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

Dorota Jarecka[1]
Wojciech W. Grabowski[2]
Hanna Pawlowska[1]

[1] Institute of Geophysics, University of Warsaw, Poland
[2] National Center for Atmospheric Research, USA

Overview

• For atmospheric large-eddy simulation (LES) models (spatial gridlength between 10 and 100 meters), 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).

• Simple idea how to present microphysics at smaller scales:

subgrid scheme based on Broadwell and Breidenthal (JFM 1982) scale collapse model (Grabowski 2007);

Description of model which we use

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

• Setup to simulate trade wind shallow convection observed during the BOMEX experiment.

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

Bulk microphysics

$$\frac{\partial \theta}{\partial t} + \frac{1}{\rho_o}\nabla \cdot (\rho_o \mathbf{u} \theta) = \frac{L_v \theta_e}{c_p T_e} C + D_\theta$$

$$\frac{\partial q_v}{\partial t} + \frac{1}{\rho_o}\nabla \cdot (\rho_o \mathbf{u} q_v) = -C + D_v$$

$$\frac{\partial q_c}{\partial t} + \frac{1}{\rho_o}\nabla \cdot (\rho_o \mathbf{u} q_c) = C + D_c$$

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

For the uniformly saturated and adiabatic air parcel, the condensation rate can be derived from the rate of change of the saturated water vapor mixing ratio.

Bulk microphysics – cont.

- In model, C is derived by saturation adjustment after calculation of advection and eddy diffusion – C^{sa}
- Water cannot exist in the grid box which is below saturation.
- In LES model, gridlength is around 10–100m.
- Thus, saturation adjustment due to turbulent stirring and homogenization cannot be instantaneous; this is because microscale homogenization occurs at scales around 1 cm and smaller.

λ approach

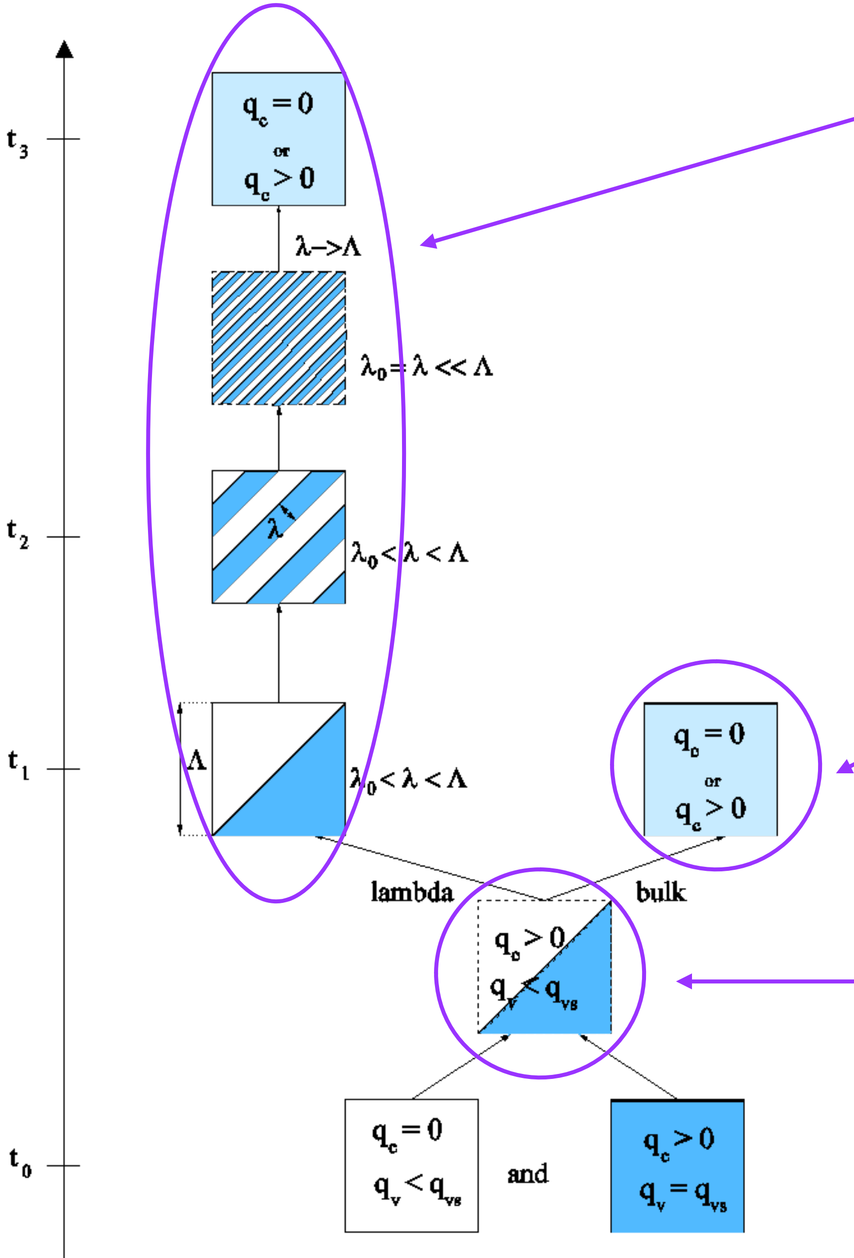
To represent the chain of events characterizing turbulent mixing (from the initial engulfment of the ambient fluid to the small-scale homogenization), Grabowski (JAS 2007) introduced an additional model variable.

This variable is the width of cloudy filaments, λ, where $\lambda_0 \leq \lambda \leq \Lambda$; Λ is the model gridlength; λ_0 is the homogenization scale; say, λ_0 = 1 cm.

Following Broadwell and Breidenthal (1982), the evolution equation for λ was proposed:

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

Delay in saturation adjustment



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

bulk model:
immediately homogenization

mixing event

Variable β

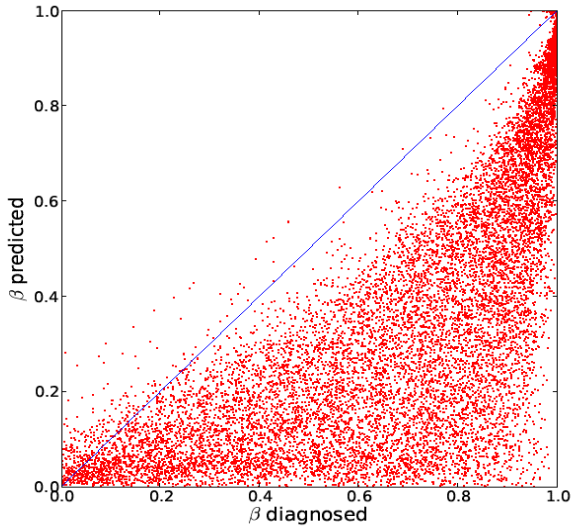
Condensation rate in a gridbox undergoing turbulent stirring depends on the fraction of the gridbox occupied by the cloudy air β.

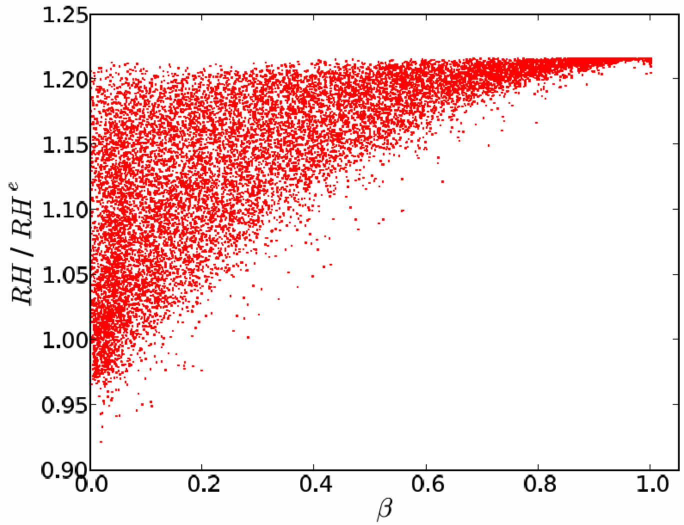
Grabowski (2007) proposed diagnostic formula for β based on the relative humidity of a gridbox and on the environmental relative humidity at a given level.

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

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

Comparison of predicted and diagnosed β



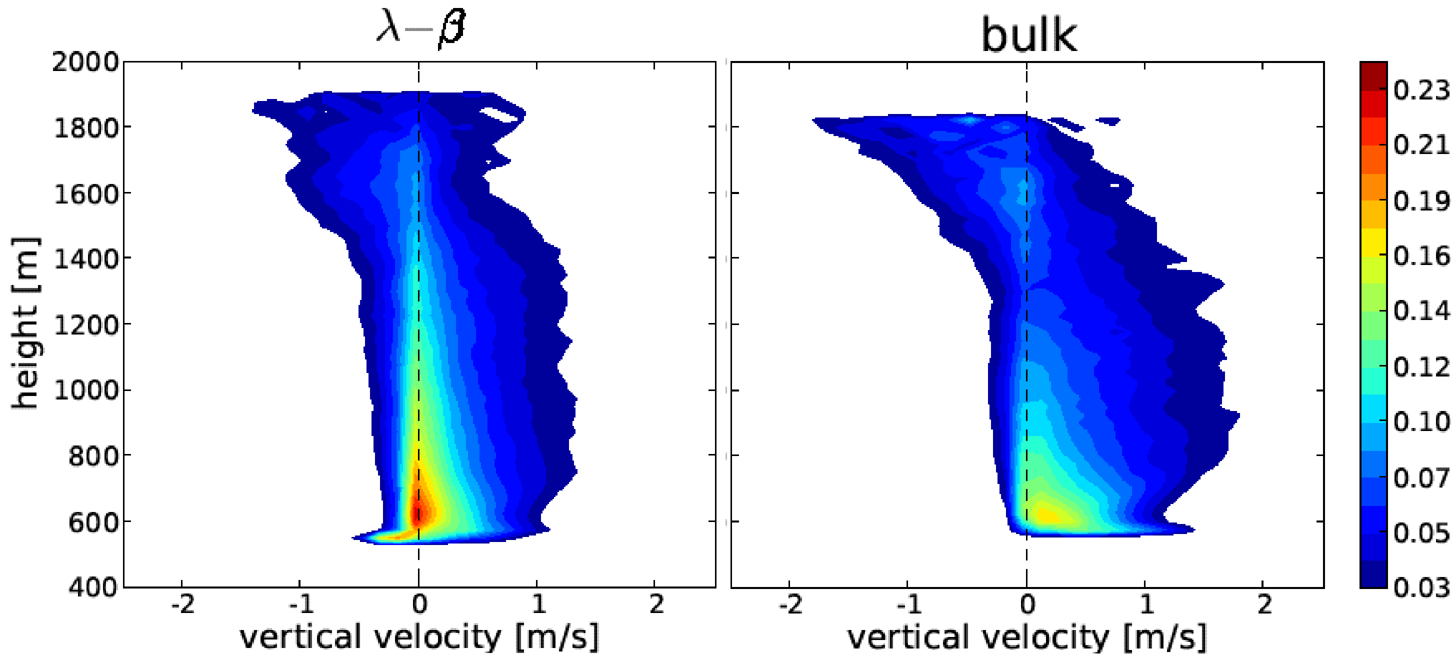


- The values predicted by the model are typically smaller than those diagnosed.

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

- β should be another variable predicted by model!

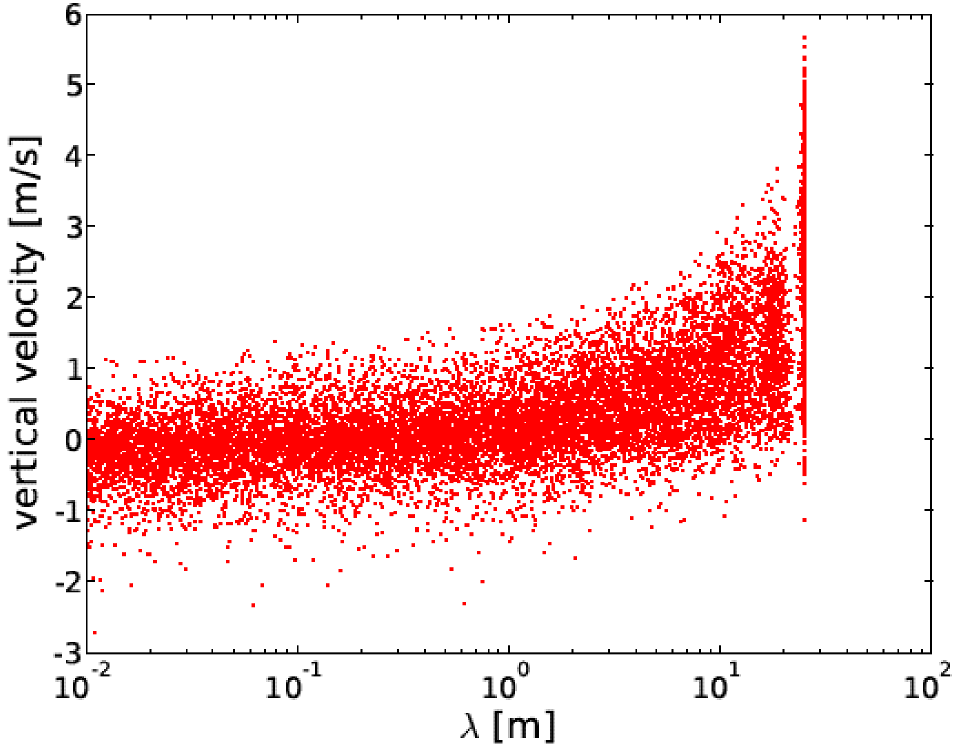
Comparison of vertical velocities in cloud



- Clouds in the λ-β model are slightly deeper than in the bulk approach

- There are more points with small vertical velocities in the λ-β model across most of the depth of the cloud field

Vertical velocity versus λ



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

Summary

- Including λ parameter in bulk model allows to simply describe progress of turbulent mixing between cloud and dry air
- B should be another model variable
- Delay in saturated adjustment influence on cloud characteristic: depth, vertical velocity, cloud water

Future plans

- Use λ approach in model with more complicated microphysics (a double-moment bulk scheme) to predict cloud droplet spectrum.
- Comparison model result with experimental date from IMPACT campaign.

IMPACT campaign

- Intensive Observation Period at Cabauw Tower (IMPACT) (1 – 31 May 2008)

- IMPACT is part of European Integrated Project on Aerosol - Climate - Air Quality Interactions (EUCAARI)

- Objectives:

Observations of boundary layer, cloud and aerosol processes in order to quantify the indirect aerosol effect

Waiting for clouds…

Thank you!!!