# Optimizing large-eddy simulations for investigating the energy-balance closure problem at typical flux measurement heights (EGU2020-19678)

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# BACKGROUND

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- **Overall goal:** investigation of the energy-balance closure problem by comparing large-eddy simulations (LES) with CHEESEHEAD* eddy-covariance (EC) measurements
- **Objective:** development of a large-eddy simulation setup that yields more realistic energy-balance ratio values at low heights than former simulations

**Table 1: advantages and drawbacks of large-eddy simulations**

| LES advantages | LES drawbacks |
|---|---|
| Provide spatial information on heat fluxes [1] | Former studies couldn‘t represent energy-balance ratios (EBR) at typical EC tower heights [3]<br>Possible explanation: prescribed surface fluxes which may suppress the development of secondary circulations are widely used boundary conditions |
| High grid resolution yields reliable results at low heights [2] | |

*Chequamegon Heterogeneous Energy-balance Study Enabled by a High-density Extensive Array of Detectors

# METHODS

- Large-eddy simulations using PALM v6 [4] with vertical grid nesting for high resolution close to the surface
- Homogeneous surface, covered by either meadow or forest
- Three atmospheric stabilities: moderately unstable (MU), strongly unstable (SU), free convective (FC)
- Four combinations of lower boundary conditions: prescribed surface fluxes (PSF) and land-surface model (LSM) over meadow, PSF and LSM over forest
- Simulation time: eight hours (first 2.5 hours: spin-up time)

**Table 2: Domain layout and settings for the different cases. The stability is regulated by geostrophic wind ($u_{geo}$), prescribed sensible and latent surface heatfluxes ($H_{sfc}$, $LE_{sfc}$) and net radiation ($R_{net}$). Different homogeneous surfaces defined by roughness length ($z_0$) or the plant canopy model.**

| run number | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| vegetation | | meadow | | forest | | meadow | | forest | | meadow | | forest | |
| Domain size (km) | | lx, ly = 7.2, lz = 2.4 | | | | | | | | | | | |
| Grid spacing (m) | coarse | dx, dy = 30, dz = 20 | | | | | | | | | | | |
| | fine | dx, dy = 6, dz = 4 | | | | | | | | | | | |
| Grid points | coarse | nx, ny = 240, nz = 120 | | | | | | | | | | | |
| | fine | nx, ny = 1200, nz = 60 | | | | | | | | | | | |
| PSF/LSM | | PSF | LSM | PSF | LSM | PSF | LSM | PSF | LSM | PSF | LSM | PSF | LSM |
| stability | | MU | | | | SU | | | | FC | | | |
| $u_{geo}$ ($m\ s^{-1}$) | | 5 | | | | 2 | | | | 0 | | | |
| $H_{sfc}$ ($K\ m\ s^{-1}$) | | 23 | 23 | 128 | 129 | 43 | 43 | 217 | 216 | 56 | 56 | 308 | 303 |
| $LE_{sfc}$ ($kg\ kg^{-1}\ m\ s^{-1}$) | | 170 | 172 | 35 | 27 | 220 | 226 | 28 | 21 | 280 | 288 | 25 | 18 |
| $R_{net}$ ($W\ m^{-2}$) | | - | 250 | - | 250 | - | 350 | - | 350 | - | 350 | - | 350 |
| $Z_0$ (m) | | 0.3 | | 2 | | 0.3 | | 2 | | 0.3 | | 2 | |

# RESULTS

- In general, dispersive heat fluxes become larger with increasing instability (MU → FC)
- Over the forest, the simulations with LSM produce much higher dispersive heat fluxes than simulations with PSF close to the ground
- Over the meadow, the use of the LSM results in larger dispersive sensible heatfluxes close to the surface. However, the dispersive latent heat fluxes are larger with PSF. Because the absolute latent heat flux is larger than the sensible heat flux, this leads to a slightly higher total dispersive heat flux when using PSF.

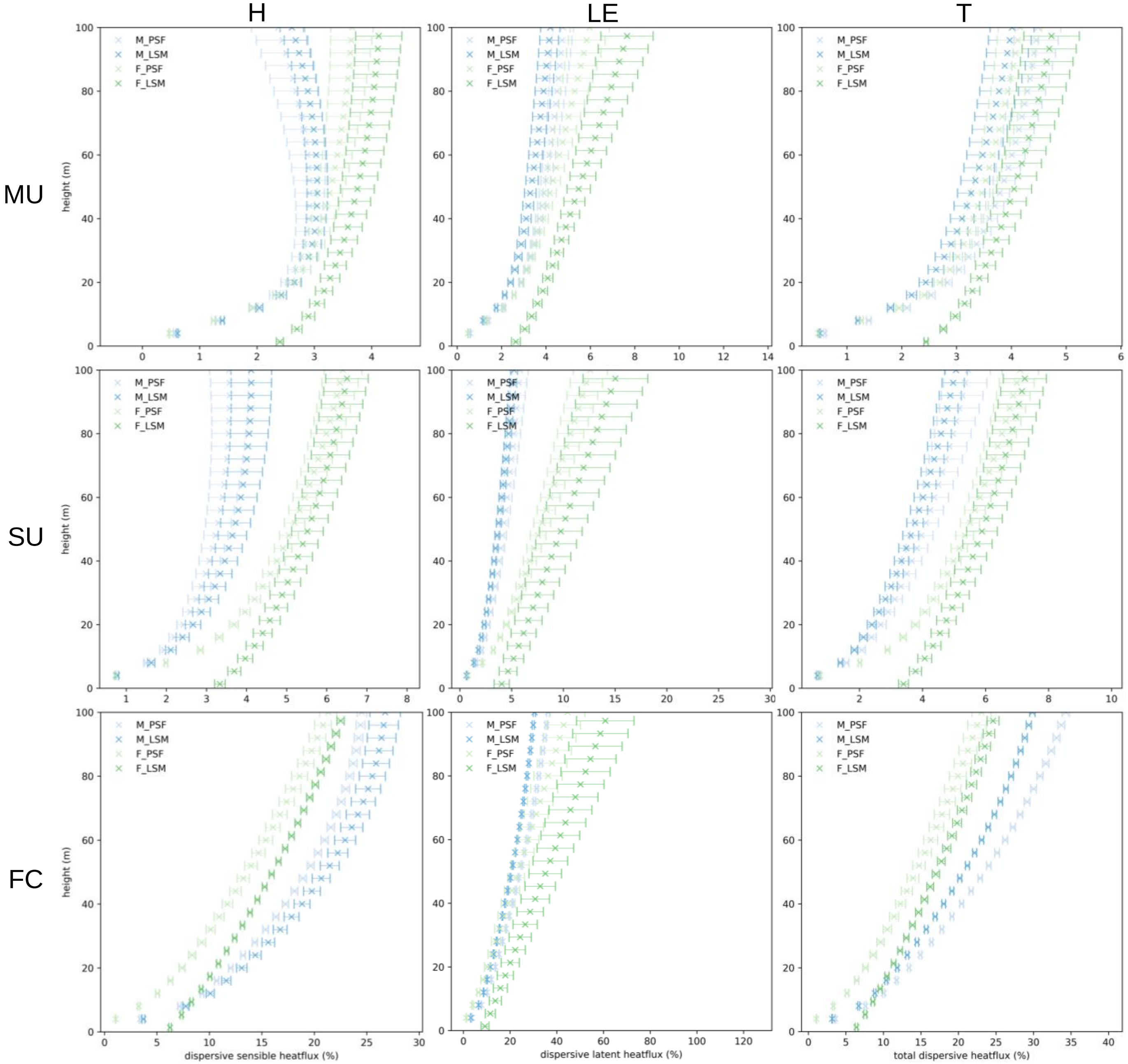


**Figure 1: Profiles of latent, sensible and total dispersive heat fluxes percentage of the respective surface heat flux for strongly and moderately unstable and free convective cases. The values are averaged over 7 half hours, error bars show the standard deviation of half-hourly values. MU: runs 1-4, SU: runs 5-8, FC: runs 9-12**

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# RESULTS

- In all three atmospheric stability, the use of the land-surface model leads to more pronounced rolls and cells over the homogeneous forest, respectively
- Above the meadow, the differences are not as distinct (not shown)

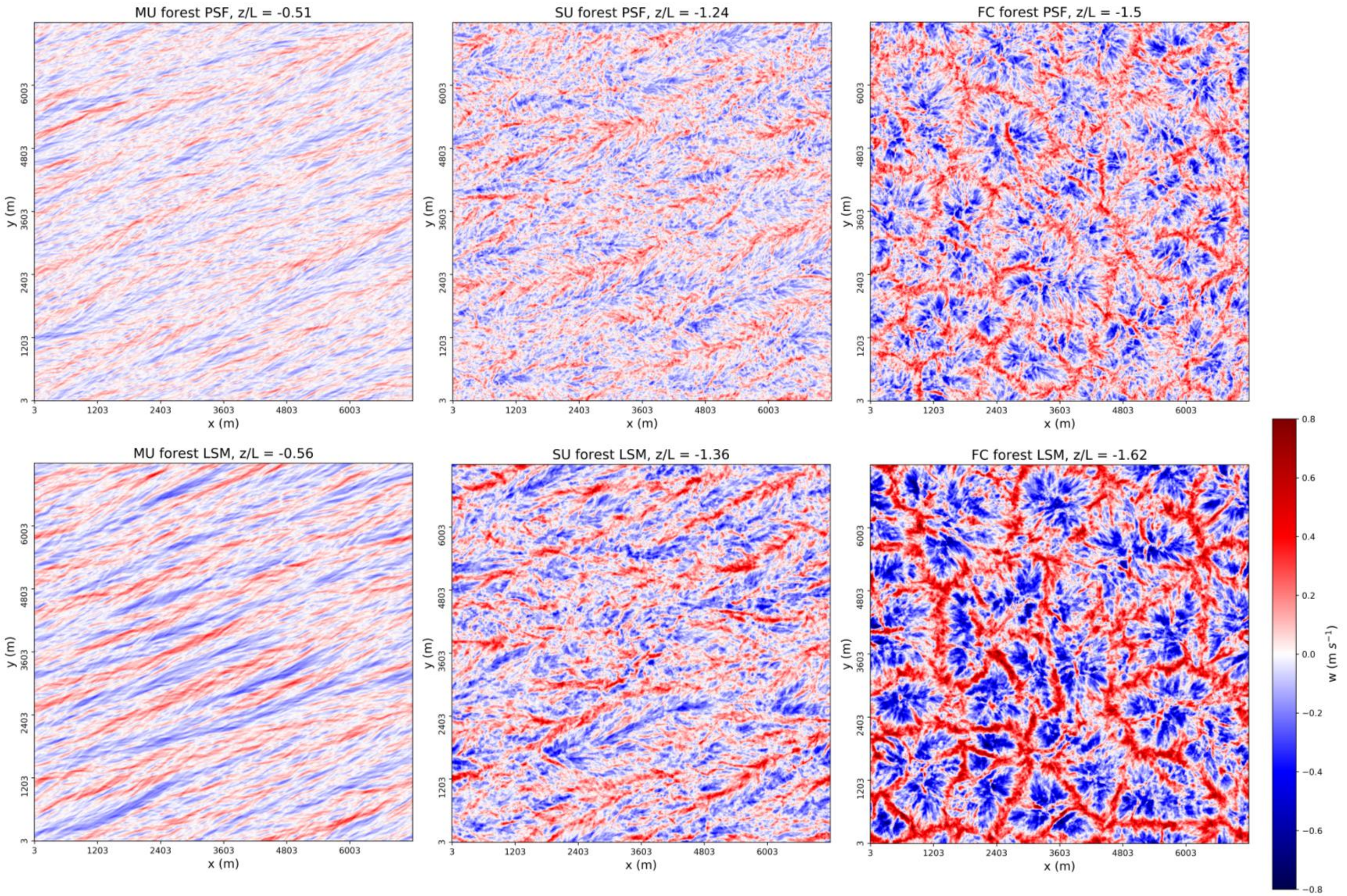


**Figure 2: xy-sections at z ≈ 25 m above zero plane displacement height showing vertical wind component w (m $s^{-1}$) averaged over 30 minutes after 3.5 hours of simulation time.**

# CONCLUSIONS

- The influence of lower boundary conditions increases with instability
- Which lower boundary condition (PSF or LSM) produces dispersive heat fluxes closer to the order of energy-balance gap in a more realistic simulation depends on the predominant vegetation type

  → LSM for forest, PSF for meadow

# OUTLOOK

- Two more aspects are going to be investigated:
  - use of dynamic subgrid-scale model
  - use alternative to Monin-Obukhov similarity theory
- The final setup will be used to carry out realistic large-eddy simulations of the CHEESEHEAD site

# ACKNOWLEDGEMENTS

The German contribution to CHEESEHEAD is funded by DFG. We thank the developers of PALM for this open source model.

# LITERATURE

[1] Schalwijk et al. 2016, Boundary-Layer Meteorology
[2] Huq et al. 2019, Geoscientific Model Development
[3] Steinfeld et al. 2007, Boundary-Layer Meteorology
[4] Maronga et al. 2019, Geoscientific Model Development