Simulation of boundary layer clouds with double-moment microphysics and microphysics-oriented subgrid-scale modeling

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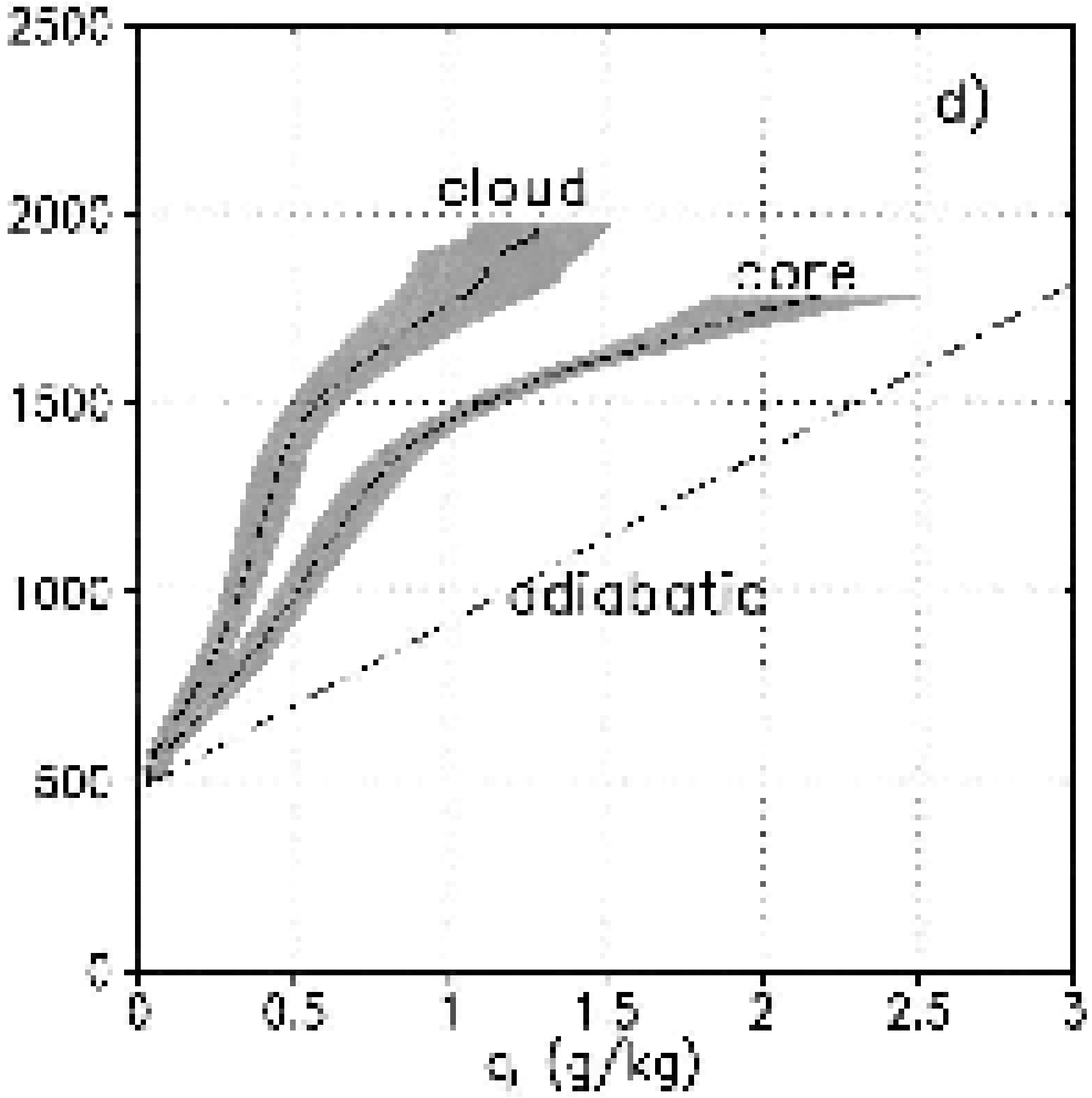
Motivation

Shallow convective clouds are strongly diluted by entrainment

http://greenearthfacts.com/weather/how-much-does-a-cloud-weigh/



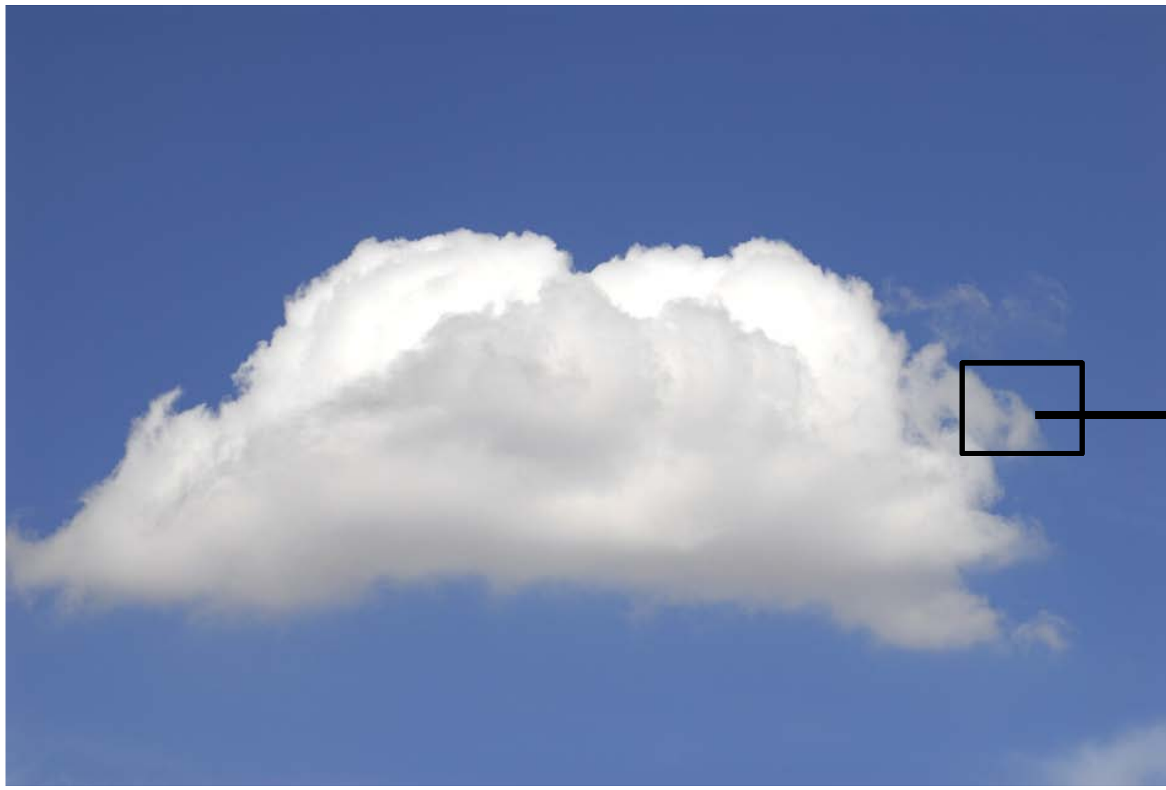
Siebesma et al. JAS 2003

QuickTime™ and a
H.264 decompressor
are needed to see this picture.

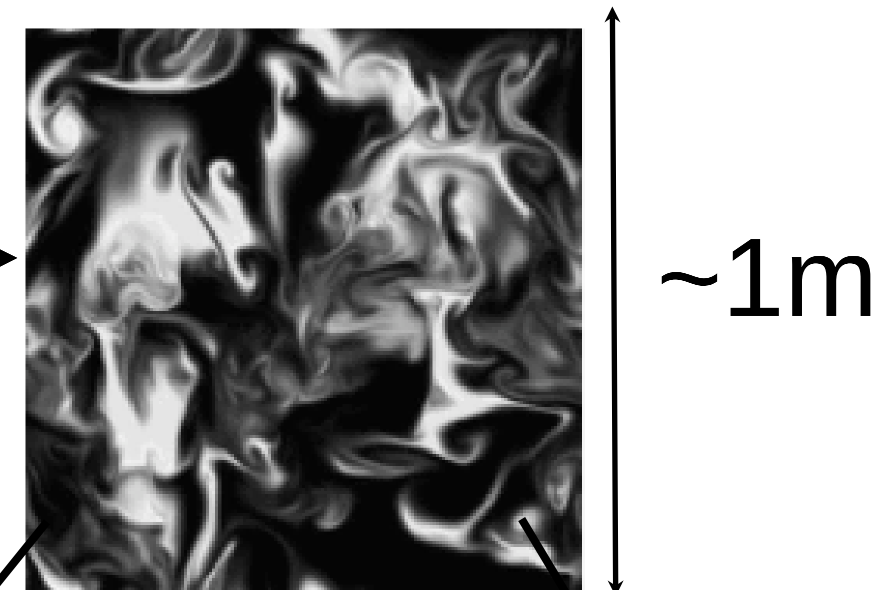
from Steve Krueger

Turbulent mixing in clouds

Andrejczuk et al. (2006)

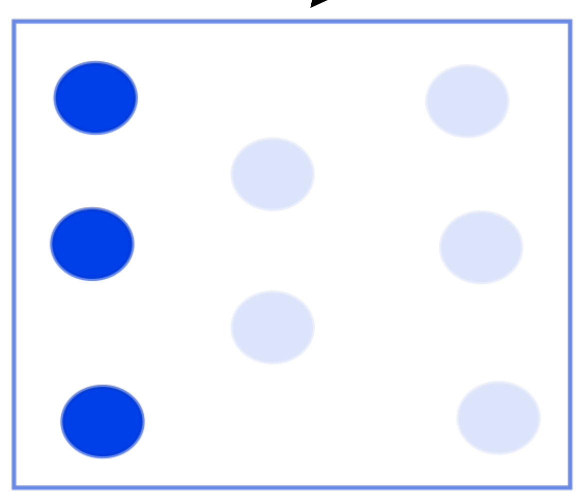


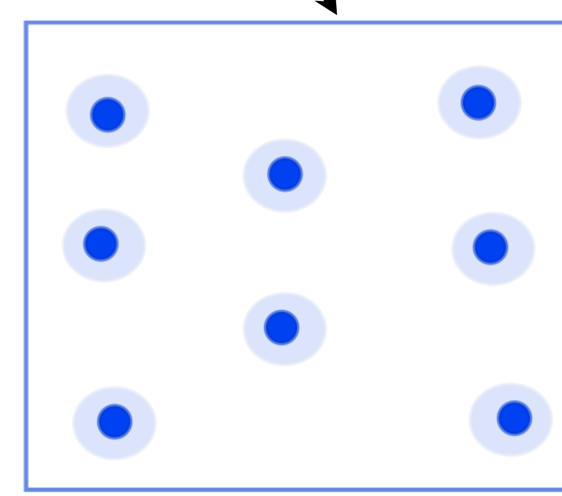
http://gccweb.gccaz.edu/earthsci/imagearchive/cumulus_pictures.htm



extremely inhomogeneous mixing

homogeneous mixing





Microphysical transformations due to subgrid-scale mixing cover a wide range of mixing scenarios.

1-moment bulk microphysics

q_l - liquid water mixing ratio, the only information about the cloud water

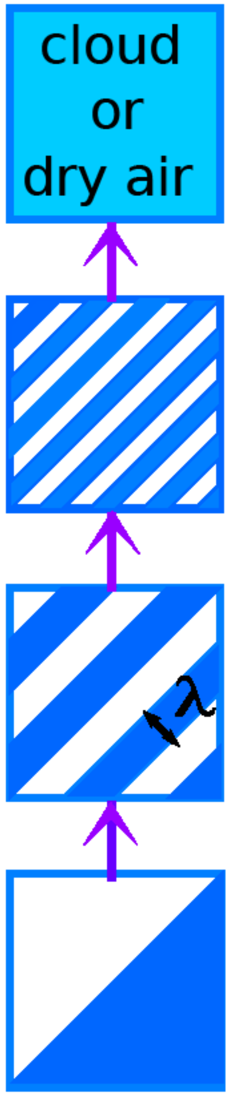
Cloud water can exist only in the saturated conditions.

In the bulk model, a rate of condensation, C, is calculated assuming the saturation adjustment – C^{sa}

Poor representation of the evaporation due to turbulent mixing!

1-moment bulk microphysics with the λ-parameterization

λ - spatial scale of the cloudy filament during turbulent mixing



$$\frac{d\lambda}{dt} = -\gamma \epsilon^{\frac{1}{3}} \lambda^{\frac{1}{3}}$$

Λ - the model gridlength;
λ_0 - the homogenization scale (~ 1 cm).

$$\lambda_0 \leq \lambda \leq \Lambda$$

γ ~ 1
ε – the dissipation rate of TKE

Broadwell and Breidenthal (1982);
Grabowski (2006)

Evaporation in model with 1-moment microphysics

Saturation adjustment is delayed until the gridbox can be assumed homogenized:

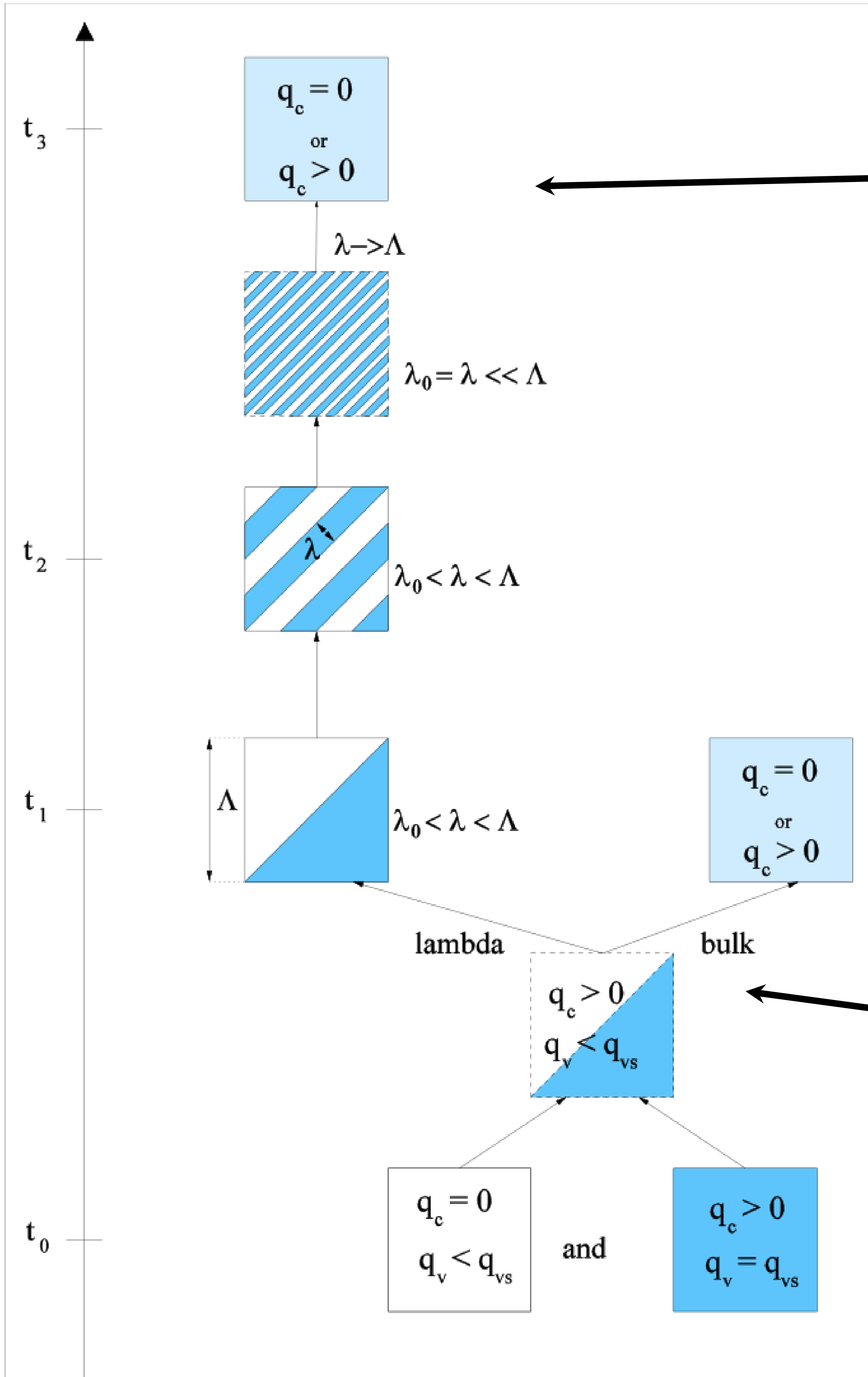
$\lambda = \Lambda$ or $\lambda \le \lambda_0$ $\quad C = C^{sa}$ (saturation adjustment)

$\lambda_0 \le \lambda \le \Lambda$ $\quad C = \beta\, C^{a}$ (adiabatic C)

β – fraction of the gridbox covered by cloudy air

$$C^a = -\frac{dq_{vs}}{dt}$$ – adiabatic condensation rate

Delay in evaporation in model with 1-moment microphysics



Modified model with λ approach:
homogenization delayed until turbulent stirring reduces the filament width λ to the value corresponding to the microscale homogenization scale λ_0

Bulk model:
immediate homogenization

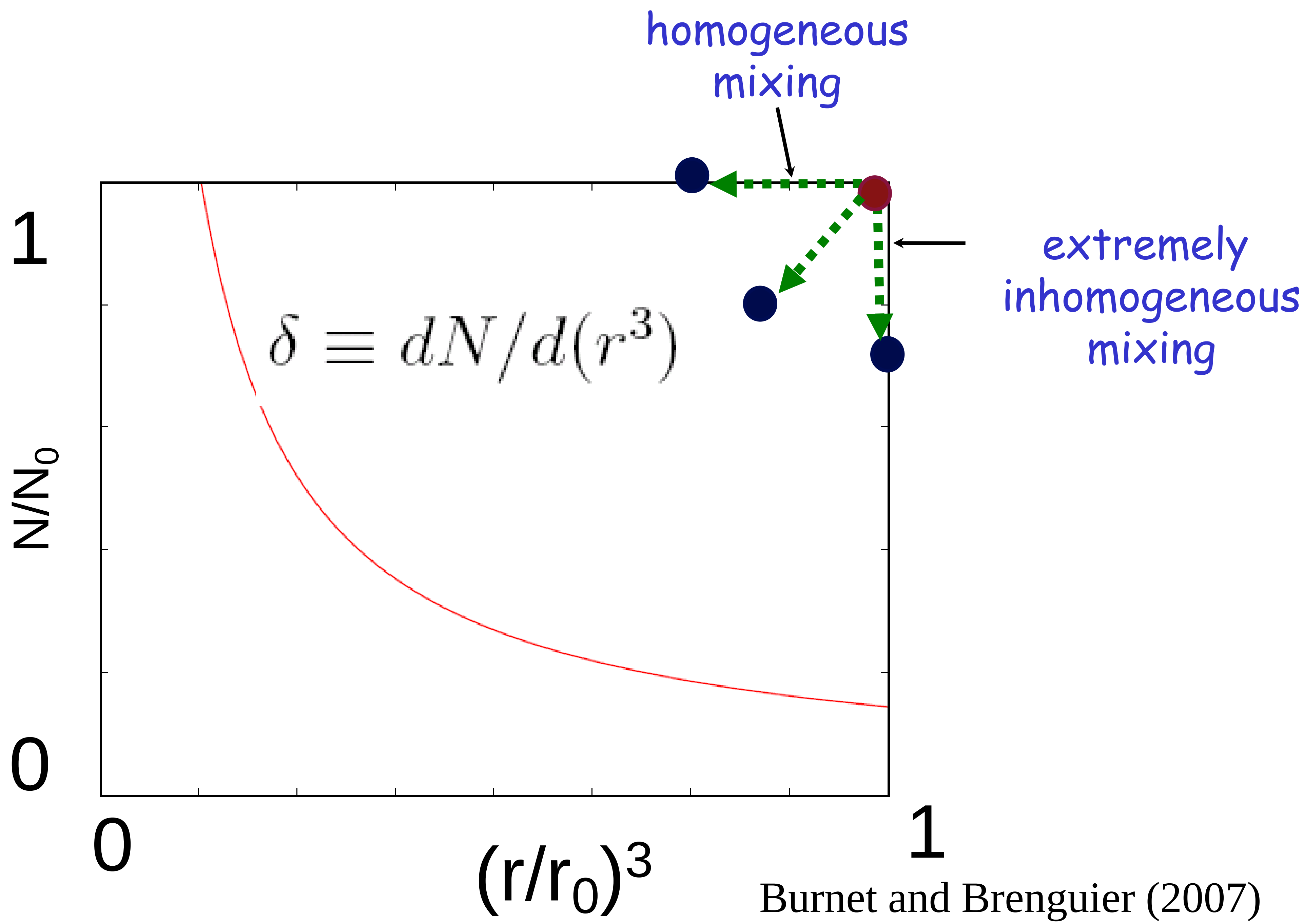
mixing event

Grabowski (2006), Jarecka et al. (2009)

2-moment microphysics and the mixing diagram

q_l, N_l - two variables to describe liquid water

which mixing scenario?



Burnet and Brenguier (2007)
Andrejczuk et al. (2006)

2-moment microphysics - mixing scenarios

$$N_f = N_i \left(\frac{q_f}{q_i} \right)^{\alpha}$$

Morrison and Grabowski (2008)

q_i, q_f – initial and final cloud water mixing ratios

N_i – droplet concentration after turbulent mixing, the initial value for the microphysical adjustment

N_f, - final (after turbulent mixing and microphysical adjustment) value of the droplet concentration

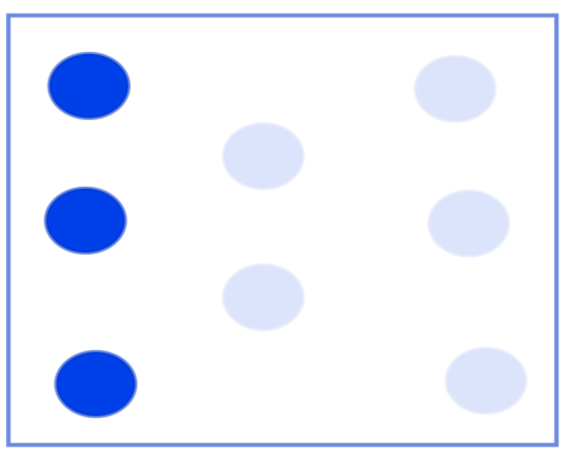
2- moment microphysics - mixing scenarios

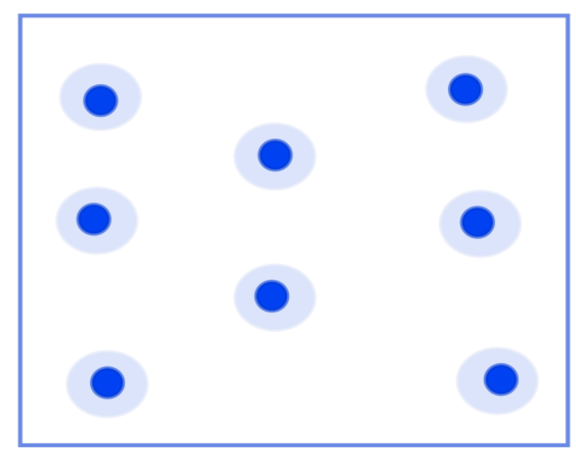
$$N_f = N_i \left(\frac{q_f}{q_i} \right)^{\alpha}$$

$\alpha = 1$ extremely inhomogeneous mixing	$\alpha = 0$ homogeneous mixing

$r \sim q/N = \text{const}$

$N_f < N_i$





$N = \text{const}$

$r_f < r_i$

Previous studies (Slawinska et al. 2010): α=const for entire simulation.

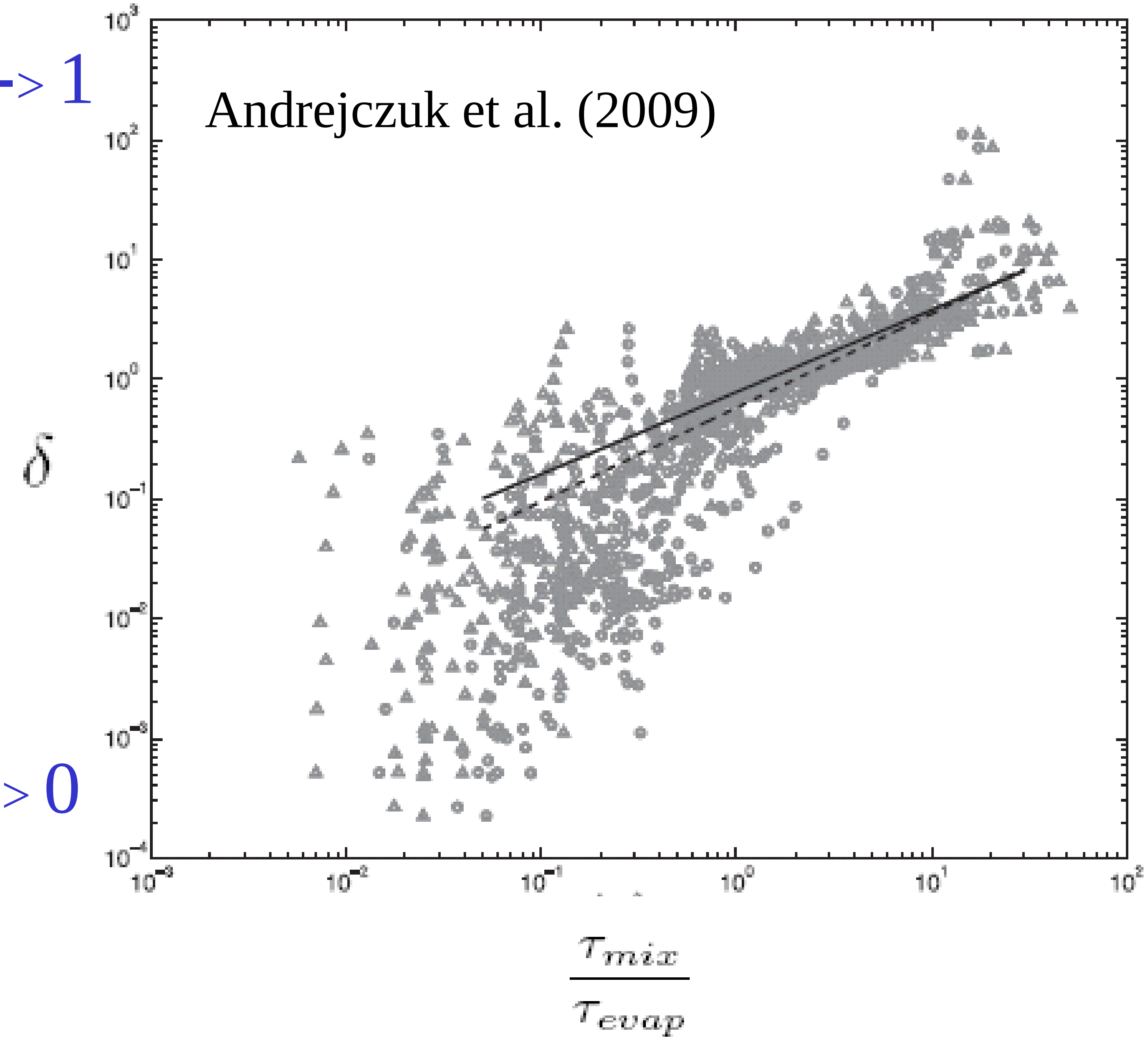
Using DNS results for λ- parameterization: mixing scenarios

$$\tau_{mix} = \frac{\lambda}{u(\lambda)} = \frac{\lambda^{\frac{2}{3}}}{TKE^{\frac{1}{2}} * \Lambda^{\frac{1}{3}}}$$

$$\tau_{evap} = \frac{r^2}{A * (1 - RH_d)}$$

α -> 1

α -> 0



$\alpha = f(\lambda, TKE, RH_d, r)$

We can calculate α locally as a function of these parameters !!

Model and model setup

3D numerical model EULAG

www.mmm.ucar.edu/eulag/

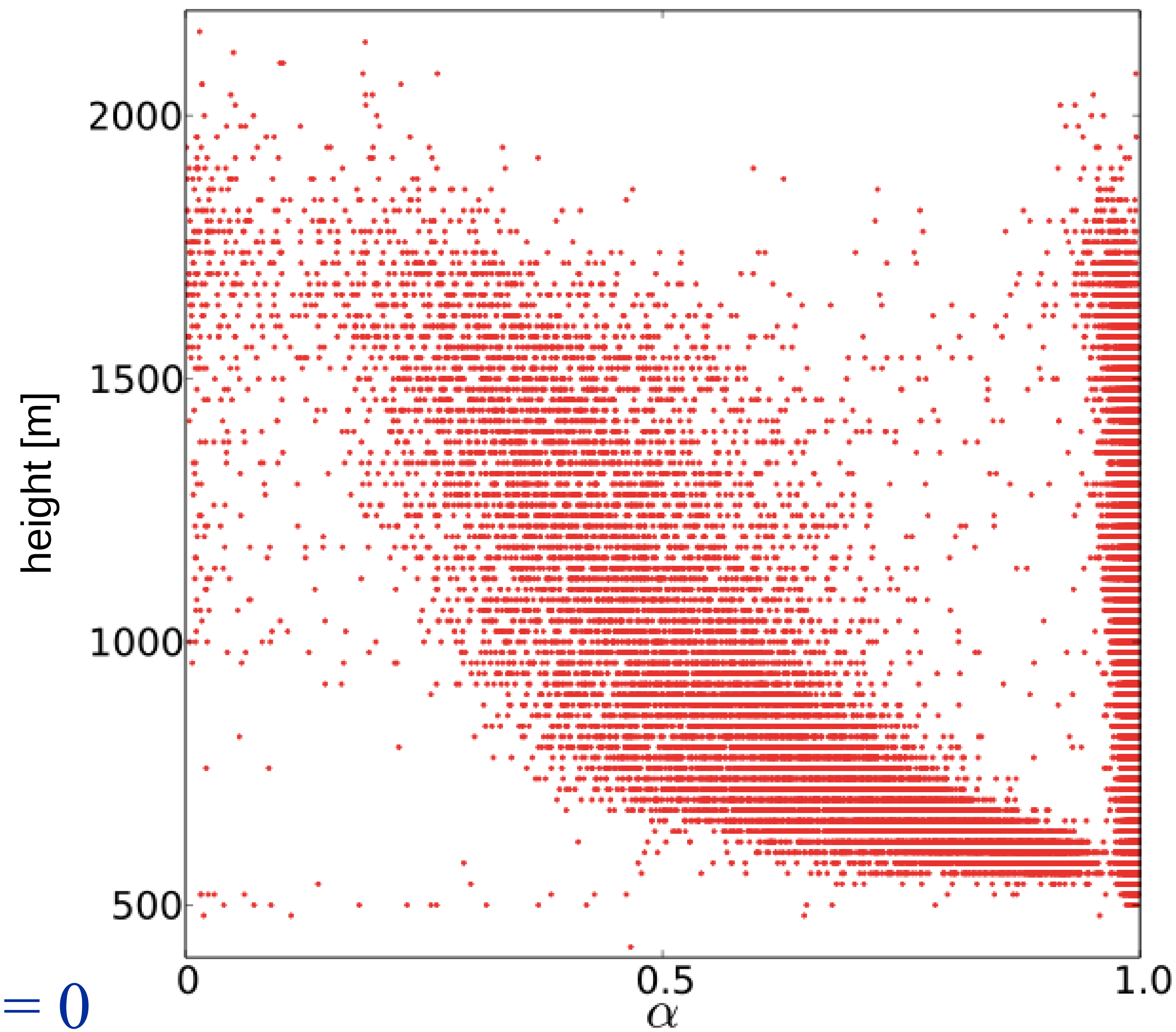
- Eulerian version
- Cartesian mesh
- Anelastic form
- 2-moment warm-rain microphysics scheme

(Morrison and Grabowski 2007, 2008)

Simulation setup - BOMEX

- Domain: 6.4km, 6.4km, 3km
- Grid size: 50m, 50m, 20m
- Time step: 1s
- Initial profiles from Siebesma et al. 2003

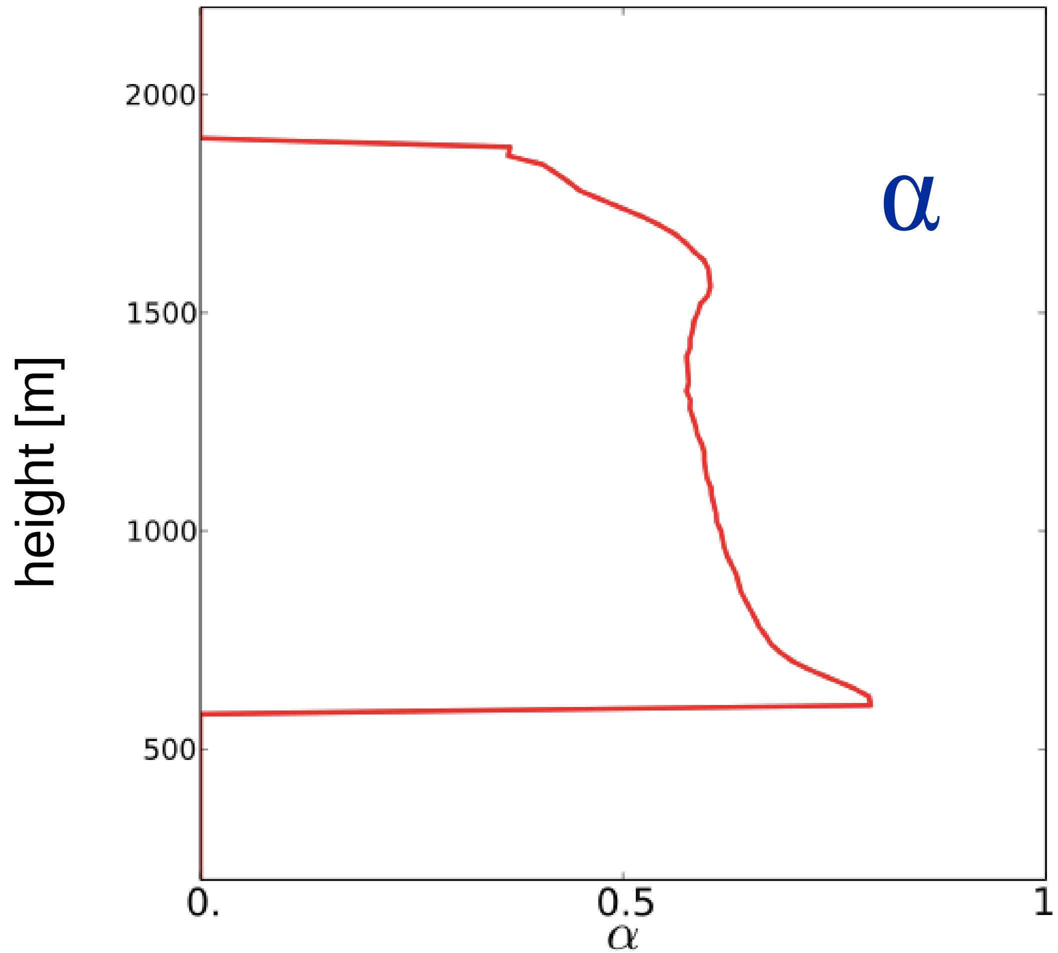
Changes of the parameter α with height

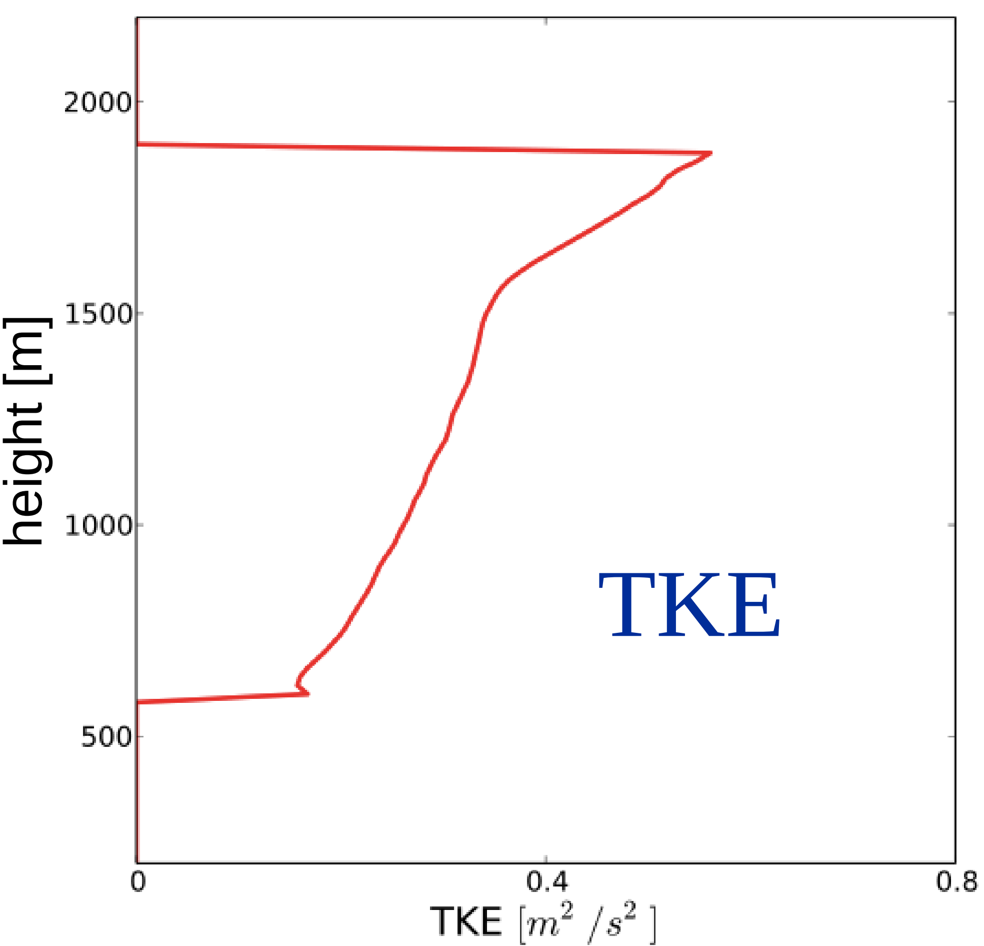


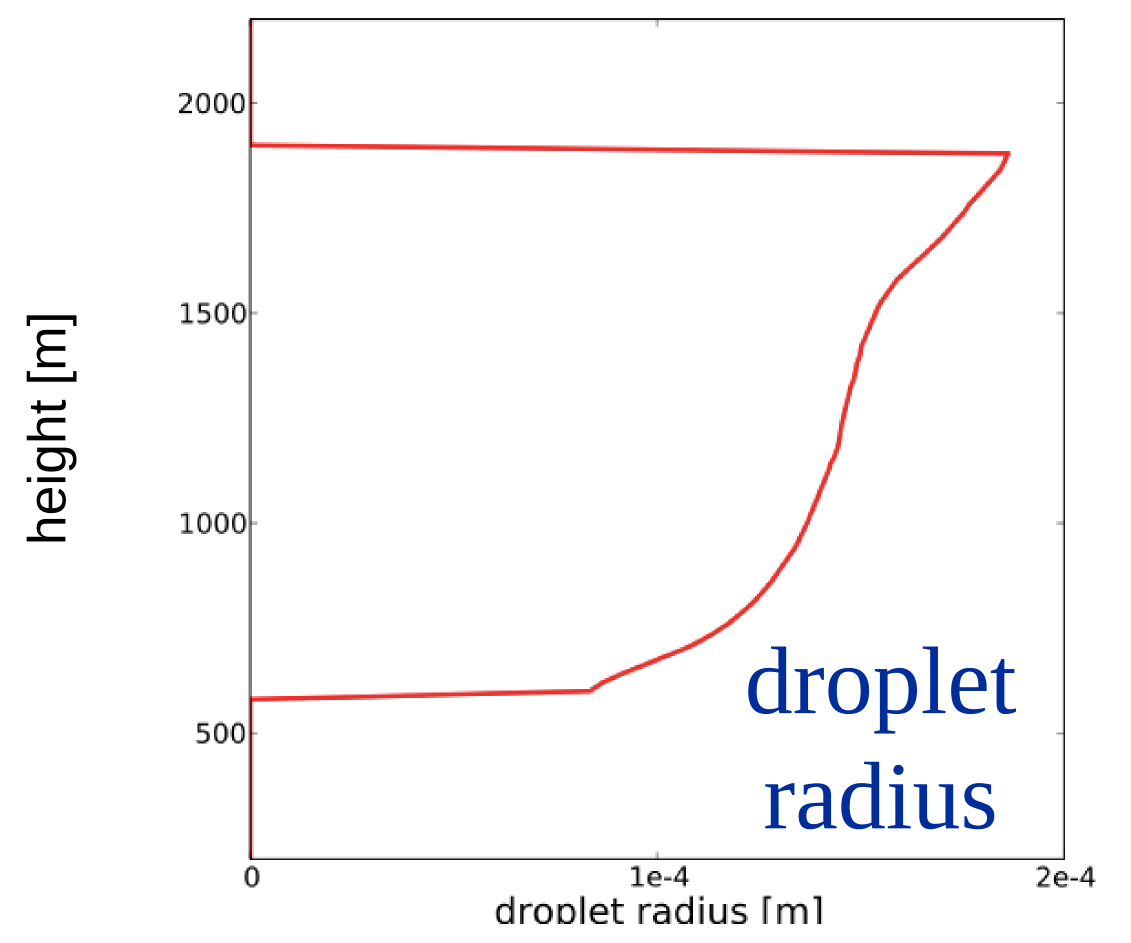
$\alpha = 0$
homogeneous mixing

$\alpha = 1$
extremely inhomogeneous mixing

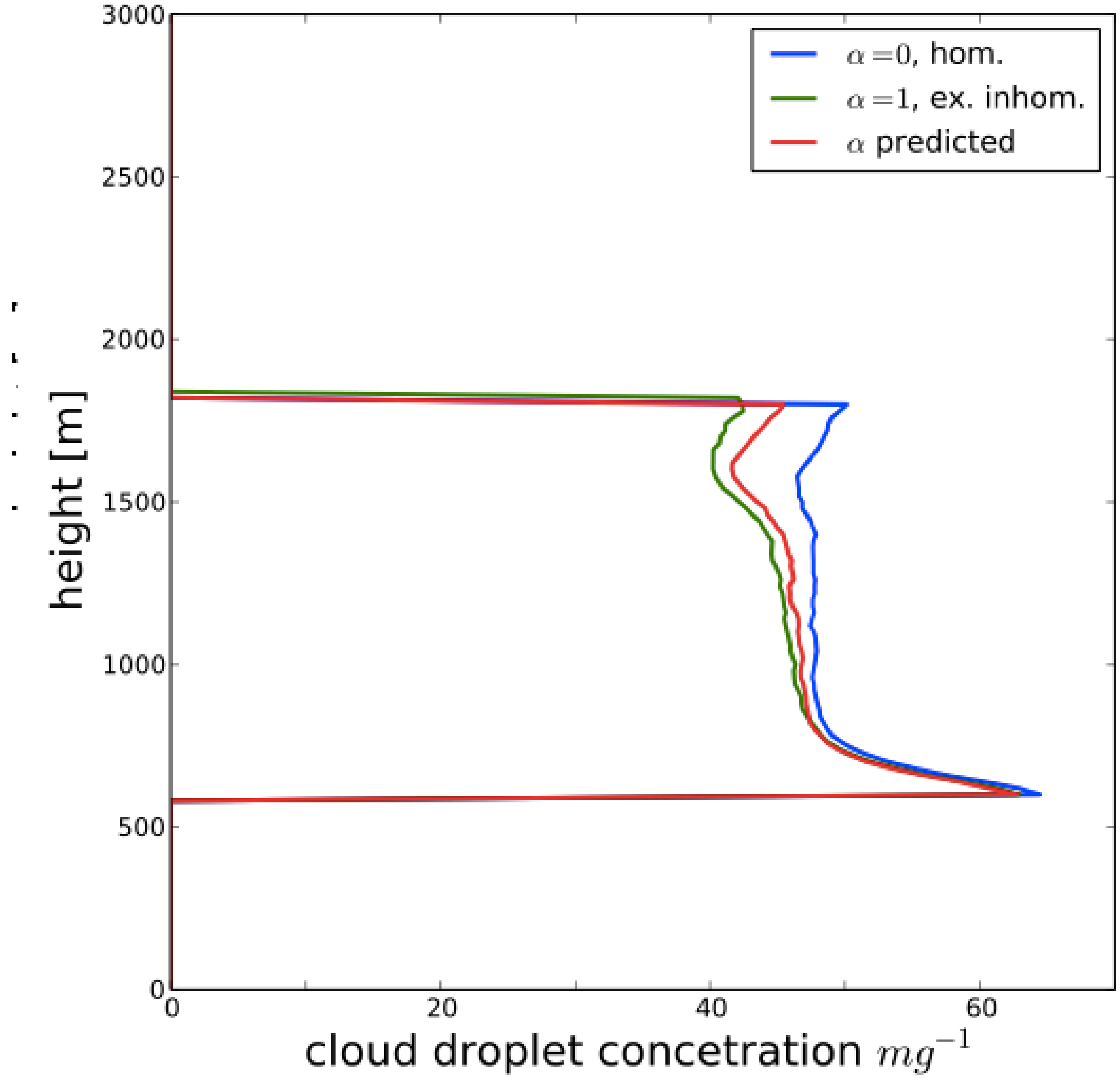
Vertical profiles of α, droplet radius and TKE







Cloud droplet concentration in simulations with various mixing scenarios



Summary

- Predicting scale of cloudy filaments λ allows representing in a simple way progress of the turbulent mixing between cloudy air and entrained dry environmental air.

- Parameter α and the mixing scenario can be predicted as a function of λ, TKE, RH, and droplet radius r.

- In BOMEX simulations, α decreases with height on average, i.e., the mixing becomes more homogeneous. This is consistent with both TKE and droplet radius increasing with height.