MODELING OF SUBGRID-SCALE MIXING IN LARGE-EDDY SIMULATION OF SHALLOW CONVECTION

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Motivation

Shallow convective clouds are strongly diluted by entrainment

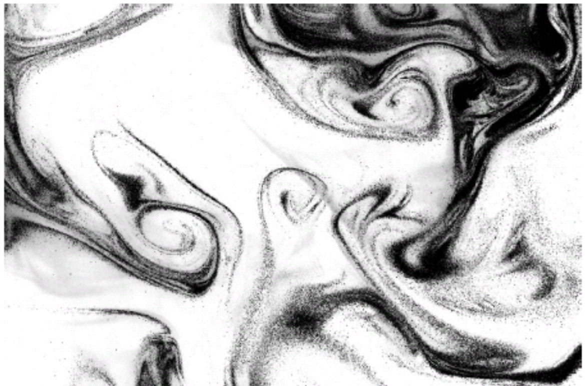
Overview

For atmospheric LES models, subgrid-scale mixing should cover wide range of situations:

- from extremely inhomogeneous at scales close to model gridlength,

- to homogeneous at scales close to the Kolmogorov scale (typically around 1 mm).

domain size ~ 64cm x 64cm;
Andrejczuk et al. JAS 2006



physical area ~ 9cm x 6cm;
Malinowski et al. NJP 2008

Description of model

- The Eulerian version of 3D anelastic semi-Lagrangian-Eulerian model EULAG (Smolarkiewicz et al.).

- Two versions of 1-moment microphysics were used (predicting mixing ratios only):
  - traditional bulk microphysics
  - modified bulk microphysics with additional parameter λ to describe turbulent mixing.

Bulk microphysics

- Condensation rate C is defined by constraints that the cloud water can exist only in saturated condition and the supersaturation is not allowed.

- In the bulk model, C is derived by saturation adjustment after calculation of advection and eddy diffusion – C^{sa}

Bulk microphysics

Instantaneous adjustment is questionable for the cloud-environment mixing…

This is because microscale homogenization occurs at scales around 1 cm and smaller!

Possible approaches

- Simple approach: a subgrid scheme based on Broadwell and Breidenthal (JFM 1982) scale collapse model (Grabowski 2007);

- Sophisticated approach: embedding Kerstein's Linear Eddy Model (LEM) in each LES gridbox ("One-Dimensional Turbulence", ODT; Steve Krueger, U. of Utah).

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λ approach

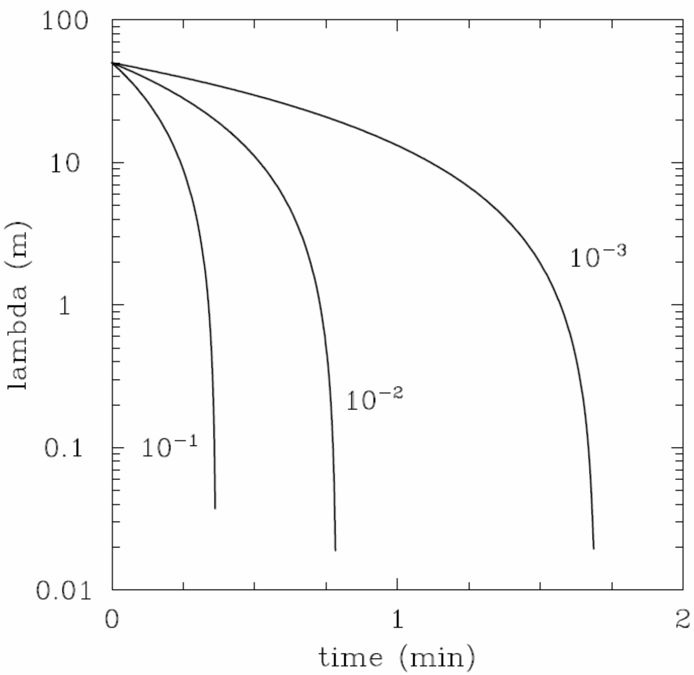
To represent the chain of events characterizing turbulent mixing, Grabowski (JAS 2007) introduced an additional model variable.

spatial scale λ of the cloud filaments during turbulent mixing

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

ε - dissipation rate of TKE

(Broadwell and Breidenthal 1982),



Application of the λ equation into model

$$\frac{\partial \lambda}{\partial t} + \frac{1}{\rho_o}\nabla \cdot (\rho_o \mathbf{u} \lambda) = -\alpha \epsilon^{1/3} \lambda^{1/3} + S_\lambda + D_\lambda$$

λ has to be between two scales: $\lambda_0 \leq \lambda \leq \Lambda$;
Λ is the model gridlength; λ_0 is the homogenization scale; say, $\lambda_0 = 1$ cm.

S_λ - ensures transitions between cloud-free and cloudy gridboxes (initial condensation) or between inhomogeneous to homogeneous cloudy volume

D_λ - subgrid transport term

Evaporation

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

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

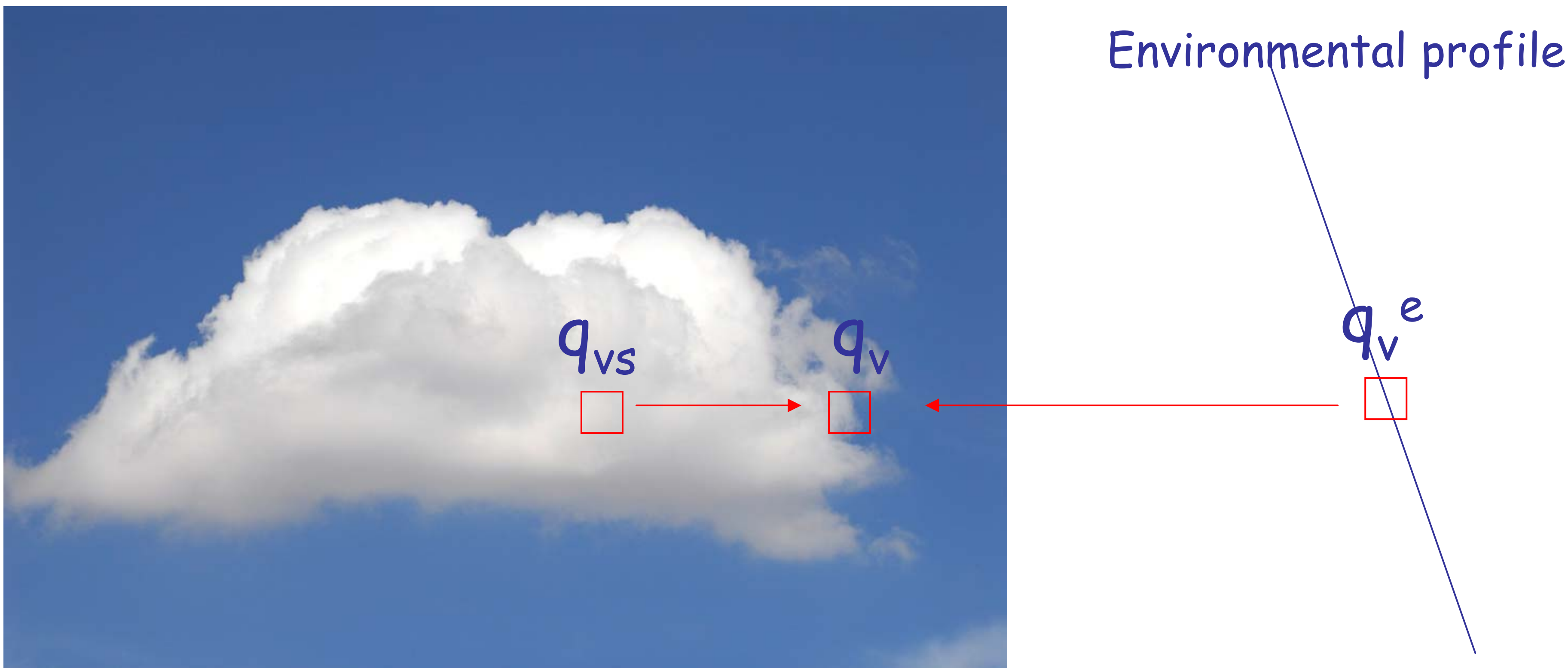
$\lambda_0 \leq \lambda \leq \Lambda$ $C = \beta\, C^a$ (adiabatic)

β – fraction of the gridbox covered by cloudy air

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

β diagnosed

Grabowski (2007) proposed diagnostic formula for β based on the relative humidity of a gridbox and on the environmental relative humidity at a given level.



β diagnosed

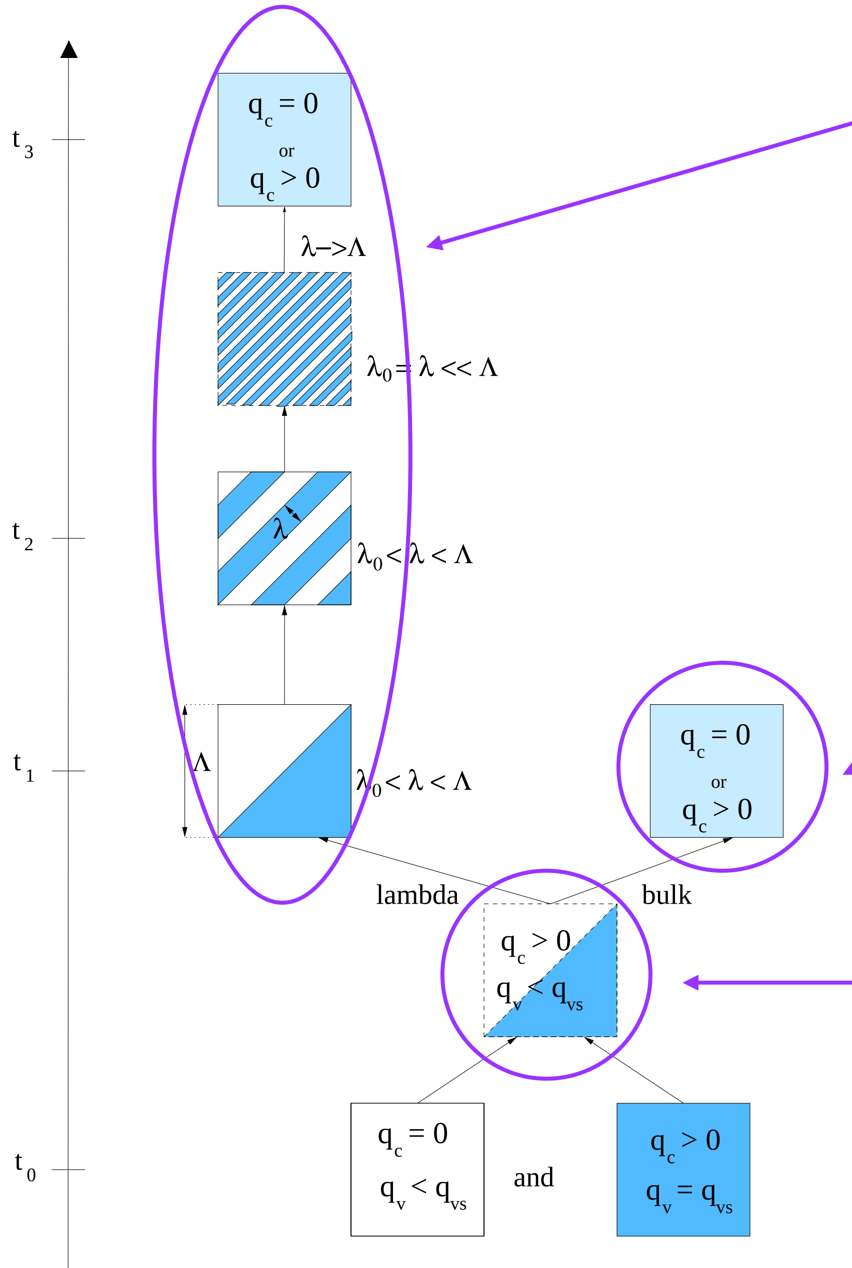
$$RH \approx \beta + (1-\beta)RH^e$$

$$\beta = \max\left(0, \min\left(1, \frac{RH - RH^e}{1 - RH^e}\right)\right)$$

RH - relative humidity of the gridbox

RH^e - environmental relative humidity at this level

Delay in saturation adjustment



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

Bulk model:
immediate homogenization

mixing event

Simulation of shallow convection observed in BOMEX experiment.

- 1 km deep trade wind convection layer overlays a 0.5 km deep mixed layer near the ocean surface and is covered by 0.5 km deep trade wind inversion layer.
- The cloud cover is about 10%.

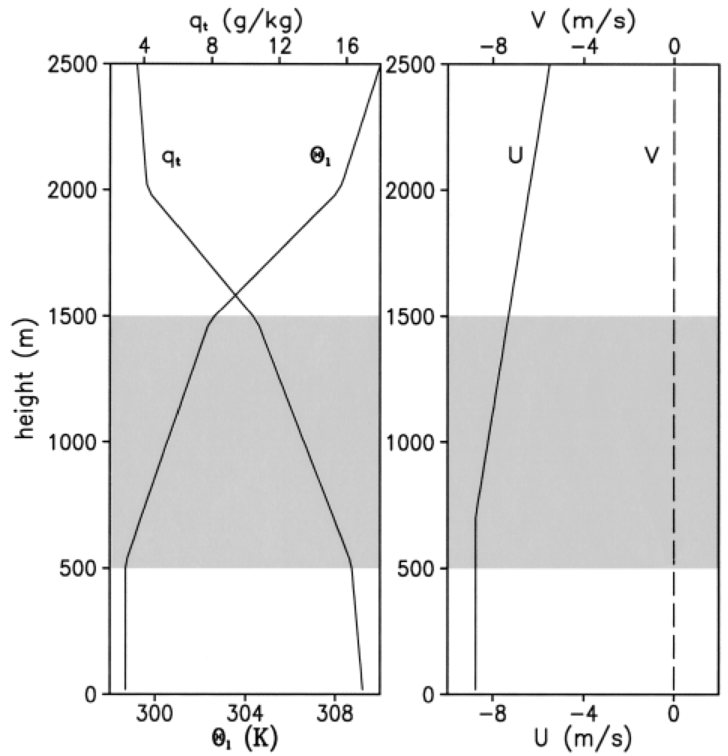


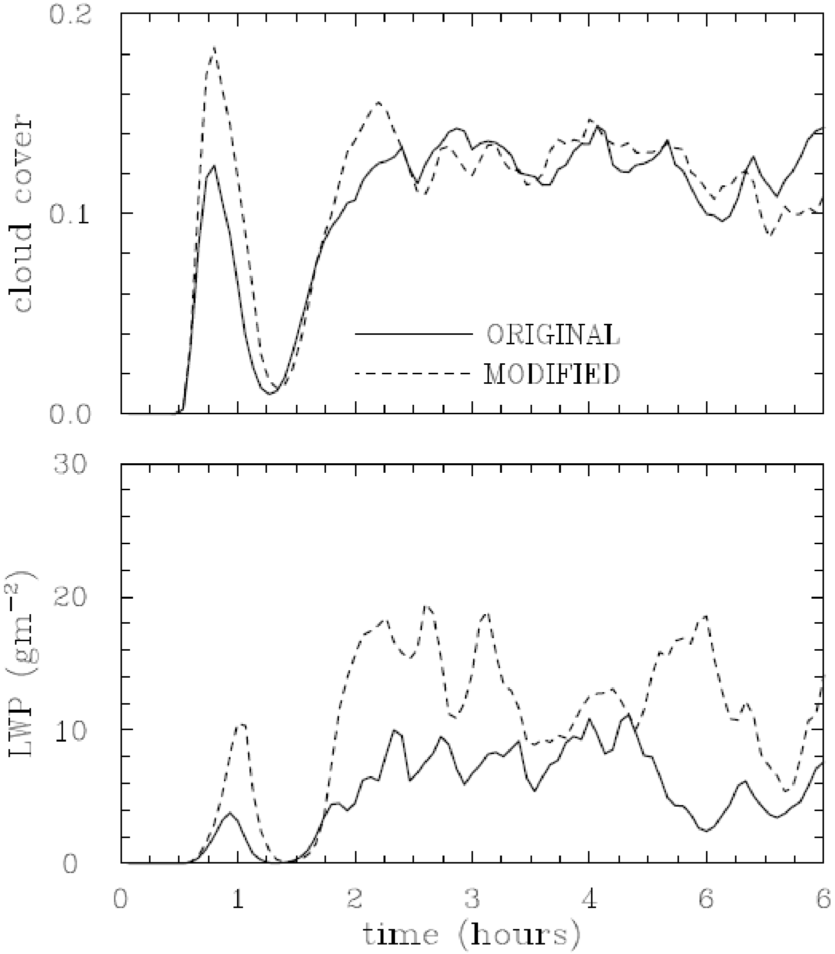
FIG. 1. Initial profiles of the total water specific humidity q_t, the liquid water potential temperature θ_ℓ, and the horizontal wind components u and v. The shaded area denotes the conditionally unstable cloud layer.

Model setup

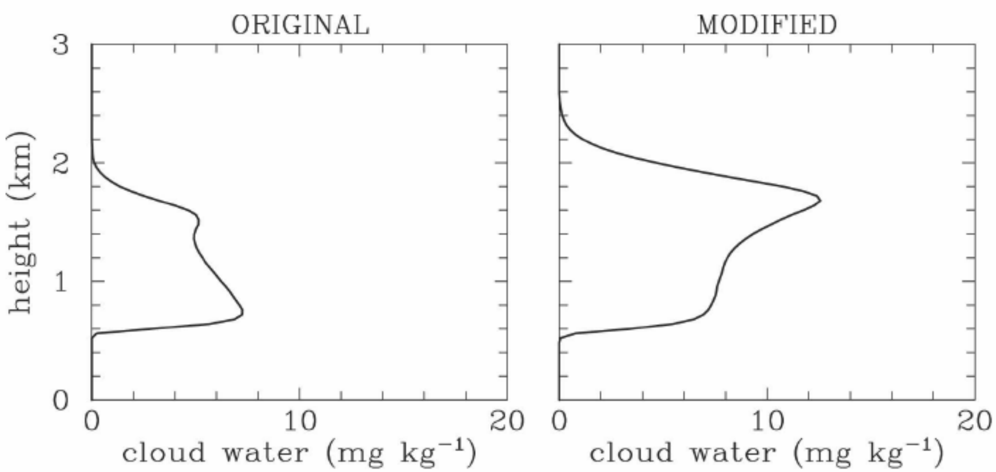
Model setup is as described in *Siebesma et al., JAS 2003* but applying different domain sizes and model gridlengths
(i.e., the same number of gridpoints in the horizontal 128 x 128, 3-km vertical extent of the domain).

Three different model gridlengths were considered:

- 100m / 40m (i.e., as in Siebesma et al.)
- 50m / 40m
- 25m / 25m



Comparison between original and modified model in *Grabowski JAS 2007*



Gridlength: 100m / 40m

β diagnosed

Grabowski (2007) proposed diagnostic formula for β based on the relative humidity of a gridbox and on the environmental relative humidity at a given level.

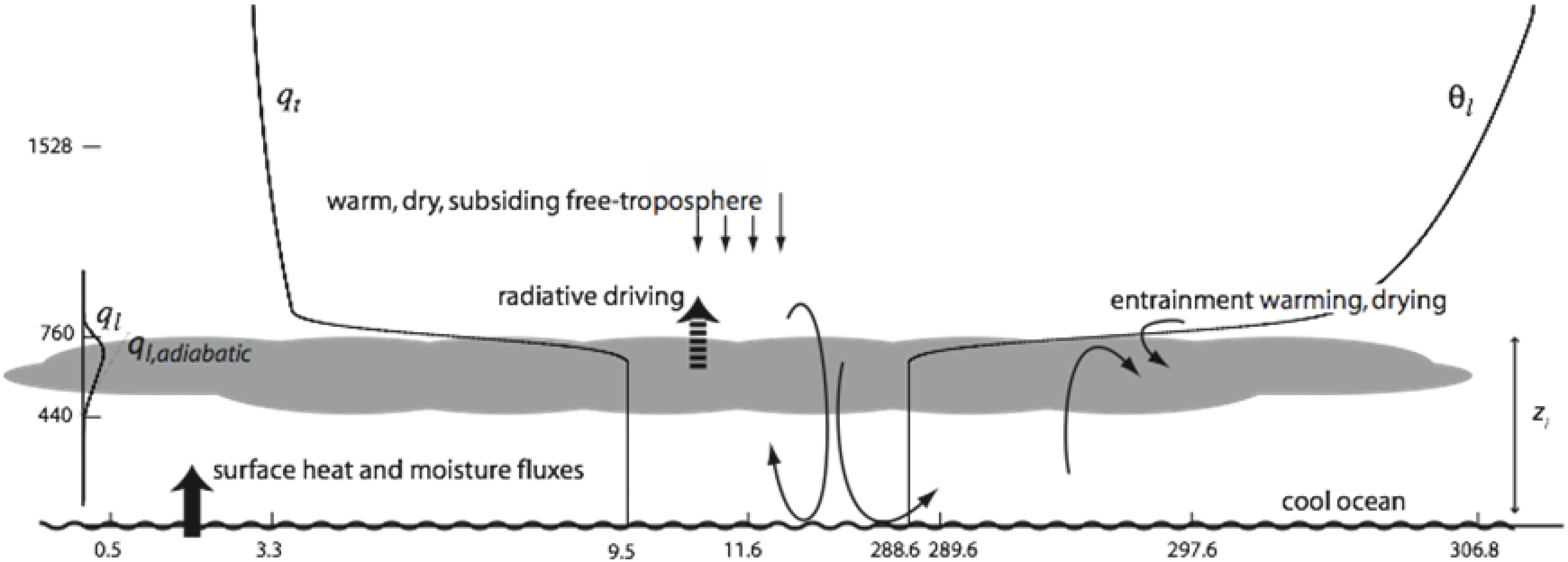
$$\beta = \max\left(0, \min\left(1, \frac{RH - RH^e}{1 - RH^e}\right)\right)$$

RH - relative humidity of the gridbox

RH^e - environmental relative humidity at this level

http://www.dkimages.com/discover/previews/929/50171279.JPG

For stratocumulus, cloud-environment mixing takes place primarily at the cloud top, where environmental profiles change rapidly.



β predicted

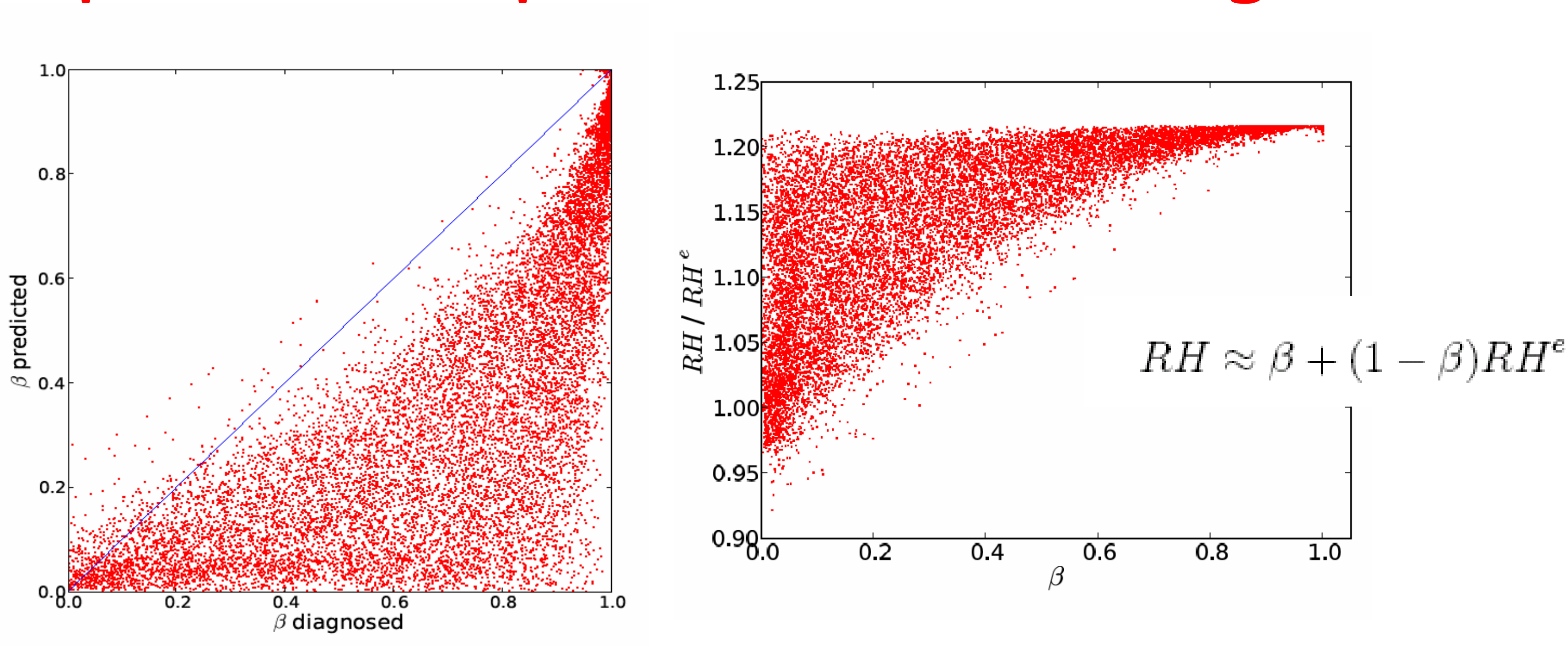
We propose to use a prognostic equation for β and check *a posteriori* if the diagnostic formula is accurate for shallow convection:

$$\frac{\partial \beta}{\partial t} + \frac{1}{\rho_o} \nabla \cdot (\rho_o \mathbf{u} \beta) = S_\beta + D_\beta$$

S_β - source/sink source

D_β - subgrid transport term

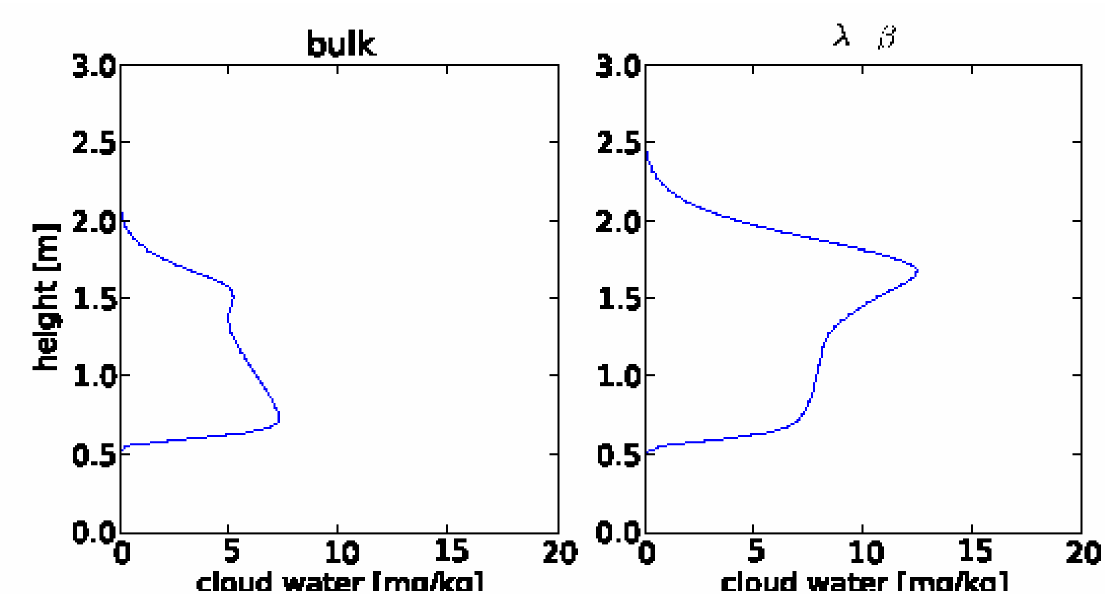
Comparison of predicted and diagnosed β

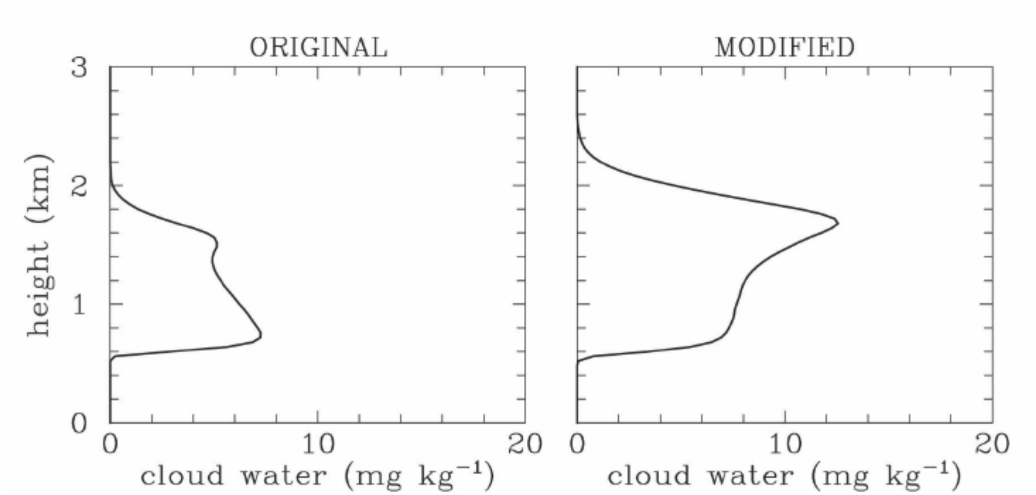


- The values predicted by the model are typically smaller than those diagnosed.

- The entrained air is typically more humid than far-environmental air at this level.

Comparison between modified models



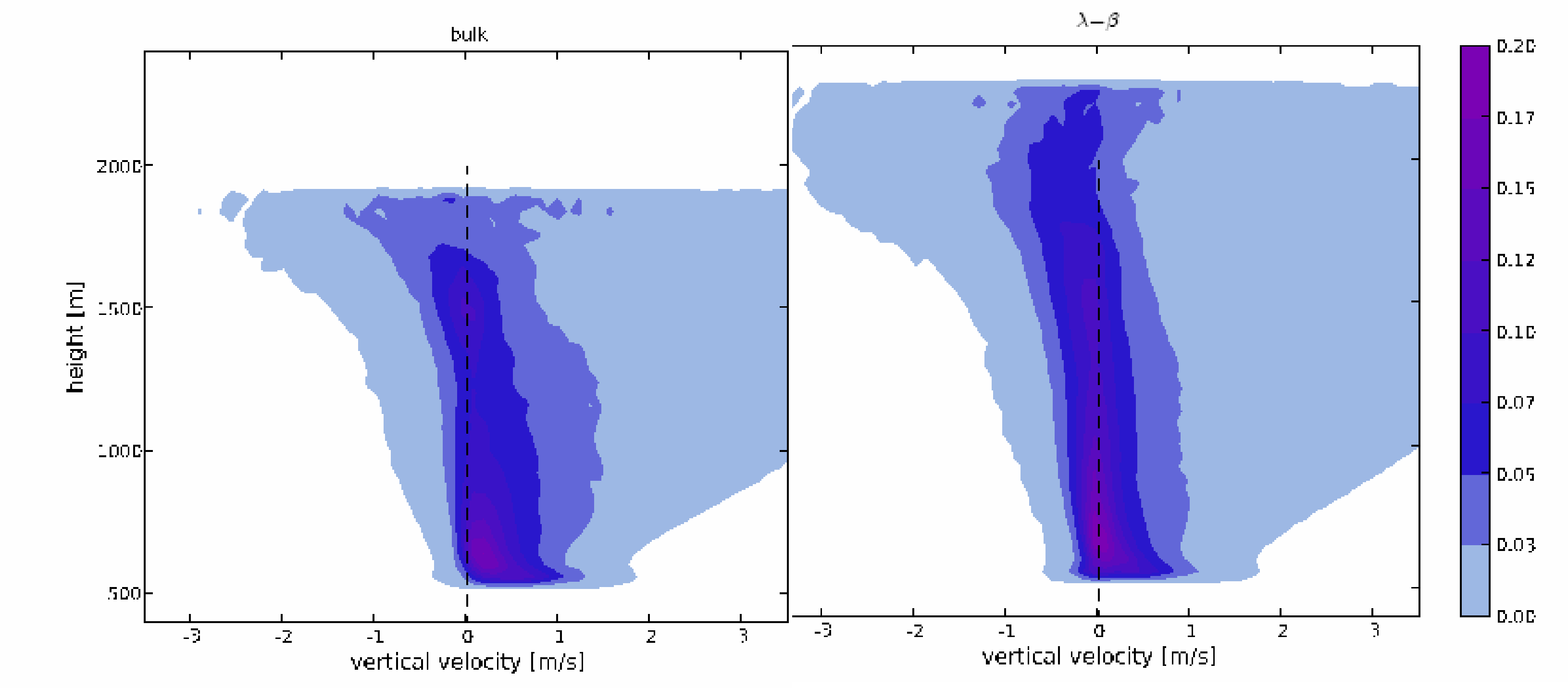


Differences?

Comparison of vertical velocities in cloud

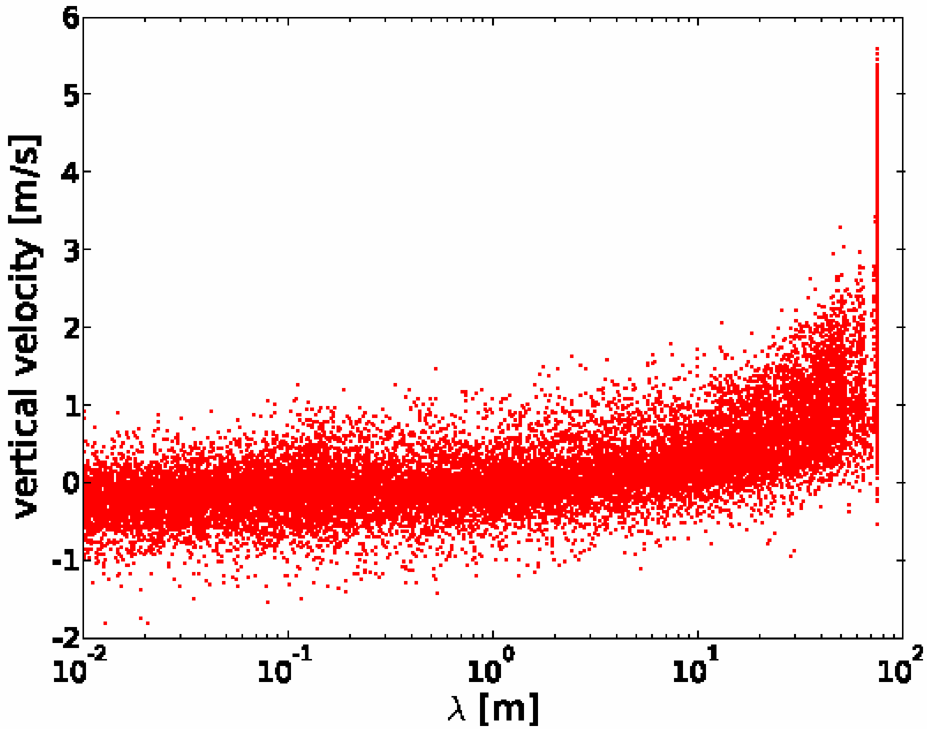
Countoured Frequency by Altitude Diagrams

bulk λ-β



Gridlength – 100m / 40m

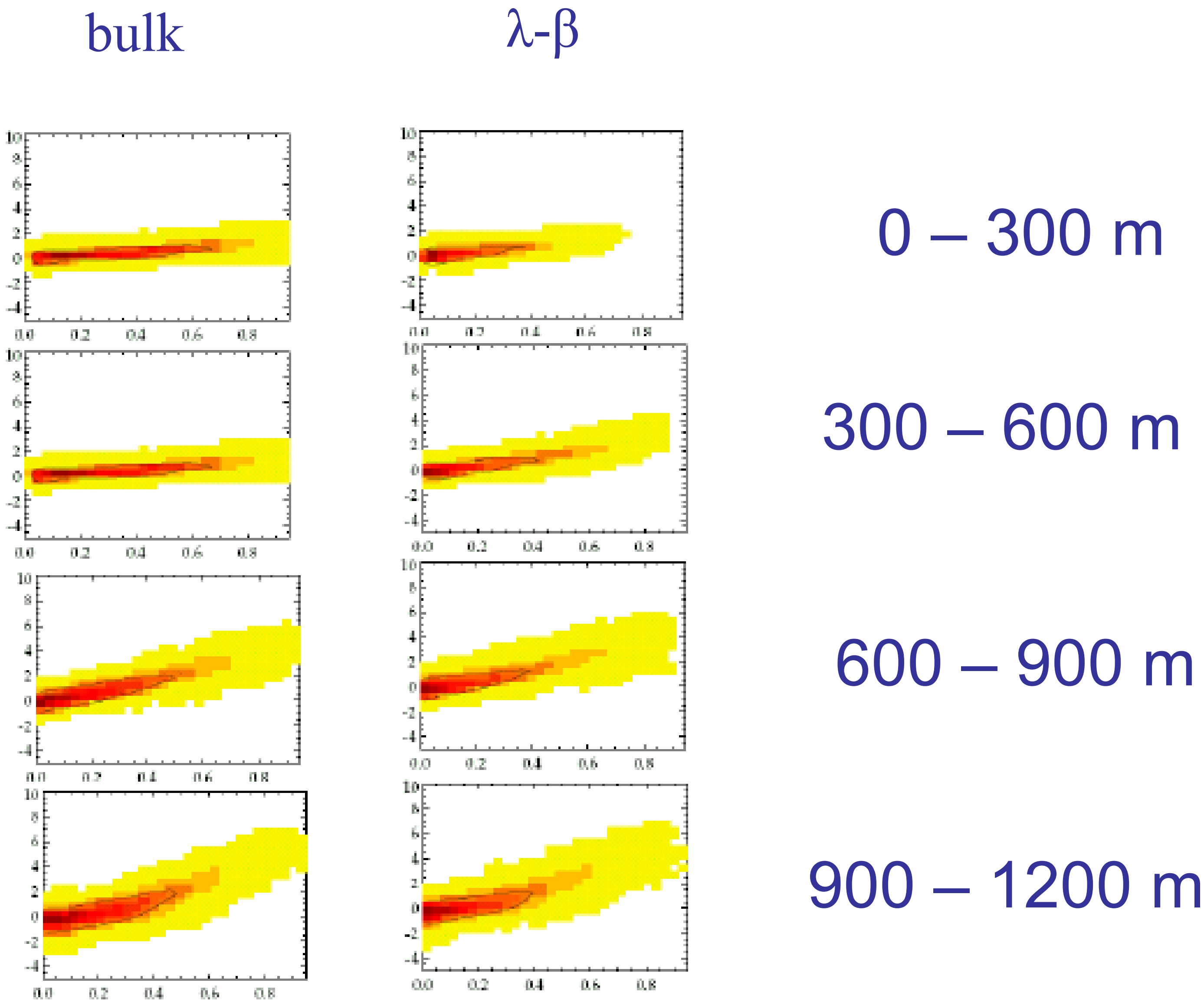
Vertical velocity versus λ



Gridlength – 100m / 40m

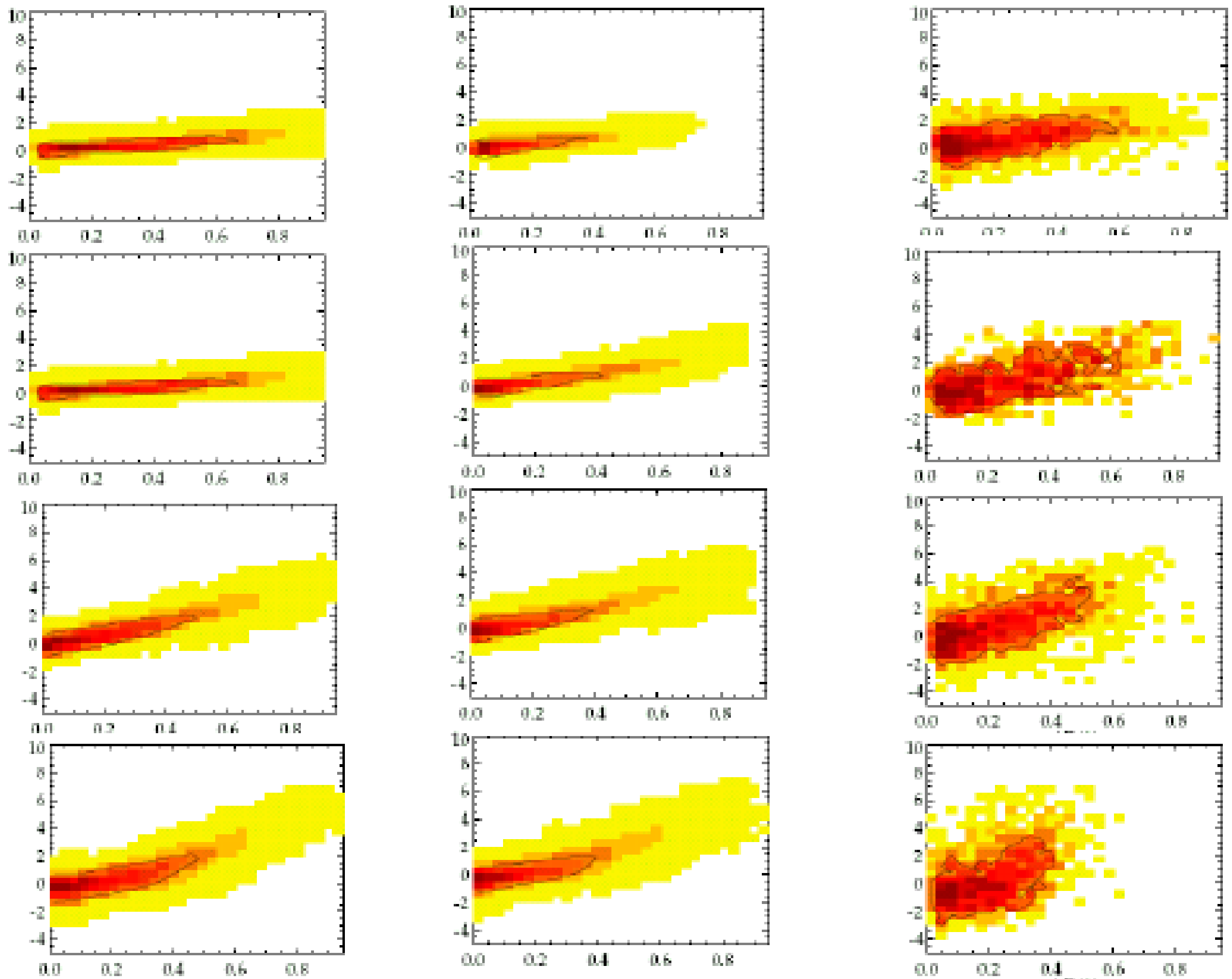
The grid boxes with intermediate values of λ are characterized by small positive and negative vertical velocities.

Vertical velocity versus Adiabatic Fraction (AF) -comparison of models



Vertical velocity versus Adiabatic Fraction (AF) -comparison with RICO experiment

bulk | λ-β | RICO experiment



Summary

- Including λ parameter in the bulk model allows representing in a simple way progress of turbulent mixing between cloudy air and entrained dry environmental air

- β should be another model variable

Future plans

- Use λ approach in a model with more complicated microphysics (a double-moment bulk scheme) to predict changes of the mean size of cloud droplets.

- Apply λ approach to stratocumulus cases.

- Compare model result with experimental date from RICO, IMPACT campaign.