A stochastic downscaling method for sub-grid turbulence modeling

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Objective and idea

Objective

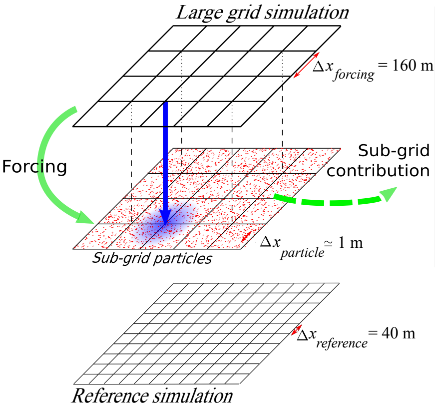
Starting from a grid point model, modeling the turbulence inside the grid cells

- Wind
- TKE

Idea

Use of a mesh-free model

- Particle system
- Stochastic Lagrangian model



Outline

1. The models
2. The downscaling method
3. The results

Plan

1 The models

2 The downscaling method

3 The results

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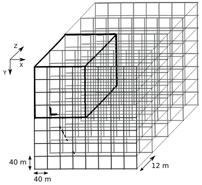
The models

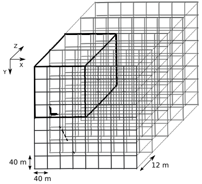
→ Atmospheric model Meso-NH



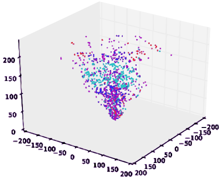
→ Stochastic Lagrangian model for local turbulence modeling

The models

→ Atmospheric model Meso-NH



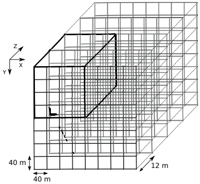
→ Stochastic Lagrangian model for local turbulence modeling



The models

→ Atmospheric model Meso-NH

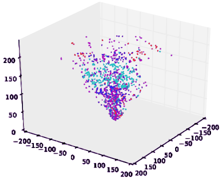
Lafore et al. (1997)



- LES simulations performed for the BLLAST experiment
- Time step : 5 seconds
- Grid size : 40m x 40m x 12m
- Experience over 15 minutes from 13h55, 20/06/2011
- Downscaling domain : 8 x 8 x 4 grid points,
  heights from 360m to 400m

The models

→ Stochastic Lagrangian model
for local turbulence modeling



3D velocity $\mathbf{V}_k = (V_k, W_k)$, 3D position X_k, time step k

$$\begin{cases} X_{k+1} = X_k + \mathbf{V}_k \, \Delta t + \sigma^X \Delta B^X_{k+1} \\ V_{k+1} = V_k - \nabla_x \overline{p} \, \Delta t - C_1 \frac{\varepsilon_k}{K_k} [V_k - < V >] \, \Delta t + \sqrt{C_0 . \varepsilon_k} \, \Delta B^V_{k+1} \\ W_{k+1} = W_k + \Delta_k W - C_2 \frac{\varepsilon_k}{K_k} [W_k - < W >] \, \Delta t + \sqrt{C_0 . \varepsilon_k} \, \Delta B^W_{k+1} \end{cases}$$

Baehr (2008)

- The control parameters are provided by the grid point model.

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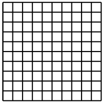
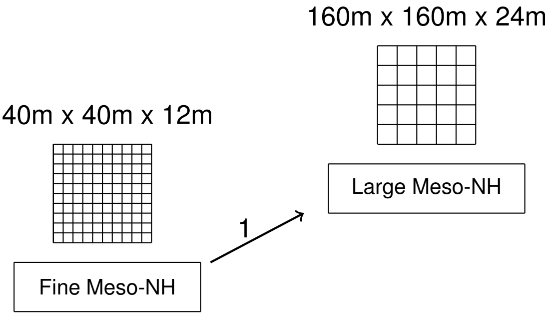
The downscaling experience

40m x 40m x 12m

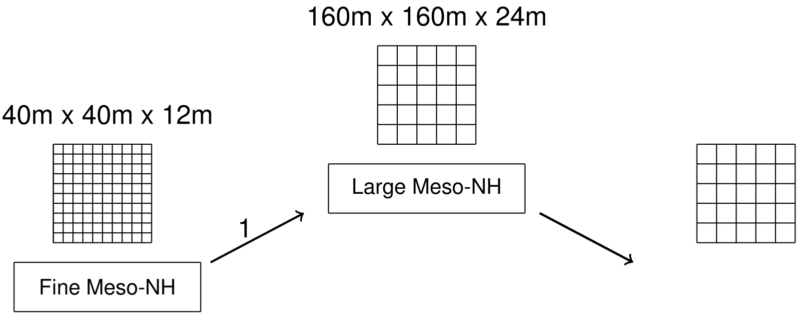


Fine Meso-NH

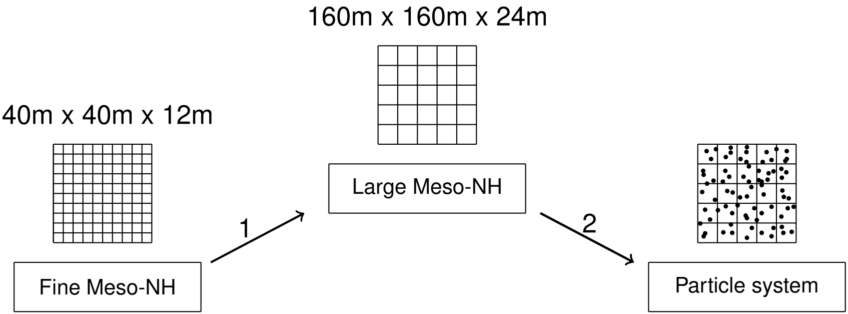
The downscaling experience



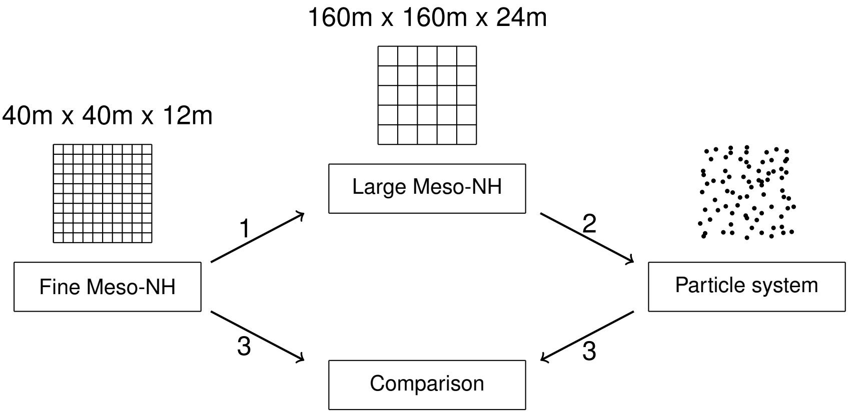
The downscaling experience



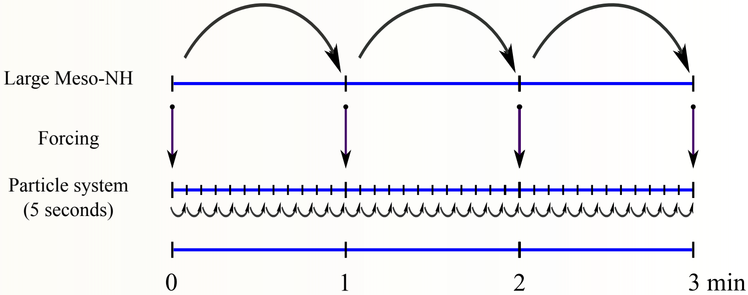
The downscaling experience



The downscaling experience



The forcing method



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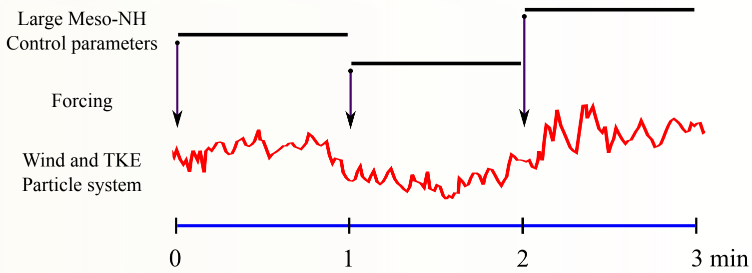

How to compare particle simulations and grid point simulations ?

Particle wind and TKE

The particle velocities are averaged cell by cell.

- For N particles in the grid cell α,

$$V^{\alpha} = \frac{1}{N} \sum_{i=1}^{N} V^{i}$$

⇝ Method adjustable to the grid size.

- TKE computed from the particle system :

$$\text{TKE} = \frac{1}{N} \sum_{i=1}^{N} \frac{1}{2} < (V^{i} - < V^{i} >_{N})^{2} >_{N}$$

⇝ $< V^{i} >_{N}$ is the local average of the particle velocities.

TKE modeled by Meso-NH

TKE = resolved TKE + sub-grid TKE

- Resolved TKE

$$K_{res} = \frac{1}{2}(\overline{(u-\overline{u})^2} + \overline{(v-\overline{v})^2} + \overline{(w-\overline{w})^2})$$

- Spatial average
  - ⇝ here, average over the whole domain
- Sub-grid TKE
  - ⇝ prognostic variable of Meso-NH
  - ⇝ computed using a parametrization (Cuxart et al., 2000)
- The resolved TKE represents 80% of the total TKE.

Plan

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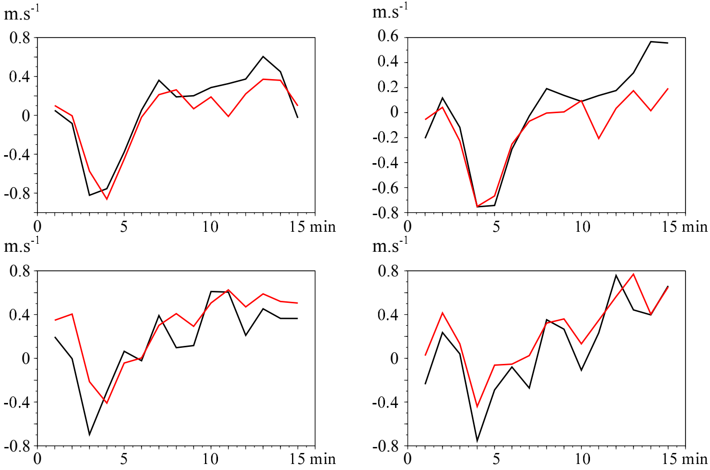
Meridian wind at the forcing scale : 160m x 160m

Four cells of the coarse grid.

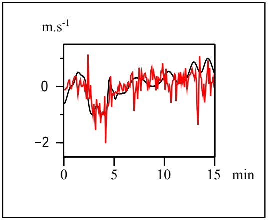
V



Wind modeled by the **particles** and **Meso-NH**

Meridian wind at fine scale : 40m x 40m

Wind at fine scale for one cell



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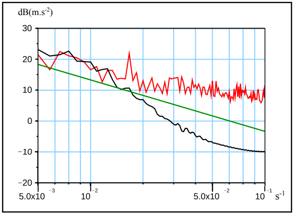
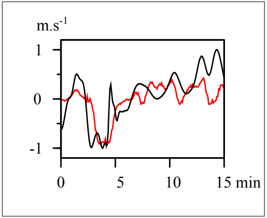


Low frequency component



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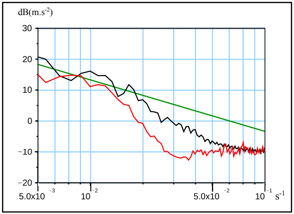
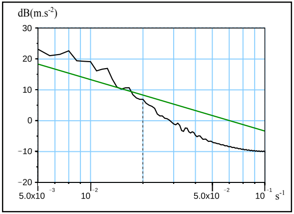
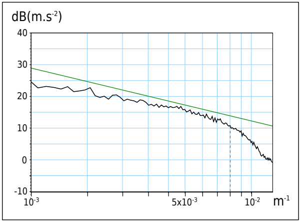


Meso-NH effective resolution

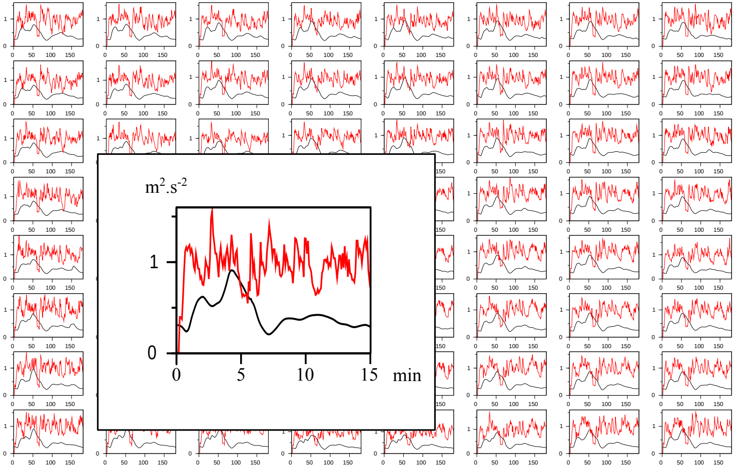
- Effective temporal resolution :
  50 s $\sim$ $10.\Delta t$



- Effective spatial resolution :
  125 m $\sim$ $3.\Delta x$



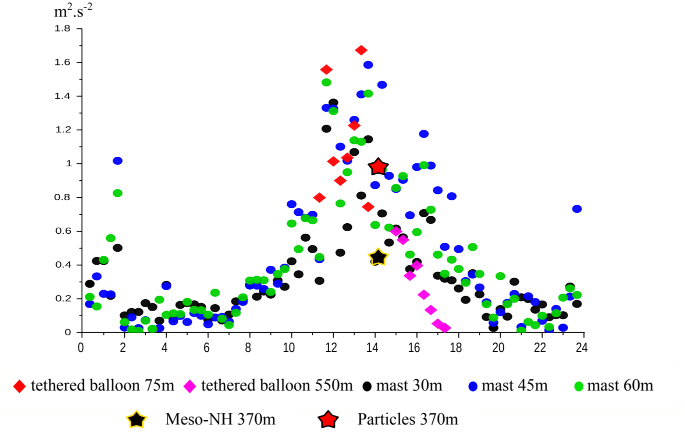
High resolution TKE



TKE modeled by the **particles** and **Meso-NH**

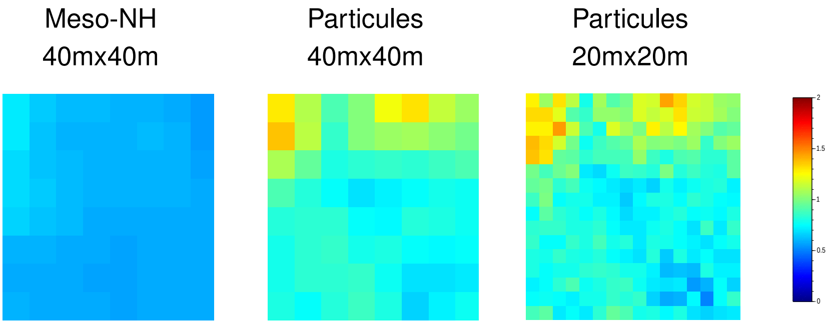
Observed and modeled TKE

BLLAST experiment, 20/06/2011



Canut et al. (2015)

Meso-NH TKE vs particle TKE



- How to validate the particle simulations ?
- What is the resolution of the turbulent field modeled by the particles ?
- Application of the downscaling method to a longer period and a larger domain.
- A new tool to work on turbulence parametrization ?

Article

Rottner, L., Baehr, C., Couvreux, F., Canut, G., and Rieutord, T. :
A new downscaling method for sub-grid turbulence modeling,
Atmos. Chem. Phys. Discuss., doi :10.5194/acp-2015-1015, in review, 2016.

Thank you for your attention !

The local average

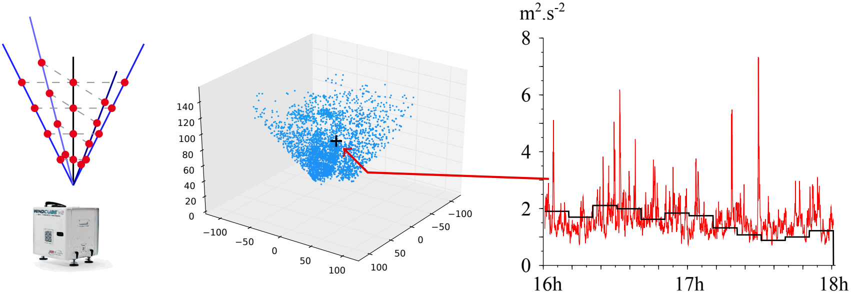
The ensemble average $< \cdot >$ is approximated by a discrete spatial average calculated from the particles.

- Regularisation function $G^{\delta}(X^i, X^j) = exp(-\frac{||X^i - X^j||^2}{2\delta^2})$
- Local average of the wind : $< \mathbf{V}^i >_N = \sum_{j=1}^{N} \frac{G^{\delta}(X^i, X^j)}{\sum_{l=1}^{N} G^{\delta}(X^i, X^l)} \mathbf{V}^j$

Advertising page

Atmosphere reconstruction

The key element is the observation !

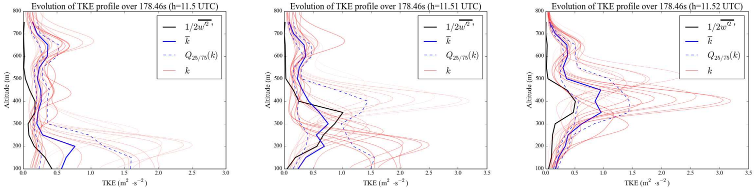


An instrument, the particles, the real time TKE and the classic 10 min TKE.

Data provided by Leosphere, coastal site in Greece, from 08/20/2010 to 08/27/2010.

Vertical lidar for the BLLAST experiment

- Ongoing application of the turbulence estimation method to the vertical lidar.



Références I

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Joan Cuxart, Philippe Bougeault, and J-L Redelsperger. A turbulence scheme allowing for mesoscale and large-eddy simulations. *Quarterly Journal of the Royal Meteorological Society*, 126(562) : 1–30, 2000.

Références II

Jean Philippe Lafore, J Stein, N Asencio, Ph Bougeault, V Ducrocq, J Duron, C Fischer, P Héreil, P Mascart, V Masson, et al. The meso-nh atmospheric simulation system. part i : adiabatic formulation and control simulations. In *Annales Geophysicae*, volume 16, pages 90–109. Springer, 1997.