On the benefit of driving Large-Eddy Simulation with spatially resolved surface fluxes derived from environmental response functions

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Background

Large-Eddy Simulation (LES) is well-suited for studying turbulence in the atmospheric boundary layer under controlled conditions. However, for LES studies in heterogeneous terrain it is important to accurately prescribe the surface conditions, especially the surface fluxes. One possibility is to use surface fluxes derived from environmental response functions (ERF) [1]. The ERF allow a spatially explicit regionalization of the surface heat fluxes from airborne or tower-based flux measurements. Furthermore, the surface data from the ERF have high spatial resolution (100 m) and exhibit temporal variation during the course of the day.

We can devise two ways to benchmark the simulations driven by the ERF derived fluxes. One would be to compare with LES driven by other remotely sensed data, such as satellite measurements, which also represent the surface heterogeneity, albeit more coarsely resolved in space or time. Another way would be to compare the heterogeneous ERF-driven simulations with simulations in simple homogeneous terrain, where the surface data is obtained by single tower measurements. The former comparison has the advantage to concentrate on whether the ERF would offer a significant advantage for the LES by providing more precise surface data. The latter comparison focuses rather on the question if surface heterogeneity by itself offers an advantage over homogeneous simulations. Because the LES driven by satellite data (temperature and enhanced vegetation index) suffer from uncertainties in the determination of the surface moisture, we will focus on the latter question.

Objectives

- Does the heterogeneous LES predict the tower data better?
- Does the heterogeneous LES enhance the boundary layer circulations?

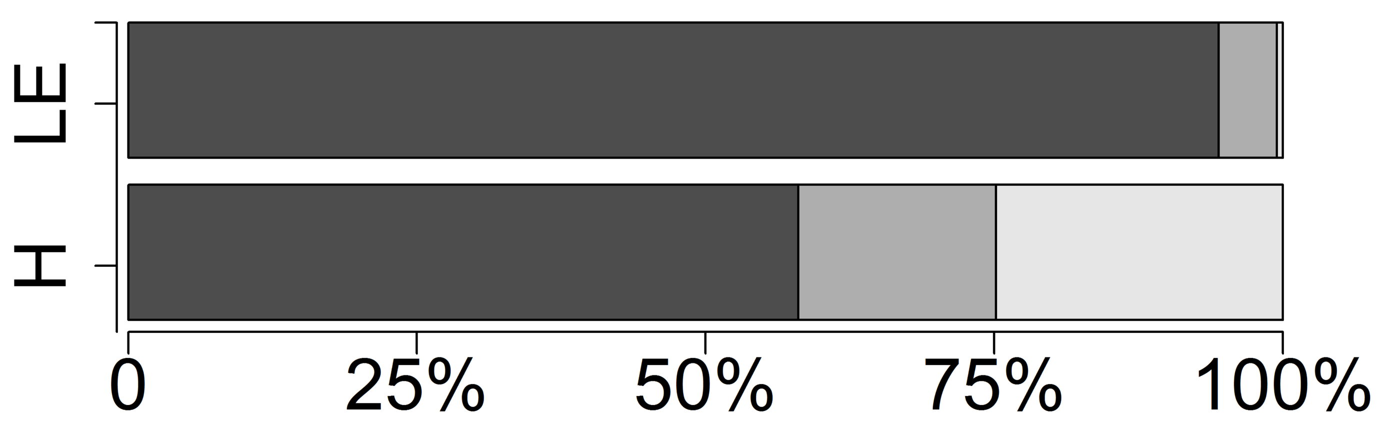
Tower data at 30 – 122 – 396 m to evaluate the simulations

Boundary layer characteristics	
L	$= -1.4 \cdot 10^2\,\mathrm{m}$
z_i	$= 1.3 \cdot 10^3\,\mathrm{m}$
$u_\star$	$= 8.2 \cdot 10^{-1}\,\mathrm{m/s}$

Simulation design	
Timestep	$0.5 - 1\,\mathrm{s}$
Horizontal grid resolution	$10 - 20\,\mathrm{m}$
Gridpoints	$O(10^3 \times 10^3 \times 10^2)$
Vertical grid resolution	$5 - 10\,\mathrm{m}$
Horizontal area	$100 - 400\,\mathrm{km}^2$

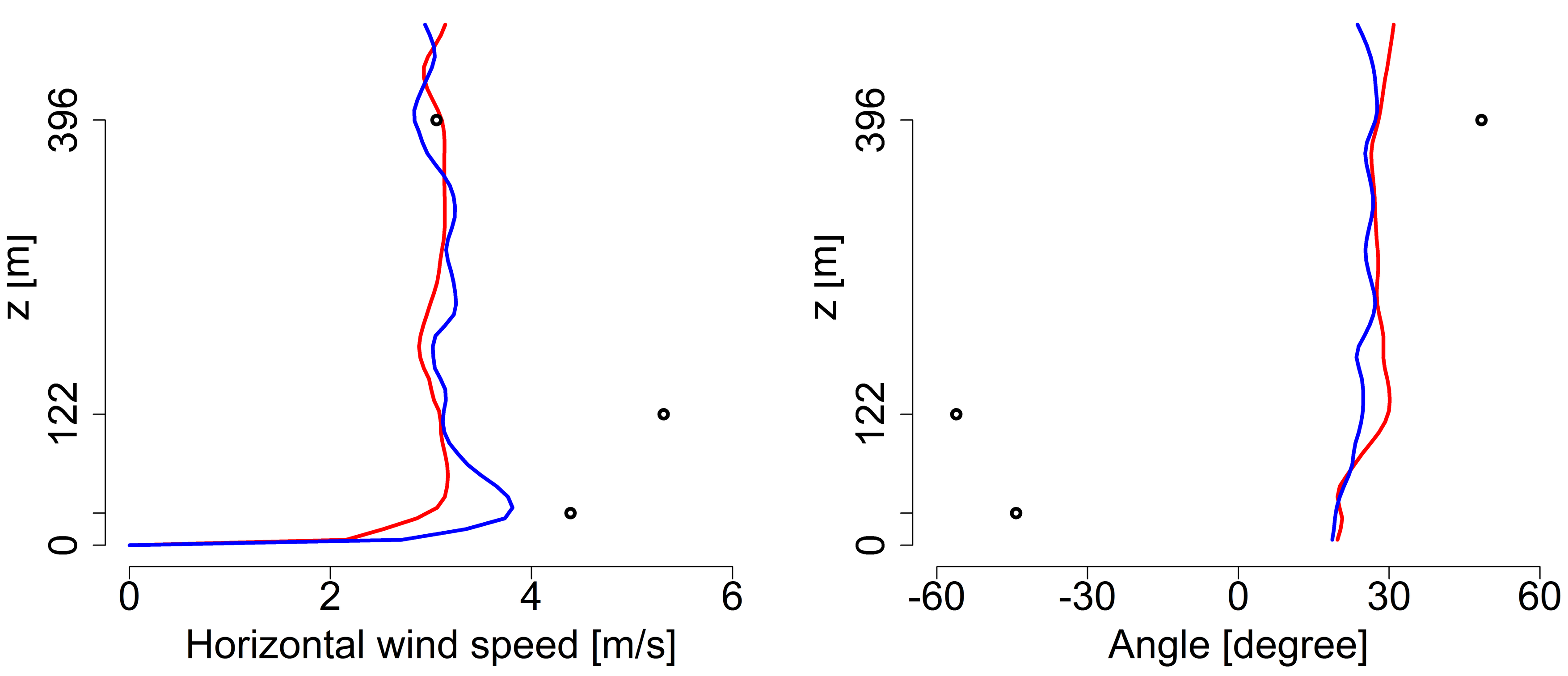
The data was obtained from the tall tower at Park Falls, Wisconsin, USA. We mainly focused on 20 August 2011, around noon. We have initialized our LES domain with the profiles from the tower (homogeneously). The heat fluxes at the surface are the main driving force of the turbulence, but a background wind is present too, which was estimated from the tower values. Further reducing the timestep without simultaneously reducing the grid spacing does not yield additional turbulence.

Eddy fluxes from the homogeneous LES correspond better to the tower data



Virtual EC fluxes as fraction of the tower measurement at 12:00-13:00, 30 m
Darkgray: heterogeneous; Medium-gray: homogeneous

The simulated wind field does not match with the tower measurements near the surface

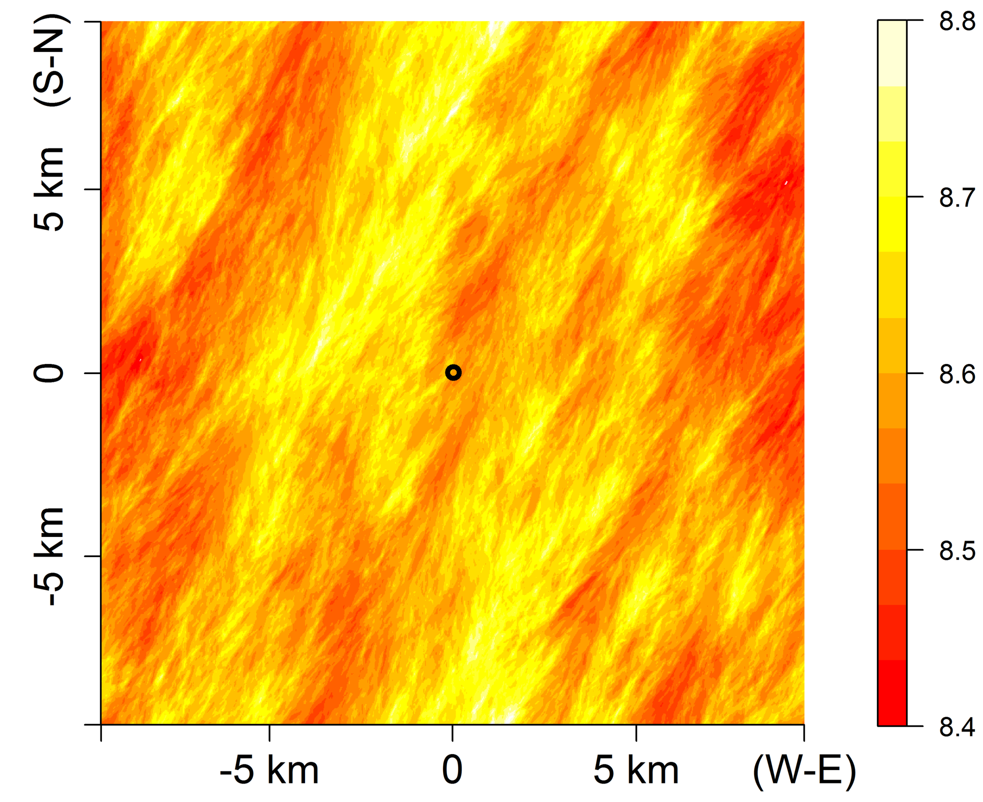


Red: ERF-driven LES; blue: homogeneous; dots: tower data

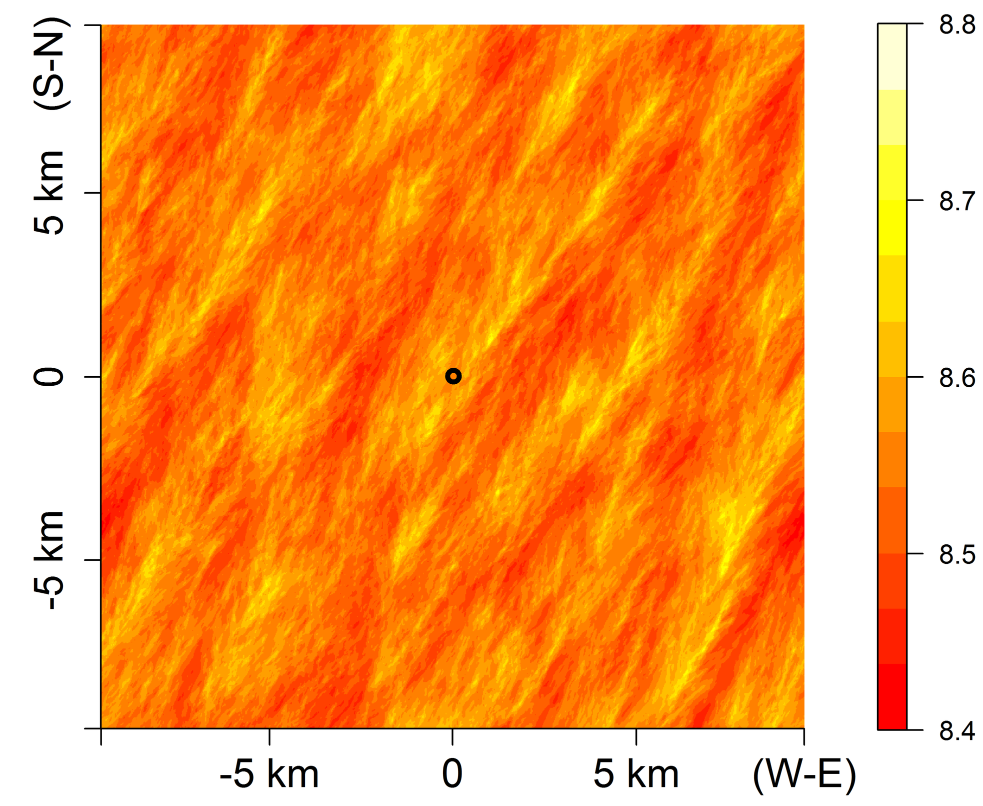
Slightly stronger structures in heterogeneous terrain (?)

When we compare the horizontal variation of the temperature and humidity, we find that the heterogeneous case yields slightly larger values. For the vertical wind component, the situation is opposite. The horizontal structures, which are closer to roll-like than to cellular convection, are clearly broader in the heterogeneous LES.

$\sigma_{xy}(\cdot)_{het} - \sigma_{xy}(\cdot)_{hom}$	30 m	122 m	396 m
T [K]	$+8.7 \cdot 10^{-3}$	$+9.6 \cdot 10^{-3}$	$+1.1 \cdot 10^{-2}$
q [g/kg]	$+2.2 \cdot 10^{-2}$	$+2.3 \cdot 10^{-2}$	$+2.3 \cdot 10^{-2}$
w [m/s]	$-5.6 \cdot 10^{-3}$	$-2.2 \cdot 10^{-2}$	$-3.8 \cdot 10^{-2}$



Heterogeneous $\bar{q}(xy)$ at 122 m [g/kg]



Homogeneous $\bar{q}(xy)$ at 122 m [g/kg]

Conclusion: in complex terrain too few information can be worse than no information

For comparison with tower measurements, large-eddy simulation in heterogeneous domain requires that the footprint of the tower is well represented, therefore the simulated wind field has to correspond well with the actual wind field in the surface layer. This is especially important under weakly unstable (and stable) conditions. **If the footprint is misrepresented, a simpler large-eddy simulation for only homogeneous terrain can yield equal or even better results**. The simulated horizontal wind field is not guaranteed to approximate the measurements when only the surface heterogeneity (heat fluxes, temperature, moisture, roughness,…) is known. To achieve a close correspondence, also precise knowledge about the local vertical profiles of the pressure gradient (or geostrophic wind) is necessary.

Outlook: We plan to further improve the simulated wind field, so we can decide whether the heterogeneous LES can yield the correct tower values when the simulated footprint corresponds with reality. In addition, to make the simulations more realistic, the ERF also allows us to simulate the diurnal evolution of the boundary layer as well.

References

[1] S. Metzger, W. Junkermann, M. Mauder, K. Butterbach-Bahl, B. Trancón y Widemann, F. Neidl, K. Schäfer, S. Wieneke, X. H. Zheng, H.P. Schmid, and T. Foken. Spatially explicit regionalization of airborne flux measurements using environmental response functions. *Biogeosciences*, 10:2193–2217, 2013.

Acknowledgements

We thank the PALM group at Leibniz University Hannover for their open-source PALM code. This work was conducted within the Helmholtz Young Investigators Group “Capturing all relevant scales of biosphere-atmosphere exchange — the enigmatic energy balance closure problem”, which is funded by the Helmholtz-Association through the President's Initiative and Networking Fund, and by KIT. Additional funding by the DOE Ameriflux Network Management Project, the U.S. National Science Foundation, and NEON, Inc.

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