Modelling Turbulence at the kilometric scale

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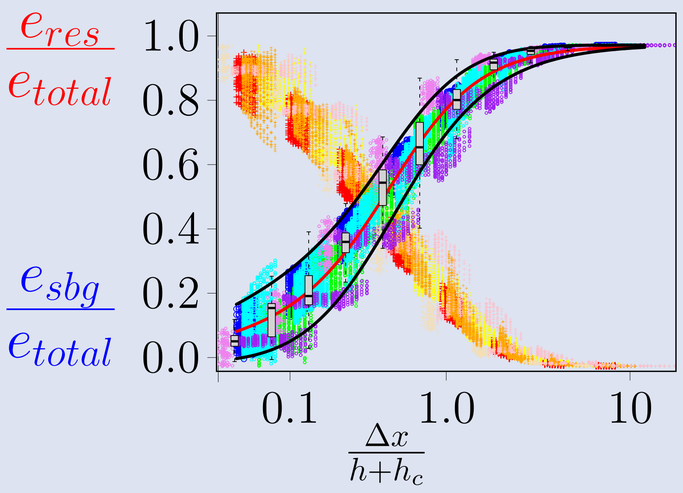
Introduction

Thanks to increasing numerical ressources, numerical weather prediction models are now running operationnaly with a 2 km grid spacing. In a near future such model will reach resolutions of the order of 1 km or even 500 m entering the grey zone of turbulence.

1/ The grey zone of turbulence

TKE in the mixed layer

$$0.05 \leq \frac{z}{h} \leq 0.85$$



True subgrid/resolved partitioning by averaging 5 LES

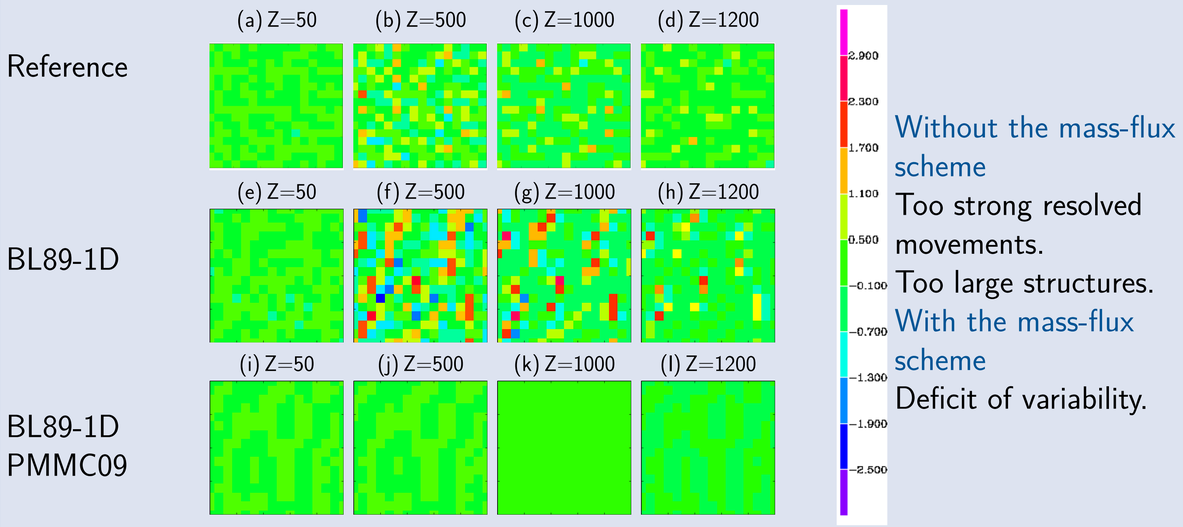
Grey-Zone : $\Delta x \leq 2(h + h_c)$

Δx horizontal resolution
h boundary-layer height
h_c depth of the cloud layer

One part of the turbulence has to be resolved

Honnert R., V. Masson, and F. Couvreux, 2011 : A diagnostic for Evaluating the Representation of Turbulence in Atmospheric Models at the Kilometric Scale. *J. Atmos. Sci.*, **68**(12), 3112-3131, doi : 10.1175/JAS-D-11-061.1

2/ Model Defaults in the Grey zone



Without the mass-flux scheme
Too strong resolved movements.
Too large structures.
With the mass-flux scheme
Deficit of variability.

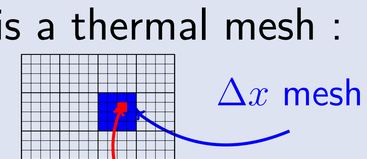
The representation of the sub-grid thermals has the most significant impact.

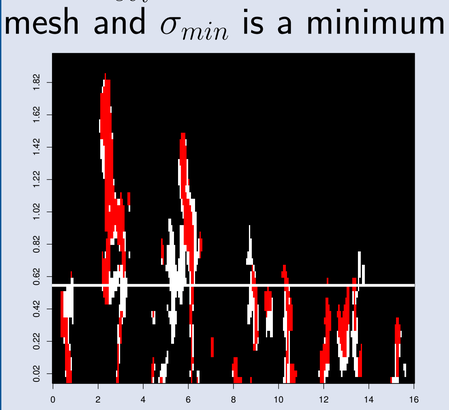
3/ Subgrid Thermals

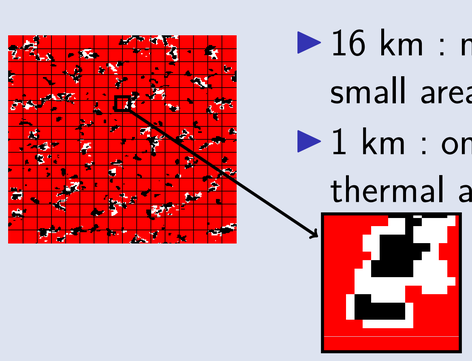
A new Conditional Sampling detects the subgrid thermals thanks to the concentration sv of a passif scalar emmitted at the surface and w the vertical velocity. An LES mesh i is a thermal mesh :

$$if \quad sv_i - \overline{sv}^{\Delta x} > max(\sigma_{svi}, \sigma_{min})$$
$$w_i > 0$$
$$w_i - \overline{w}^{\Delta x} > 0$$

where $\overline{sv}^{\Delta x}$ is the average value of sv over the Δx mesh σ_{svi} is the standart deviation of sv over the Δx mesh and σ_{min} is a minimum threshold





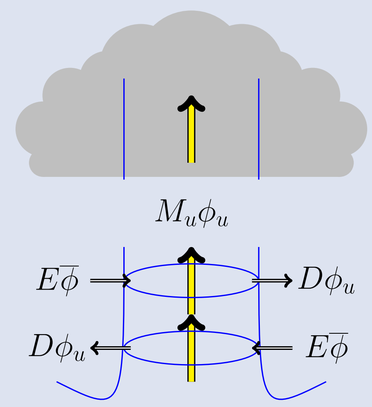


- 16 km : numerous, over small area
- 1 km : one whole thermal at the most

Vertical and horizontal cross-sections of a sub-grid thermal field at 500 m resolution

One part of the thermal is resolved. Some of the meso-scale mass-flux assumptions may not be verified anymore.

4/ Meso-scale Mass-Flux Assumptions



Meso-scale Mass-Flux assumptions provide the relationship (*Siebesma (1997)*) :

$$\frac{\partial M_u \phi_u}{\partial z} = E\overline{\phi} - D\phi_u + \alpha(F_u)$$

- ϕ a variable, $\overline{\phi}/\phi_u$ resolved/updraft value of ϕ
- M_u the mass flux
- E et D entrainment/detrainment
- F_u sums and sinks of ϕ over the updraft area
- α thermal fraction

In the Grey Zone

- The thermal fraction is small : $\alpha << 1 \rightarrow$ False
- The resolved vertical velocity is null : $\overline{w} = 0 \rightarrow$ False
- Stationnarity $\rightarrow$ False
- Intra-Thermal Turbulence is negligible $\rightarrow$ True

Mass-Flux equations have to be modified

Honnert R., V. Masson, and F. Couvreux : A parameterization of the turbulence at the kilometric scales. What is a subgrid thermal at the Kilometric Scale ? *QJRMS*, *submitted*.

5/ Grey-zone mass-flux scheme

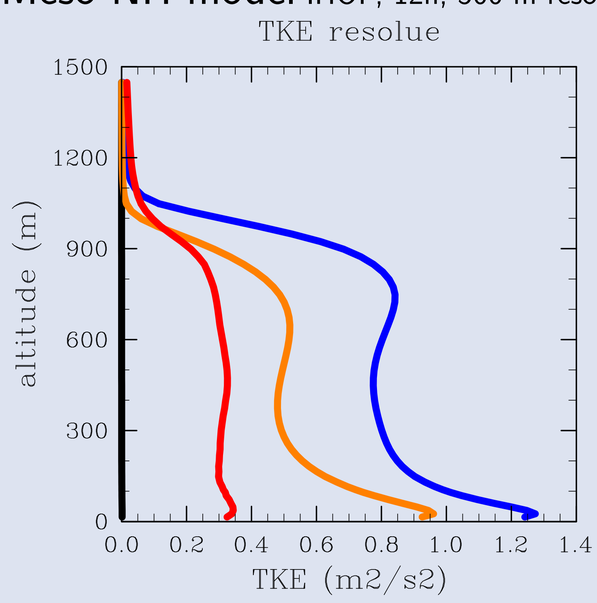
$$\frac{\partial M_u \phi_u}{\partial z} = \tilde{E}\phi_e - \tilde{D}\phi_u + \alpha(F_u - \overline{F})$$

Similar to the meso-scale equation but ...

- α sub-grid thermal fraction, α not negligeable
  $\rightarrow \phi_e \neq \overline{\phi}$, ϕ_e average value of ϕ over the environment
- $\overline{w}$ not negligeable $\rightarrow M_u = \alpha(w_u - \overline{w})$
- $\tilde{E}$ et $\tilde{D}$ include exchanges and non-stationnarities

6/ Preliminary tests

Méso-NH model IHOP, 12h, 500 m resolution



- LES
- with *Pergaud et al. (2009)*
- without *Pergaud et al. (2009)*
- *Honnert et al. (2013)*

At 500 m resolution, the LES produces resolved TKE. The simulation with Pergaud et al. (2009) does not produce resolved TKE. The simulation without Pergaud et al. produces too much resolved TKE. The new scheme produces resolved TKE, less than without Pergaud et al. but still too much.

Conclusions and Perspectives

- The gray zone in the convective boundary layer, by mean of LES coarse graining and Conditional sampling to determine :
  - True resolved and sub-grid partioning
  - The characteristics of sub-grid thermals
- Representation of non-local turbulence is the main problem, because meso-scale mass-flux hypothesis are not valid
- Determination of a new mass-flux parameterization
- Subsequently : closure and tests of the mass-flux scheme in the gray zone

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