Microphysical effects of entrainment in large-eddy simulation of boundary layer clouds

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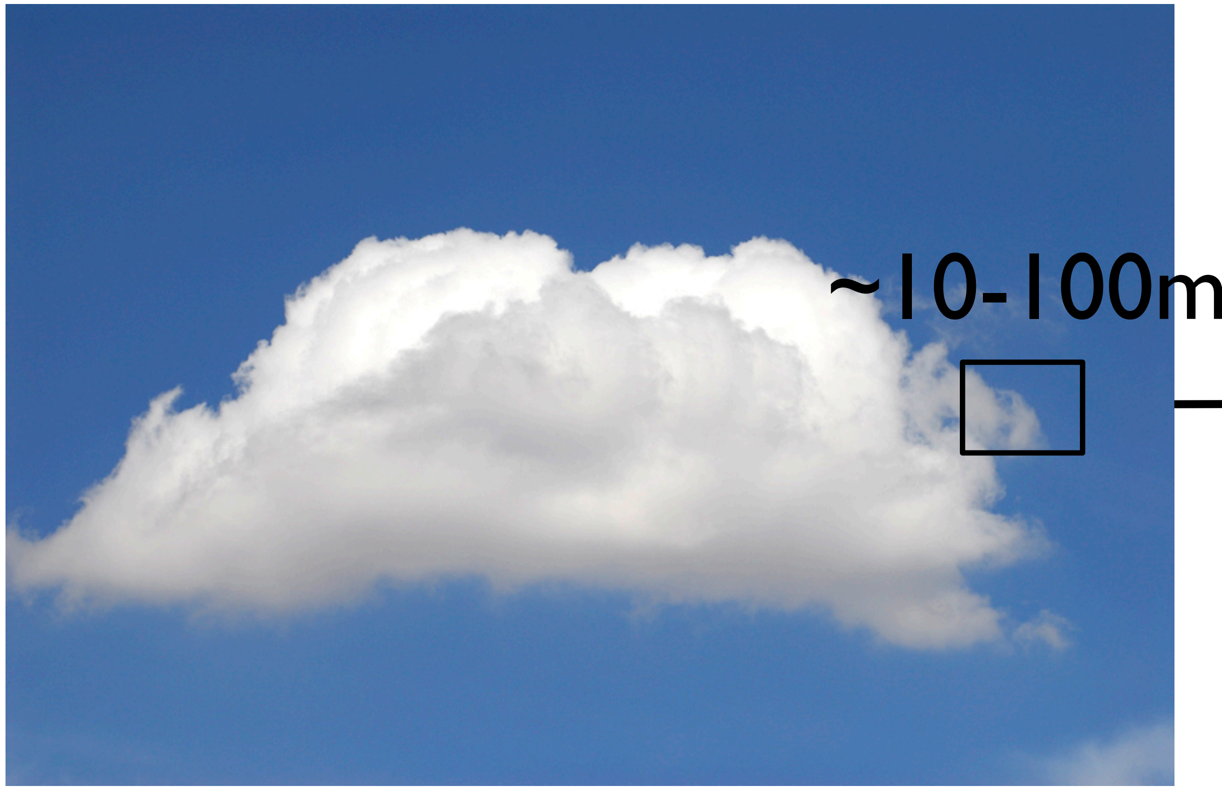
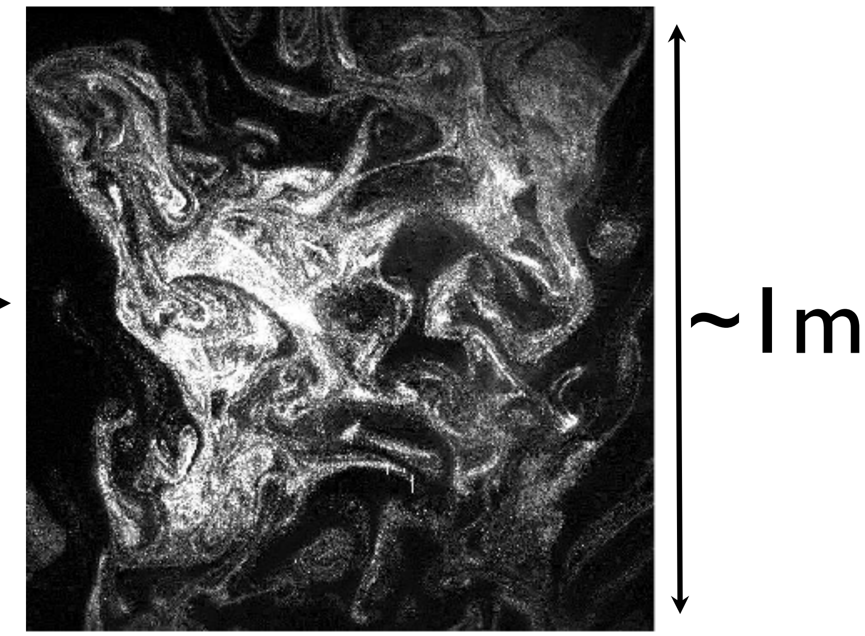
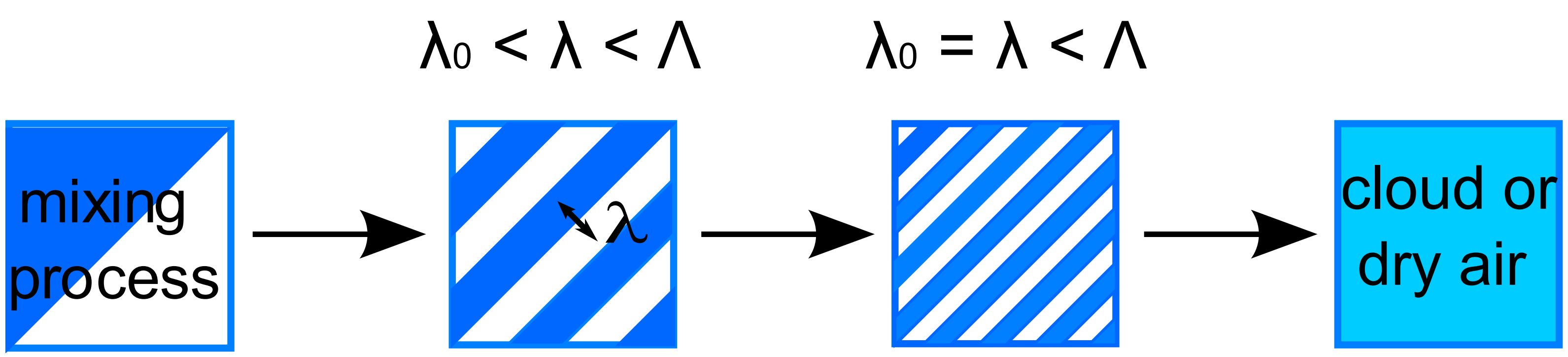
Turbulent mixing in clouds



Malinowski et al. (2008)





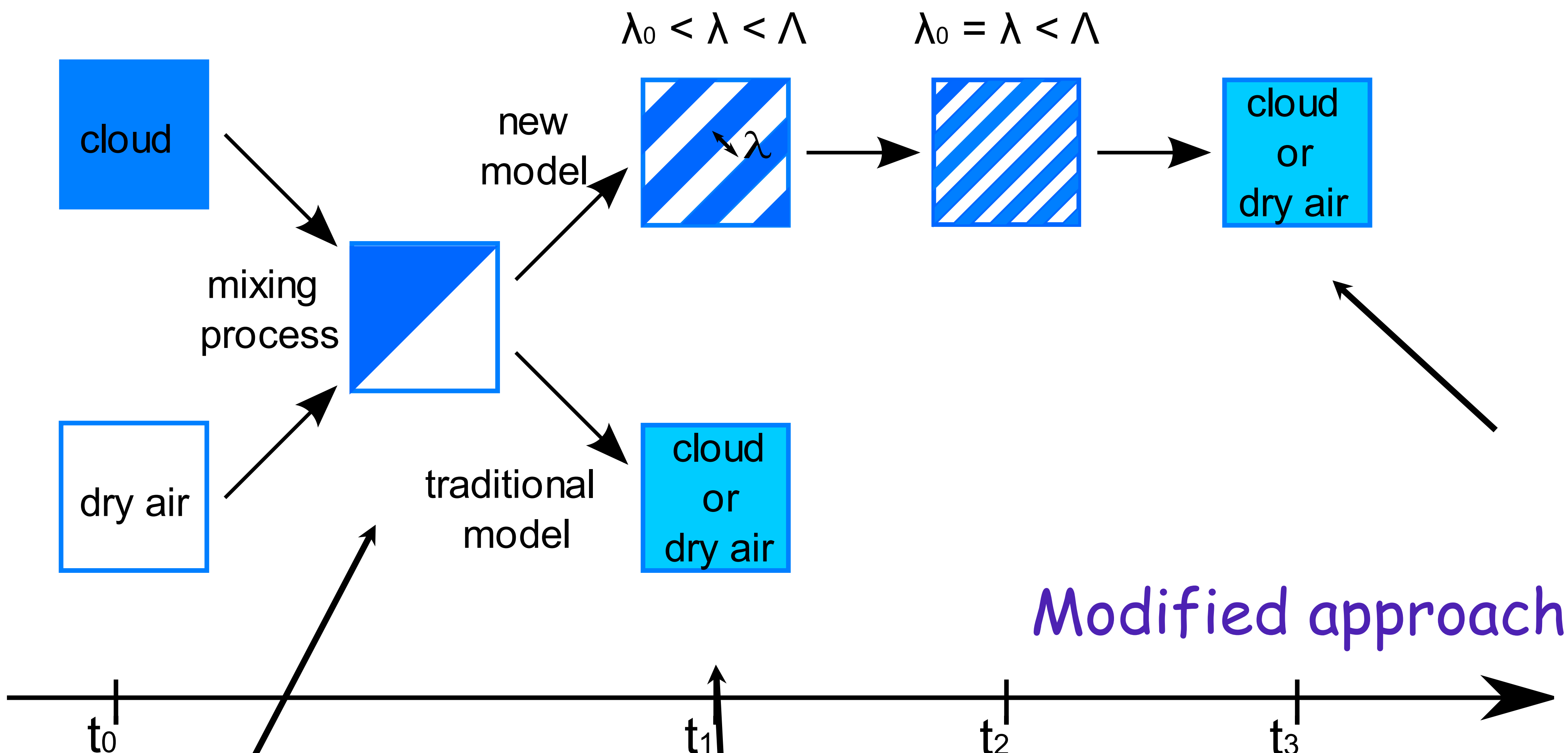
λ - spatial scale of the cloudy filaments during turbulent mixing

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

Broadwell and Breidenthal (1982); Grabowski (2006)

Delay of evaporation during turbulent mixing

λ - spatial scale of the cloudy filaments during turbulent mixing



Modified approach:

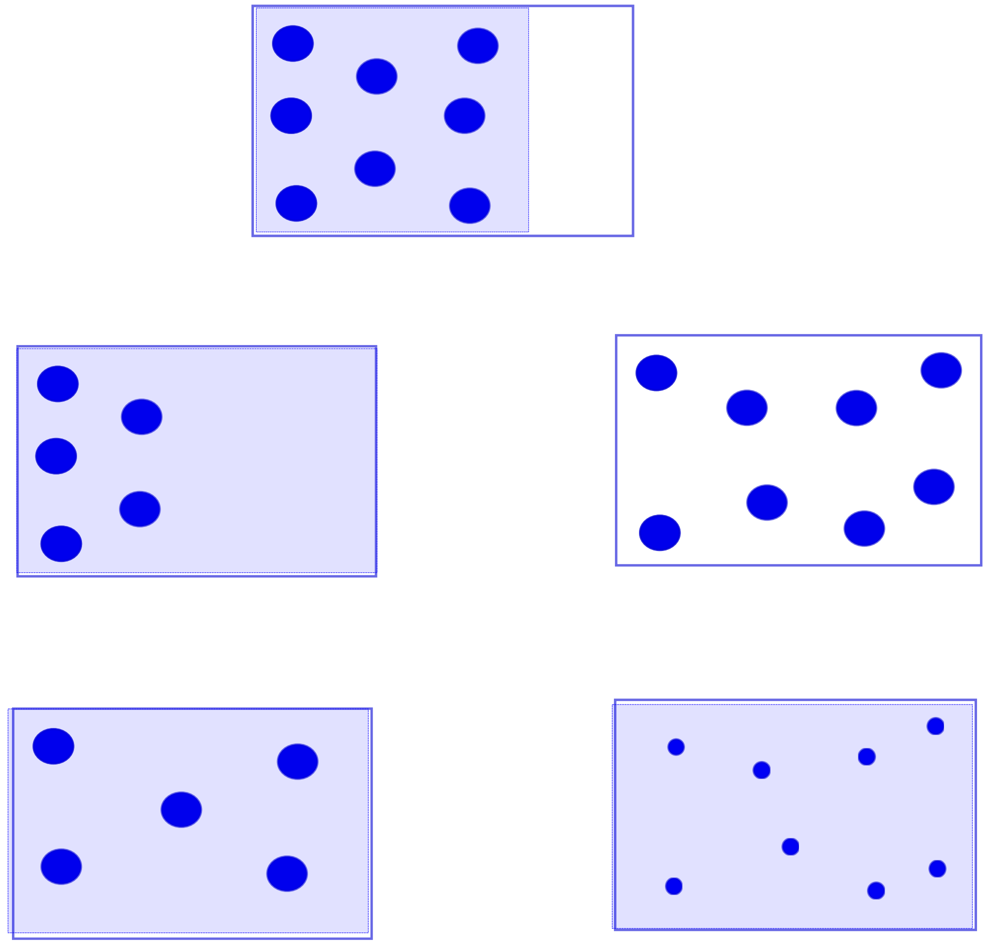
homogenization delayed until turbulent stirring reduces the filament width λ to the λ_0 ~ 1cm, when homogenization takes place

Traditional model:
immediate
homogenization

mixing event

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

Mixing scenarios within clouds



process of evaporation fast comparing to turbulent mixing

$$\tau_{evap} \ll \tau_{mix}$$

some droplets evaporate completely; other don't change sizes

process of mixing fast comparing to evaporation

$$\tau_{evap} \gg \tau_{mix}$$

droplets evaporating in homogenous environment

extremely inhomogeneous mixing

homogeneous mixing

2-moment microphysics - mixing scenarios

$$N_c^i - \Delta N_c^{mix} = N_c^i \left(\frac{q_c^i - \Delta q_c^{mix}}{q_c^i} \right)^{\alpha}$$

Morrison and Grabowski (2008)

$q_c^i, \; N_c^i$ - values of cloud water mixing ratio and cloud droplet concentration before evaporation due to the mixing

Δq_c^{mix} - cloud water predicted to evaporate due to the subgrid scale turbulent mixing

ΔN_c^{mix} - change of the droplet concentration due to the subgrid scale turbulent mixing.
It depends on the mixing scenario.

Predicting mixing scenario

Droplet evaporation time scale

from diffusional growth equation

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

Turbulent homogenization time scale

approximated by the one turnover time of an eddy

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

results from DNS simulations (Andrejczuk et al., 2009)

additional model variables are used

$$\alpha = \mathrm{f}\,(\tau_{mix},\, \tau_{evap}) = \mathrm{f}\,(\lambda,\, TKE,\, RH_d,\, r)$$

We can predict α locally from model variables!

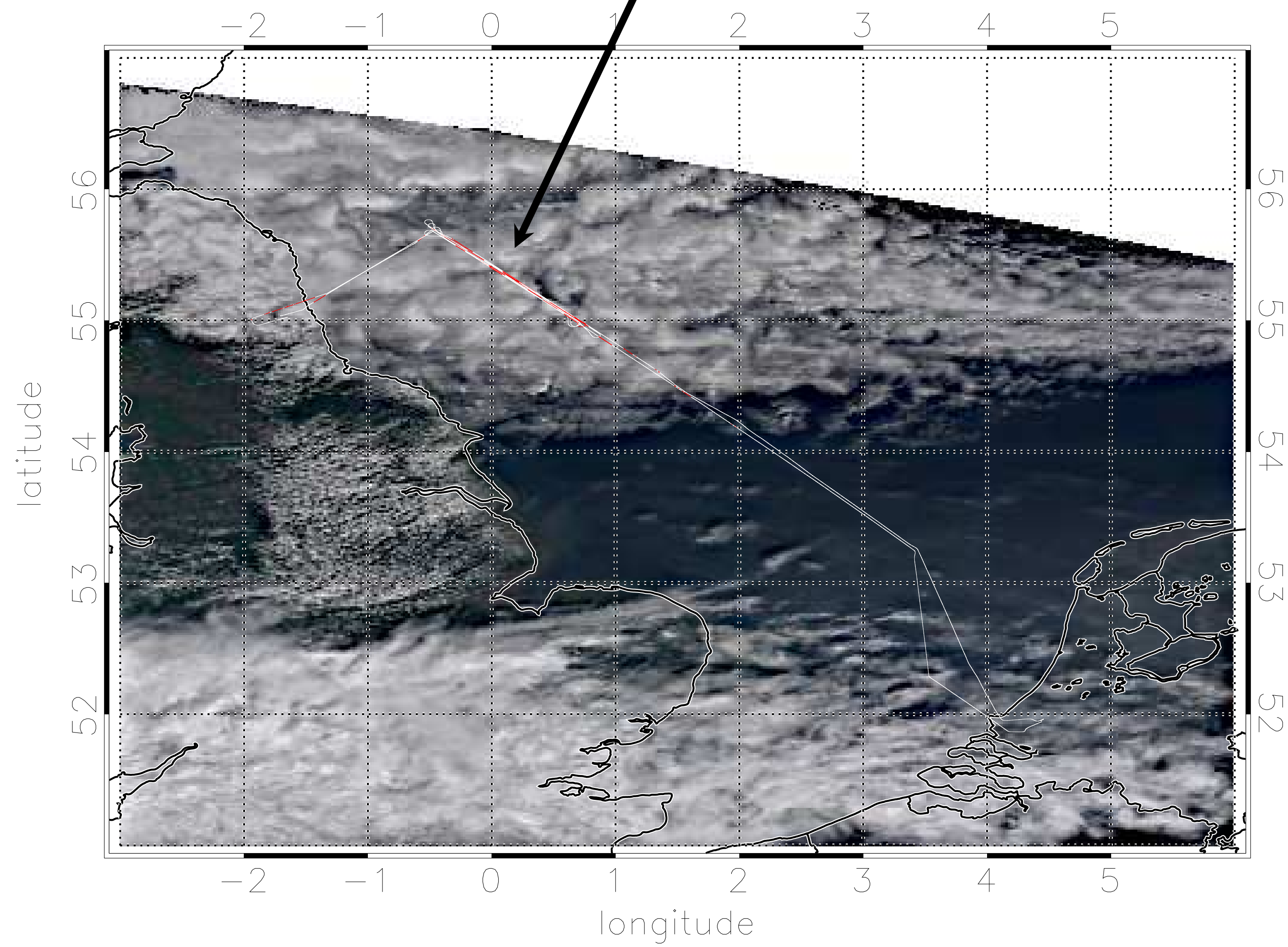
LES cloud model used for simulations

3D numerical model EULAG www.mmm.ucar.edu/eulag/

- Euleriain version, anelastic form
- 2-moment warm-rain microphysics scheme

(Morrison and Grabowski 2007, 2008)

stratocumulus over the North Sea

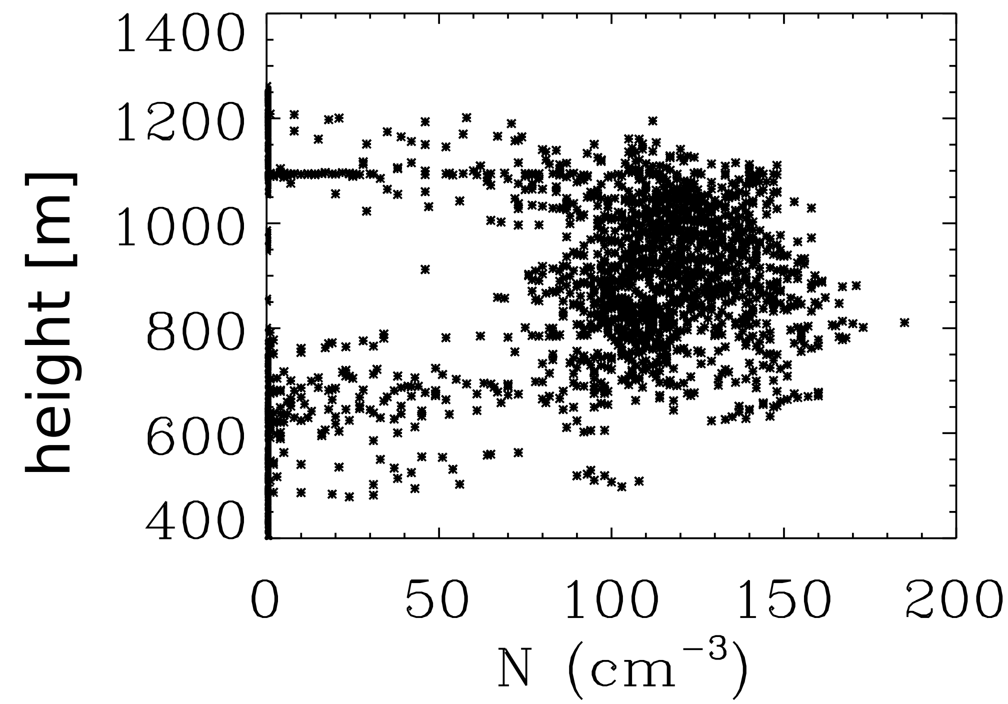


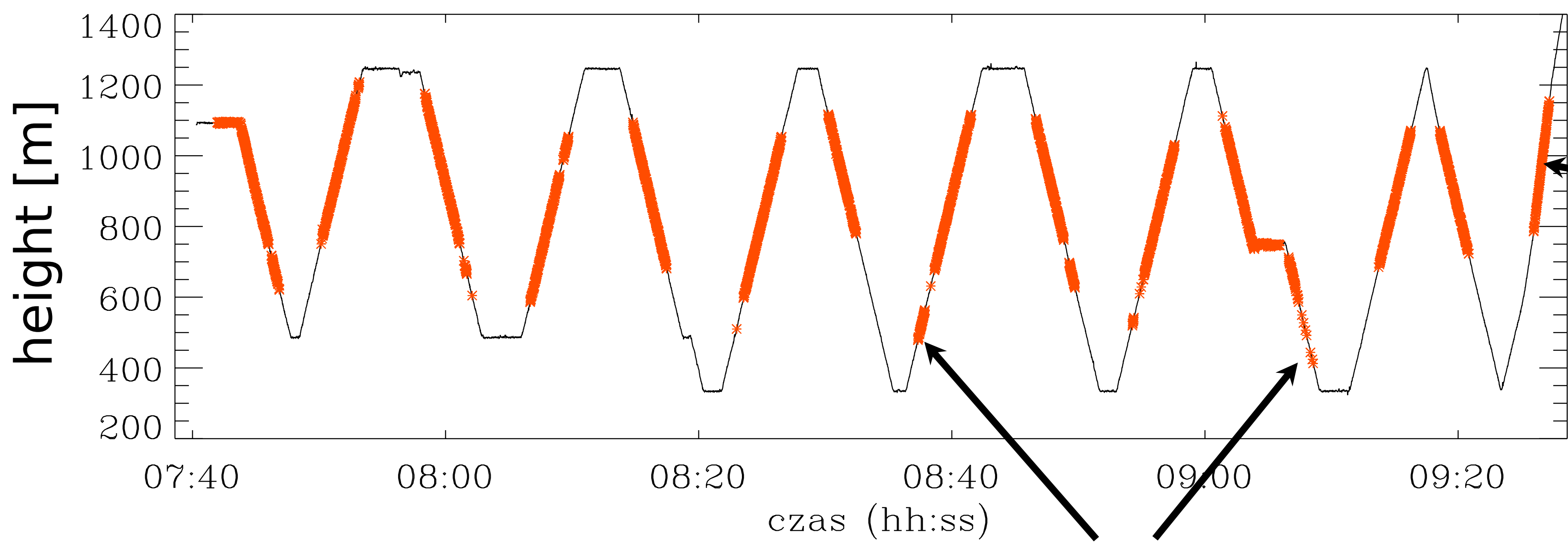
Setup based on experimental data from IMPACT (Intensive Observation Period at Cabauw Tower): flight over the North Sea, 15 May 2008

- Domain: 6.4km, 6.4km, 3km
- Grid size: 50m, 50m, 20m
- Time step: 1s

Observed cloud field during IMPACT

Cumulus clouds under stratocumulus layer





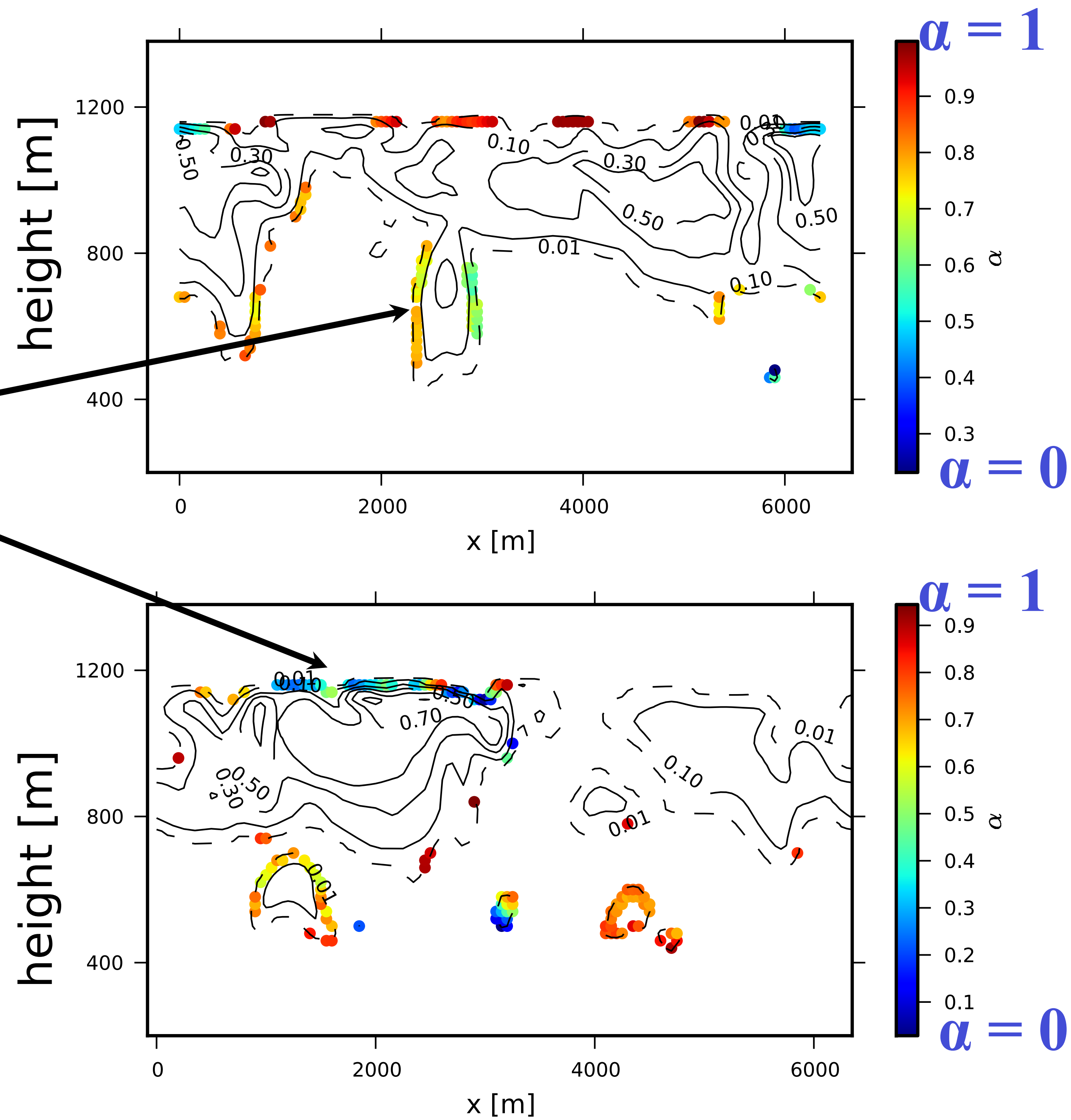
strotocumulus layer

cumulus clouds

Cloud field and mixing events in the model

Cumulus clouds under stratocumulus layer

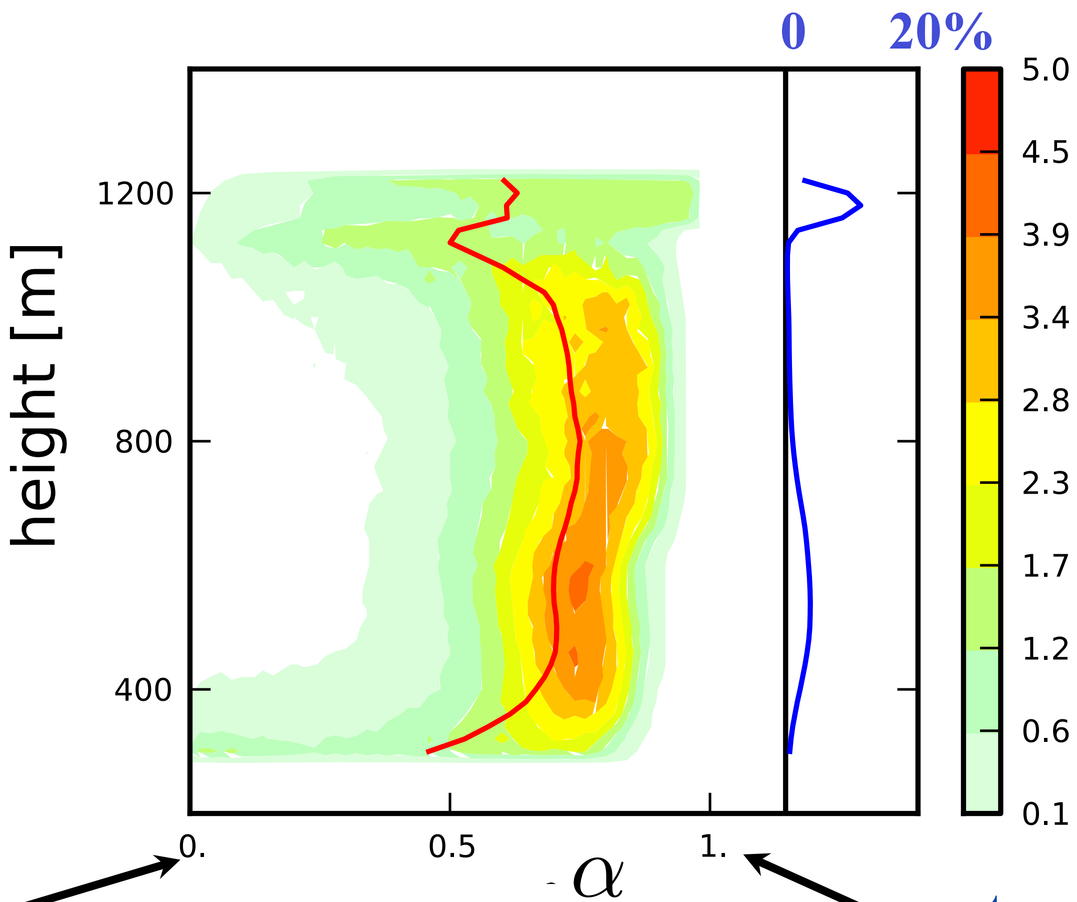
evaporation due to mixing processes



Mixing occurs mostly at the cumulus layer and at the top of the stratocumulus

Mixing scenario in the model

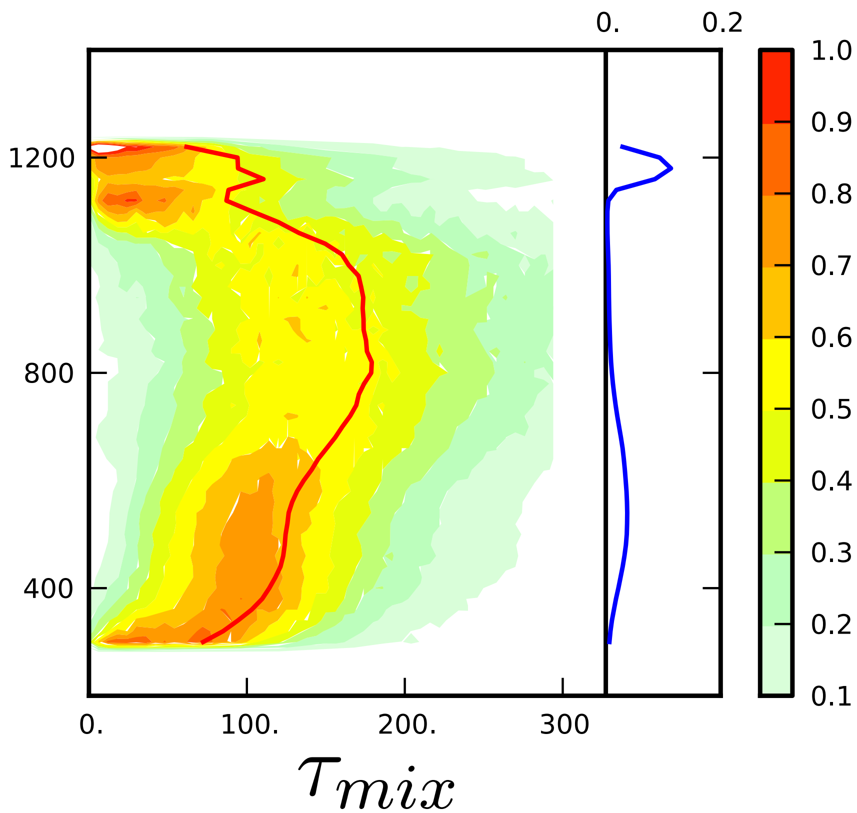
CFADs and mean profiles from IMPACT simulation

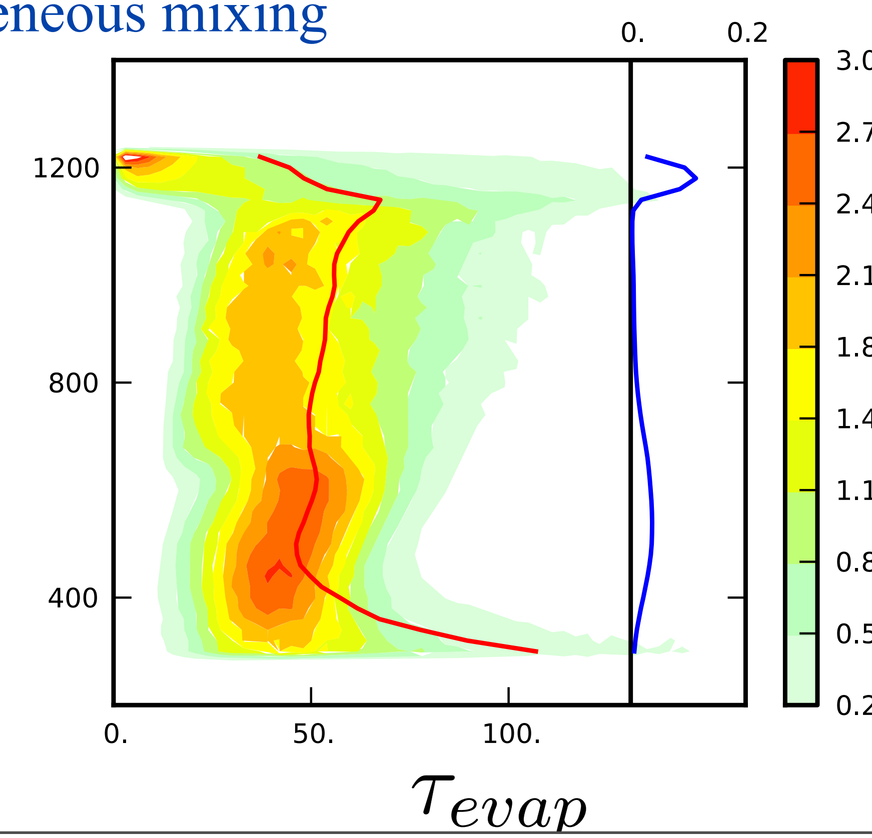


homogeneity of mixing locally can vary significantly!

homogeneous mixing

extremely inhomogeneous mixing





Summary

✦ Predicting scale of cloudy filaments λ allows representing progress of the turbulent mixing between cloudy air and entrained environmental air.

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

http://www.atmos-chem-phys-discuss.net/13/1489/2013/acpd-13-1489-2013.html

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