Large-eddy simulation of the energy balance closure in fully heterogeneous terrain

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Energy balance closure problem

Eddy-covariance: $H + LE < R_n - G$
- storage terms (e.g. canopy)
- instrumental errors
- missing flux in low-frequencies

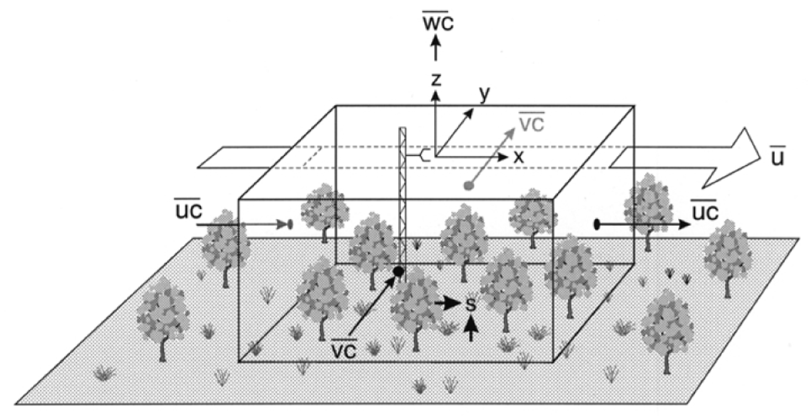
Strong imbalance in complex terrain [5]
→ quasi-stationary secondary circulations

The classic LES-method for the imbalance [3] uses domain-averaging "$[[\cdot]]$" and is limited to regular terrain. The imbalance is explained by advection.

Objective: investigate an alternative characterization of the energy balance that can be extended to virtual eddy-covariance tower measurements in heterogeneous terrain. The question of the near-surface imbalance has to await technical advancements in the LES model [2].

Virtual control volumes in fully heterogeneous terrain

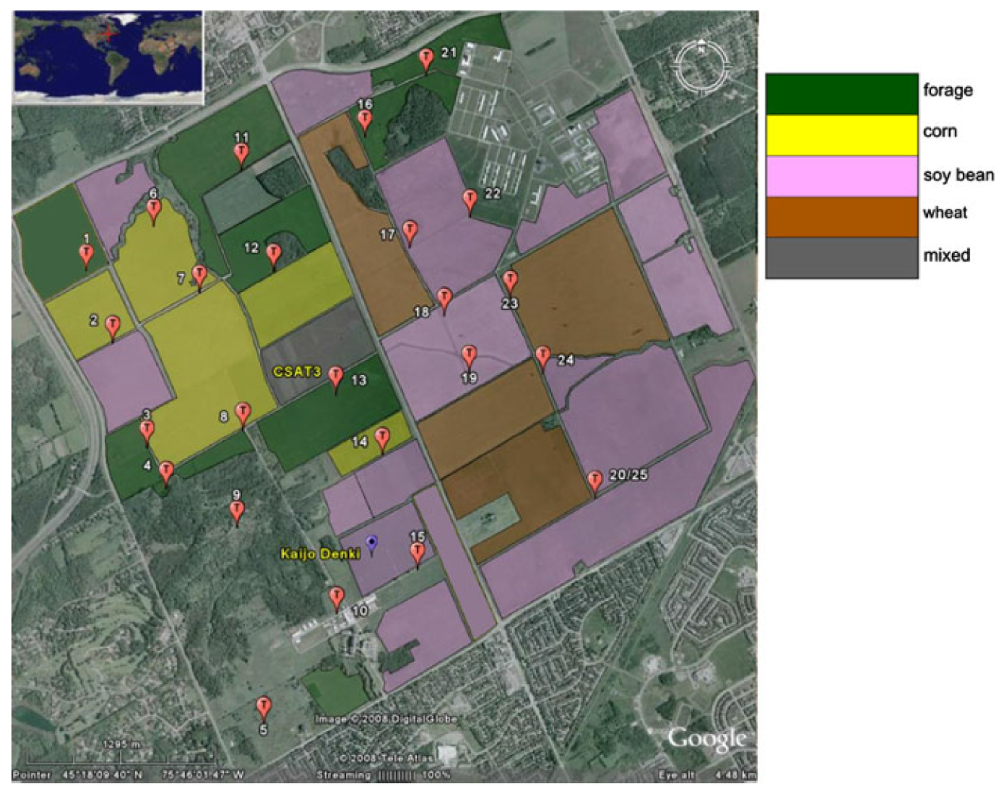
Advantages:
- Account for local advective fluxes
- Imbalance around specific location
- "Footprint" of the tower included



Impression of a control volume, from [1]

Simulations for agricultural field site [4] without significant topography

Simulation design



- $1200^2 \times 200$ grid points
- $12.5\,\mathrm{m}$ resolution
- driven by variable surface heat flux

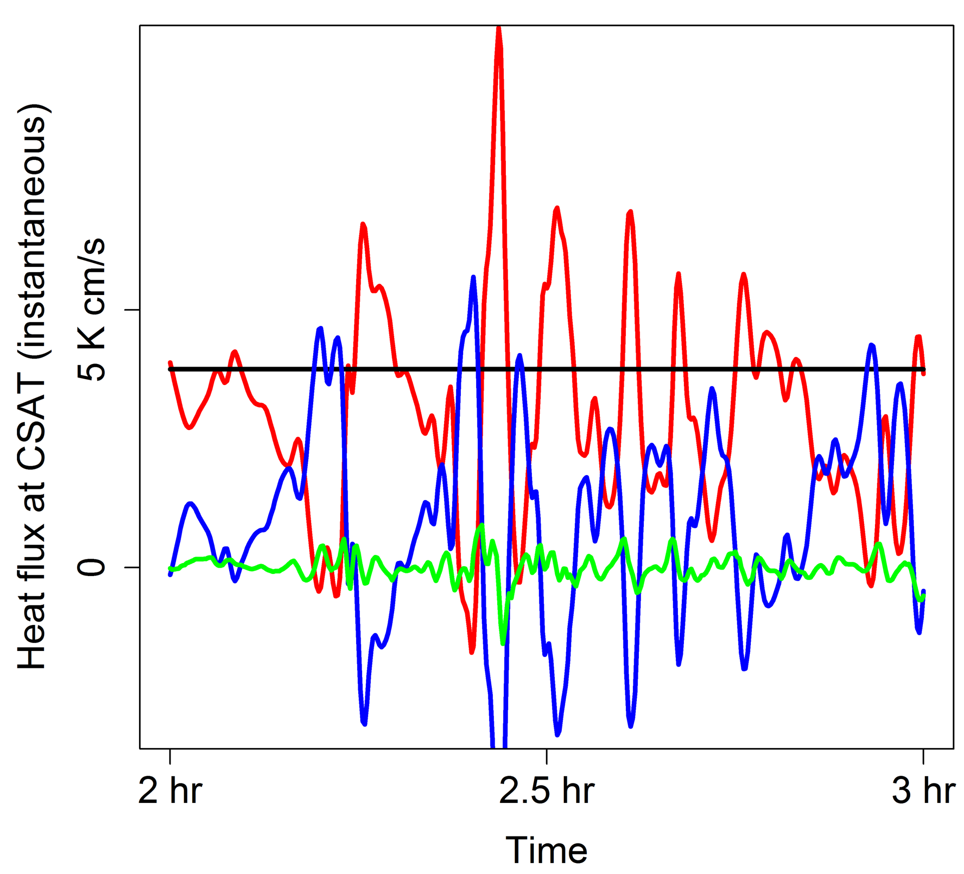
Methods

- The classic computation of the energy imbalance in homogeneous terrain [3] is based on $[[\bar{w}\bar{T}]] = [[\overline{w'_s T'_s}]] - [[\overline{w'_t T'_t}]]$ with the missing flux from advection being equal to the total flux at the measurement height minus the turbulent flux.
- In our approach the advection is accounted for by subtracting a base temperature from the virtual measurements: $[wT]_c = [wT](z_m) - [w(z_m)][T_b]$. The (corrected) turbulent flux is determined analogously: $\overline{[w'T']_c} = \overline{[wT]_c} - [\bar{w}]([\bar{T}] - [\bar{T}_b])$. The base temperature is determined from the horizontal advection into the control volume, with "$[\cdot]$" area-averaging.

Comparison in homogeneous terrain

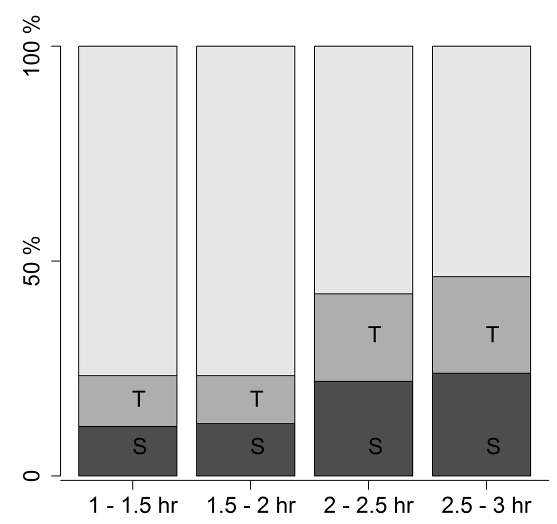
- For an ensemble of scattered control volumes, the ensemble mean of $\overline{[wT]_c}$ is within $5\,\%$ of the $[[\overline{w'_s T'_s}]]$ of [3]. The turbulent fluxes are clearly smaller.
- For 1024 control volumes that cover the whole domain, the domain-averaged corrected turbulent flux is within $10\,\%$ of the turbulent flux found by [3], but further study is needed to clarify the differences between both methods.

Virtual heat fluxes for tower 13

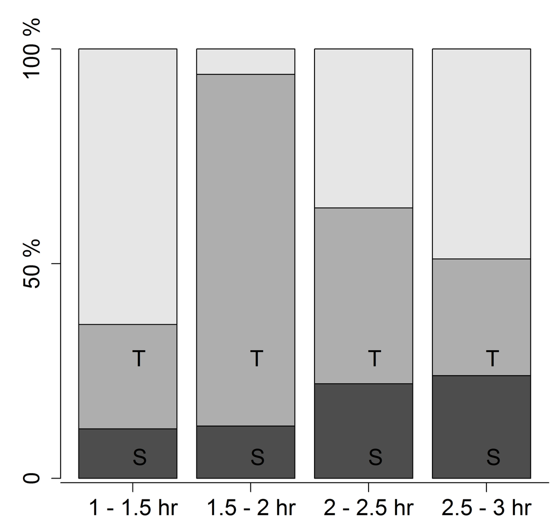


Fluctuations of the instantaneous virtual heat flux at the measurement height (red). The available energy (black) is taken as the surface heat flux. The storage term (blue) matters due to the significant measurement height. The model non-conservation residual (green) is close to zero but fluctuates more strongly if the area of the control volume is smaller.

Energy balance for tower 13



Standard turbulent flux $\overline{[w]'[T]'}$ (T) and storage change (S)



Corrected turbulent flux $\overline{[w'T']_c}$ (T) and storage change (S)

Conclusions

- To suppress fluctuations in $\triangle$, the control volumes have to comprise a minimal amount of grid points: in the horizontal about 10^2. Yet the area may not become too large, because for each c.v. area-averaged quantities are being calculated.
- The standard turbulent term is rather small, which could be caused by an underestimation of the high-frequency turbulent flux (related to the grid length), or by a suppression of fluctuations due to the area-averaging over the upper lid of the control volume. We conclude that a separate virtual measurement of the turbulent flux should be added. Then the primary use of the control volume becomes to clarify the cause of the imbalance.

References

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Acknowledgements

We thank the PALM group at Leibniz University Hannover for their open-source PALM code. This work was conducted within the Helmholtz Young Investigator 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.