathbf{U}(\mathbf{r},t) = \sum_{\mathbf{k}_n} \text{random Fourier modes}$$




- Statistical structure

$$\langle W\rangle = 0 \qquad \langle W^2\rangle = \sigma_w^2(z)$$

$$\langle W(x',z)W(x'+x,z)\rangle = \hat{C}_w(x)\,\sigma_w^2(z) \qquad \ell = \int_0^\infty \hat{C}_w(x)\mathrm{d}x \approx 200\ \text{m}$$

Pinsky *et al.*, JAS, **65** (2008)

## Stochastic activation

Growth equation:

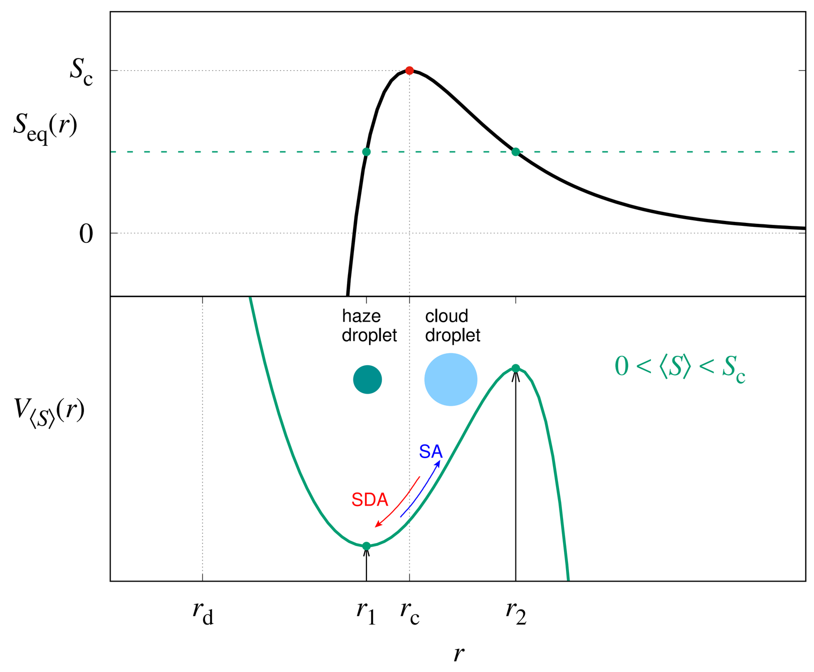
$$r\frac{\mathrm{d}r}{\mathrm{d}t} = D\left[\langle S\rangle + S' - \frac{A}{r} + \frac{B}{r^3}\right]$$

Define:

$$x \equiv r^2$$

"Brownian motion" for $x$:

$$\frac{\mathrm{d}x}{\mathrm{d}t} = -\frac{\partial V}{\partial x} + 2DS'$$

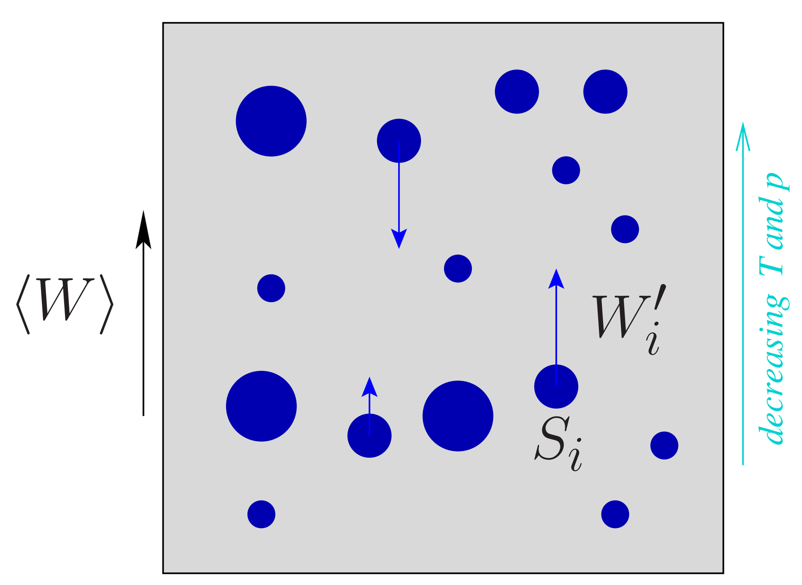



Köhler potential, stochastic activation (SA), and stochastic de-activation (SDA).

Abade, Grabowski and Pawlowska, JAS, **75** (2018)

## Lagrangian supersaturation fluctuations

$$S = \langle S\rangle + S' \qquad W = \langle W\rangle + W'$$



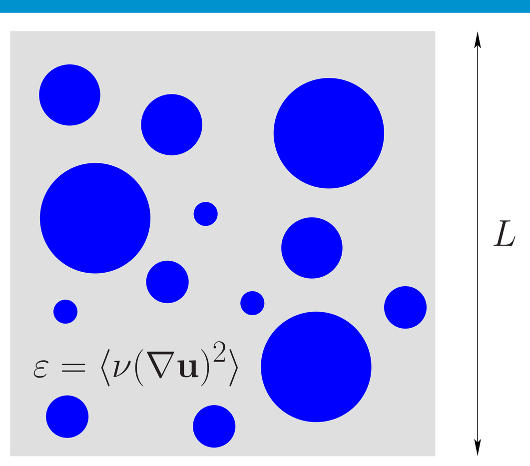

$$\frac{\mathrm{d}S_i'}{\mathrm{d}t} = -\frac{S_i'}{\tau_c} - \frac{S_i'}{\tau_m} + aW_i'(t)$$

$\tau_c \sim \dfrac{1}{DN\langle r\rangle}$ (condensation)

$\tau_m \sim$ eddy turnover time (mixing)

Celani *et al.*, EPL, **70** (2005); Grabowski and Abade, JAS, **74** (2017)

## Vertical velocity fluctuations




$$\langle W'(t)\rangle = 0$$

$$\langle W'(0)W'(t)\rangle = \sigma_{W'}^2 \exp\left(-|t|/\tau_m\right)$$

$$\sigma_{W'}^2 \sim (L\varepsilon)^{2/3} \qquad \tau_m \sim \frac{L^{2/3}}{\varepsilon^{1/3}}$$

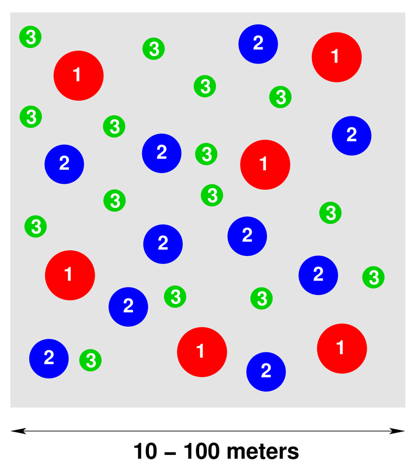
## Droplets positions

$$\boldsymbol{X}_i(t+\delta t) = \boldsymbol{X}_i(t) + \delta\boldsymbol{X}_i(\delta t)$$

$$\delta\boldsymbol{X}_i = \delta\boldsymbol{X}_i^{(\text{mean})} + \delta\boldsymbol{X}_i^{(\text{sgs})}$$

## Superdroplets (SDs)

$N_{\text{droplets}} \sim 10^{11} - 10^{14}$




Shima *et al.*, QJRMS, **135** (2009)

- Multiplicities

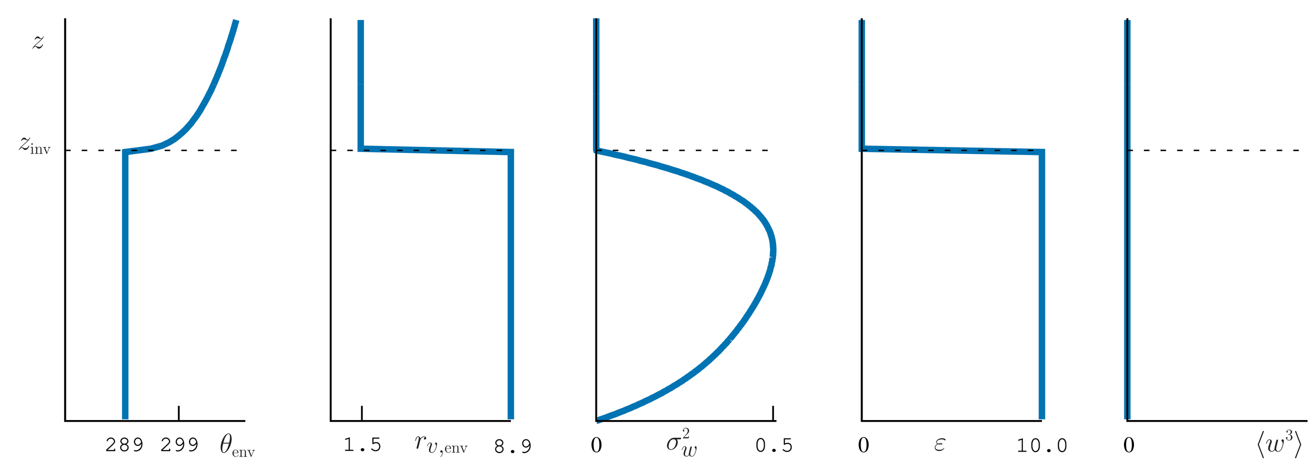
$$\xi_1 = 6,\quad \xi_2 = 10, \ldots$$

- SDs have the same attributes

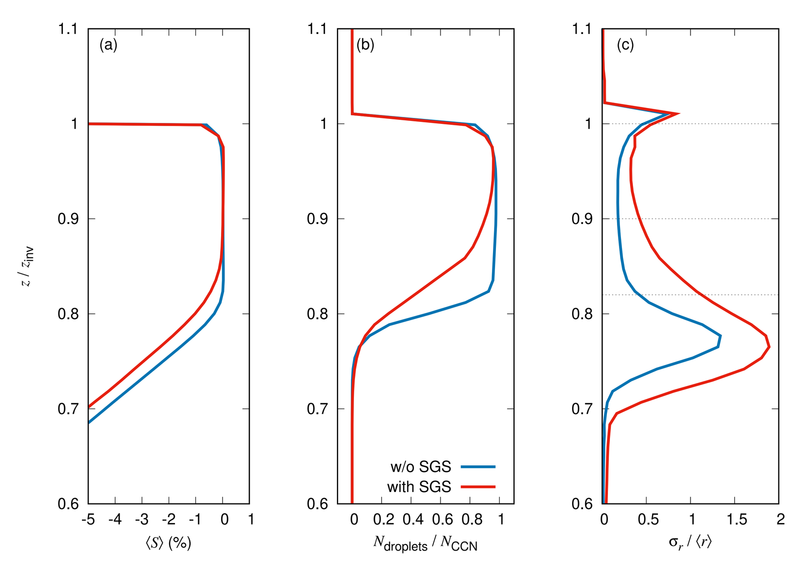
$$(r, \ldots, S', W', \ldots)$$

- Well-mixed

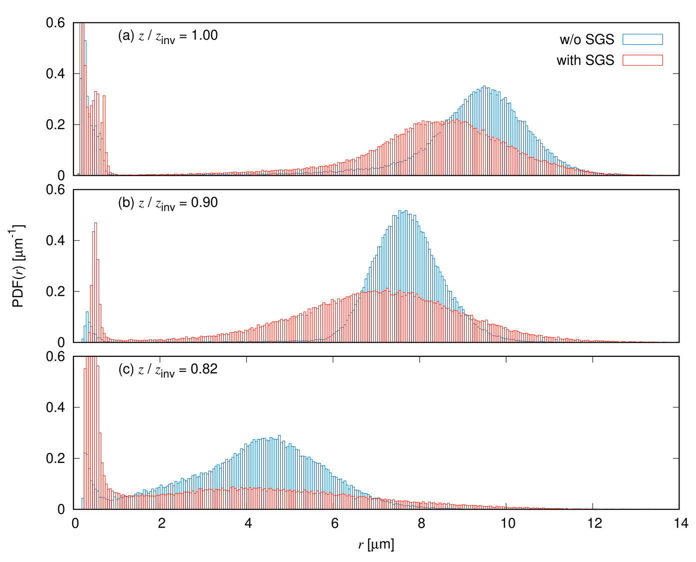
## Setup




## PRISTINE conditions ($N_{\text{CCN}} = 100\ \text{cm}^{-3}$)

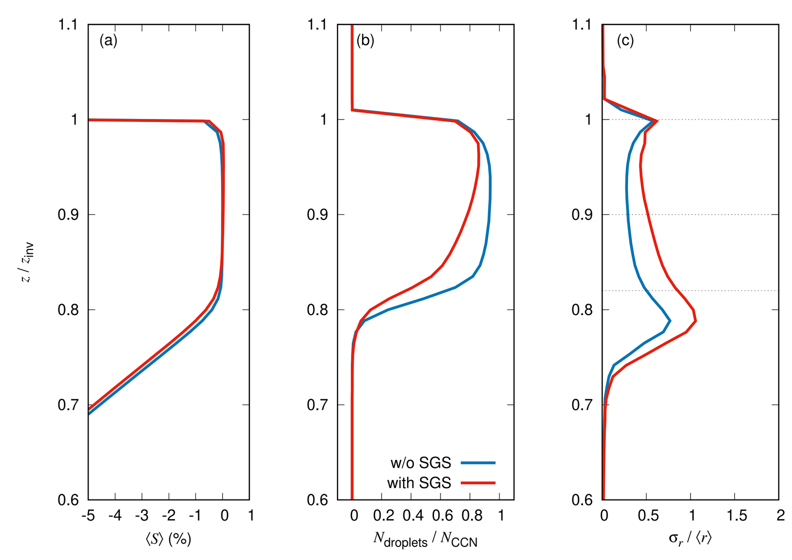



Microphysical profiles

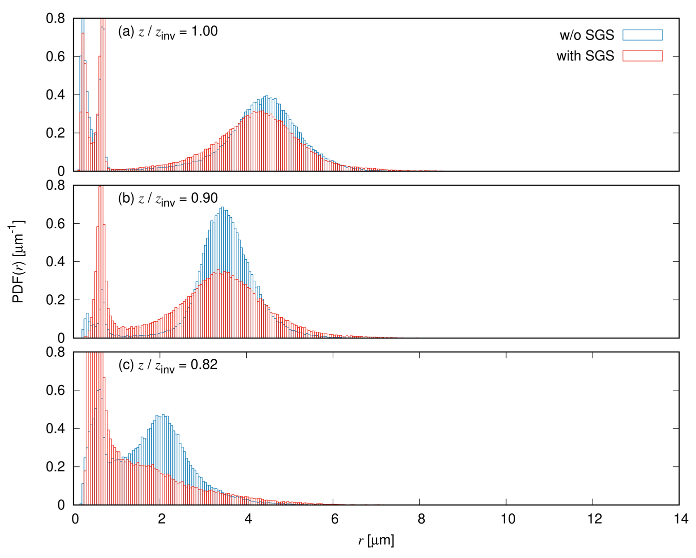



Probability density function (PDF)

## POLLUTED conditions ($N_{\text{CCN}} = 1000\ \text{cm}^{-3}$)




Microphysical profiles




Probability density function (PDF)

## Remarks

- SGS turbulence plays a key role in broadening the droplet-size distributions
- Feedback on vapor due to stochastic activation extends the distance over which entrained CCN are activated inside the cloudy layer
- Multimodal droplet-size distributions with two populations: interstitial aerosols and cloud droplets.

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