Entrainment and detrainment in EDMF

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Outline

Entrainment/detrainment in EDMF

New: The dry convection part
(implementation in Harmonie/Arome)

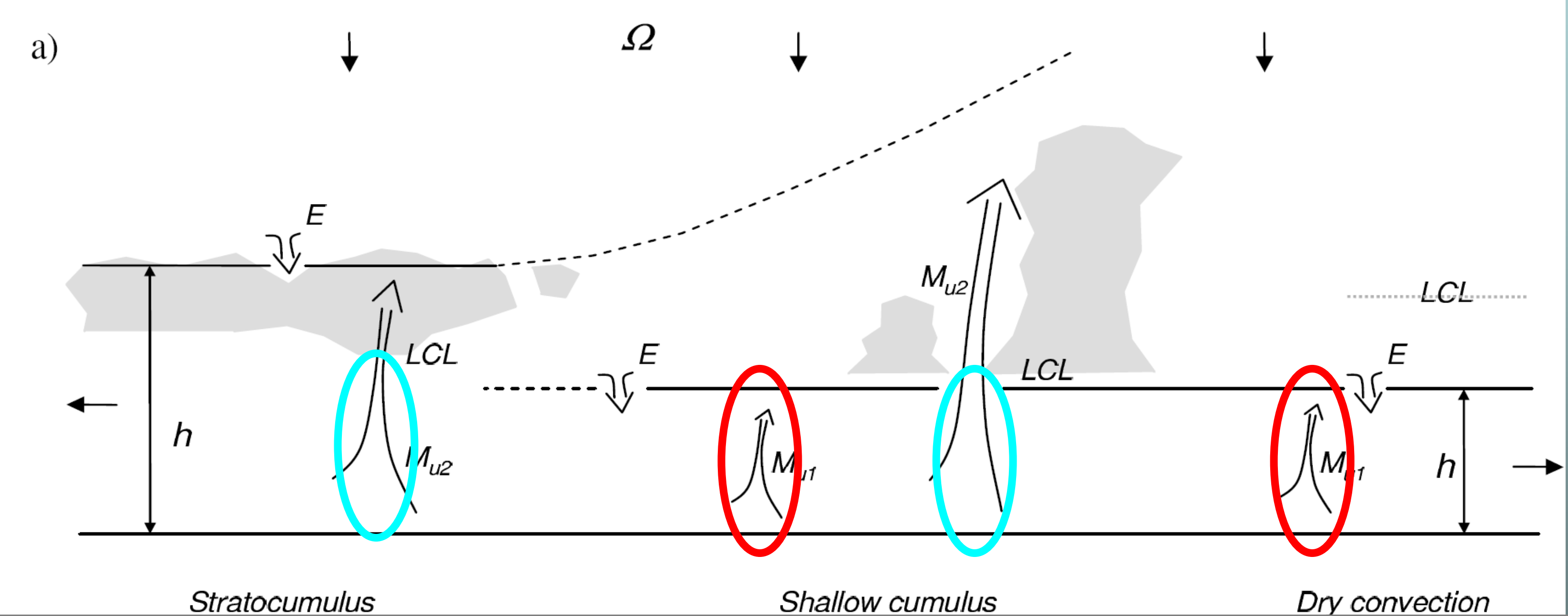
Not new: The moist part
Traditional <-> Unconventional

Conclusions/recommendations

Where dry?

Dual mass flux framework (used in Harmonie)

Roel Neggers et al. 2009



Only moist updraft | Dry and moist updraft | Only dry updraft

Dry

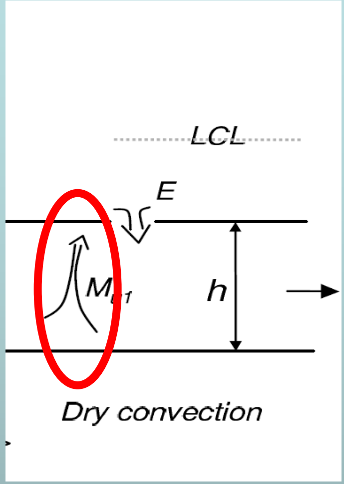
Entrainment formulation for dry convective BL

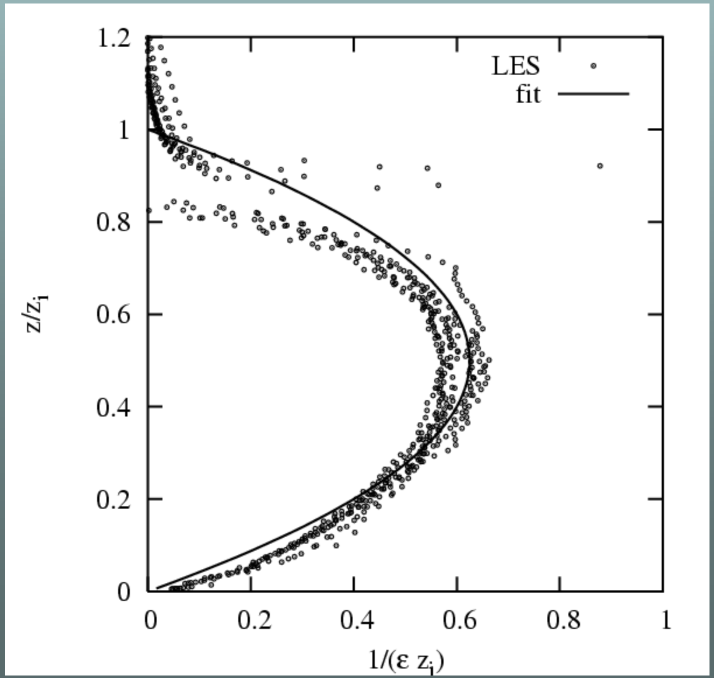
Siebesma et al. 2007

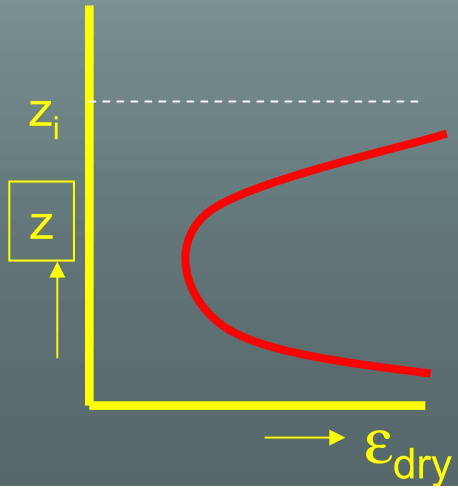
Sampling based on percentile high w

$$\varepsilon = -\frac{\partial \theta_{lu}}{\partial z} / \left(\theta_{lu} - \overline{\theta}_l \right)$$

$$\varepsilon = c_e \left(\frac{1}{z} + \frac{1}{z_i - z} \right)$$







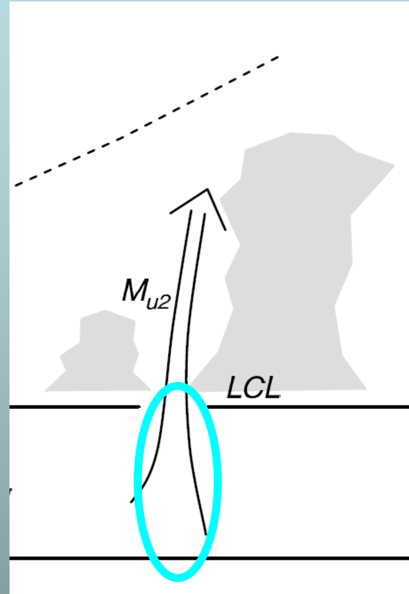
Dry

Entrainment formulation for sub-cloud layer

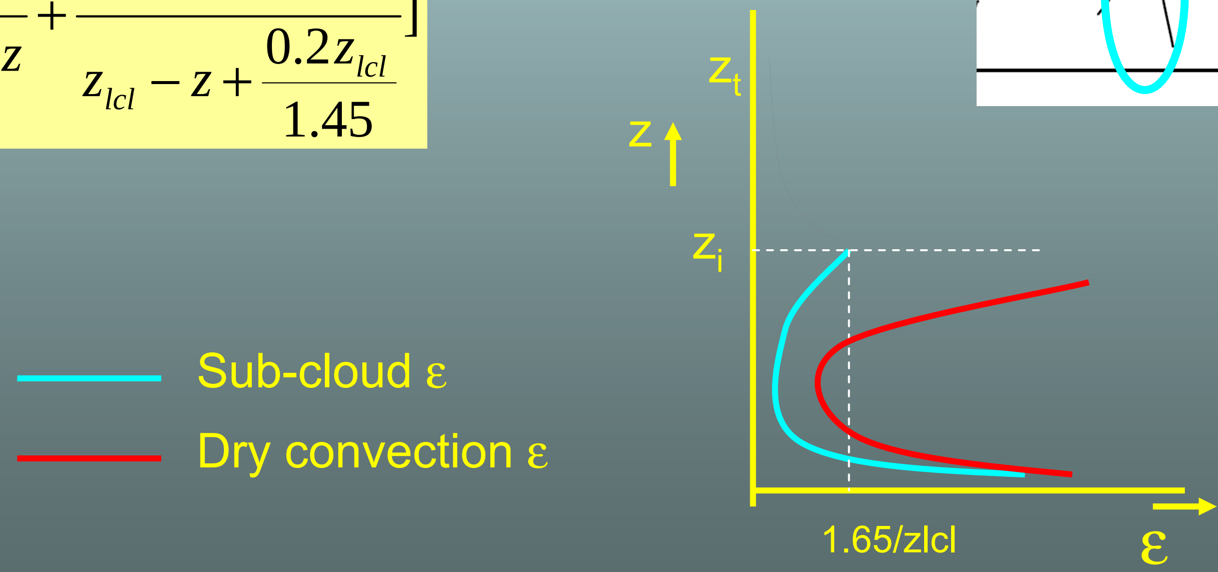
Difference with dry convective BL:

- Vertical velocity ≠ 0 for $z=z_i$
- Stronger, bigger thermals (that can become cloud)

⇒ Building on the work of *Siebesma et al. 2007*



$$\varepsilon = 0.2[\frac{1}{z} + \frac{1}{z_{lcl} - z + \frac{0.2 z_{lcl}}{1.45}}]$$



Where is δ in the dry part?

Nowhere

Some simplifications:

In dry convection mass flux is determined by w_u (constant a)

In sub-cloud linked to mass flux closure at cloud base

Moist

Entrainment and detrainment in the cloud layer

ε and δ have a different role

Continuity eq.: $$\frac{\partial M}{\partial z} = (\varepsilon - \delta) M$$

Entraining plume model: $$\frac{\partial \phi_u}{\partial z} = \varepsilon(\phi_u - \overline{\phi}) \qquad \phi \in \{q_t, \theta_l\}$$

So:
ε and δ determine the mass flux profile
and
ε determines the dilution

Moist

In the cloud layer

- Almost all convection (and EDMF) schemes prescribe some kind of function for ε and δ

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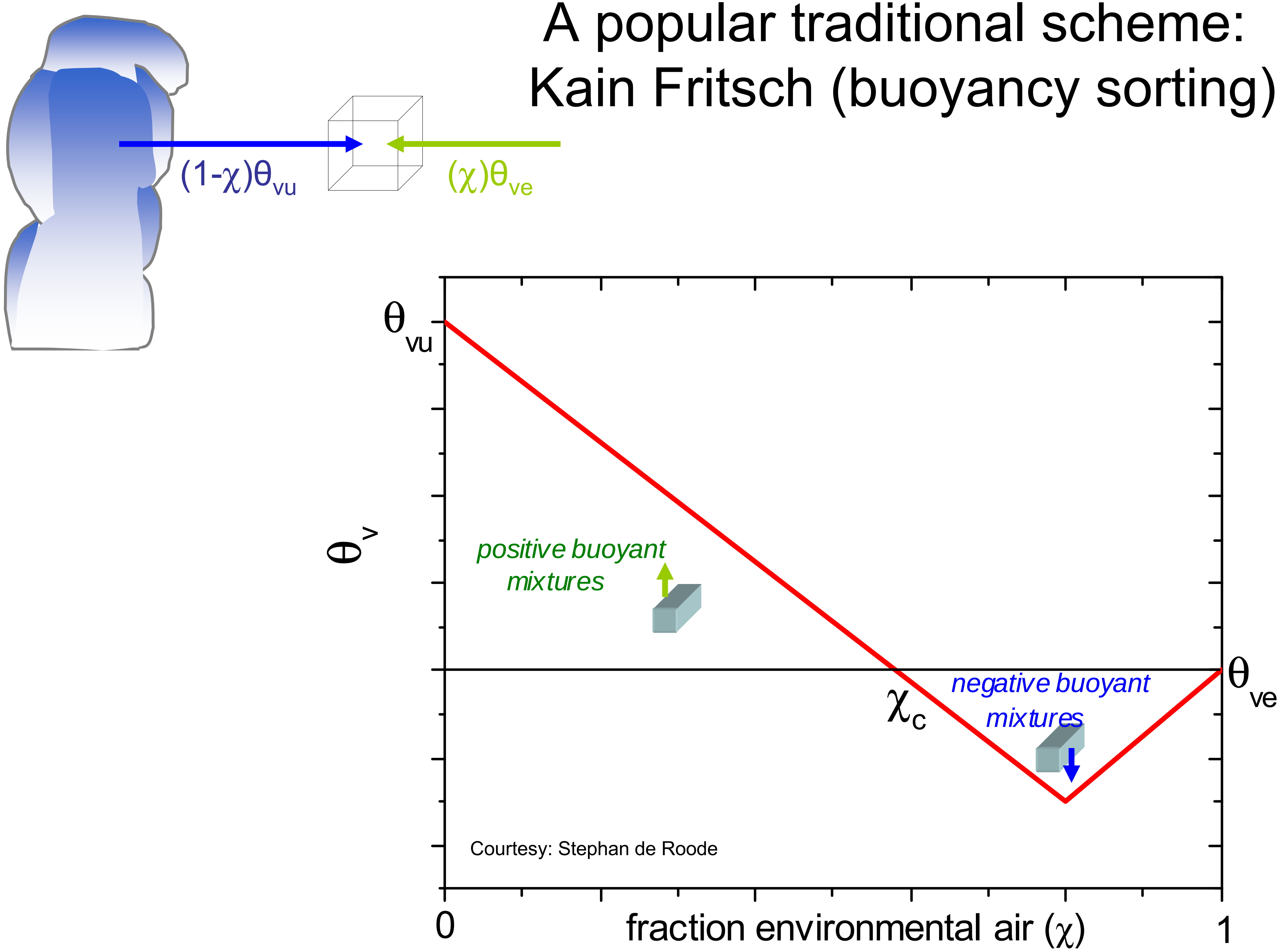
Example of such a “traditional” scheme (Kain Fritsch)

A popular traditional scheme: Kain Fritsch (buoyancy sorting)



Kain Fritsch

- Several (tunable) parameters have to be chosen but in principle:

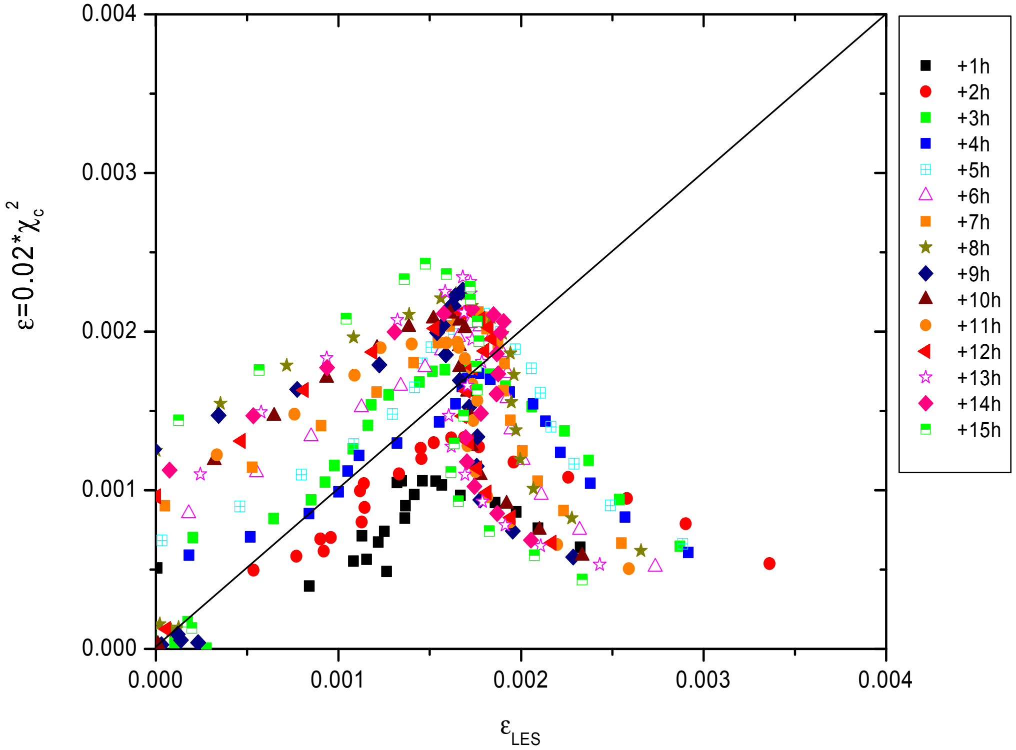
$$\varepsilon_{KF} = \varepsilon_0 \cdot \chi_c^2$$

$$\delta_{KF} = \varepsilon_0 \cdot (1 - \chi_c^2)$$

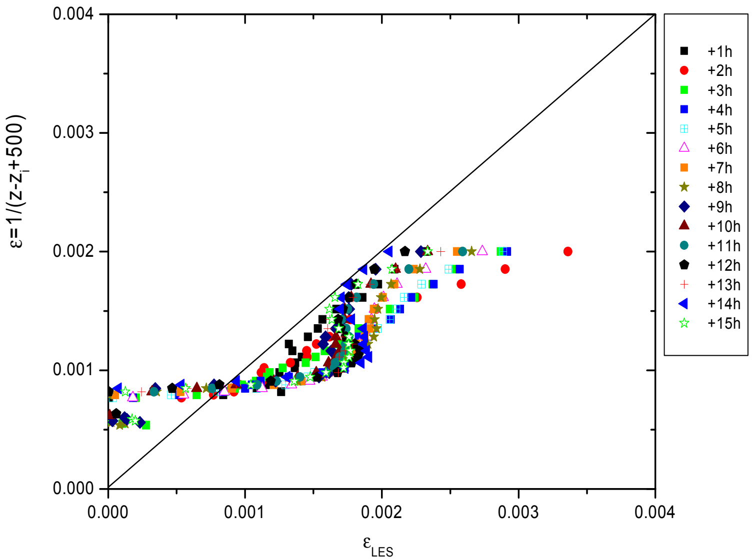
How well do they perform?
(validated against LES diagnosis)

Kain Fritsch entrainment (dilution)

BOMEX case: Kain Fritsch ε with optimal ε_0



BOMEX case: $\varepsilon=(z-z_i+500)^{-1}$



Kain Fritsch ε not very suitable for describing the dilution

But there is something else

how about the mass flux profile?

$$\varepsilon_{KF} = \varepsilon_0 \cdot \chi_c^2 \qquad \delta_{KF} = \varepsilon_0 \cdot (1 - \chi_c^2)$$

ε_{KF} and δ_{KF} vary in a similar but opposite way to χ_c^2 and therefore have a similar influence on mass flux profile variations

However

- Variations in the mass flux profile are strongly dominated by δ!

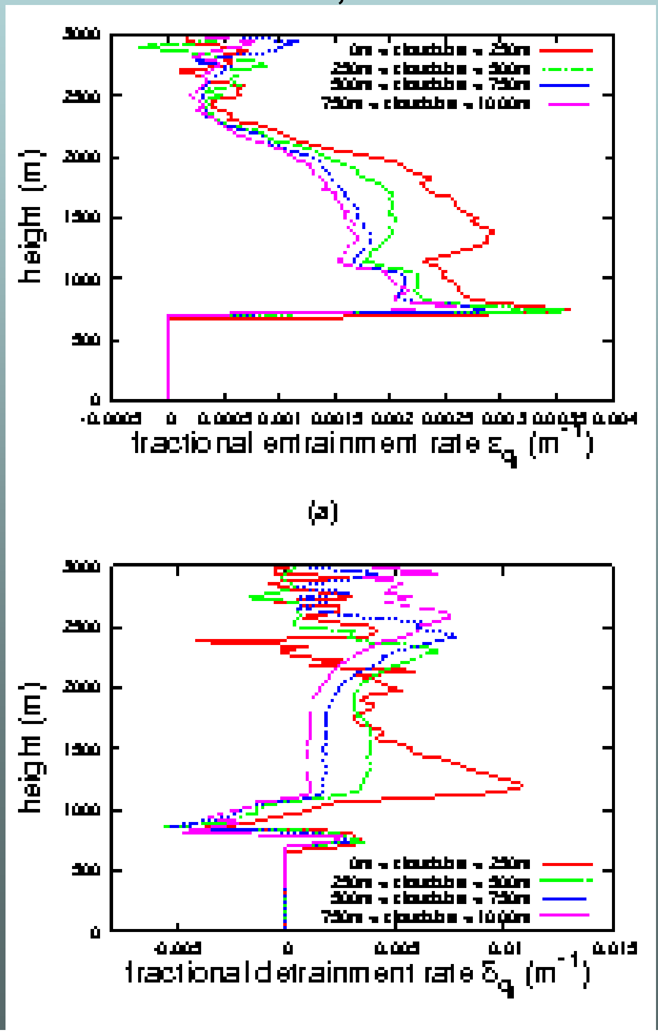
•Empirical arguments

•Theoretical arguments

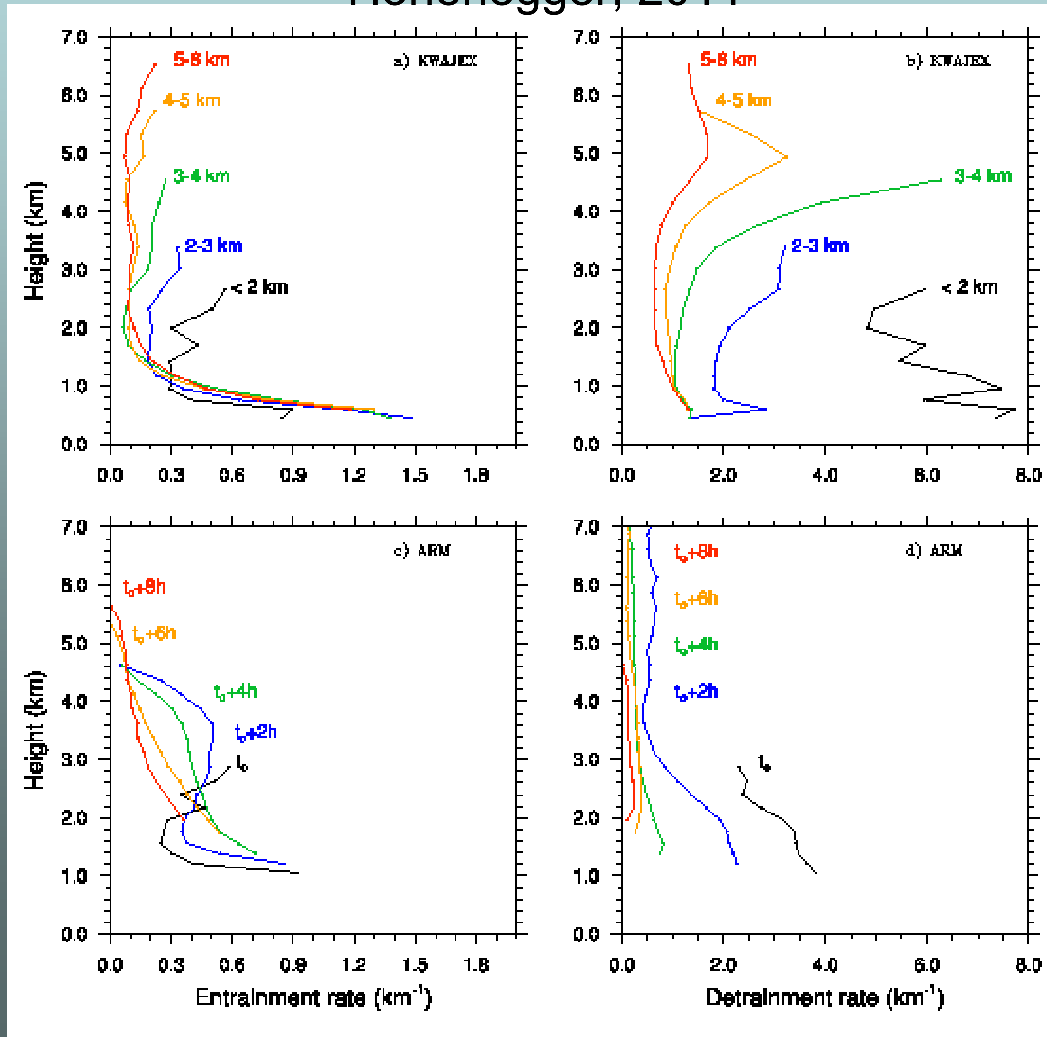
Empirical arguments

Much larger variation in δ from case to case, hour to hour, different cloud sizes

Jonker et al., 2006

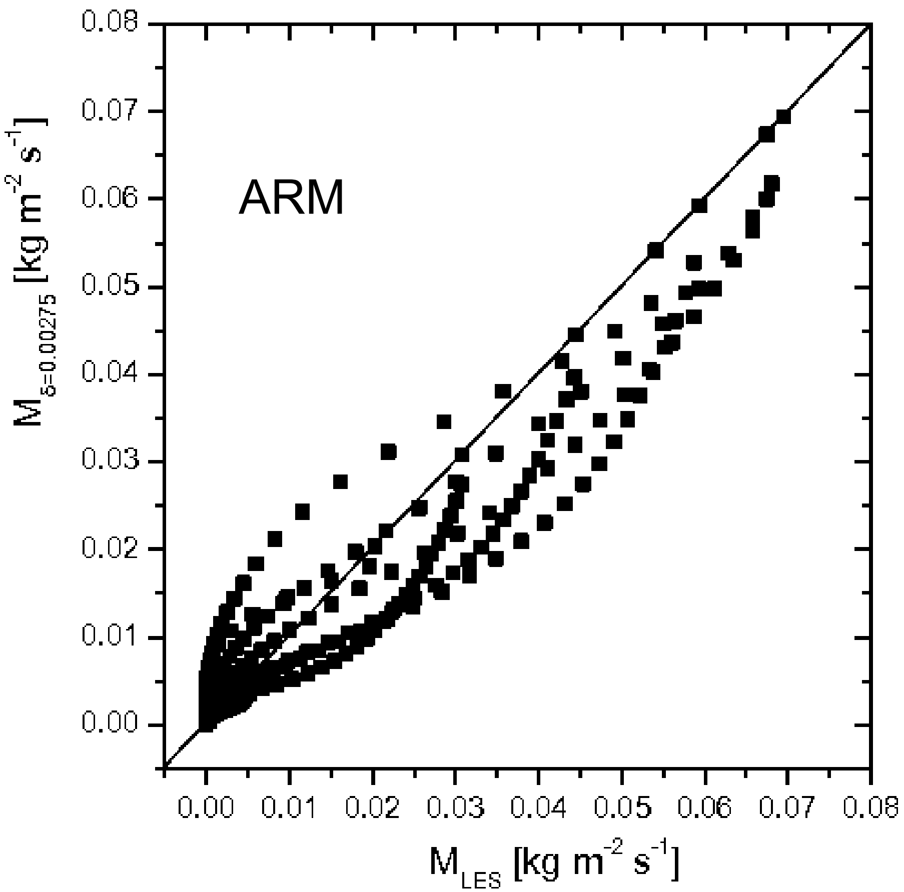


Hohenegger, 2011

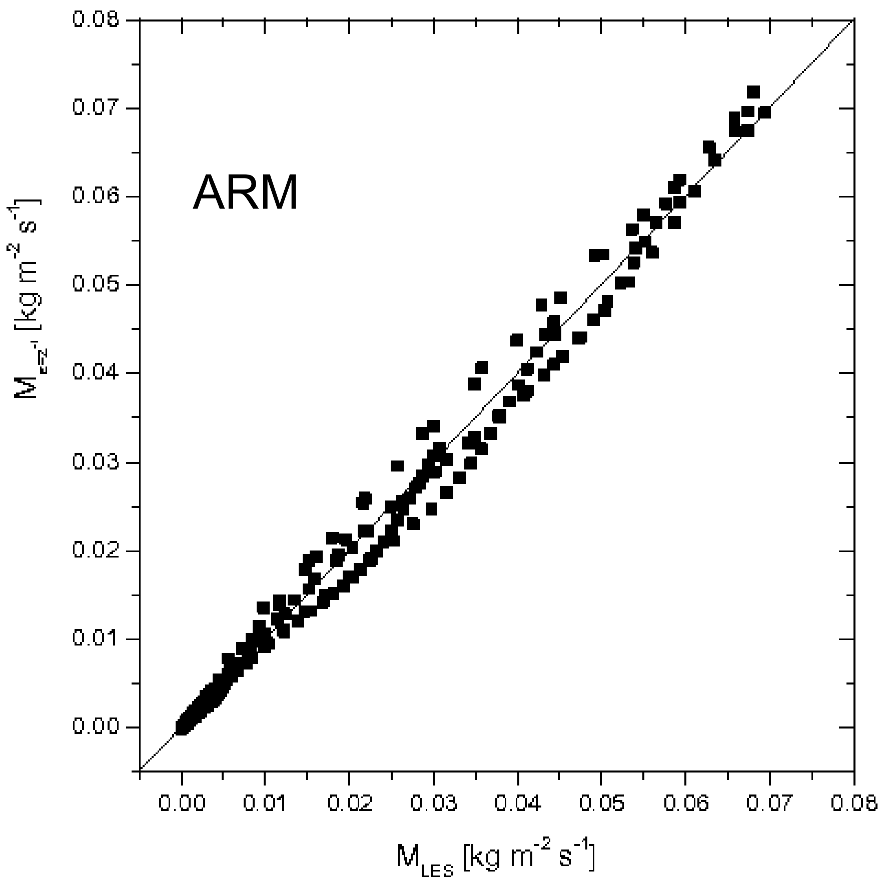


Empirical arguments

Optimal fixed δ and ε_{LES}



Optimal fixed ε and δ_{LES}



De Rooy & Siebesma, 2008

Theoretical arguments

De Rooy & Siebesma, QJRMS 2010

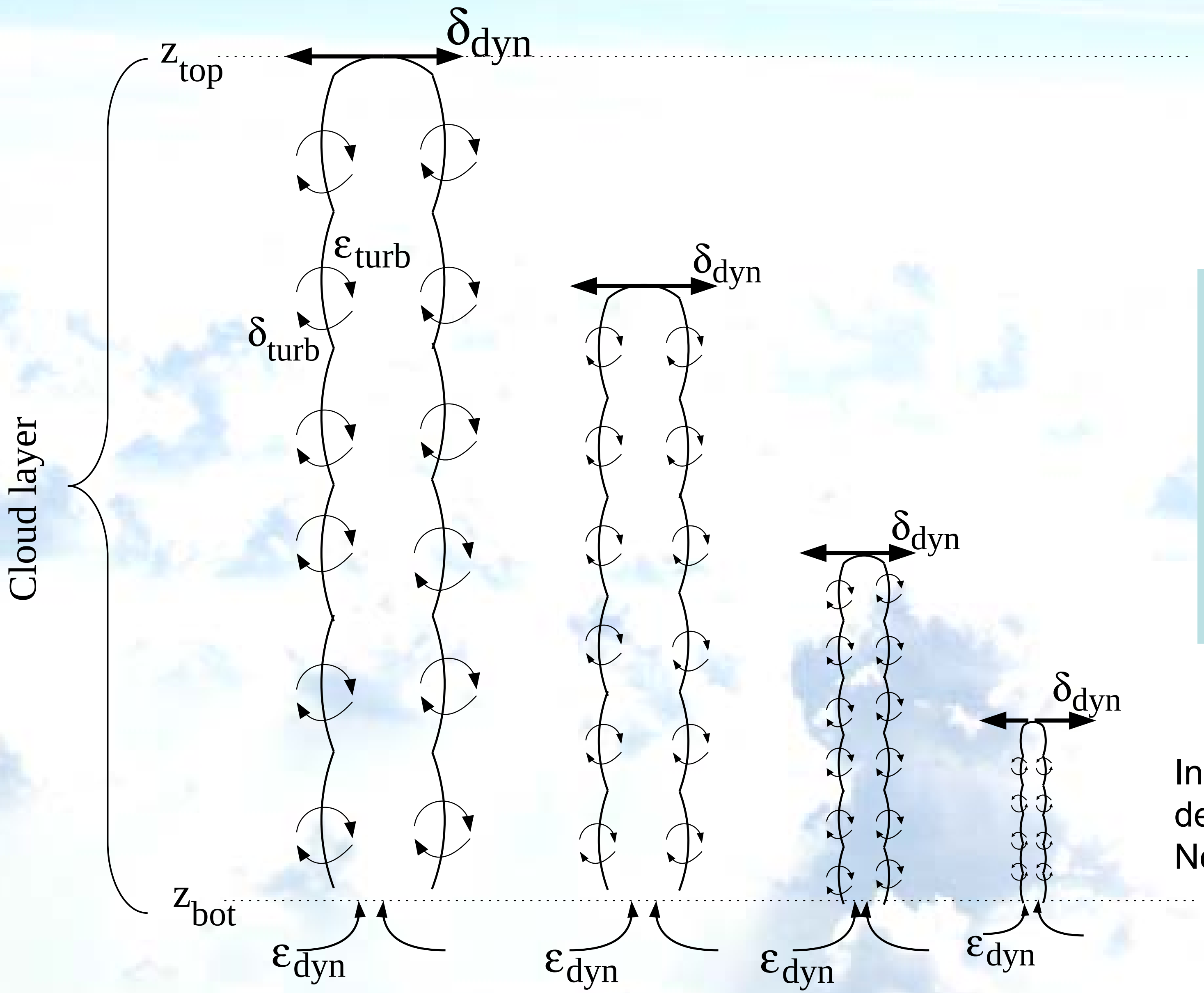
Starting from general in-cloud field budget equation for q_t (Siebesma, 1998)

$$\varepsilon = \frac{\eta L_b}{A_c} + H(-u_b)\frac{1}{M}\frac{\partial M}{\partial z} \equiv \varepsilon_{turb} + \cancel{\varepsilon_{dyn}}$$

$$\delta = \frac{\eta L_b}{A_c} - H(u_b)\frac{1}{M}\frac{\partial M}{\partial z} = \delta_{turb} + \delta_{dyn}$$

Shallow Convection:
Usually dM/dz<0

Cloud ensemble (divergent (shallow) condition)



$$\varepsilon = \varepsilon_{turb} + \cancel{\varepsilon_{dyn}}$$

$$\delta = \delta_{turb} + \delta_{dyn}$$

In the cloud layer:

$$\delta \sim \frac{1}{M}\frac{\partial M}{\partial z} \sim$$

$$\frac{1}{M}\frac{\Delta M}{\Delta z} \sim \frac{1}{\Delta z}$$

Included in:
de Rooy & Siebesma 08
Neggers et al. 09

What are the consequences?

As far as variations in the (non-dim) mass-flux profile concerns:
Use a (simple) fixed function for ε but a flexible δ

=

Parameterize the mass-flux profile
(in terms of environmental and updraft conditions)

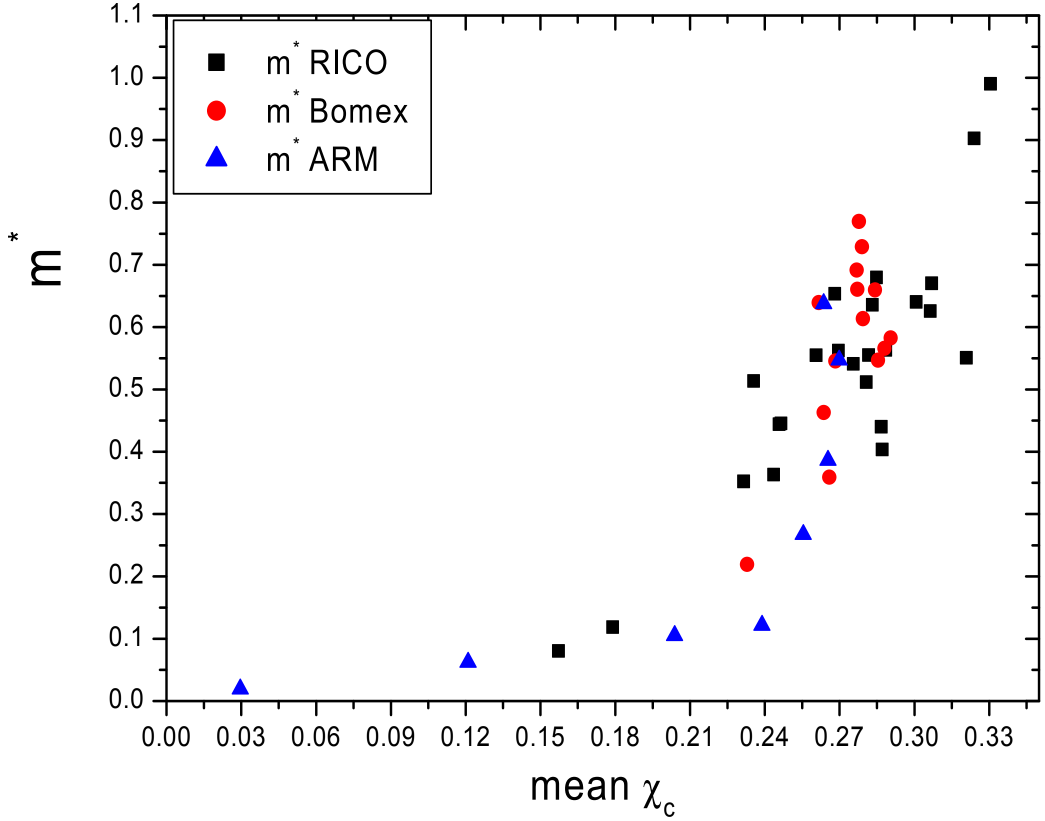
So no explicit ε and δ for M profile!

Unconventional:
Separate entrainment (dilution) and mass flux profile!
De Rooy & Siebesma 2008
Neggers et al. 2009

Some advantages:

- Mass flux parameterizations can be related to observations and LES
- Function of ε can be dedicate to a good description of the dilution

From LES, the change of the non-dimensionalized mass flux as a function of $\overline{\chi}_c$



De Rooy & Siebesma, 2008

Short D-tour: How can we proceed with the expressions:

$$\varepsilon = \frac{\eta L_b}{A_c} + H(-u_b)\frac{1}{M}\frac{\partial M}{\partial z} \equiv \varepsilon_{turb} + \varepsilon_{dyn}$$

$$\delta = \frac{\eta L_b}{A_c} - H(u_b)\frac{1}{M}\frac{\partial M}{\partial z} = \delta_{turb} + \delta_{dyn}$$

Use continuity eq. to eliminate u_b

Use vertical velocity eq. to eliminate η

Expressions independent of divergence/convergence

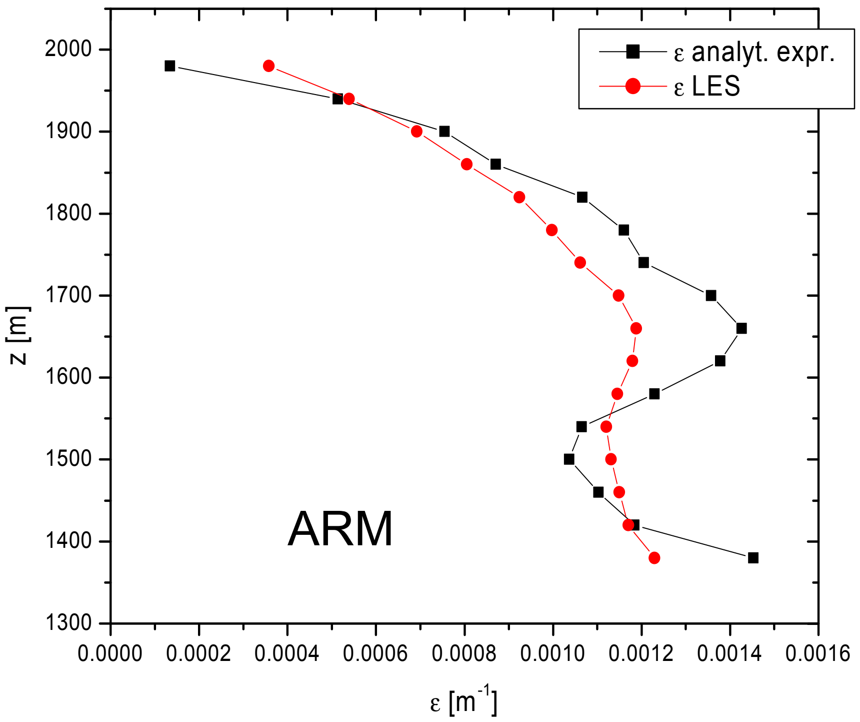
$$\varepsilon_{\exp} = \frac{\alpha B}{w_c^{\ 2}} - \frac{1}{w_c}\frac{\partial w_c}{\partial z}$$

$$\delta_{\exp} = \frac{\alpha B}{w_c^{\ 2}} - \frac{2}{w_c}\frac{\partial w_c}{\partial z} - \frac{1}{a_c}\frac{\partial a_c}{\partial z}$$

!

How do the analytical expressions perform against LES?

Example for $\varepsilon_{\exp} = \frac{\alpha B}{w_c^{\ 2}} - \frac{1}{w_c} \frac{\partial w_c}{\partial z}$



Analytical expression cannot be directly applied as parameterization

However, iteration procedure Alison Stirling & R. Wong (to be submitted to QJRMS) Expressions perform well for a wide variety of conv. cases

Conclusions/Recommendations

- Keep parameterizations as simple as possible.
  Just enough complexity to include the most relevant processes
- Proposed ε, δ are strongly coupled to LES (i.o. tuned)
- Treat dilution (ε) and mass-flux profile separately
  - Empirical/physical bases
  - Flexibility
  - Robustness
- Analytical expressions give insight. Also: ε_{exp} promising as parameterization of dilution


Thank you
Questions?