Can we produce realistic boundary layer turbulence by coupling large-eddy simulations with mesoscale model data?

Rieke Heinze
Lennart Böske
Siegfried Raasch
Christopher Moseley
Bjorn Stevens

Session: Theoretical and practical issues associated with multi-scale simulations
11th June 2014
Realistic boundary layer turbulence

- Important for e.g.
  - Environmental applications (wind engineering)
  - Parameterization development
- Method of choice: large-eddy simulation (LES)
  - Single-day LES
  - Long-term LES
- Long-term LES: recent approach (Neggers et al., 2012, Neggers and Siebesma, 2013)

⇒ Verification by observations from measurement campaign HOPE
Main goal:
Build and run a climate/NWP model with very high resolution ($\Delta x \approx 100m$): ICON-LES

Sub-project HOPE:
April-May 2013 centered around Jülich Forschungszentrum

LES coupled with mesoscale model data
**HOPE: HD(CP)² Observational Prototype Experiment**

**Main goal:**
Build and run a climate/NWP model with very high resolution ($\Delta x \approx 100m$): ICON-LES

**Sub-project HOPE:**
April-May 2013 centered around Jülich Forschungszentrum

**Equipment**
- Remote sensing instruments (lidars, radars, microwave radiometers)
- Radiosondes
- EC-stations
- Meteorological tower
- Radiation measurements
- ...

**Setup**

**Results**

**Conclusions**

**LES coupled with mesoscale model data**
**Models and large-scale forcing**

- **LES models**: PALM and UCLA-LES
  - $\Delta = 50$ m, $t = 72$h (24-26 April 2013)
  - Prescribed $\theta(t)$ and $q(t)$ at surface
  - Initial profiles from large-scale forcing
  - Two-moment, warm microphysics

- Large-scale hor. advection:
  COSMO-DE analysis data (2°x2° mean)

- Large-scale vert. advection:

  $\frac{\partial \varphi}{\partial t} \bigg|_{\text{SUB}} = -w_{\text{LS}} \frac{\partial \varphi}{\partial z}$

- Geostrophic wind: $\vec{v}_g(t)$

- Nudging: $\tau = 6$ h
24-26 April – as seen by remote sensing instruments

- **24 April**: clear-sky CBL
- **25 April**: cumulus-topped CBL
- **26 April**: frontal passage

CloudNet product from JOYCE (gop.meteo.unikoeln.de)

LES coupled with mesoscale model data
Boundary layer depth

\[ z_i: \text{height where } \frac{R_{ib}}{R_{ib}} = \frac{g}{\theta_0} \frac{\theta_v - \theta_{v0}}{u^2 + v^2} \text{ is larger than 0.25} \ (\text{e.g. Richardson et al., 2013}) \]

\[ \Rightarrow \text{LES produce daily cycles in reasonable agreement with observations} \]
Clouds and precipitation

- Deeper cloud layers on 26/4 can be simulated by both LES models.
- Shallow cloud layer on 25/4 is missing (completely) in LES.
Clouds and precipitation

- Deeper cloud layers on 26/4 can be simulated by both LES models
- Shallow cloud layer on 25/4 is missing (completely) in LES
- Peak in rain water at same time as in forcing
- LES were run with warm-microphysics only

⇒ Clouds are a bit tricky

LES coupled with mesoscale model data
Animation

- Model: PALM
- Quantities: $q_c$ and $q_r$
- Note: large-scale forcing from 0.25°x0.25° COSMO mean used
• Long-term LES approach gives reasonable daily cycles
  ⇒ Observed situations can principally be reproduced

• Shallow cumulus clouds could not be simulated
  ⇒ Strong dependence on large-scale advective forcing

⇒ Long-term LES approach works - but LES remain a virtual laboratory

Outlook:
• In-depth evaluation of large-scale forcing dependency
• Heterogeneous surface
Supplementary material
Large-scale forcing tendencies

Large-scale horizontal advection:

\[ \left. \frac{\partial \varphi}{\partial t} \right|_{\text{LSA}} = - \left( u_{\text{LS}} \frac{\partial \varphi_{\text{LS}}}{\partial x} + v_{\text{LS}} \frac{\partial \varphi_{\text{LS}}}{\partial y} \right) \]

Large-scale vertical advection:

\[ \left. \frac{\partial \varphi}{\partial t} \right|_{\text{SUB}} = - w_{\text{LS}} \frac{\partial \varphi}{\partial z} \]

LES coupled with mesoscale model data
Surfaces fluxes

Surface sensible (shf) and latent (lhf) heat fluxes

⇒ LES fluxes are representative for HOPE site
LES coupled with mesoscale model data

Liquid water path
Mean profiles: Boundary layer developing on 24/4

Simulated boundary layers are colder than in observations
Sensitivity to relaxation time scale $\tau$

Nudging tendency: \[
\left. \frac{\partial \varphi}{\partial t} \right|_{\text{NUD}} = -\frac{\langle \varphi \rangle - \varphi_{\text{LS}}}{\tau}
\]

⇒ Virtually no dependence on relaxation time scale $\tau$
Setup for animation

Note: large-scale forcing from 0.25°x0.25° COSMO mean

Results are sensitive to large-scale forcing
Setup for animation

Note: large-scale forcing from 0.25°x0.25° COSMO mean

Results are sensitive to large-scale forcing