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

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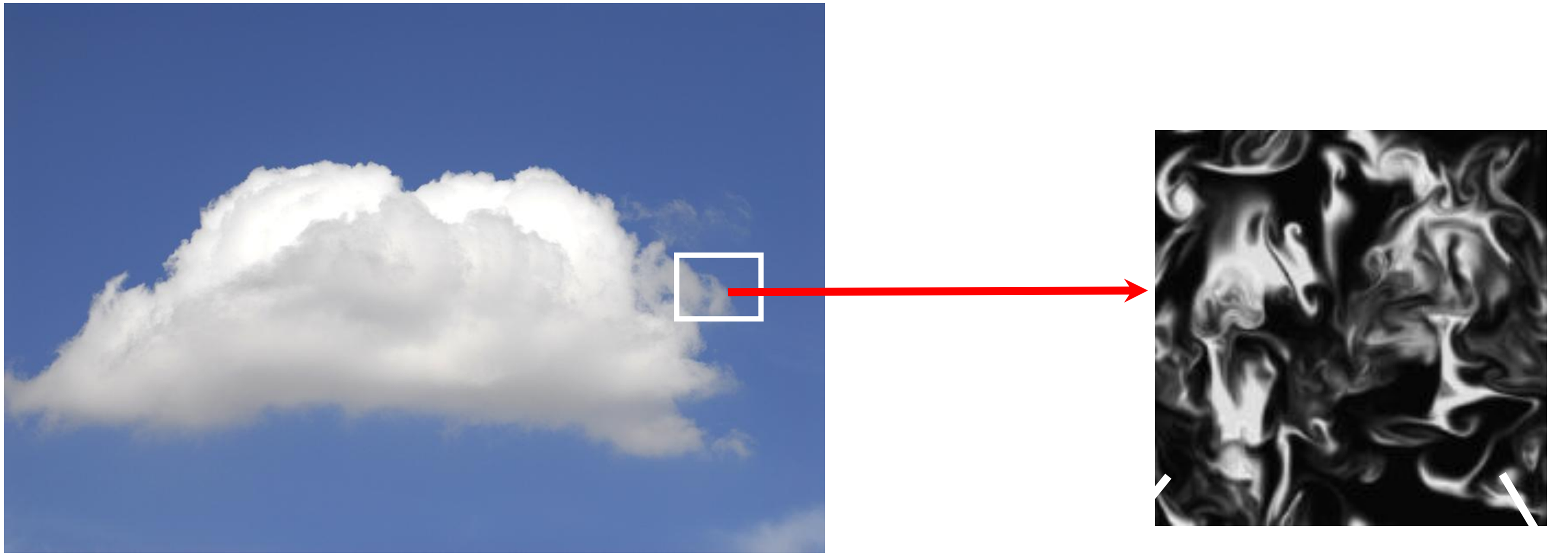
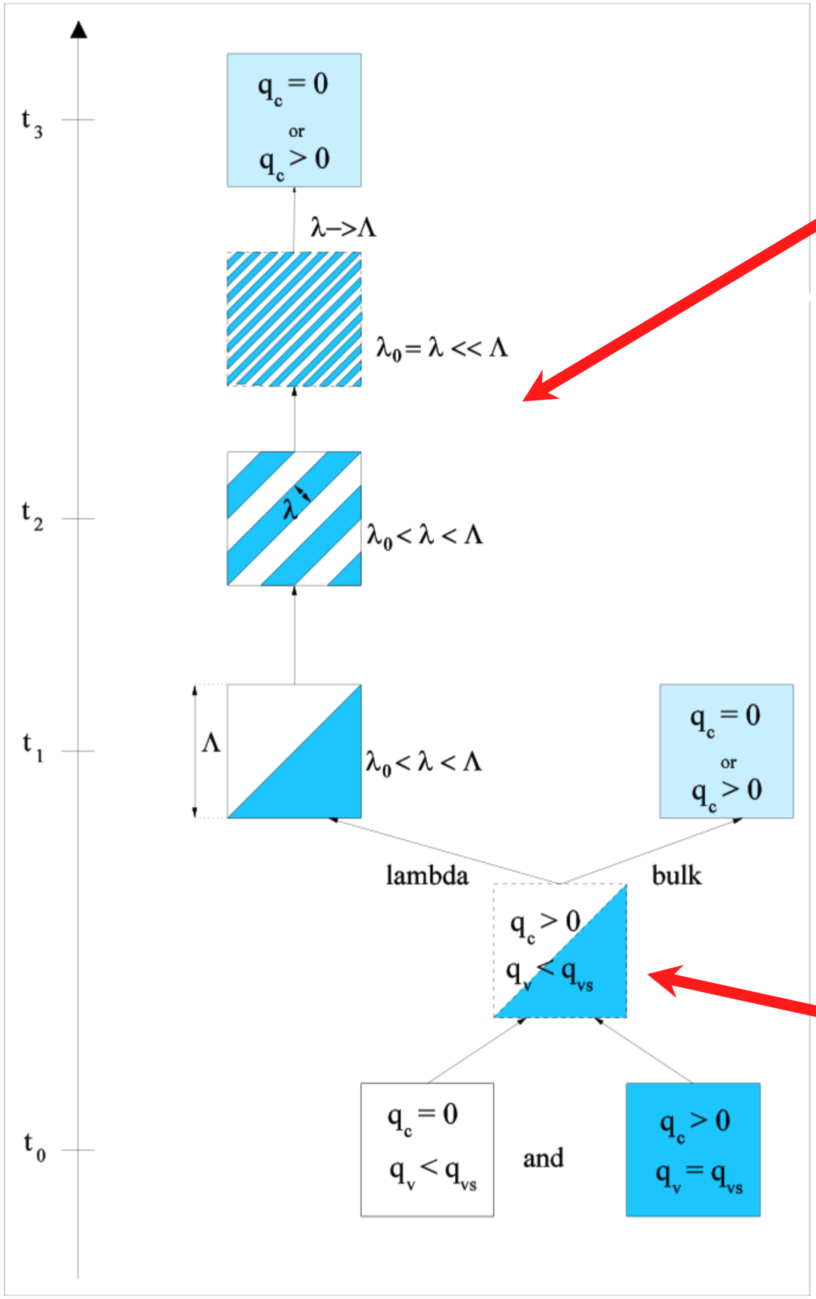
NOAA
U.S. DEPARTMENT OF ENERGY
ASR Atmospheric System Research
CMMAP Reach for the sky.

Turbulent cloud-environment mixing



Microphysical transformations due to subgrid-scale mixing are not instantaneous…

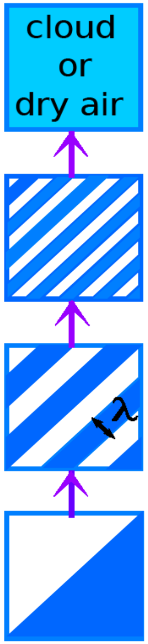


Modified model with λ approach: homogenization delayed until turbulent stirring reduces the filament width λ to the value corresponding to the microscale homogenization scale λ_0

Bulk model: immediate homogenization

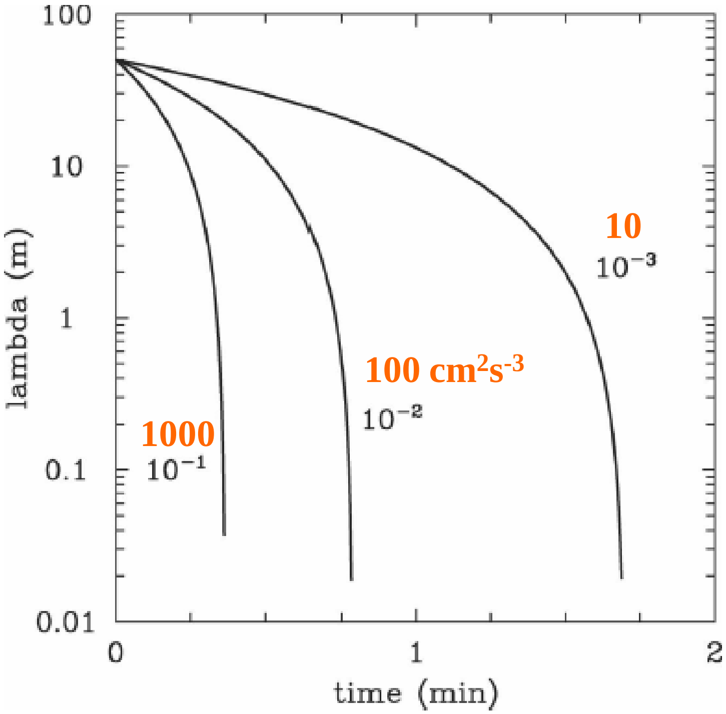
mixing event

λ - spatial scale of the cloudy filaments during turbulent mixing



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

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



Λ - model gridlength;

λ_0 - homogenization scale (~ 1 mm).

γ ~ 1

ε – dissipation rate of turbulent kinetic energy

Broadwell and Breidenthal (1982); Grabowski (2007)

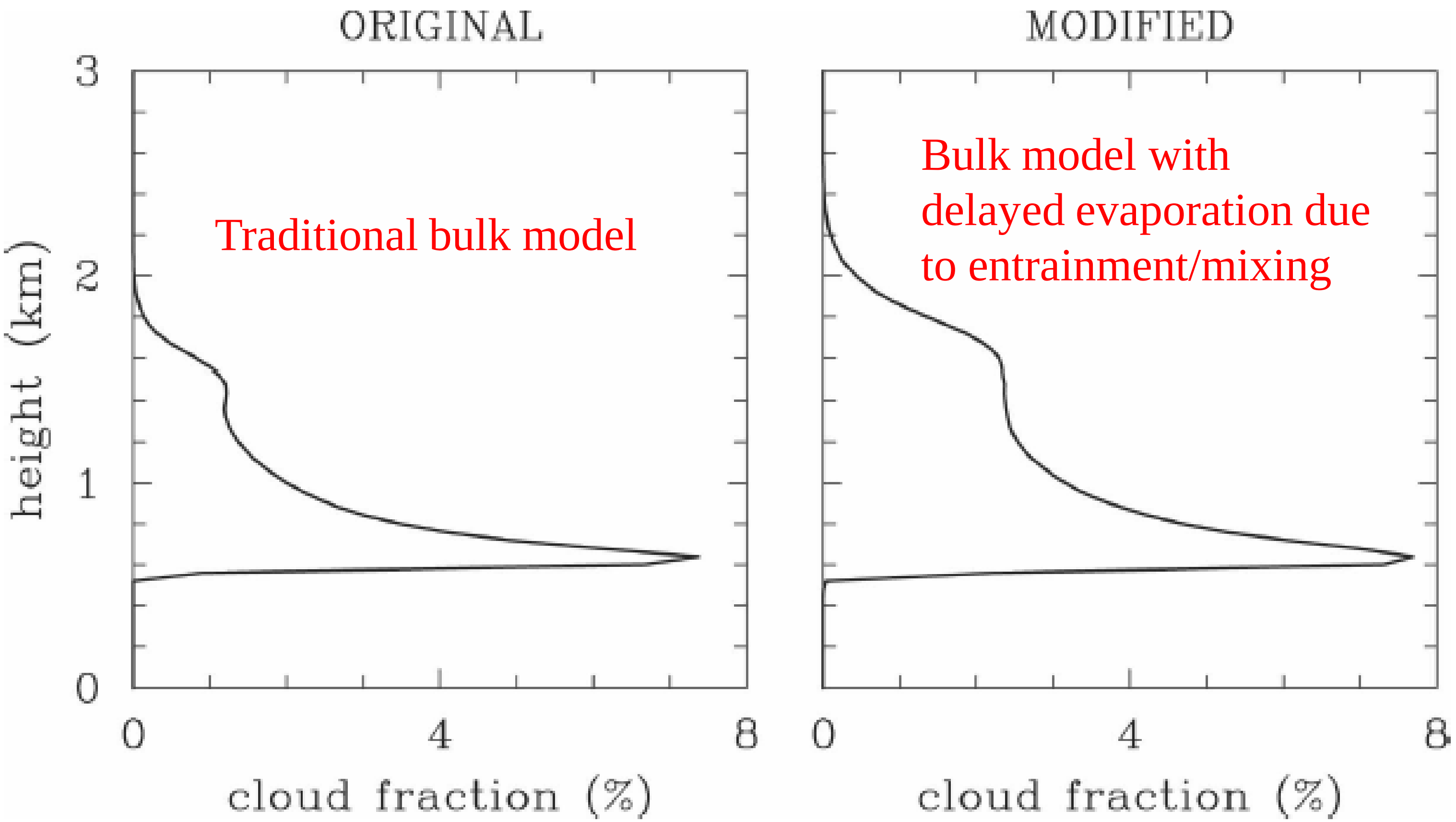
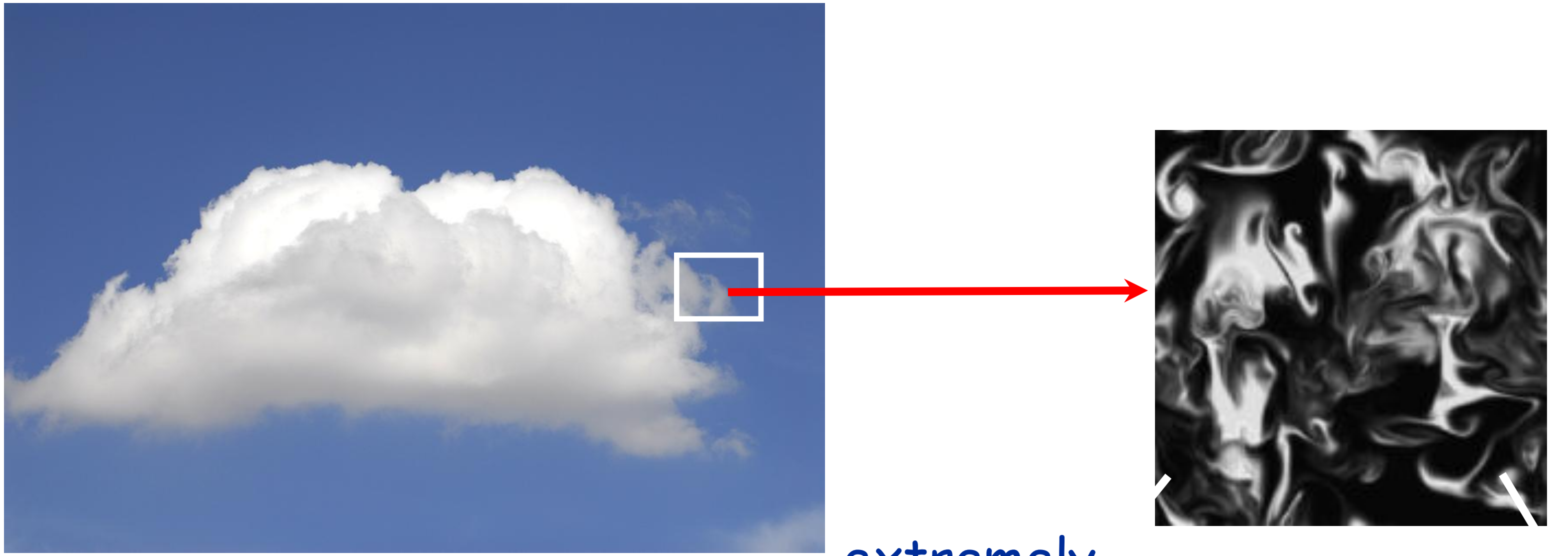


FIG. 9. Profiles of the cloud fractions (4-h averages) in BOMEX simulations using either the (left) original or (right) modified approaches.

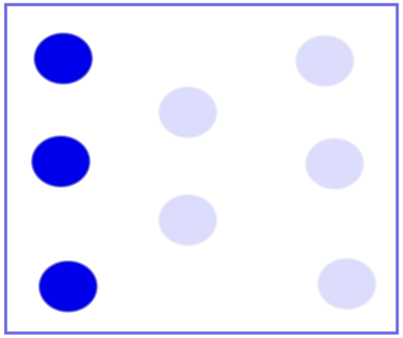
Simulation of a field of shallow non-precipitating convective clouds (Grabowski, *JAS* 2007)

Turbulent cloud-environment mixing: impact on cloud microphysics

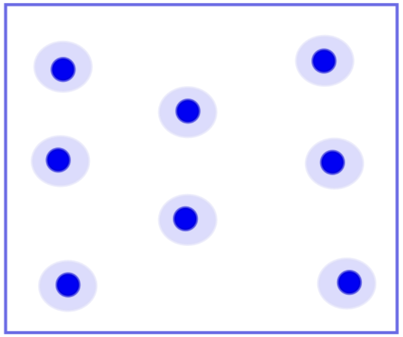


Microphysical transformations due to subgrid-scale mixing may cover a wide range of mixing scenarios.

extremely inhomogeneous mixing



homogeneous mixing



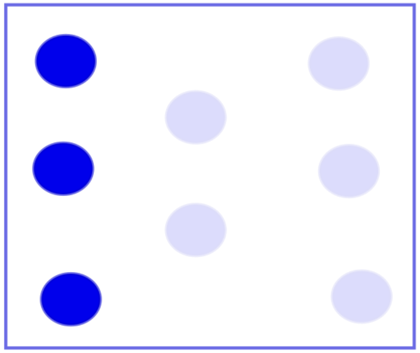
2-moment microphysics - mixing scenarios

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

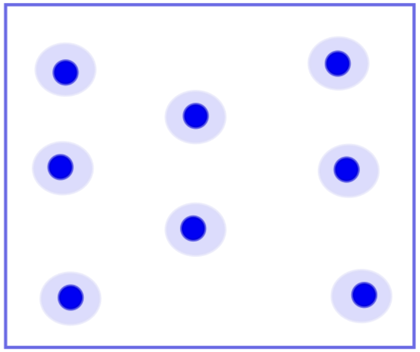
i – initial (before microphysical adjustment)

f – final (after the adjustment)

$\alpha = 1$
extremely inhomogeneous mixing



$\alpha = 0$
homogeneous mixing



Previews study (Slawinska et al. *JAS* 2011): α=const for entire simulation to contrast results with different mixing scenarios.

Using DNS results to predict α

Andrejczuk et al. (*JAS* 2009)

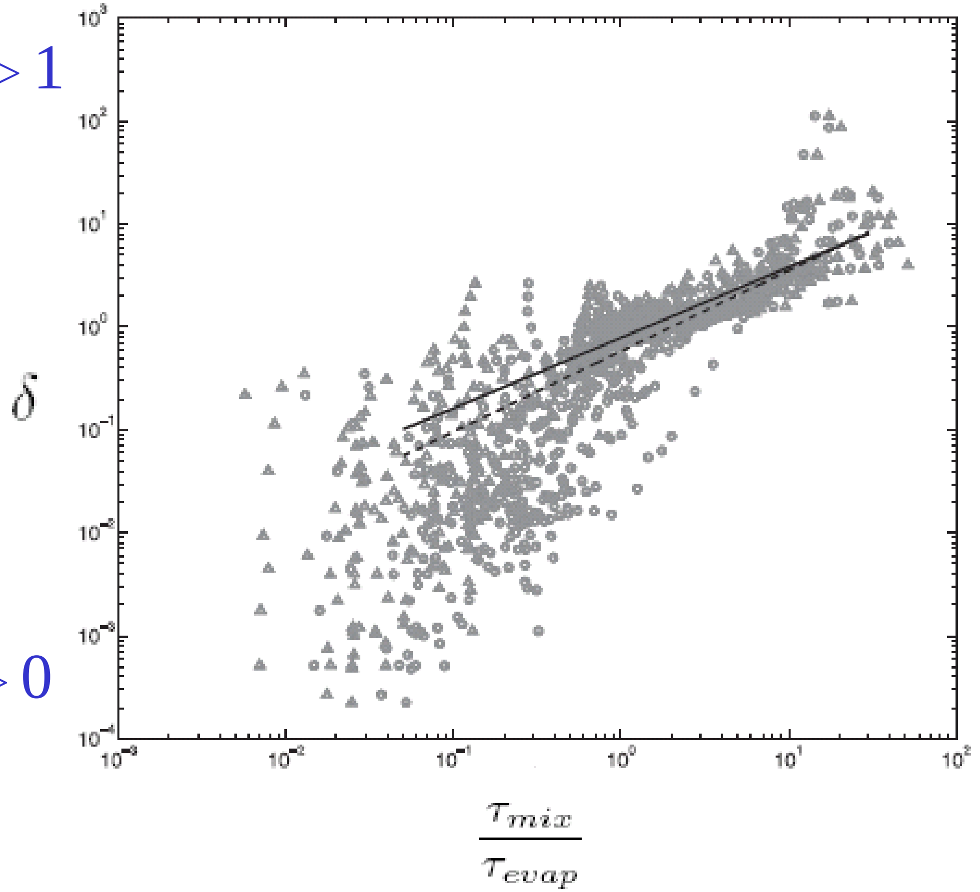
$$\tau_{mix} = \frac{\lambda}{u(\lambda)} = \frac{\lambda^{\frac{2}{3}}}{TKE^{\frac{1}{2}} * \Lambda^{\frac{1}{3}}}$$

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

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

α -> 1

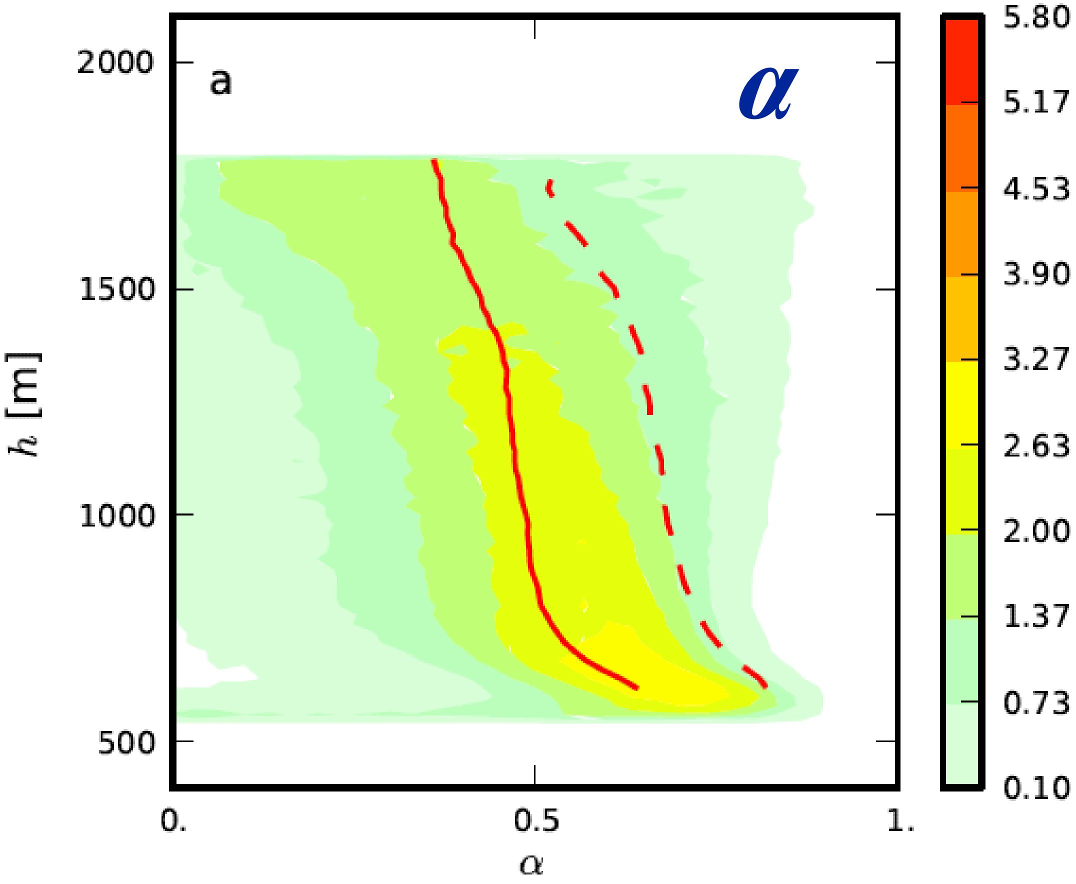
α -> 0



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

Changes of the parameter α with height: sampling all cloudy points with $\lambda_0 < \lambda < \Lambda$

Shallow Cu:
BOMEX

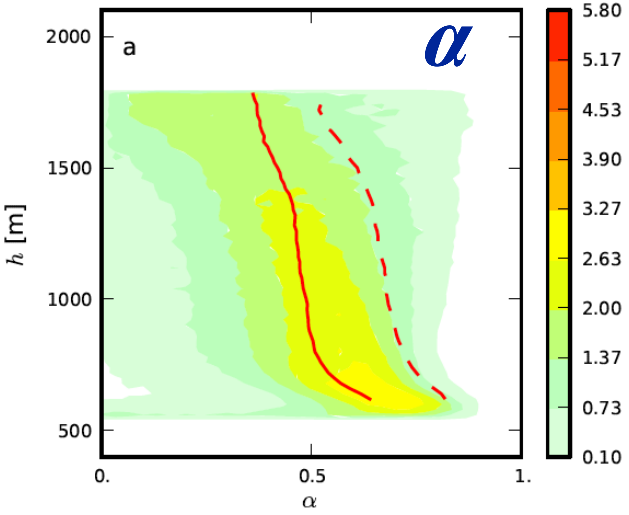


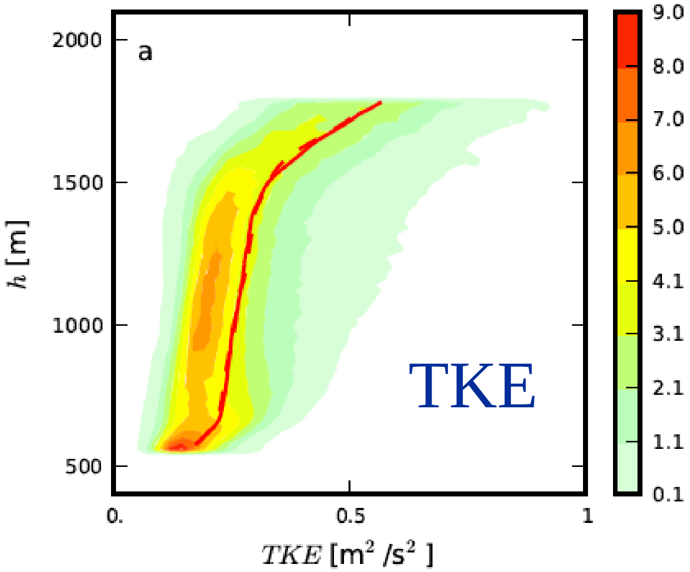
homogeneous
mixing

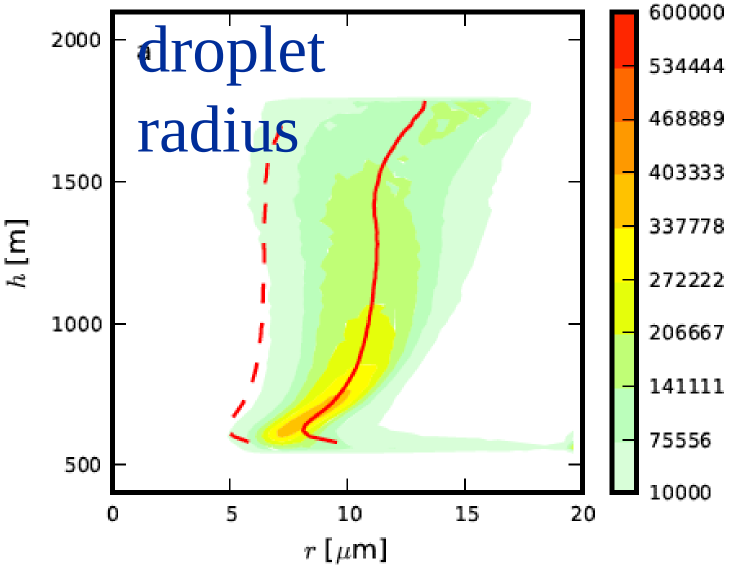
extremely
inhomogeneous mixing

Vertical profiles of α , droplet radius and TKE

Shallow Cu:
BOMEX

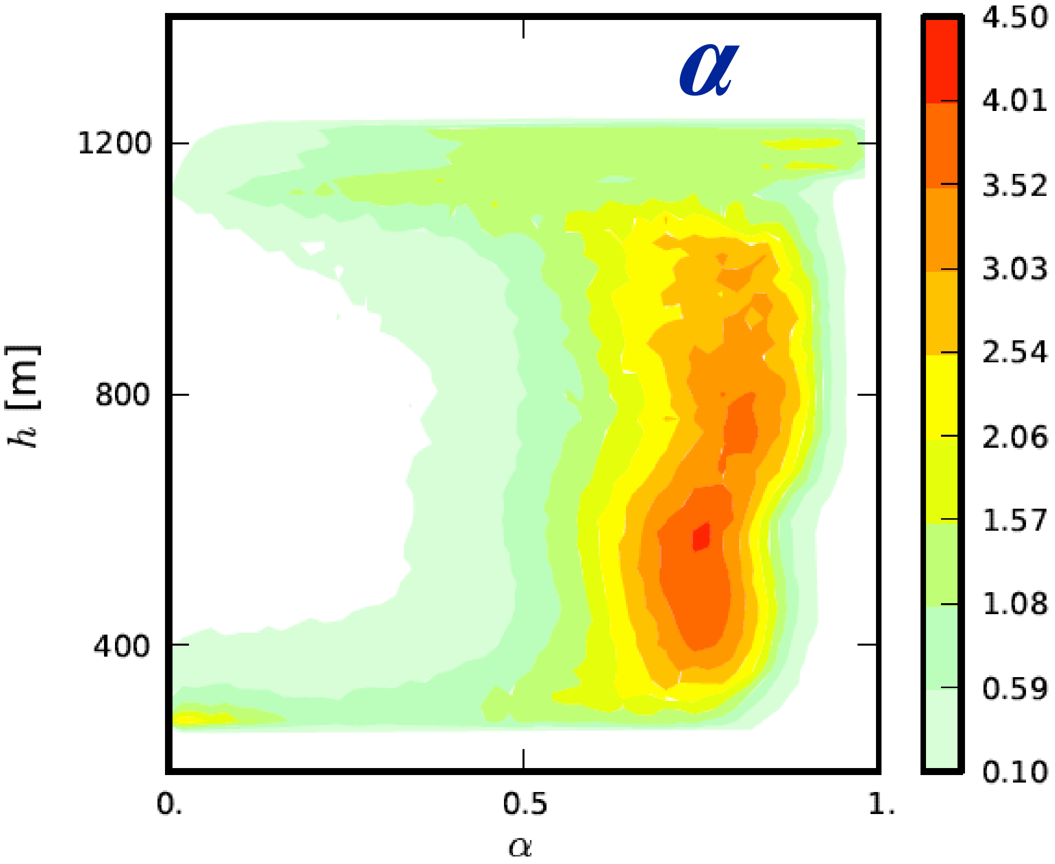

α


TKE


droplet
radius

Changes of the parameter α with height: sampling all cloudy points with $\lambda_0 < \lambda < \Lambda$

Sc: IMPACT

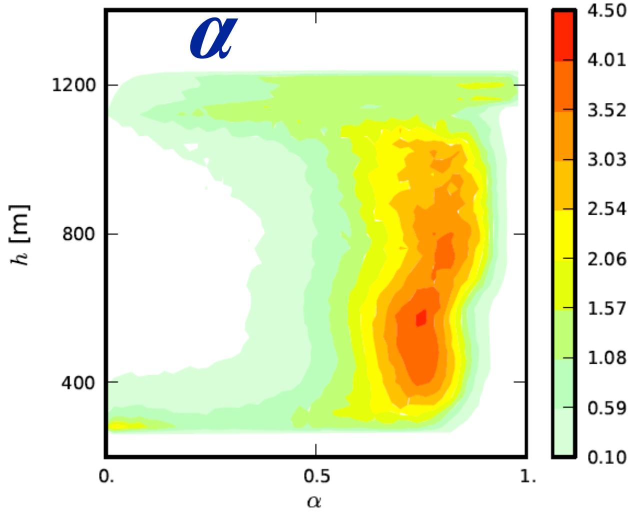


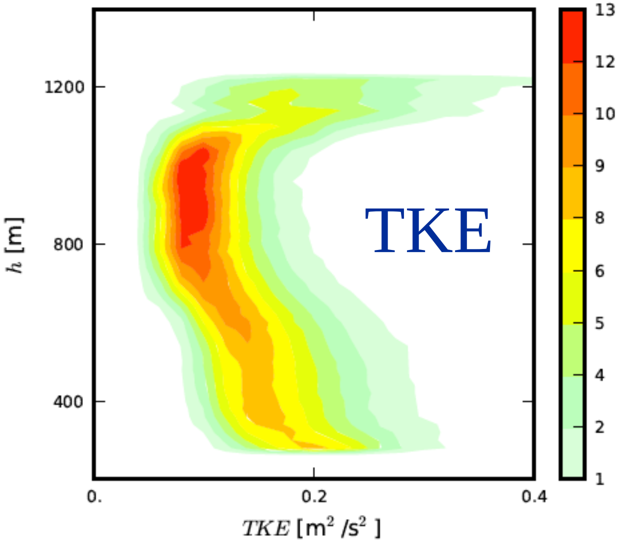
homogeneous
mixing

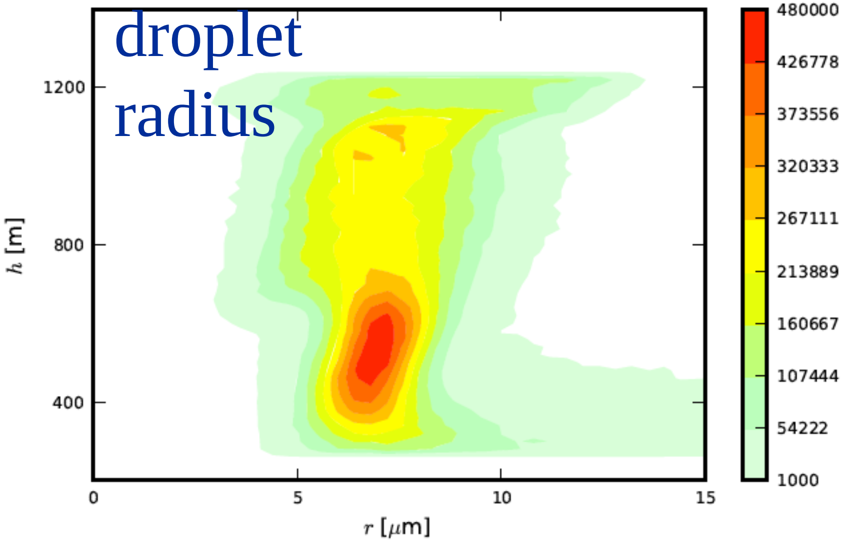
extremely
inhomogeneous mixing

Vertical profiles of α , droplet radius and TKE

Sc: IMPACT







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

Parameter α (and thus 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., mixing becomes more homogeneous. This is consistent with both TKE and droplet radius increasing with height.

In IMPACT simulations, mixing is close to extremely inhomogeneous across most of the cloud depth, and wide range is simulated near the cloud top.