A new multi-plume model for the shallow cumulus convection based on the buoyancy-sorting mechanism

Ji Nie[1,2] and Zhiming Kuang[2]
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1. Columbia University
2. Harvard University

Motivation:

Comparing with a bulk plume model, a multiple plume(parcel) model has the advantages that

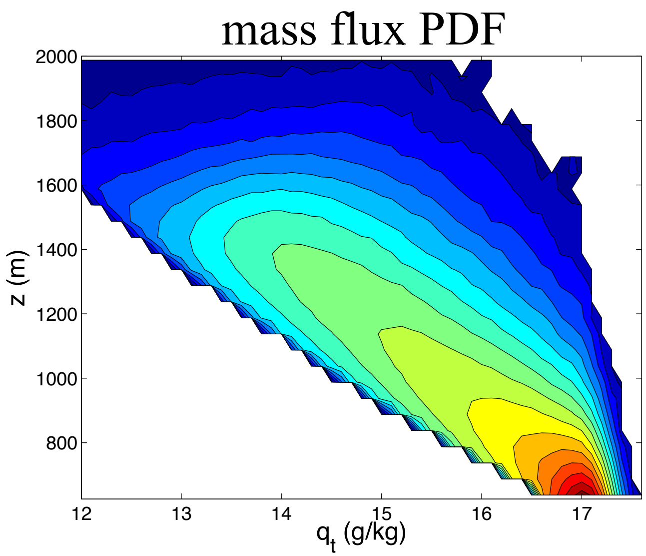
- it can represent heterogeneity among cloudy updrafts.
- it can be used with sophisticated microphysics scheme.
- it allows more realistic representation of entrainment and detrainment.

In this talk,

we propose a simply multiple plume model that applies the buoyancy-sorting mechanism to a mapping framework.

background:
a multiple plume representation of convection

A multiple plume model should aim to reproduce realistic cloudy updraft PDFs.



Large-Eddy Simulation(LES): SAM 25m

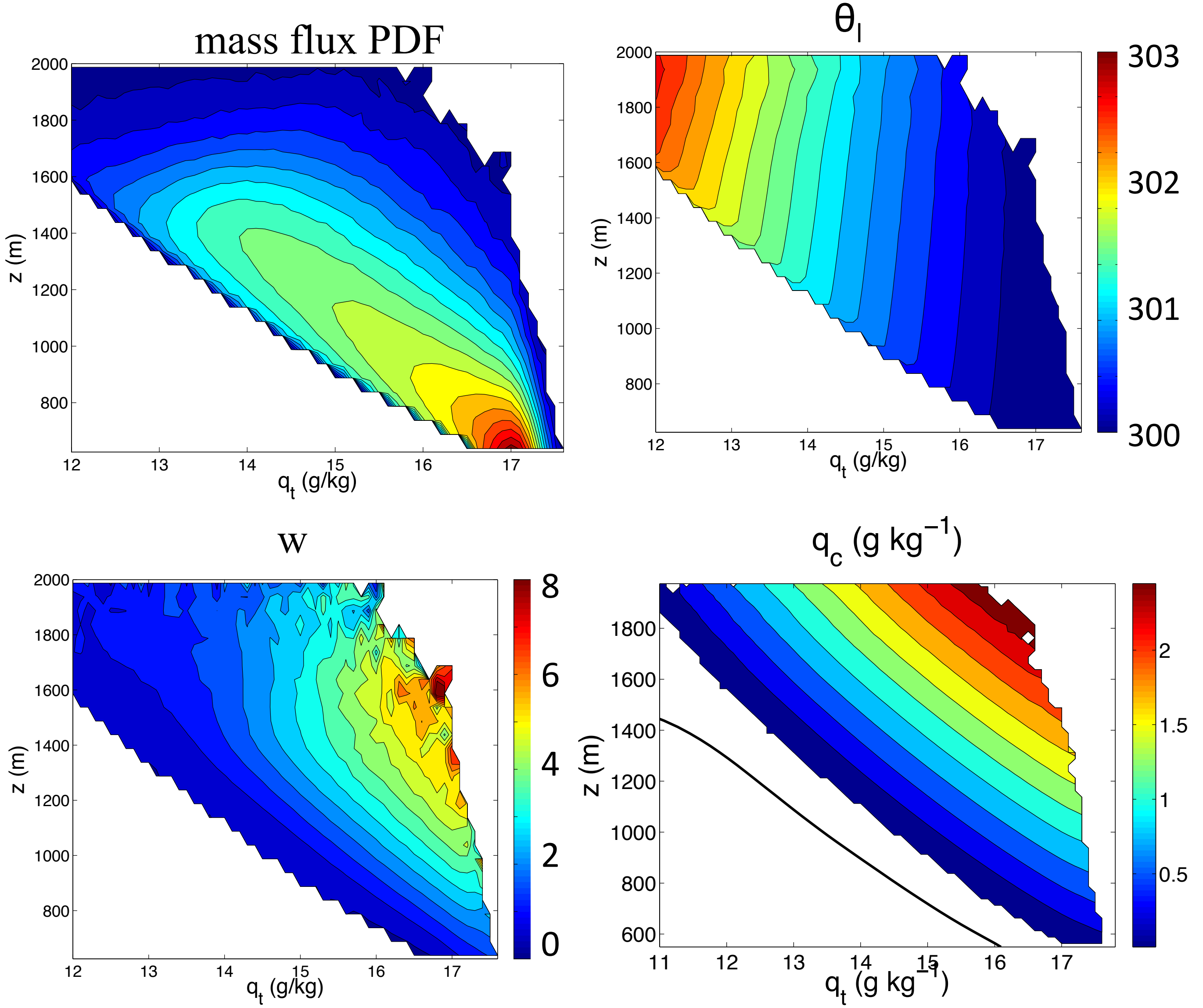
BOMEX case: shallow cumulus convection

background:
a multiple plume representation of convection

A multiple plume model should aim to reproduce realistic cloudy updraft PDFs.

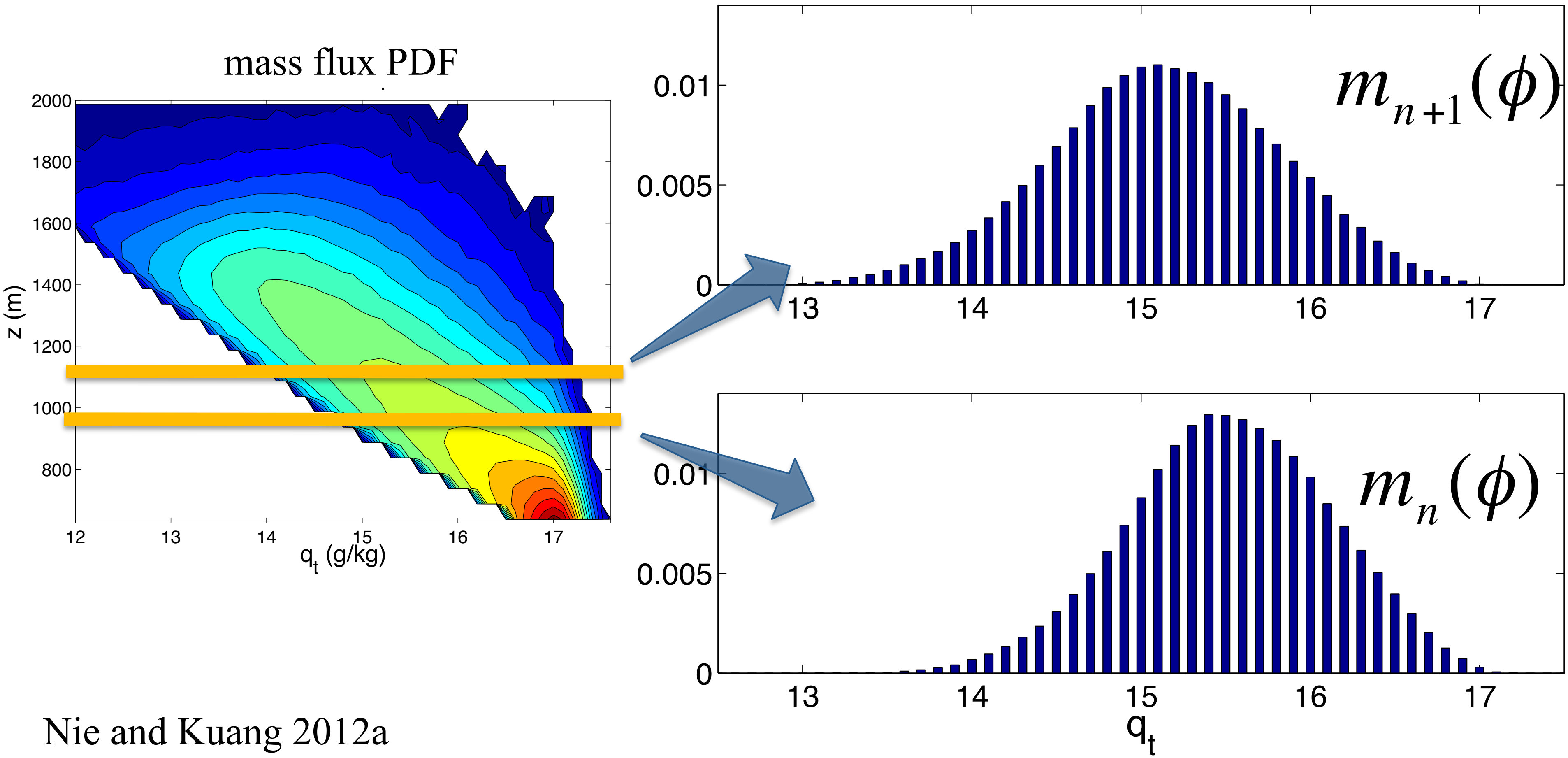
$$m_n(\phi)$$

$$\phi \sim q_t$$



a mapping view of the multiple plume models:

$$m_{n+1}(\phi) = G(\phi, \phi) m_n(\phi)$$



Nie and Kuang 2012a

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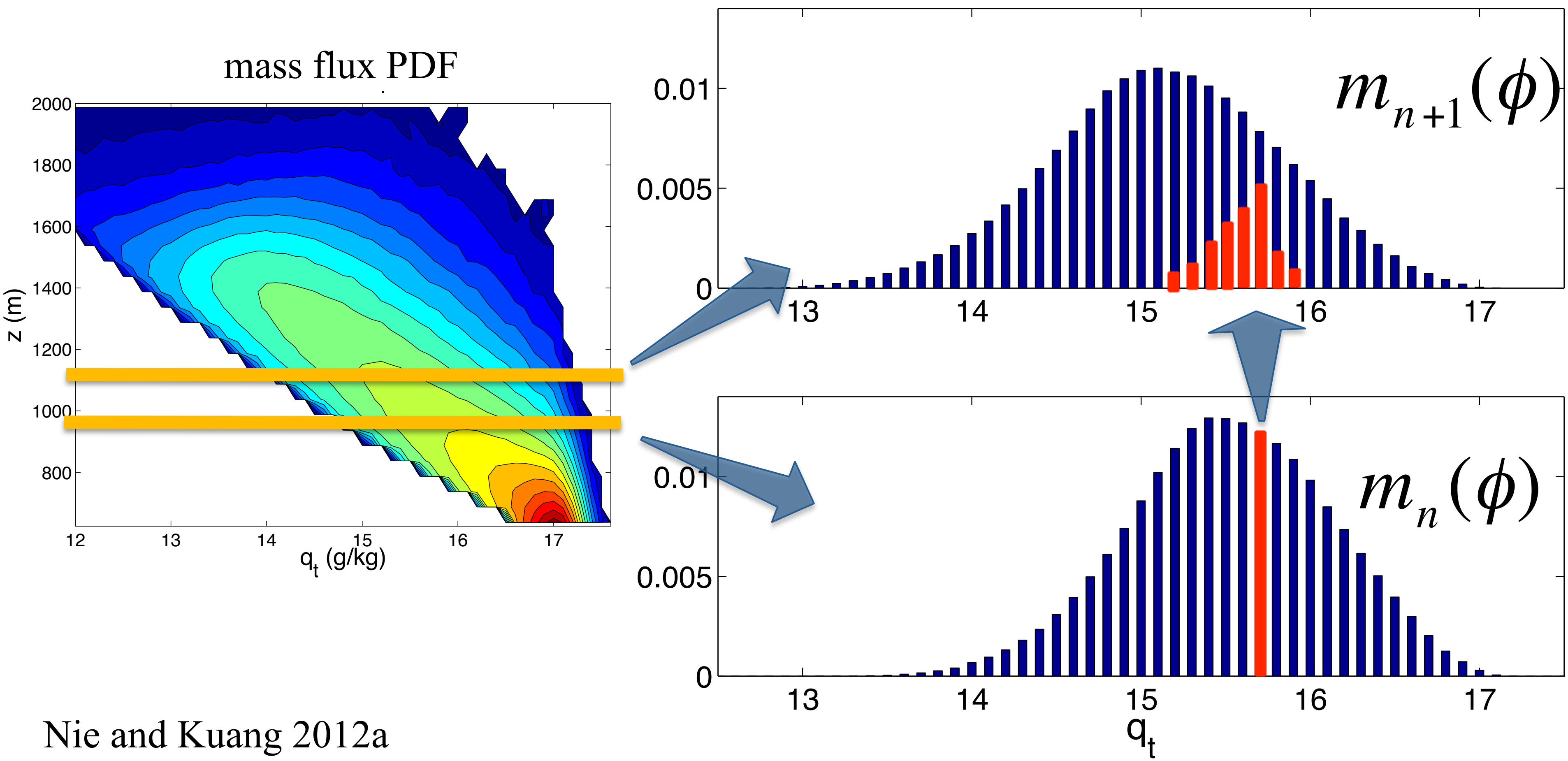
$$m_{n+1}(\phi) = G(\phi,\phi)m_n(\phi)$$



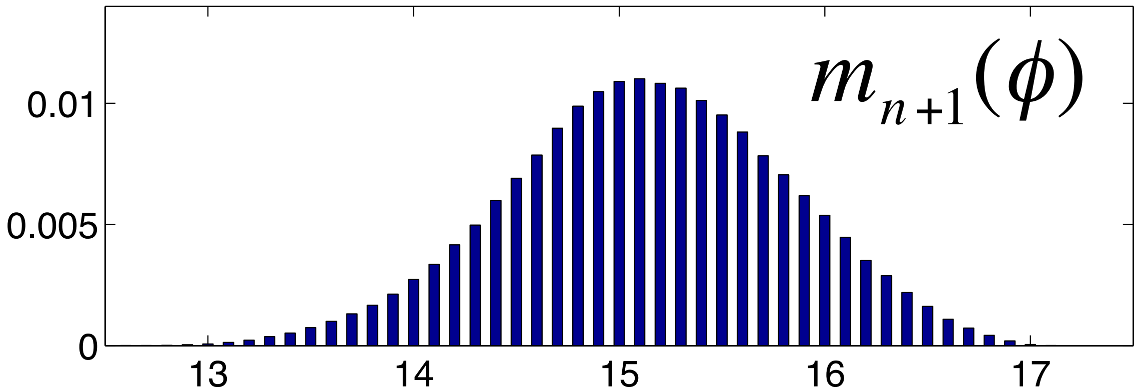
Nie and Kuang 2012a

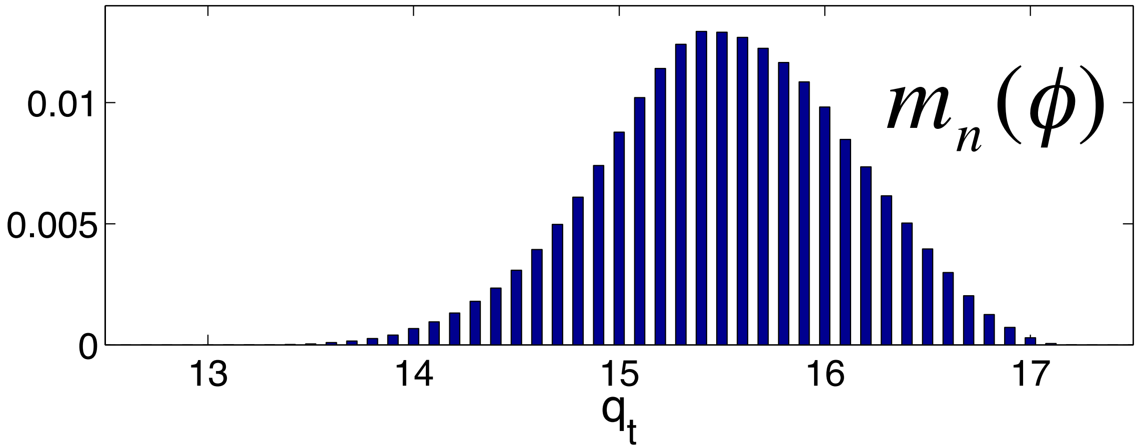
By tracking Lagrangian partials, one can diagnose the mapping matrices from LES. (Nie and Kuang 2012a)

In the mapping framework, we want to build a multi-plume model with least complexity.

Building the model:

$$m_{n+1}(\phi) = G(\phi,\phi) m_n(\phi)$$

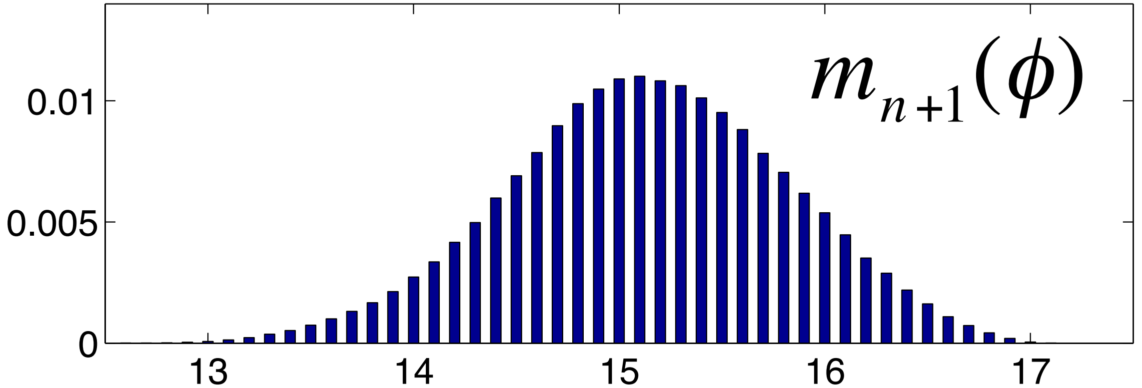


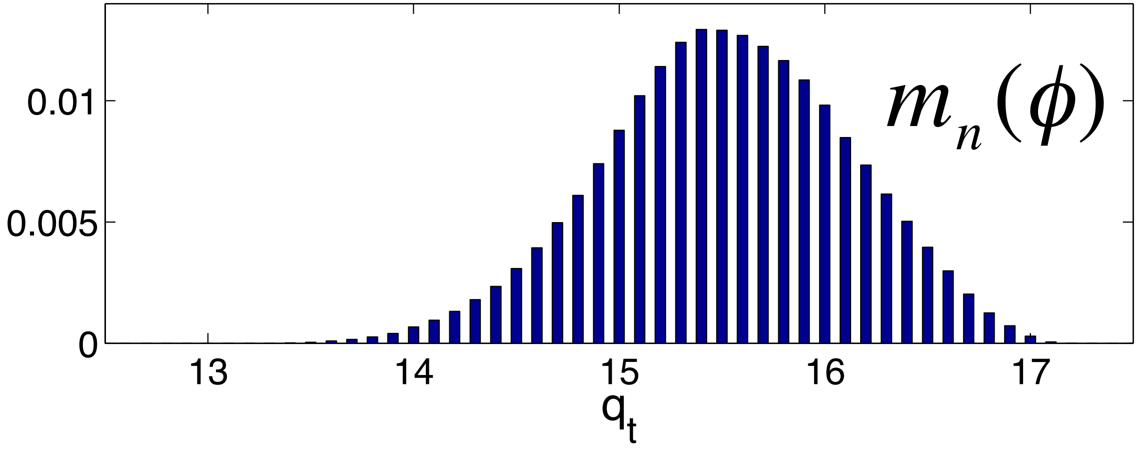


Building the model:

the buoyancy-sorting mechanism

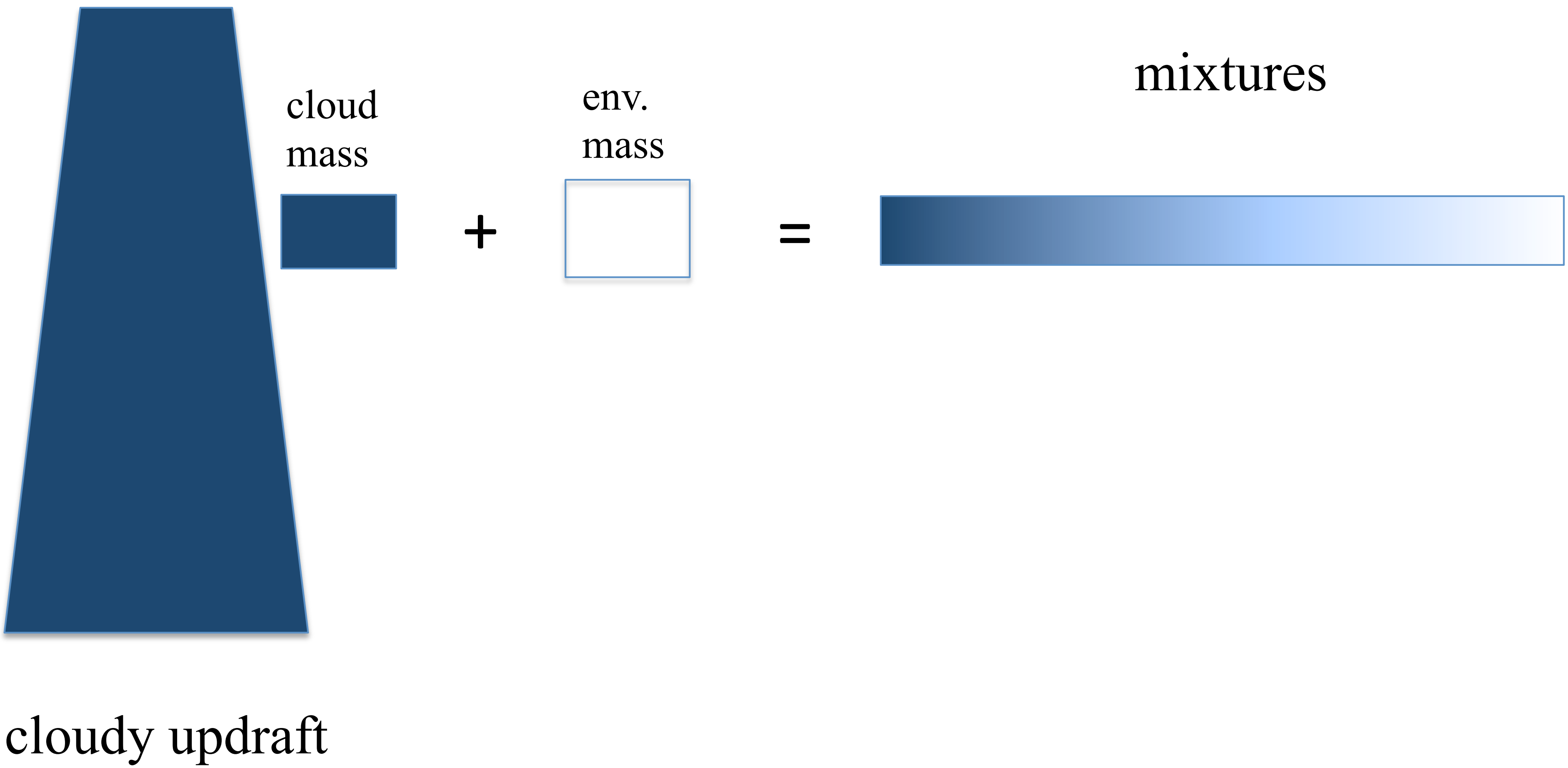
$$m_{n+1}(\phi) = G(\phi,\phi)m_n(\phi)$$





the buoyancy-sorting mechanism:

(e.g. Raymond and Blyth 1986, Emanuel 1991, Bretherton *et al.* 2004, …)

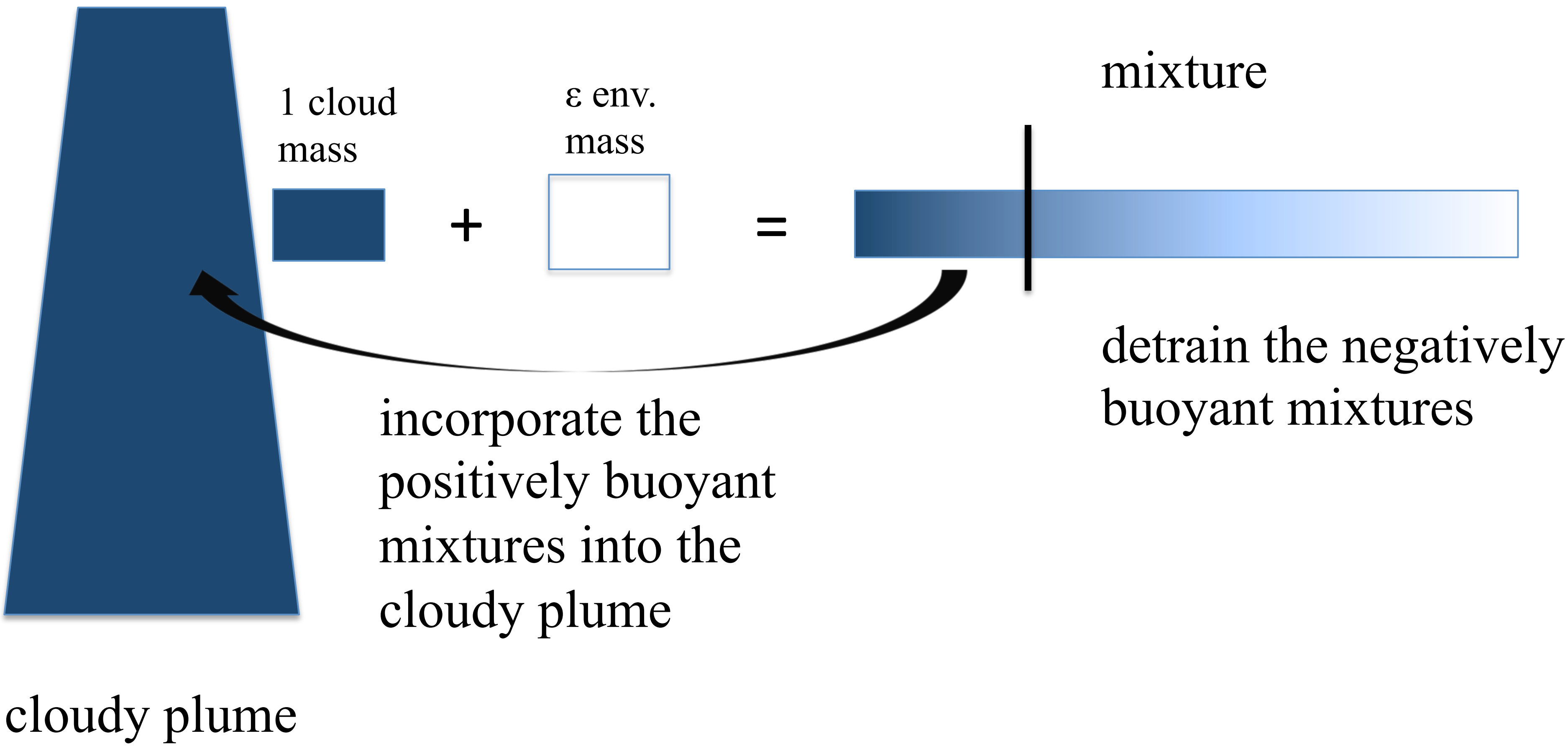


UW convective scheme

(Bretherton *et al.* 2004)

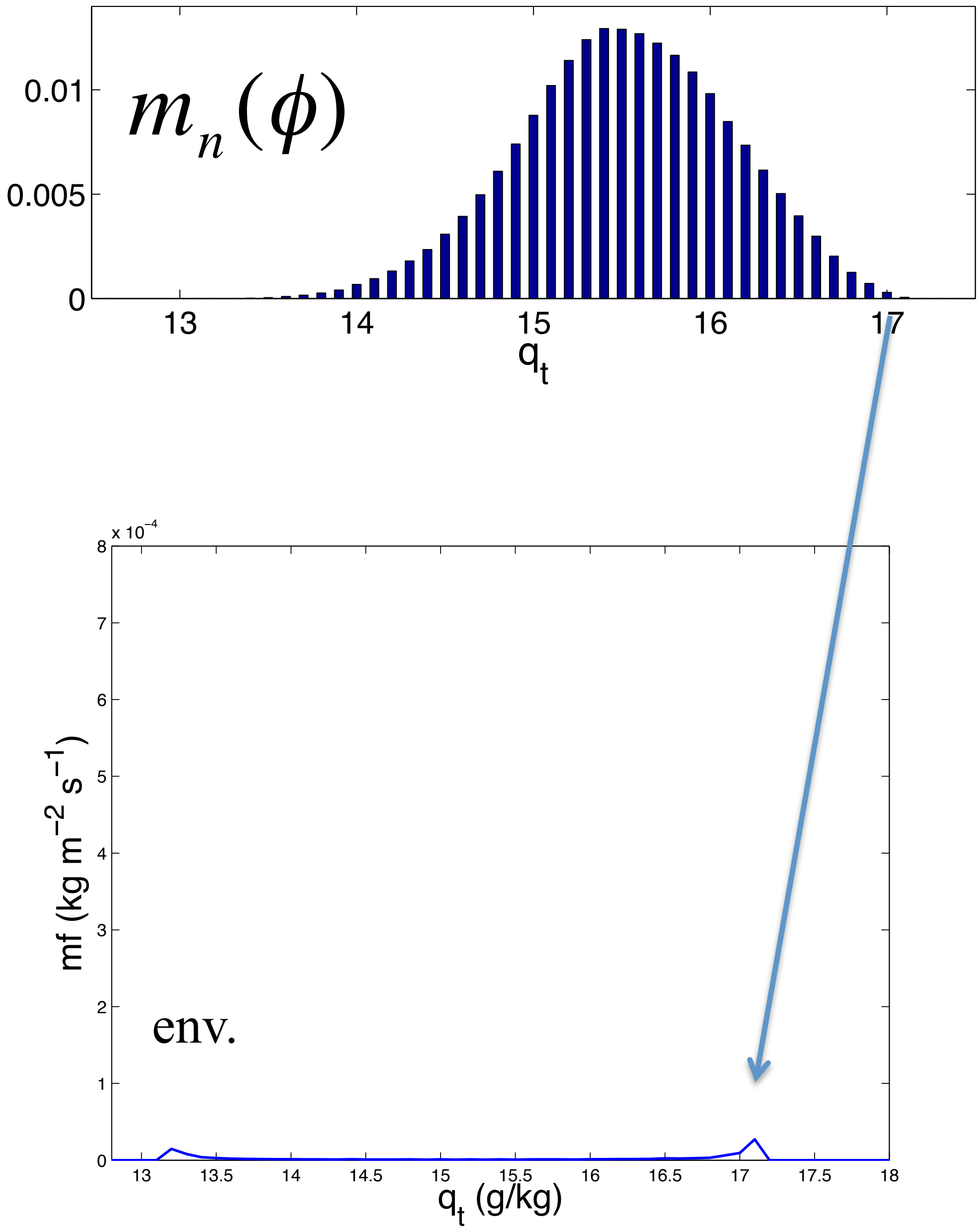
introductions of the buoyancy-sorting mechanism:

(e.g. Raymond and Blyth 1986, Emanuel 1991, Bretherton *et al.* 2004, …)

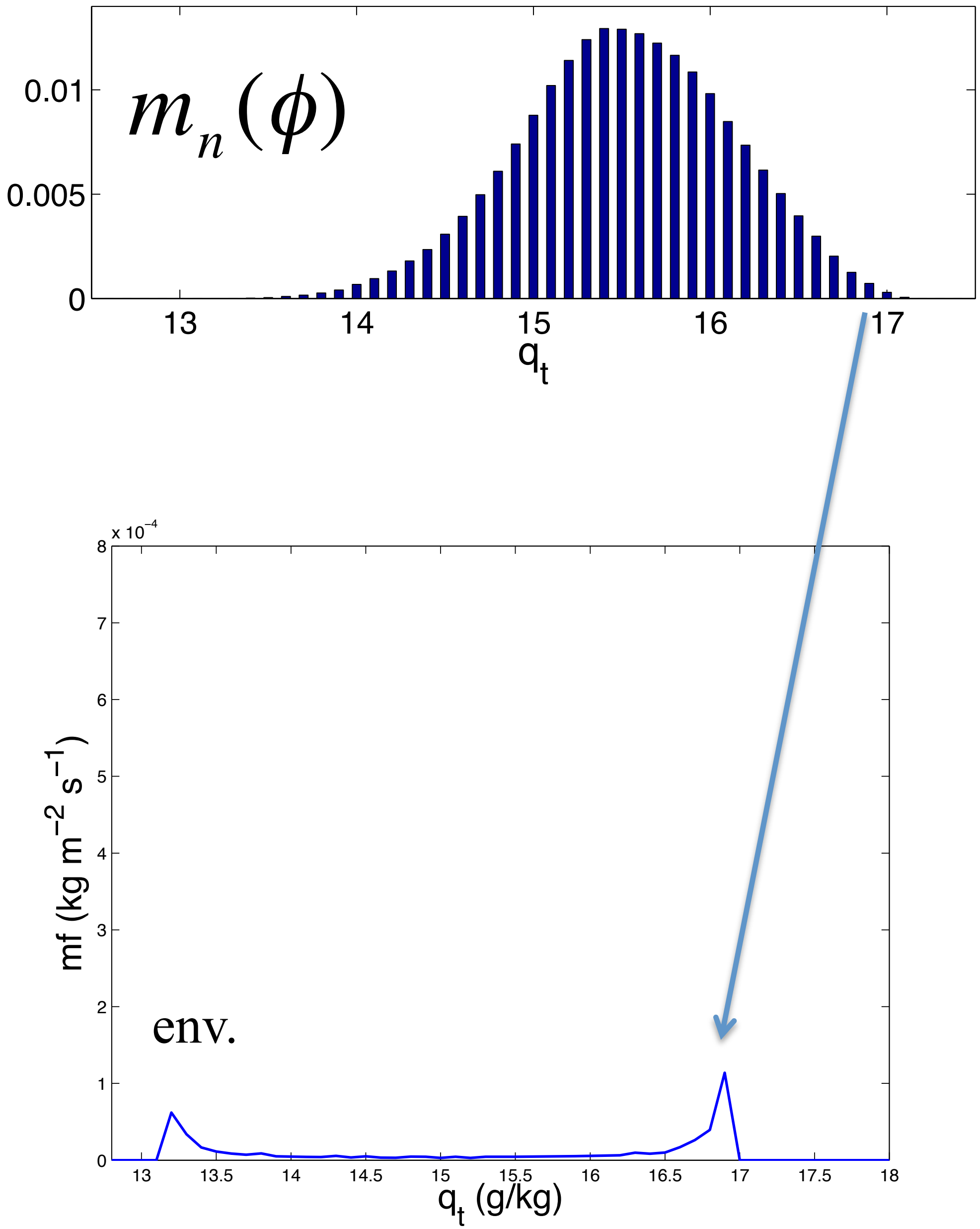


UW convective scheme
(Bretherton *et al.* 2004)

Building the model:
mapping from level n to n+1



Building the model: mapping from level n to n+1



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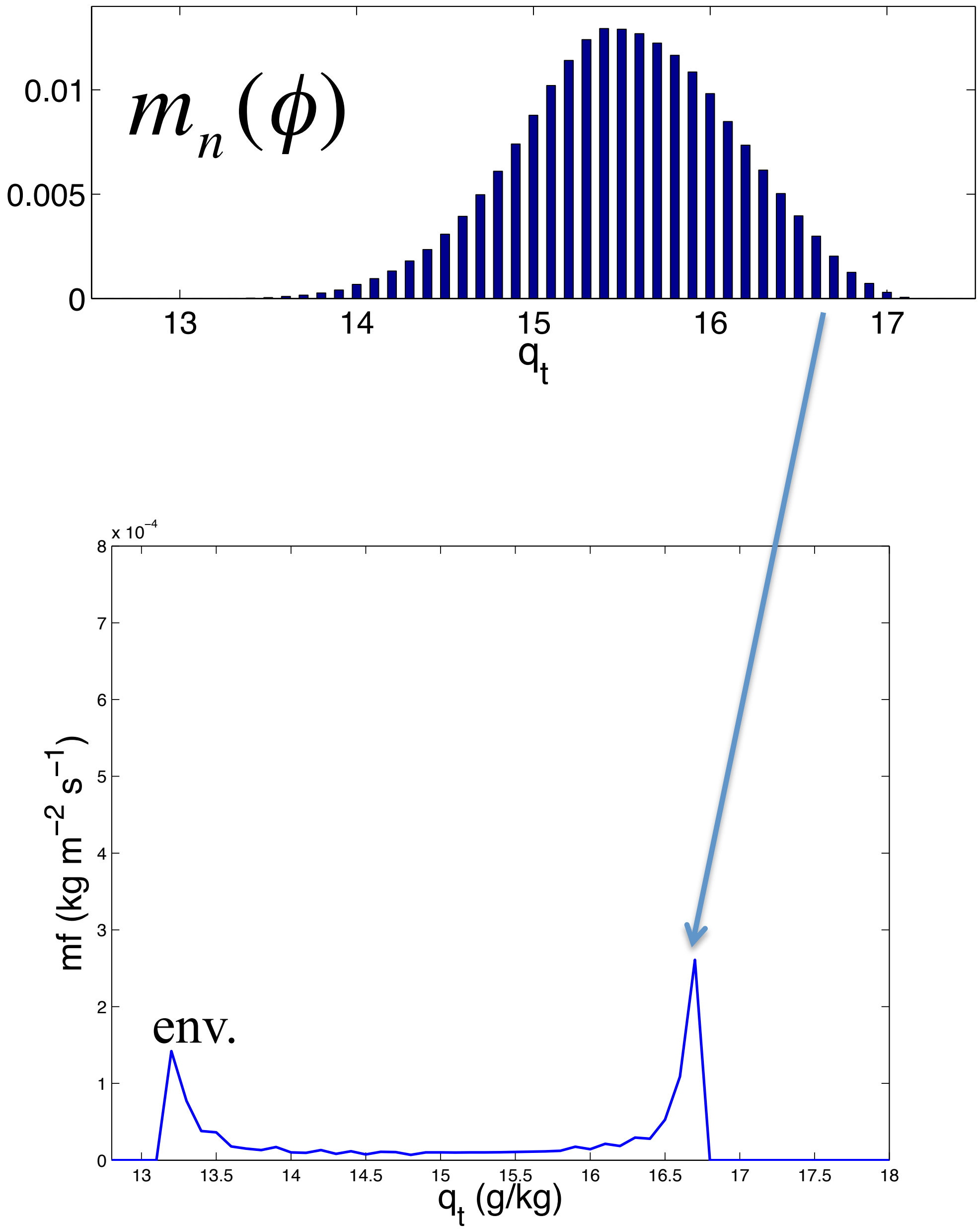

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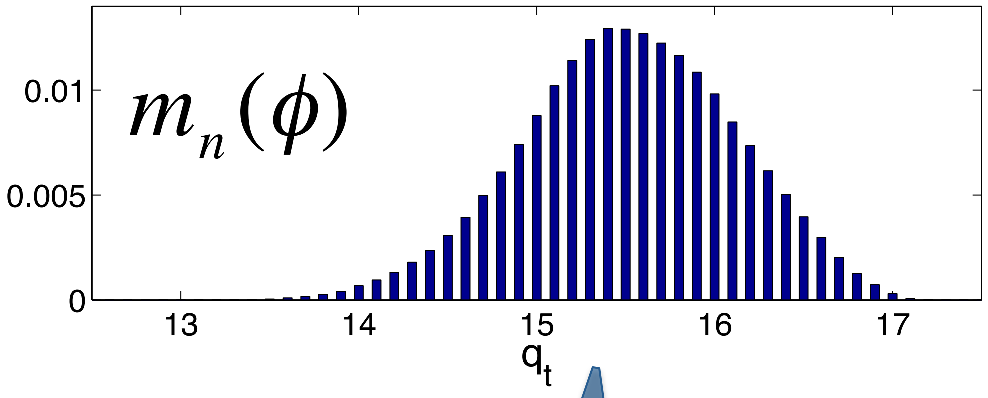
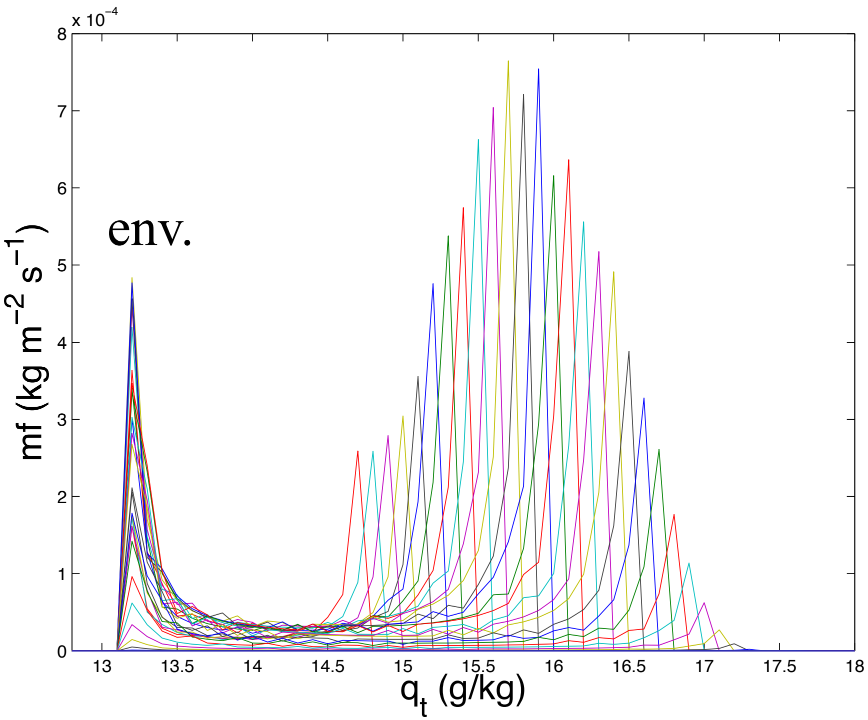
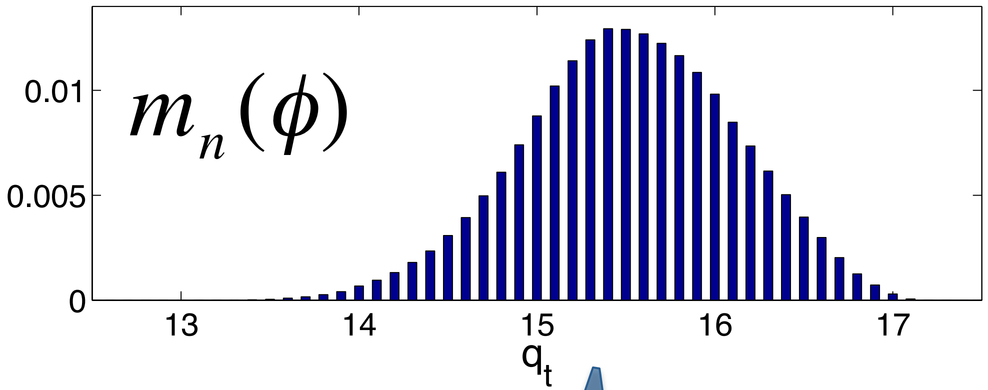


mixing with env.



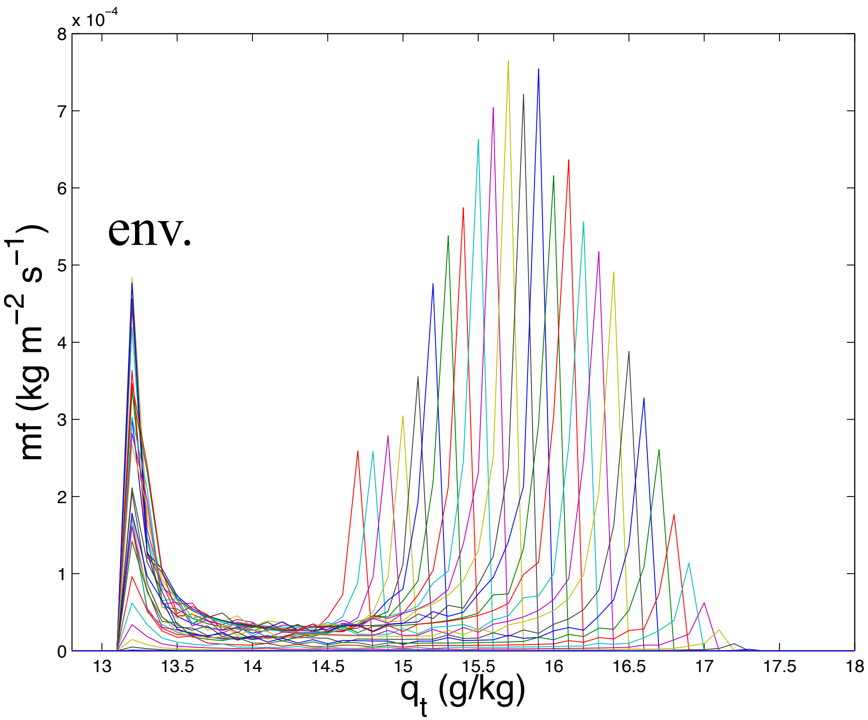
Building the model: mapping from level n to n+1

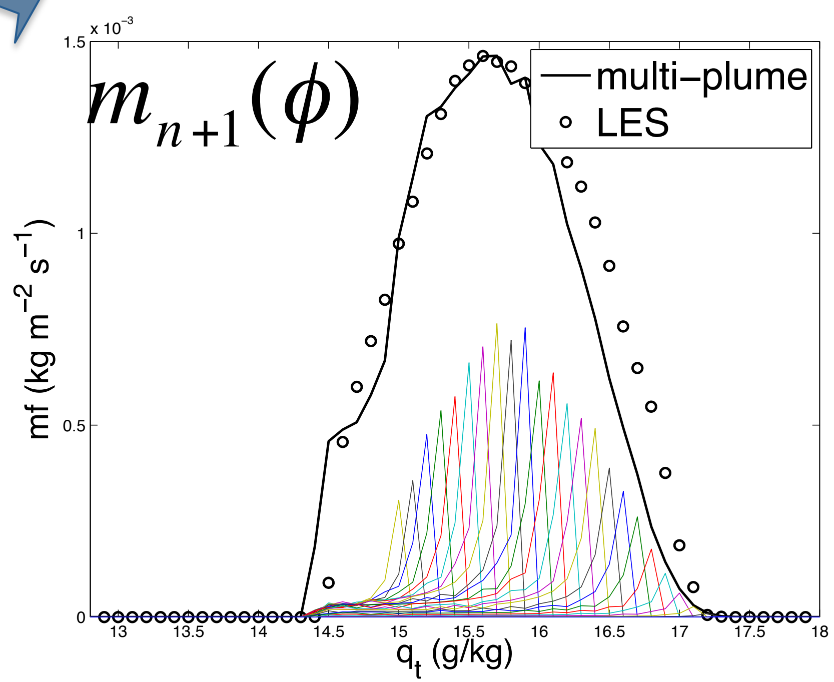


Only “active mixtures” (qc>0 and w>0) are kept.
insensitive to the criteria.

mixing with env.

sorting





Choices of mixing distribution functions

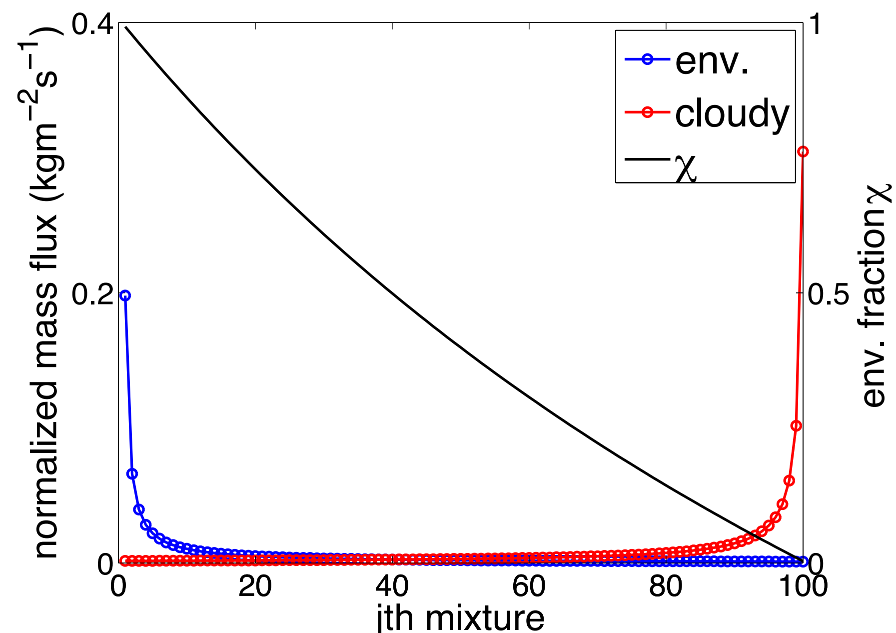
$$P1(\chi_j) = \frac{1}{N}$$ Emanuel 1991

$$P2(\chi_j) = \frac{1-\chi_j}{\sum 1-\chi_j}$$ Raymond and Blyth 1986, Bretherton *et al.* 2004

$$P3(\chi_j) = (1-\chi_j)G(\chi_j)$$ Kain and Fritsch 1990

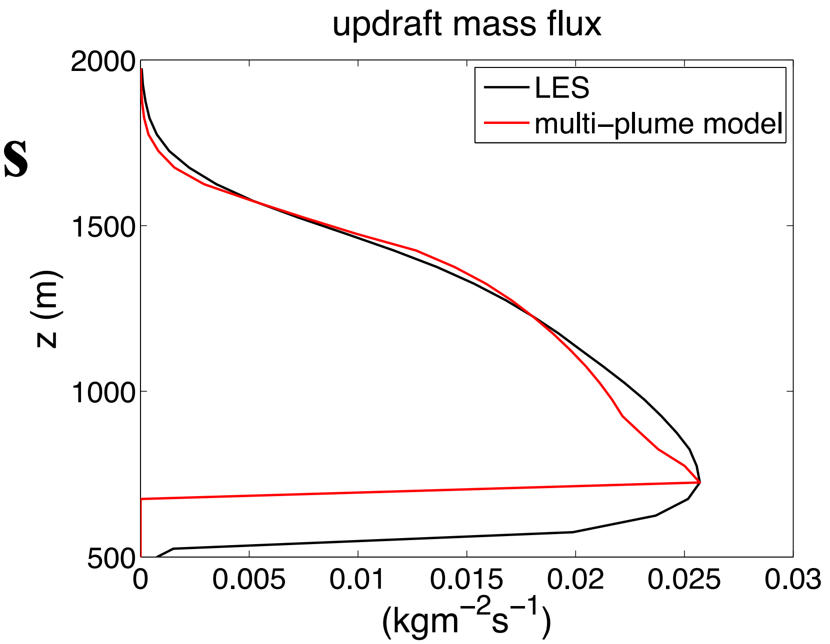
☑ $$P4(\chi_j) = \frac{1/\chi_j}{\sum 1/\chi_j}$$ Cohen 2000

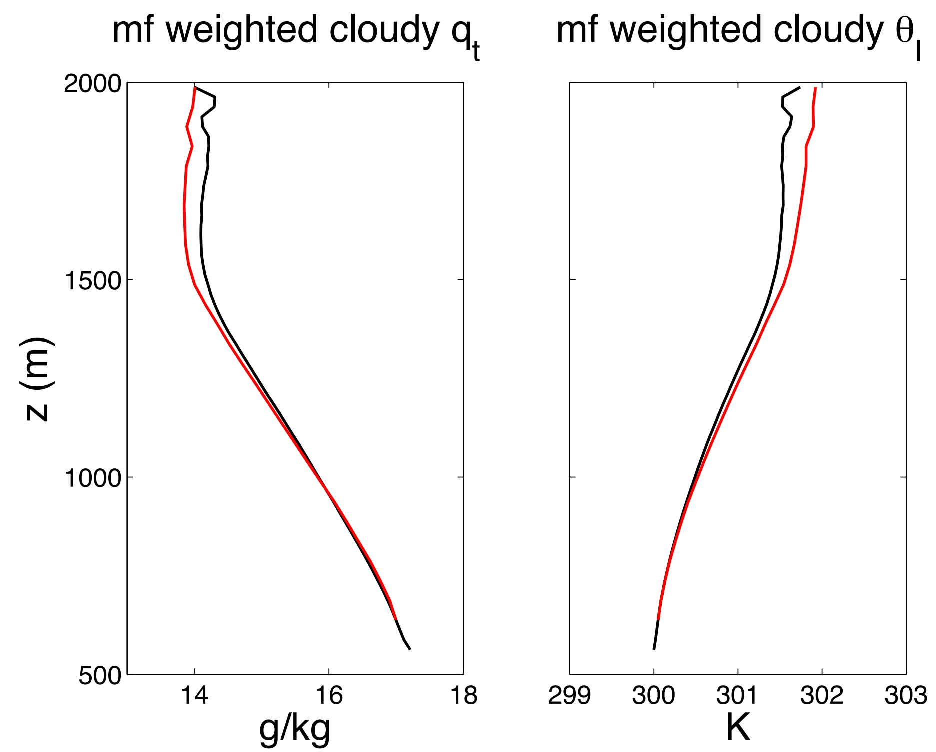
- Unlike Zhao and Austin 2003, the model here is sensitive to the choice of mixing distribution function!
- some indirect observational supports of P4 (Lu et al. 2012)
- consistent with some stochastic entraining parcel models (Romps and Kuang 2010, Nie and Kuang 2012b, Suselj et al. 2013)



Evaluating the model-1: thermodynamical tracers

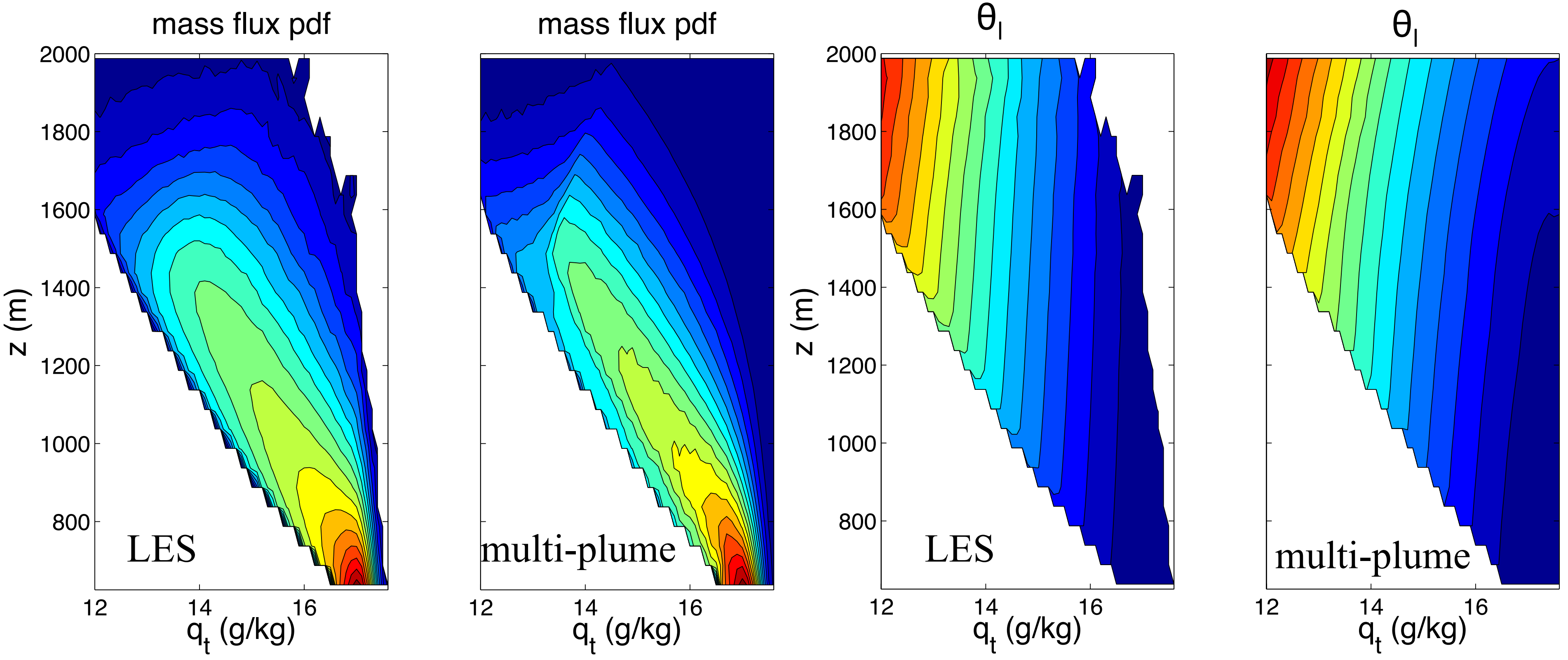
the mf, qt, and θ_l profiles



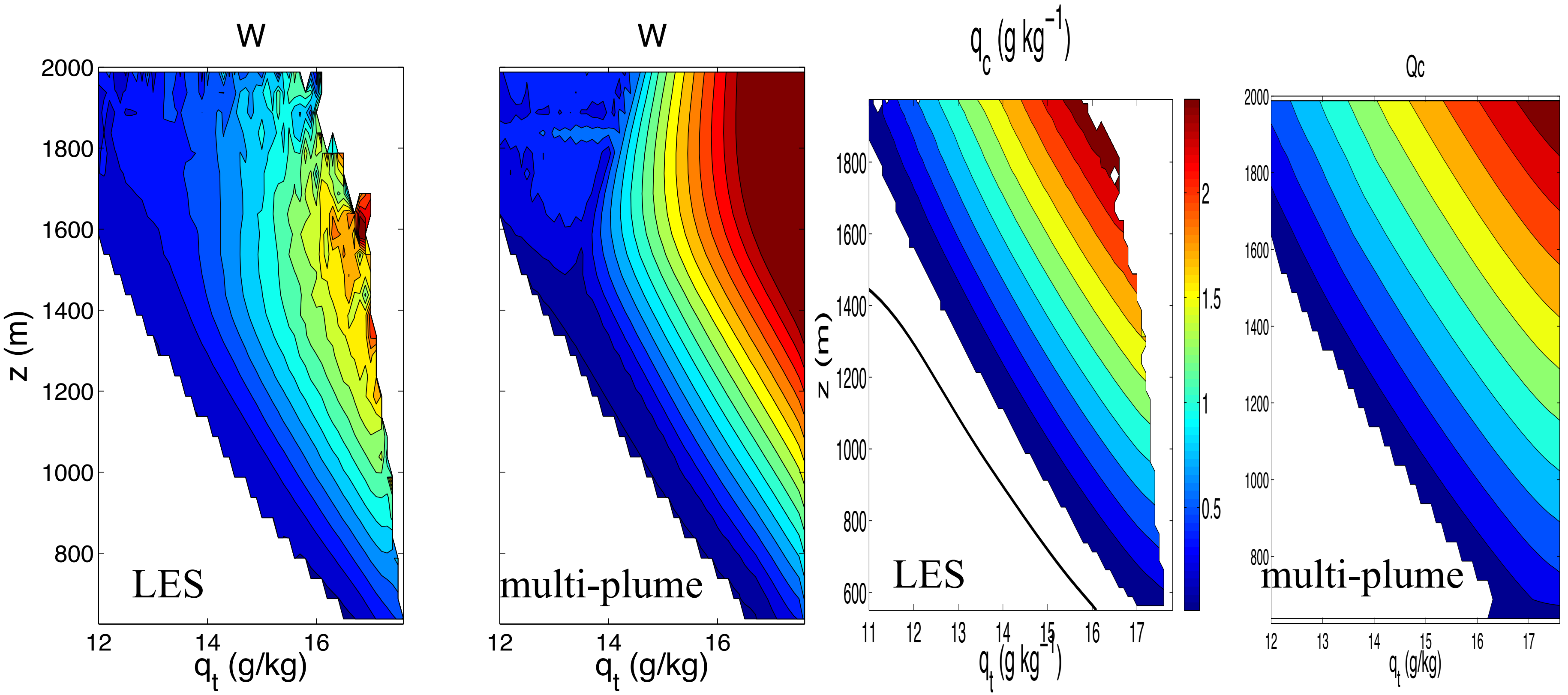


Evaluating the model-1: thermodynamical tracers

the mf pdf and mean θ_l



Evaluating the model-1: thermodynamical tracers



Evaluating the model-2: reactive chemical tracers

A LES simulation inspired by SO_2 aqueous phase oxidation by H_2O_2 :

- Tracer 1 (analogous to SO_2) is released from surface with a fixed flux.
- Tracer 2 (analogous to H_2O_2) is relaxed to a constant reference profile
- In the presence of cloud liquid water, the two tracers react

$$\text{Tracer1} + \text{Tracer2} \rightarrow \text{Tracer3}, \qquad q_c > 0$$

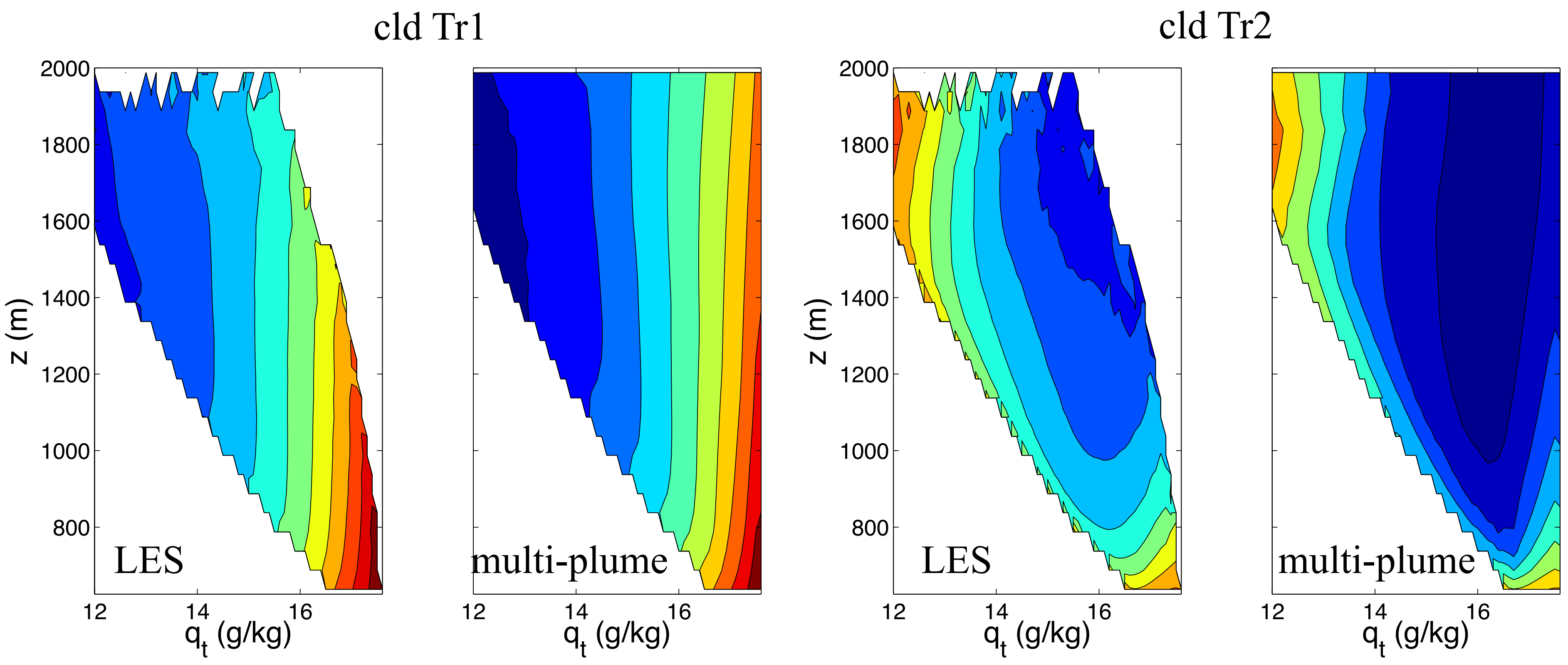
$$\text{“}SO_2\text{”} + \text{“}H_2O_2\text{”} \rightarrow \text{“}H_2SO_4\text{”}, \qquad q_c > 0$$

$$r = k \times Tr1 \times Tr2 \quad ,k = 10^{-3}$$

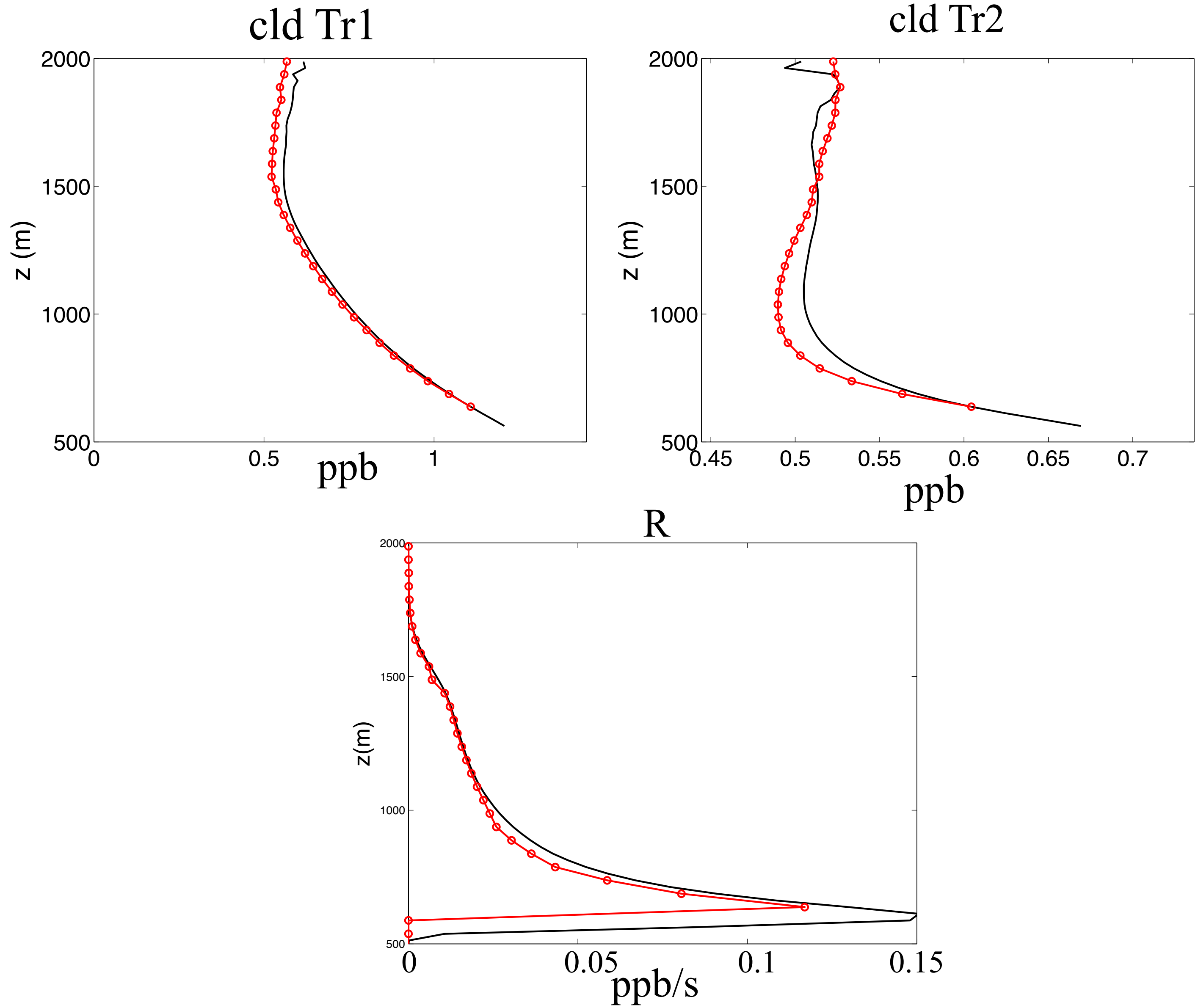
Tr1 flux = 1.16 ppb/m^2/s

Tr2 ref. = 1 ppb

Evaluating the model-2: reactive chemical tracers



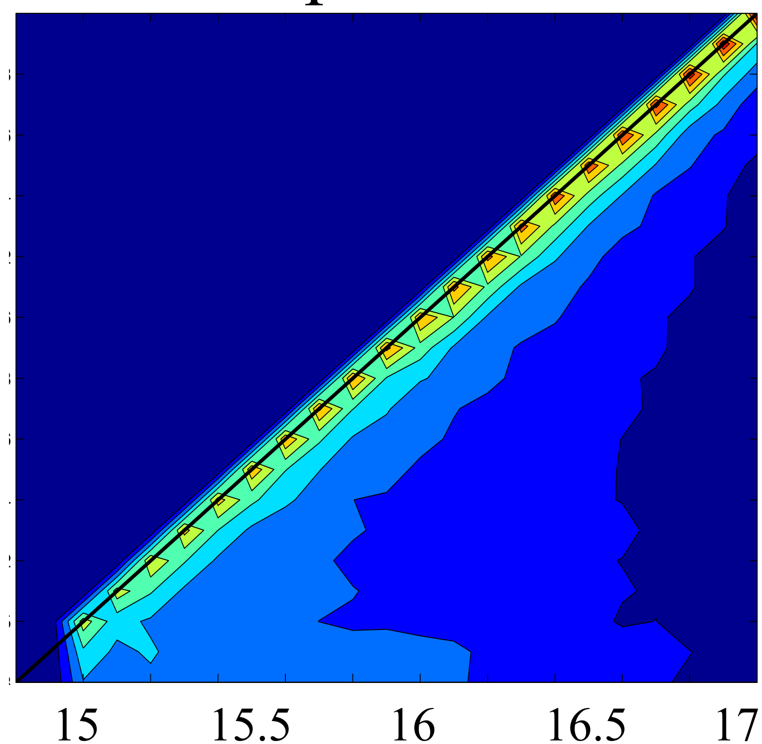
Evaluating the model-2: reactive chemical tracers



Discussions:
comparison of the Mapping Matrices

$$m_{n+1}(\phi) = G(\phi,\phi)m_n(\phi)$$

multi-plume model



mapping from 975m to 1025m

Discussions:
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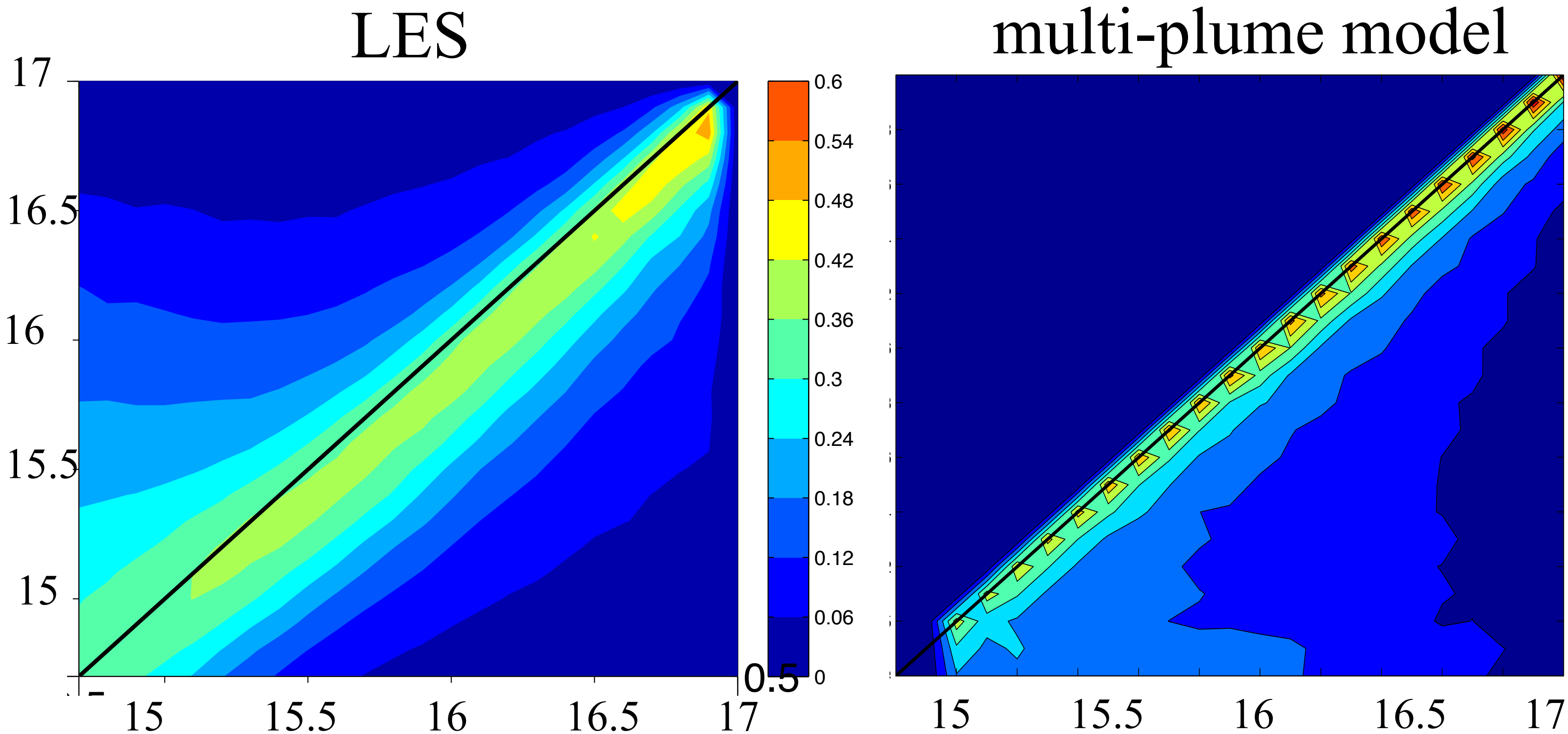

mapping from 975m to 1025m

Discussions:

- comparing it with the UW scheme:
  extend UW scheme from a bulk plume model into a multi-plume model

- comparing it with the stochastic entraining parcel models(e.g. Romps and Kuang 2010, Nie and Kuang 2012b, Suselj et al. 2013):
  a economical way to be applied in GCMs
  (although not strictly equivalent.)

Conclusions:

- We built a simple multi-plume model for shallow cumulus convection combining the idea of mapping and buoyancy-sorting.
- Initial evaluation show that the simply multi-plume model well reproduces the PDFs of thermodynamical variables and reactive chemical tracers.

Building the model:
the vertical equation

UW scheme:

$$\frac{1}{2}\frac{\partial}{\partial z}w^2 = aB - b\varepsilon w^2$$

a=1, b=2

The multiply plume model:

$$\frac{1}{2}\frac{\partial}{\partial z}w^2 = aB$$

$$w_j = (1 - b\chi_j)w$$

a=1, b=1.5