**Limitations of two energy balance closure parameterizations**

Fabian Eder¹,², Frederik De Roo¹, Katrin Kohnert¹,³,⁴, Raymond L. Desjardins⁵, Hans Peter Schmid¹, Matthias Mauder¹,²

¹ Institute of Meteorology and Climate Research, Atmospheric Environmental Research (IMK-IFU), Karlsruhe Institute of Technology (KIT), 82467 Garmisch-Partenkirchen, Germany
² Institute of Geography and Geocology (IFG), Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany
³ Department of Micrometeorology, University of Bayreuth, Universitätsstrasse 24, 95440 Bayreuth, Germany
⁴ now: Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, Telegrafenberg, 14473 Potsdam, Germany
⁵ Agriculture and Agri-Food Canada, 960 Carling Avenue, Ottawa, Ontario, K1A 0C6, Canada

**Motivation: the energy balance closure problem**

The eddy-covariance technique tends to underestimate the fluxes of sensible \( (Q_s) \) and latent heat \( (Q_u) \) by 10-30%. Consequently, the turbulent heat fluxes are not in balance with the net radiation \( (\gamma) \), and the ground heat flux \( (Q_h) \), which is known as the energy balance closure problem. The energy balance ratio \( (R) \),

\[
R = \frac{Q_h + Q_s + Q_u}{\gamma},
\]

is usually smaller than 1.

Since the eddy-covariance method is widely used to determine fluxes of energy and trace gases on an ecosystem scale, a robust parameterization of the missing turbulent energy is necessary. Here, we tested two approaches that can be found in the literature: Huang et al. (2008) and Panin and Bernhofer (2009).

**Parameterization by Huang et al. (2008)**

- **Description:**
  - large-eddy simulation of the homogeneous convective boundary layer
  - considers atmospheric conditions
  - energy imbalance \((I)\) due to the presence of turbulent organized structures
  - parameterization of the energy imbalance for every 30-min period

- **Results:**
  - only daytime data were analyzed \((Q_o, \gamma > 30 \text{ W m}^{-2})\)
  - dependence of energy imbalance on \(u^* / w^*\); function \(f\) could not be confirmed; no correlation with \(u^* / w^*\) was found \((\text{Fig. 3})\)
  - dependence of energy imbalance on \(z / z_0\); also no correlation \((\text{data not shown})\)
  - but: weak dependence of imbalance on \(u^*, \text{z}_0\) at 3 of 3 TERENO sites \((\text{Fig. 4})\)

**Discussion / Conclusions:**

The parameterization is not applicable to our surface-layer data. It neglects any influence of surface heterogeneities: \(w^*\) is not an appropriate scaling parameter for the surface layer. The large-eddy simulation model used by Huang et al. (2008) has an insufficient grid resolution close to the surface.

**Parameterization by Panin and Bernhofer (2008)**

- **Description:**
  - empirical parameterization, based on eddy-covariance measurements
  - considers properties of the landscape (surface roughness heterogeneities)
  - energy imbalance due to secondary circulations generated by heterogeneities
  - parameterization of the mean energy balance correction factor \((k_f)\) for a site

- **Results:**
  - Determination of heterogeneity index \(z_{eff}/L_{eff}\)
  - surface roughness maps \((\text{Fig. 5})\)
  - Fourier transform along selected transects
  - \(k_f\) of TERENO sites is larger \((\text{i.e. energy balance closure is poorer than expected})\) \((\text{Fig. 6})\)
  - the data from Candle Lake match well with the data of Panin and Bernhofer (2008)

**Discussion / Conclusions:**

A rough qualitative estimate of the energy imbalance is possible.

- neglcts any surface heterogeneity other than surface roughness, e.g., surface temperature, surface moisture, topography
- \(L_{eff}\) is the crucial parameter, but there should be an 'optimum scale' of heterogeneities \((\text{e.g. 4-9 times } z_0, \text{cf. Patton et al. (2005)})\)