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Analyzing Atmosphere-Land Interactions with LES

Do the feedback processes in a Large-Eddy Simulation (LES), that dynamically interacts with a Land-Surface Model (LSM), have an effect on the mean atmospheric state?

Motivation

The influence of land-surface heterogeneity on the mean boundary-layer (BL) statistics have been investigated with LES since 1990 [1]. From this, we know that (stationary) surface buoyancy flux heterogeneities significantly influence mean BL dynamics [2,3,4]. Also, dynamic heterogeneities like clouds are known to self-organize under certain conditions [5]. A remaining question is, how the interaction with a land surface model changes BL dynamics. In this case, the surface heterogeneities are produced by the interaction of the land with the turbulent eddies in the atmosphere. Hence, the patch size represents the turbulent scale from the grid size to the size of the BL. What makes it more complex, these heterogeneities vary dynamically and have a maximum lifetime of the turbulent time scale. If the BL was influenced by this inherent dynamic heterogeneous surface, the validity of homogeneous LES would have to be rethought.

Method

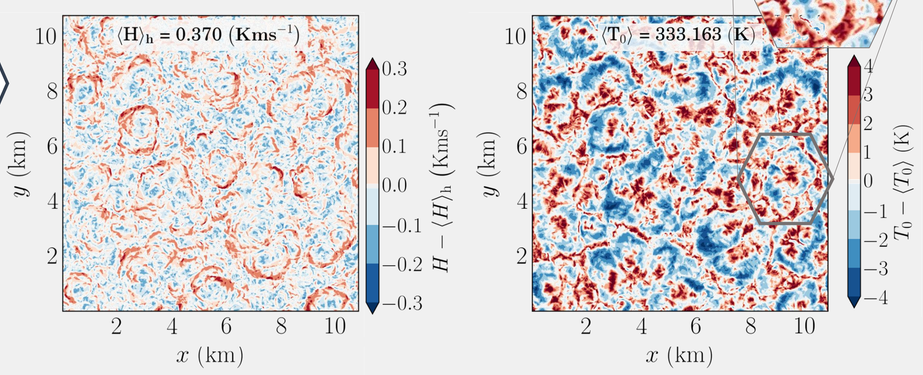
- Hypothesis: no significant influence on BL due to vastly changing irregular heterogeneities
- Method: run idealized LES interactively coupled to LSM and compare to homogeneous control run
- Model: PALM with implemented basic LSM

Simulaion setup
- bare soil surface without skin layer
- first soil layer in $1\ \mathrm{mm}$ depth
- dry atmosphere and soil
- no geostrophic wind
- constant initial profiles
- domain: $10.8\ \mathrm{km} \times 10.8\ \mathrm{km} \times 3.5\ \mathrm{km}$
- grid size: $10\ \mathrm{m} \times 10\ \mathrm{m} \times 10\ \mathrm{m}$

Results

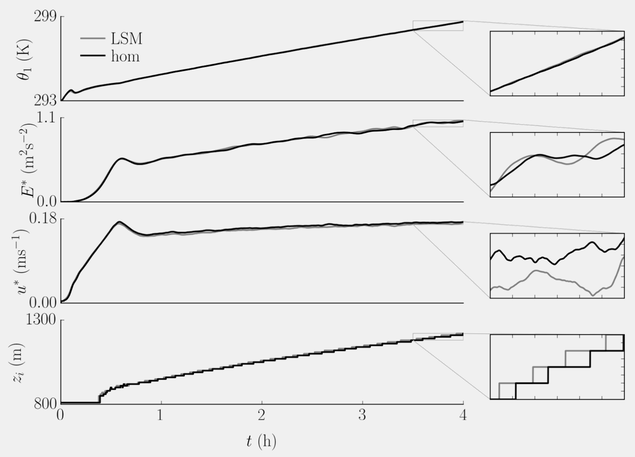
1. Analyzing horizontal cross sections of the coupled LSM-LES:
   - wide range of surface heat flux H
   - surface (radiation) temperature T_0 has maximum at the edges of the hexagonal convection cells (like in the lower BL)
   - plus maximum in the center of the cells!

1



2. Timeseries comparison:
   - difference of $O(\Delta\theta_1) = 0.01\ \mathrm{K}$
   - no systematic difference in E^*
   - $u^*$and slightly lower in LSM case
   - z_i increases faster

2



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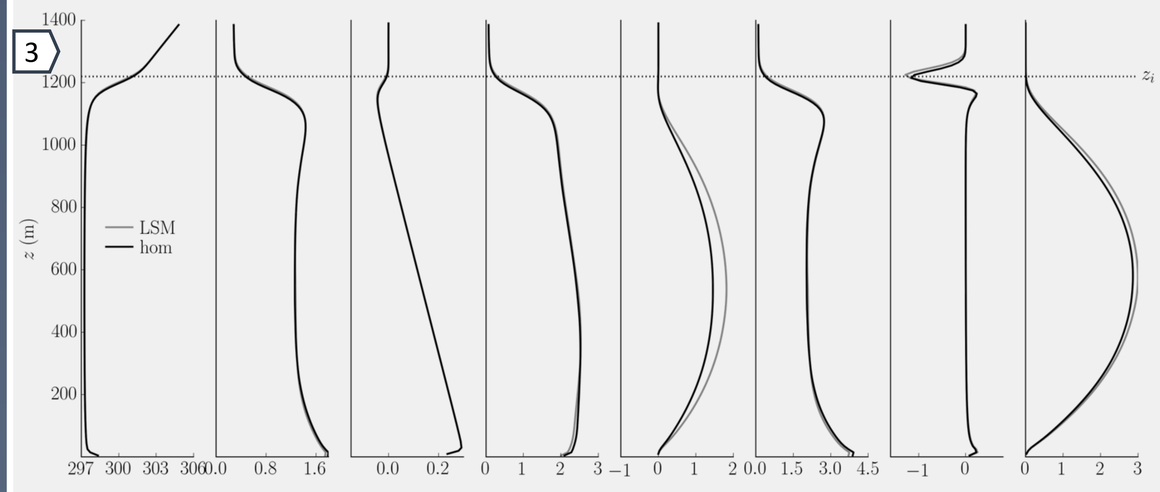

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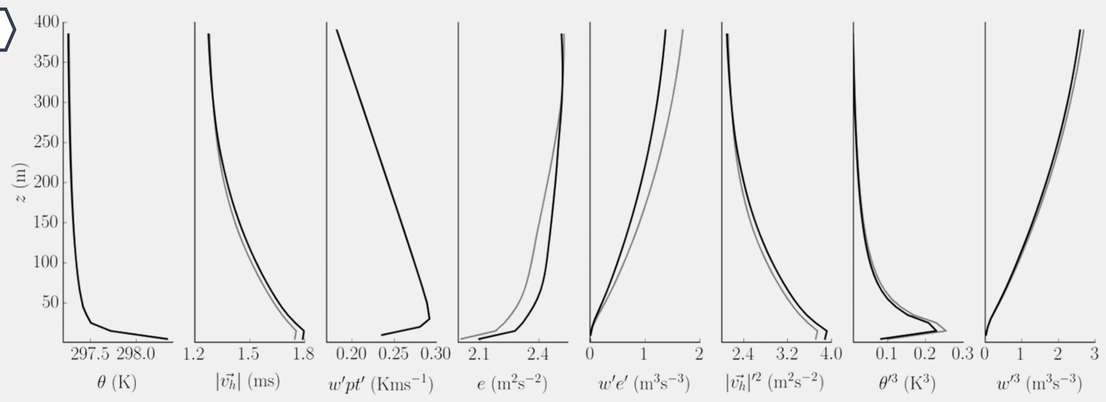
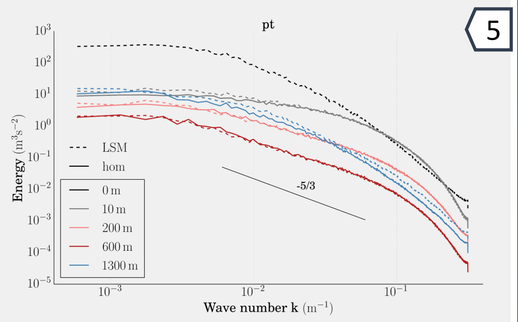


3. Profiles show no significant differences in the relevant variables:
   - higher-order moments of wind and temperature not affected
   - (resolved) turbulence kinetic energy e and vertical flux $w'e'$ most sensitive

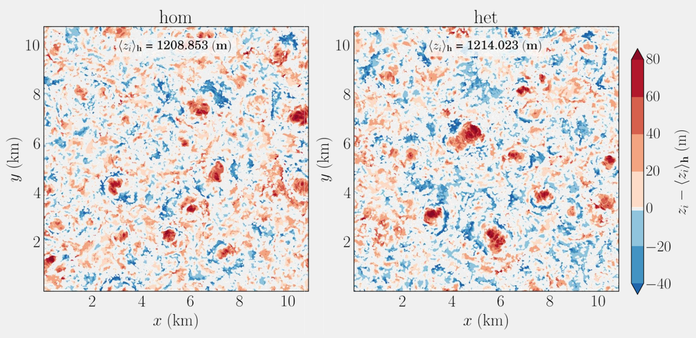
4. Some differences seen in close-up on the lower BL:
   - LSM case shows slightly smaller horizontal wind speed at model bottom
   - it remains a local effect and does not influence whole BL statistics

5. Horizontal spectra of the potential temperature in different heights reveal no different shapes for the LSM and hom cases.

5



6. The entrainment layer, which is known to react sensitive to surface heterogeneities, also shows the same overall statistics.



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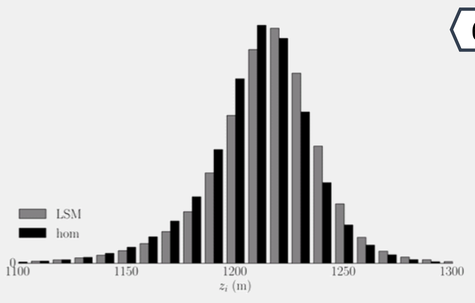

Discussion

This study has shown that the heterogeneous surface which is inherent in large-eddy simulation coupled to a land-surface model does not alter the general boundary-layer characteristics.

A previous study [6] says that an interactive LSM had “a profound impact on the simulated BL dynamics”. We have closely examined the difference between a coupled LSM-LES and a conventional homogeneously driven LES. From that we know that there is no significant - and by no means a “profound” - impact on BL dynamics due to a coupled LSM. Nonetheless, we have also seen that the interaction with the soil layers can weaken the turbulence kinetic energy in the lower quarter of the BL.

For future studies we expect the use of LSMs with LES to be very important, because realistic LES can be carried out without the need of measurement data. However, the land-surface data must be of very high quality.

References

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