A diagnostic for evaluating the Representation of Turbulence in Atmospheric Models at the kilometric scales.

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Current models: LES model

LES models:
- Research models
- Dedicated to turbulence studies
- Turbulence is mainly resolved (very fine meshes)
Atmospheric models:

- Current operational forecasting, climate and meso-scale models.
- Assumption of horizontal homogeneity: Unidirectional (1D) movements.
- Turbulence is wholly subgrid (meshes larger than 2 km).
What happens at intermediate scales?

LES

$E_{\text{Resolved}} > E_{\text{SUBGRID}}$

Gray Zone of Turbulence

1D

$E_{\text{SUBGRID}} > E_{\text{Resolved}} = 0$

10 m 100 m 250 m 500 m 1 km

2 km 10 km 20 km
Issue

How the turbulence should be represented in atmospheric models in the "Gray-Zone of turbulence"?
How to get a reference? Defaults of the current models

**Issue**

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**Goal**

To determine the true resolved and subgrid parts of the turbulence in the "Gray-Zone of turbulence" : a reference
How to get a reference?  Defaults of the current models

Issue
How the turbulence should be represented in atmospheric models in the "Gray-Zone of turbulence"?

Goal
To determine the true resolved and subgrid parts of the turbulence in the "Gray-Zone of turbulence" : a reference

Method
To consider LES as the truth.
Table of contents

1. A reference in the gray zone.

2. Defaults of the current models
1 A reference in the gray zone.

2 Defaults of the current models
LES: the "truth"

Fields campaign of dry convective boundary layers:


Fields campaign of cloudy convective boundary layers:

LES: the "truth"

Méso-NH model

Turbulence scheme: 1.5 order prognostic turbulence scheme developed by Cuxart et al. (2000).

Runs: Idealized flat diurnal boundary layers on a 16 km long domain with a 62.5 m grid spacing.

Simulations: Initialized by observed vertical profiles. The large scale environment is prescribed by surface fluxes, geostrophic wind and subsidence.
How to get a reference?

LES DOMAIN:
62.5 m resolution

Average values of the LES domain on 4 meshes:
125 m resolution

Average values of the LES domain on 16 meshes:
250 m resolution

Gray-Zone of Turbulence | R H
Calculation of the resolved and subgrid TKE

Increasing averaged grid spacing

62.5m 125m 250m 500m 1000m 2000m 4000m 8000m
Calculation of the resolved and subgrid TKE

Increasing averaged grid spacing

Resolved TKE at a resolution $\Delta x$:

$$e_{res}(\Delta x) = \frac{1}{2} \times \left( (\overline{u^2} - \langle u \rangle)^2 + (\overline{v^2} - \langle v \rangle)^2 + (\overline{w^2} - \langle w \rangle)^2 \right)$$
Calculation of the resolved and subgrid TKE

Resolved TKE at a resolution $\Delta x$:

$$ e_{res}(\Delta x) = \frac{1}{2} \times (\Delta x) \left( (u - \langle u \rangle)^2 + (v - \langle v \rangle)^2 + (w - \langle w \rangle)^2 \right) $$
Calculation of the resolved and subgrid TKE

Increasing averaged grid spacing

\[ e_{\text{res}}(\Delta x) = \frac{1}{2} \times \left( (\overline{u}_{\Delta x} - <u>)^2 + (\overline{v}_{\Delta x} - <v>)^2 + (\overline{w}_{\Delta x} - <w>)^2 \right) \]

Resolved TKE at a resolution \( \Delta x \):
\[ e_{\text{res}}(\Delta x) = e_{\text{res}}(62.5m) + e_{\text{sbg}}(62.5m) - e_{\text{res}}(\Delta x) \]

Subgrid TKE at a resolution \( \Delta x \):
\[ e_{\text{sbg}}(\Delta x) = e_{\text{res}}(62.5m) + e_{\text{sbg}}(62.5m) - e_{\text{res}}(\Delta x) \]
Calculation of the resolved and subgrid TKE

Increasing averaged grid spacing

Resolved TKE at a resolution $\Delta x$:
$$e_{\text{res}}(\Delta x) = \frac{1}{2} \times ((\overline{u^{\Delta x}} - \langle u \rangle)^2 + (\overline{v^{\Delta x}} - \langle v \rangle)^2 + (\overline{w^{\Delta x}} - \langle w \rangle)^2)$$

Subgrid TKE at a resolution $\Delta x$:
$$e_{\text{sbg}}(\Delta x) = e_{\text{res}}(62.5m) + e_{\text{sbg}}(62.5m) - e_{\text{res}}(\Delta x)$$

Other parameters: $\overline{w'q'_t}$, $\overline{w'\theta'_l}$, $\overline{q'^2_t}$, $\overline{\theta'^2_l}$, $\overline{\theta'_l q'_t}$
Similarity functions for the TKE in free CBL

Similarity function for the total parameter:

$$\frac{e_{total}}{w^*} = F_{e_{total}}(\frac{Z}{h})$$

(Lenshaw(1980), Sorbjan(1991))

Dimensional analysis:

$$\frac{e_{sbg}}{w^*} = F_{e_{sbg}}(\frac{Z}{h}, \frac{\Delta x}{h+h_c}) \equiv F_{e_{total}}(\frac{Z}{h}) \times P_{e_{sbg}}(\frac{\Delta x}{h+h_c})$$

$h$: boundary-layer height
$h_c$: height of the cloud layer

What is needed: Partial similarity function

$$\frac{e_{sbg}}{e_{total}} = P_{e_{sbg}}(\frac{\Delta x}{h+h_c})$$
Similarity functions for the TKE in free CBL

Similarity function for the total parameter:

\[
\frac{e_{\text{total}}}{w^*z^2} = F_{e_{\text{total}}} \left( \frac{Z}{h} \right)
\]

(Lenshow(1980), Sorbjan(1991))

Dimensional analysis:

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\]
Partial Similarity functions: TKE in the mixed layer

\[
\frac{e_{sbg}}{e_{total}} = P e_{sbg} \left( \frac{\Delta x}{h + h_c} \right)
\]

1 point for each altitude, time and resolution \( \frac{e_{sbg}}{e_{total}} \) and \( \frac{e_{res}}{e_{total}} \).
Partial Similarity functions: TKE in the mixed layer

\[
\frac{e_{\text{sbg}}}{e_{\text{total}}} = P_{e_{\text{sbg}}}(\frac{\Delta x}{h + h_c})
\]

Resolved part

Resolved part of TKE

+ IHOP
+ AMMA
+ Wangara
+ ARM
+ BOMEX

1 point for each altitude, time and resolution \( \frac{e_{\text{sbg}}}{e_{\text{total}}} \) and \( \frac{e_{\text{res}}}{e_{\text{total}}} \).
Partial Similarity functions: TKE in the mixed layer

\[
\frac{e_{sbg}}{e_{total}} = P_{e_{sbg}} \left( \frac{\Delta x}{h + h_c} \right)
\]

Resolved part

Subgrid part

1 point for each altitude, time and resolution \( \frac{e_{sbg}}{e_{total}} \) and \( \frac{e_{res}}{e_{total}} \).
For the fine meshes (near the LES), the subgrid part is smaller than the resolved one.

When the mesh becomes coarser, the subgrid part grows up.

For the coarsest meshes, the parameter becomes entirely subgrid as the resolved part is null.
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When the mesh becomes coarser, the subgrid part grows up.

For the coarsest meshes, the parameter becomes entirely subgrid as the resolved part is null.

\[
P_{e_{sbg}} \left( \frac{\Delta x}{h + h_c} \right)_{ML} = \frac{\left( \frac{\Delta x}{h + h_c} \right)^2 + \frac{7}{100} \times \left( \frac{\Delta x}{h + h_c} \right)^3}{\left( \frac{\Delta x}{h + h_c} \right)^2 + \frac{3}{21} \times \left( \frac{\Delta x}{h + h_c} \right)^3 + \frac{3}{42}} \pm 0.12 \times e^{-\frac{(\log(\frac{\Delta x}{h + h_c}) + 1.9)^2}{5}}
\]
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2. Defaults of the current models
The atmospheric model tested is Méso-NH.

- Various configurations: mesoscale meteorological model, cloud resolving model (CRM) or LES.
- A mass-flux scheme can be activated. It is used to simulate BL thermals (Pergaud et al. (2009))
Simulations at different grid spacings

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Simulations at different grid spacings

Simulations are performed at different grid spacings: 125 m, 250 m, 500 m, 1000 m, 2000 m, 4000 m and 8000 m.
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- **Mixing length**
  - BL89: Size of the coarsest eddies present at each altitude (Bougeault and Lacarrère (1989)).
  - DEAR: Size of the mesh in a convective case (Deardorff (1972)).
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- **The dimensionality of the scheme**
  - 1D turbulence scheme
  - 3D turbulence scheme
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- The dimensionality of the scheme
  - 1D turbulence scheme
  - 3D turbulence scheme

- Mass-Flux scheme: activation or deactivation of the mass-flux scheme: PMMC09 (Pergaud et al. (2009))
Defaults of the partitions : BL89-1D-PMMC09

BAD

GOOD

\sim 2000 \text{ m}
Defaults of the partitions

Simulations without mass-flux scheme

Simulations with mass-flux scheme

DEAR mixing length
BL89 mixing length

DEAR mixing length
BL89 mixing length

The "Gray-Zone" of turbulence is ill-represented whatever the configuration.
How to get a reference?

Defaults of the current models

Horizontal cross-sections: IHOP, 1000 m grid spacing

- Reference
- BL89-1D
- BL89-1D-PMMC09

PMMC09: mass-flux scheme

Without the mass-flux scheme
- Too important resolved movements.
- Too large structures.

With the mass-flux scheme
- Deficit of variability.
Physical explanation : Without mass-flux scheme

- 8000 m grid spacing: profile too unstable.
- K-gradient scheme: \( \overline{w'}\theta' = -K\left(\frac{d\theta}{dz}\right) \)
- Mesh is too large to produce resolved movements.
How to get a reference?

Physical explanation: Without mass-flux scheme

- BL89-1D: \( \theta \)
  - Mesh is small enough
  - Resolved eddies produced by buoyancy.
  - More realistic profile.
  - But too large structures.

The good profile for the wrong reason!

- Reference (LES)
- 8000 m: Simulation BL89-1D
- 1000 m: Simulation BL89-1D
How to get a reference?

Physical explanation: With mass-flux scheme

BL89-1D-PMMC09: $\theta$

- There is no difference between the profile at 1 km resolution and at 8 km resolution.
- They are too stable.
- No resolved eddy.
Conclusions

- A new diagnostic to determine the reference resolved/subgrid parts of the turbulence in the gray zone for the case of free dry and cloudy convective boundary layers,

- Quantification of the defaults of current models in the "Gray-Zone" of turbulence.

The "Gray-Zone" of turbulence is ill-represented whatever the configuration of the turbulence scheme.

A Diagnostic for Evaluating the Representation of Turbulence in Atmospheric Models at the Kilometric Scale, R. Honnert, Masson V., and Couvreux F. JAS, on line.
Perspectives

- Produce a new parameterization for the "Gray-Zone" of turbulence: The mass-flux can be improved by introducing the mesh size in the entrainment/detrainment rate closure.
- Test this new parameterization in other convective boundary layer.
Thank you for your attention.

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