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Application of an energy balance correction method for turbulent flux measurements based on buoyancy

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Outline

The Problem of Surface Energy Balance Closure

Observed energy balance

Often the measured energy balance cannot be closed in experiments

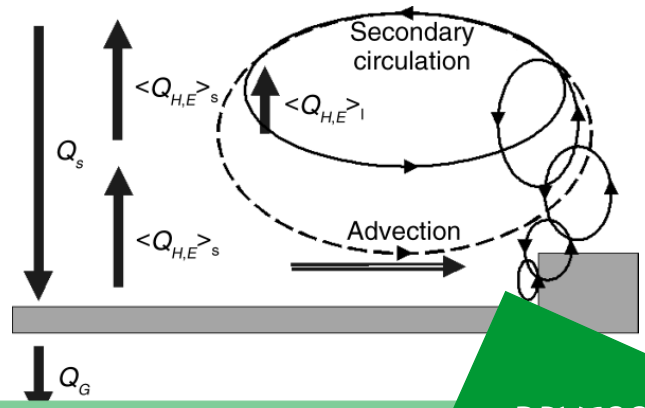
$$-Q_S^* - Q_G = Q_H + Q_E + Res$$

Typical closure ratios are 70 % - 100 % (Aubinet et al., 2000; Wilson et al., 2002; Barr et al., 2006; Foken, 2008; Hendricks Franssen et al., 2010; Stoy et al., 2013)

Possible reasons in discussion

- general measurement errors, scale mismatch between measuring methods (Foken, 2008)
- measurement errors, e.g. underestimation of the vertical wind velocity by non-orthogonal sonic anemometer types (Kochendorfer et al., 2012; Mauder, 2013; Kochendorfer et al., 2013)
- energy storage problems on half-hourly time scale (Leuning et al., 2012)
- Flux contributions not detected by eddy-covariance: advection, secondary circulation, low frequency motions (Kanda et al., 2004; Foken, 2008)

⇨ reasonable, but could not be proven yet (Eder et al., 2014)



Correction of energy balance closure (EBC)

EBC correction needed for

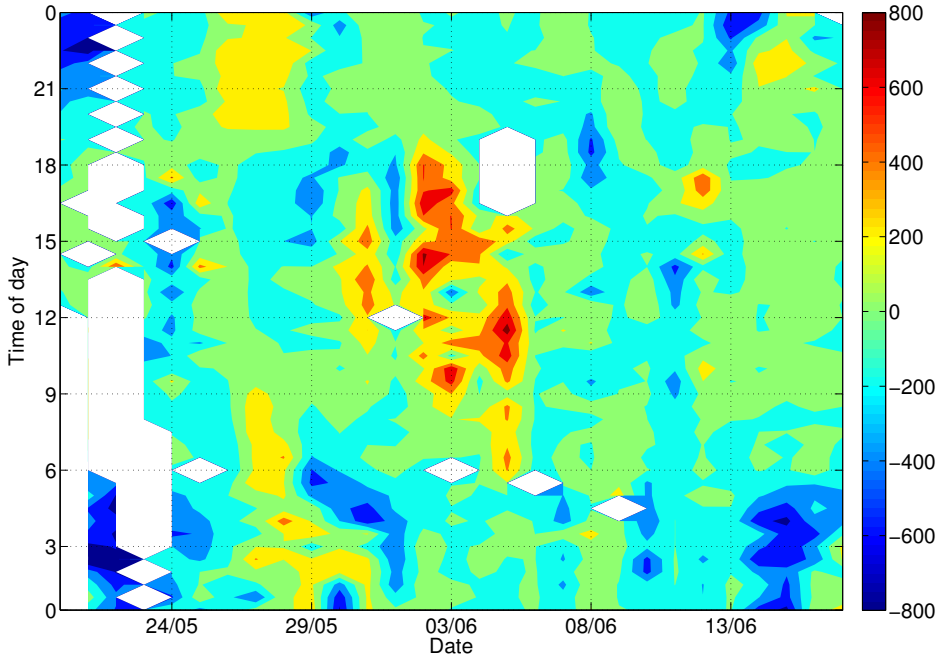
- compiling carbon and water budgets
- comparing EC data with land surface models closing the energy balance

Partitioning of the missing energy

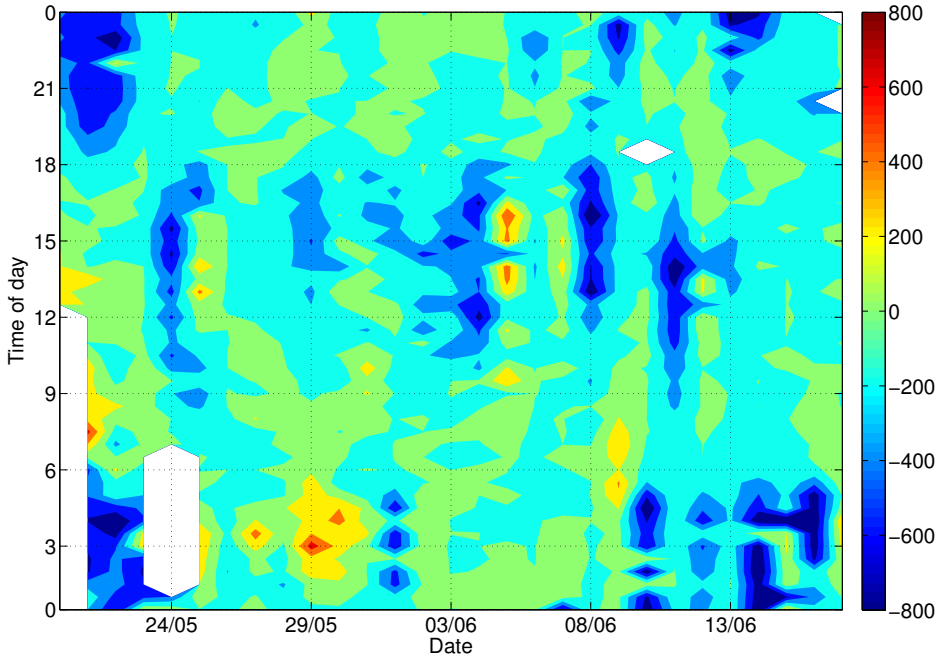
- Scalar similarity: Bowen ratio (Twine et al., 2000)
- more to the sensible heat flux (Stoy et al., 2006; Ingwersen et al., 2011; Charuchittipan, Babel et al., 2014; Brötz et al., 2014)
- more to the latent heat flux (Barr et al., 2006; Eder et al., 2014)

Separation of the ensemble averaged flux

$$\left\langle \overline{w(t)c(t)} \right\rangle = \langle \overline{wc} \rangle = \langle \overline{w} \rangle \langle \overline{c} \rangle + \langle \tilde{w}\tilde{c} \rangle + \left\langle \overline{w'c'} \right\rangle$$



$\tilde{Q}_H$, rye (maize similar)



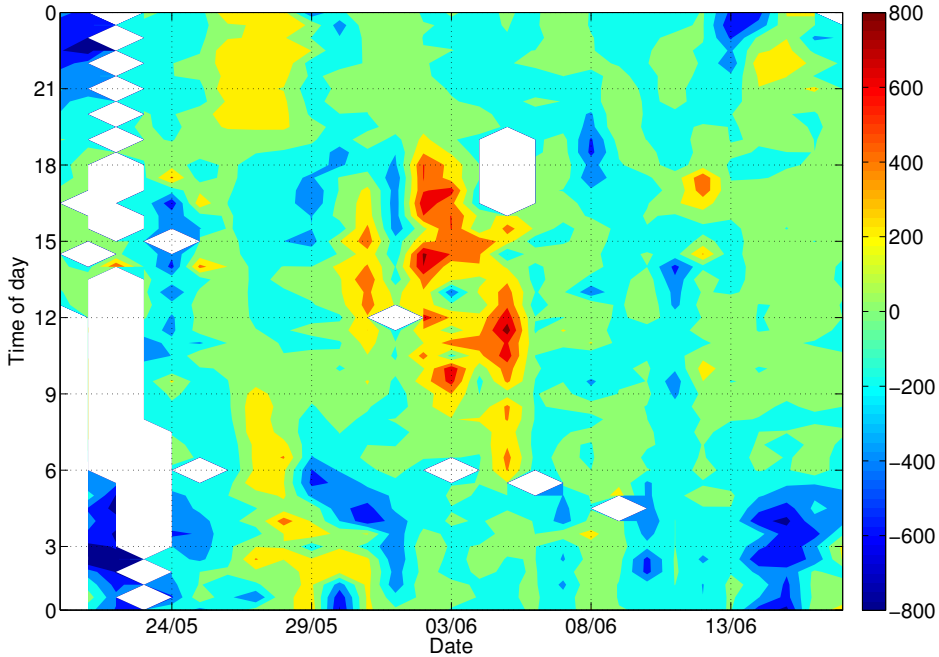
$\tilde{Q}_H$, grassland (lake similar)

Charuchittipan, Babel et al. (2014)

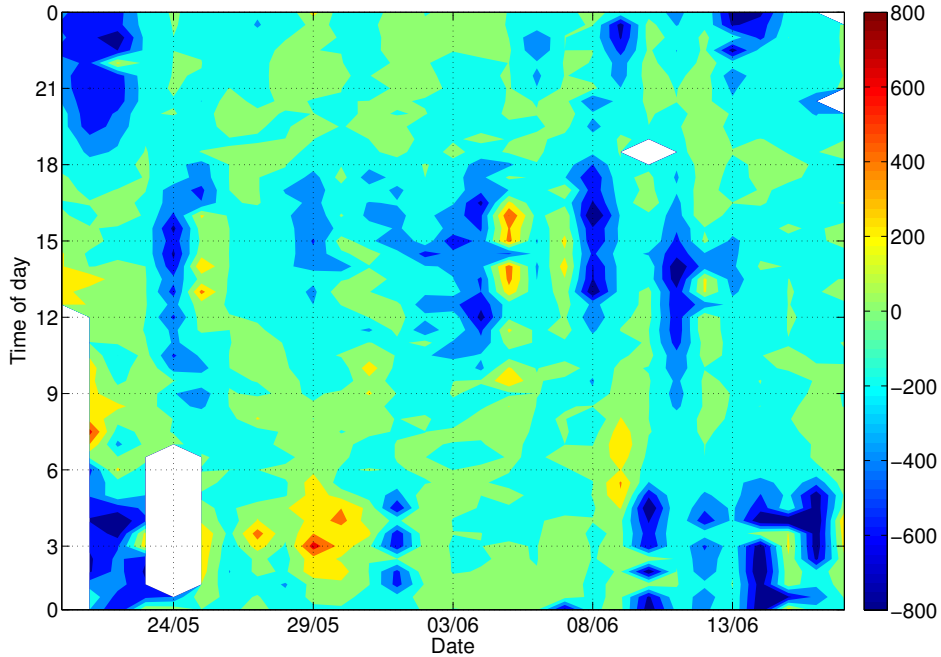
Separation of the ensemble averaged flux

$$\left\langle \overline{w(t)c(t)} \right\rangle = \langle \overline{wc} \rangle = \langle \overline{w} \rangle \langle \overline{c} \rangle + \langle \tilde{w}\tilde{c} \rangle + \left\langle \overline{w'c'} \right\rangle$$

$$= 0 \quad \text{“meso-flux”} \quad \text{“EC-flux”}$$



$\tilde{Q}_H$, rye (maize similar)

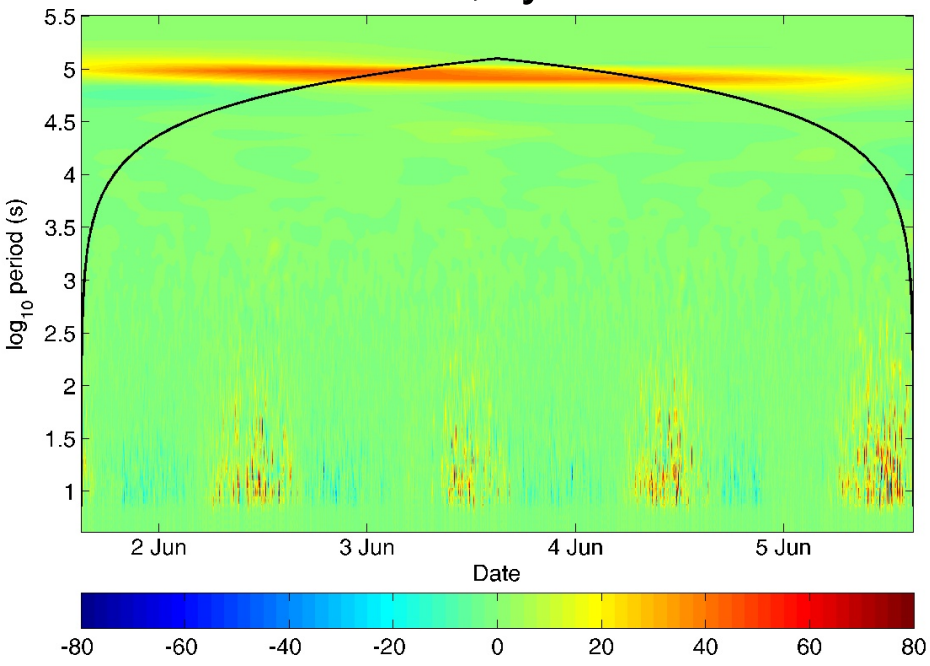


$\tilde{Q}_H$, grassland (lake similar)

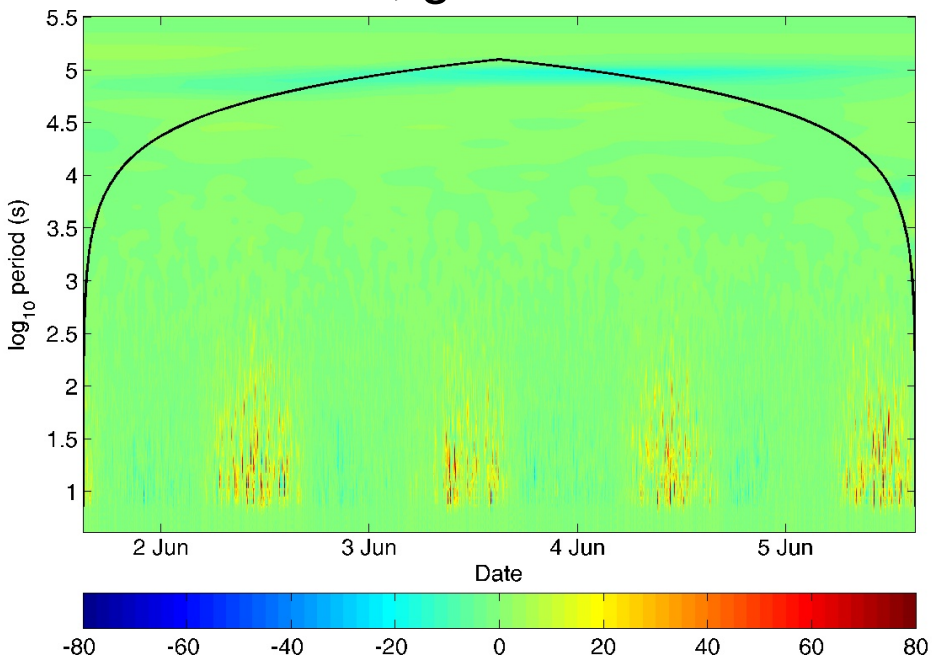
Charuchittipan, Babel et al. (2014)

Wavelet cross-scalogram

$w'T'$, rye



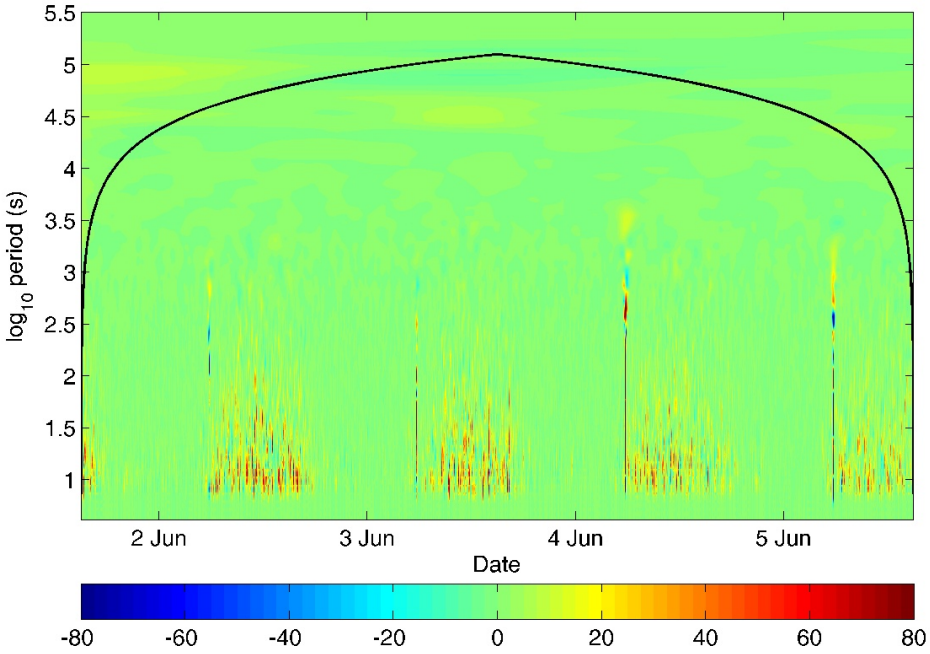
$w'T'$, grassland



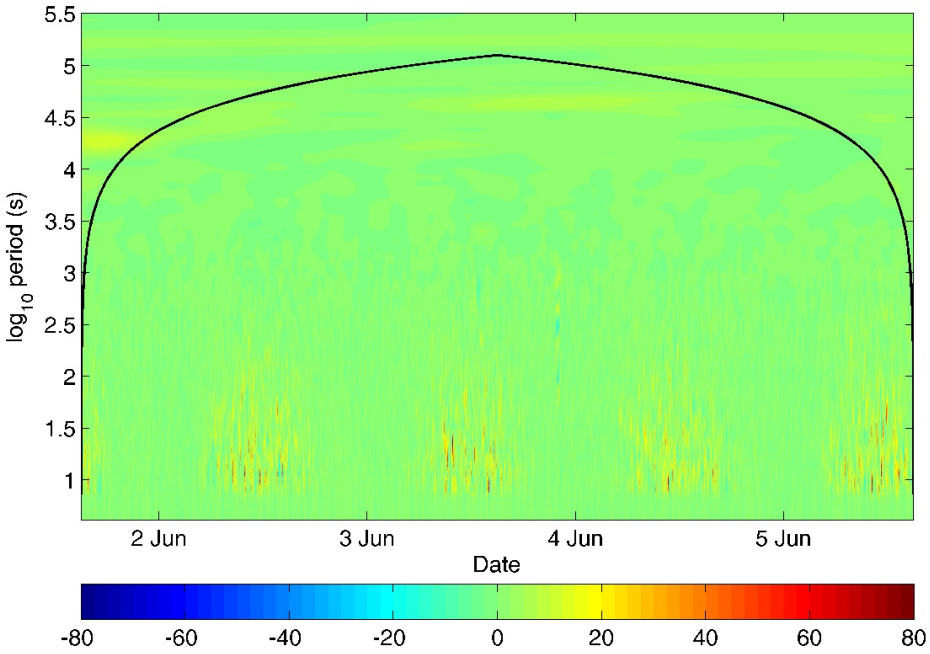
Charuchittipan, Babel et al. (2014)

Wavelet cross-scalogram

$w'a'$, rye



$w'a'$, grassland



Charuchittipan, Babel et al. (2014)

EBC correction methods

according to the Bowen ratio

Residual *Res* is distributed to Q_H and Q_E according to the Bowen ratio (Twine et al., 2000)

⇨ Hypothesis: scalar similarity, good first guess

⇨ proposed since a long time because of the lack of a better method

according to the buoyancy flux

Distribution of the residual according to the relative contribution of Q_H and Q_E to the buoyancy flux Q_B (Charuchittipan, Babel et al., 2014)

⇨ Hypothesis: secondary circulation systems, driven by buoyancy

EBC buoyancy flux correction: EBC-HB

Buoyancy flux definition and relation to sensible heat

$$Q_B = \rho c_p \overline{w' T_v'} \quad \text{with } T_v = T(1 + 0.61q)$$

$$Q_B \simeq \rho c_p \left(\overline{w' T'} + 0.61 \overline{T}\, \overline{w' q'} \right) = Q_H \left(1 + 0.61 \overline{T} \frac{c_p}{\lambda \cdot Bo} \right)$$

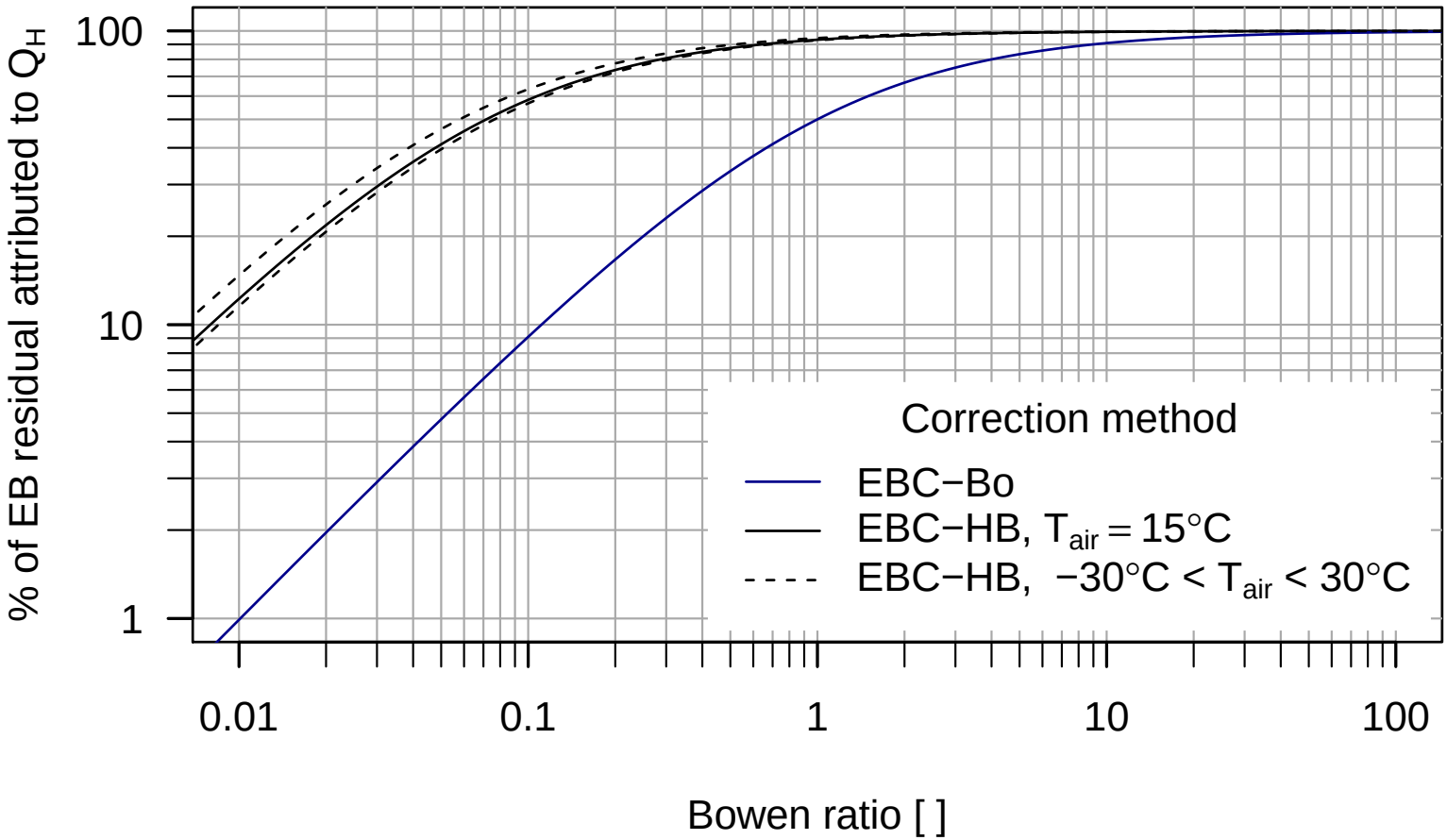
EBC-HB correction

$$Q_H^{EBC-HB} = Q_H + f_{HB} \cdot Res$$

$$Q_E^{EBC-HB} = Q_E + (1 - f_{HB}) \cdot Res$$

$$f_{HB} = \frac{Q_H}{Q_B} = \left(1 + 0.61 \overline{T} \frac{c_p}{\lambda \cdot Bo} \right)^{-1}$$

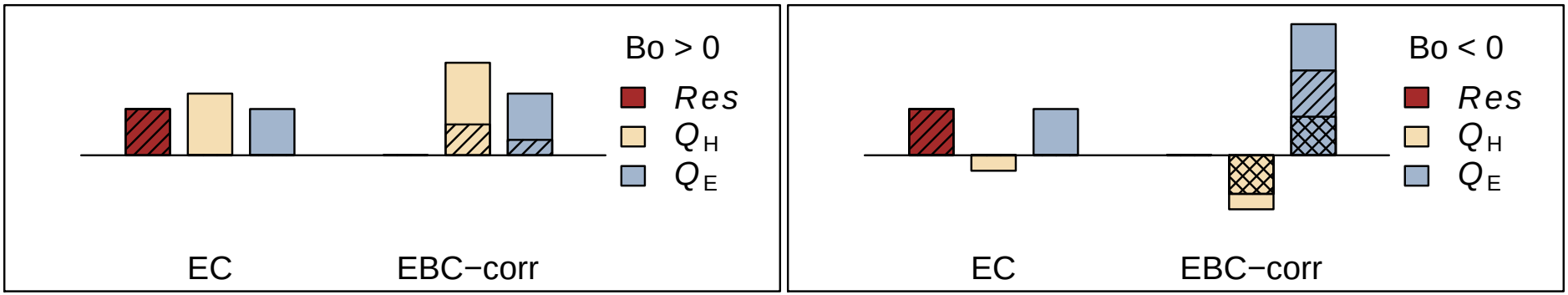
EBC correction methods



Charuchittipan, Babel et al. (2014)

Restriction for both corrections

Negative Bowen ratios



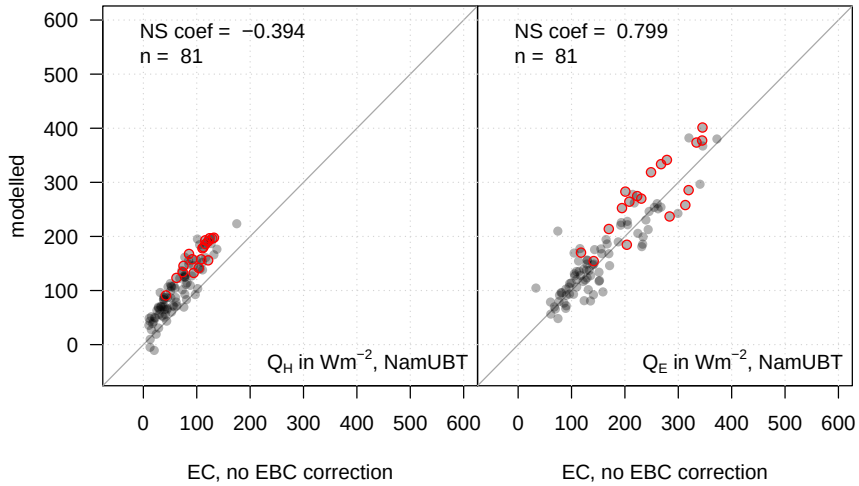
⇨ correction term larger than *Res*! Large errors expected!

Nighttime conditions

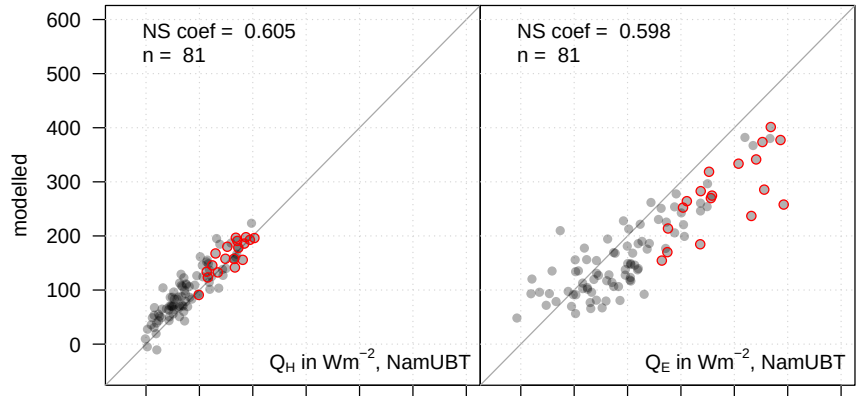
- follows mainly from the first restriction
- groundless as hypotheses not fulfilled in the night
- residual in the error range of the fluxes

Influence on model validation

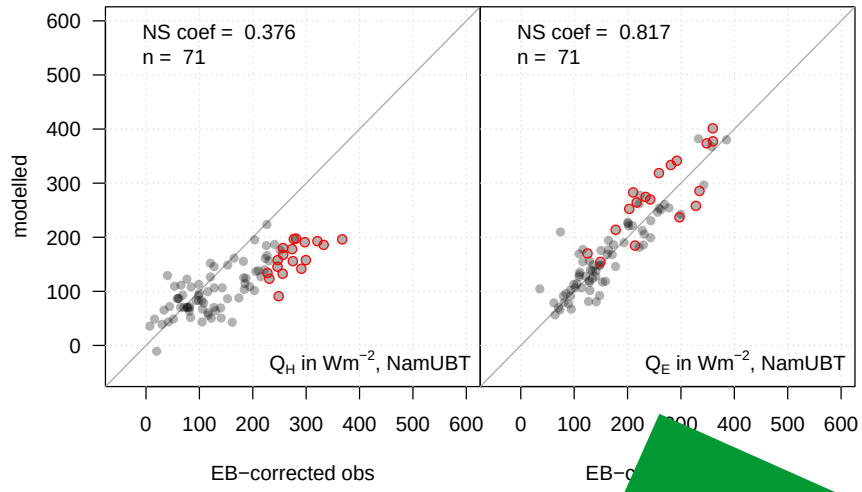
no EBC correction



Bowen ratio correction



buoyancy flux correction



wet grass, Tibetan Plateau

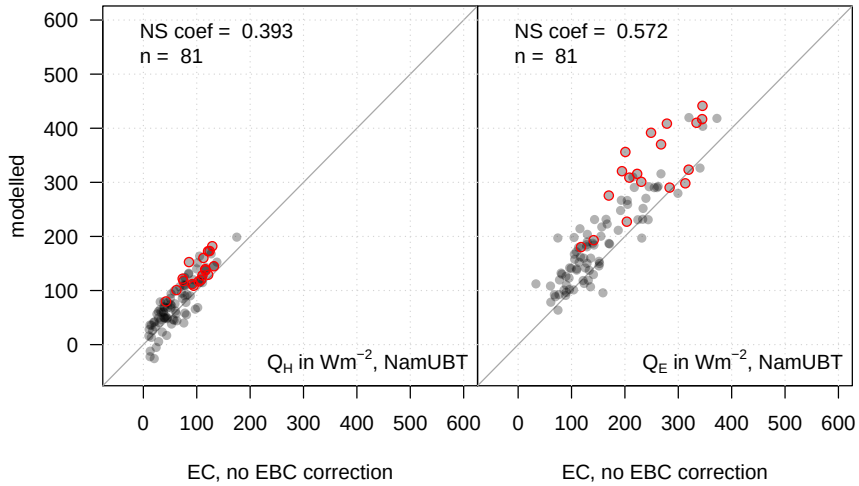
red dots: $-Res \geq 150\,\mathrm{Wm}^{-2}$

⇨ least scatter for uncorrected fluxes, but large bias

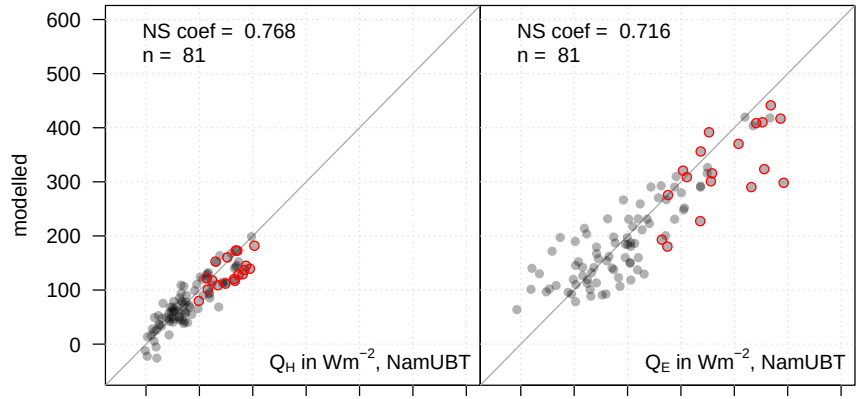
(Babel, Dissertation, 2013; model: SEWAB, Mengelkamp et al., 1999, 2001)

Influence on model validation

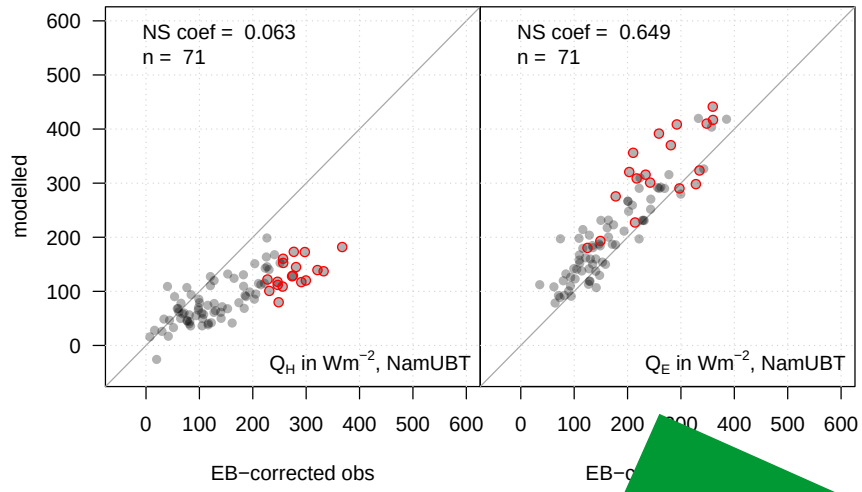
no EBC correction



Bowen ratio correction



buoyancy flux correction

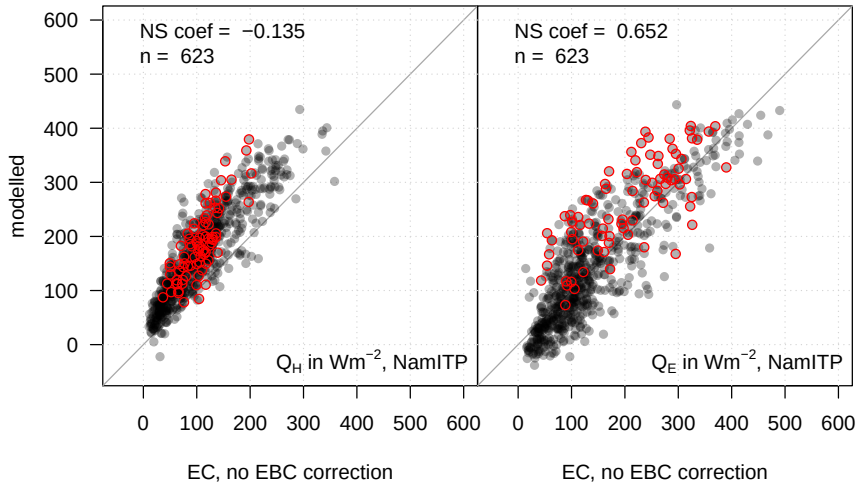


wet grass, Tibetan Plateau
different parameter set

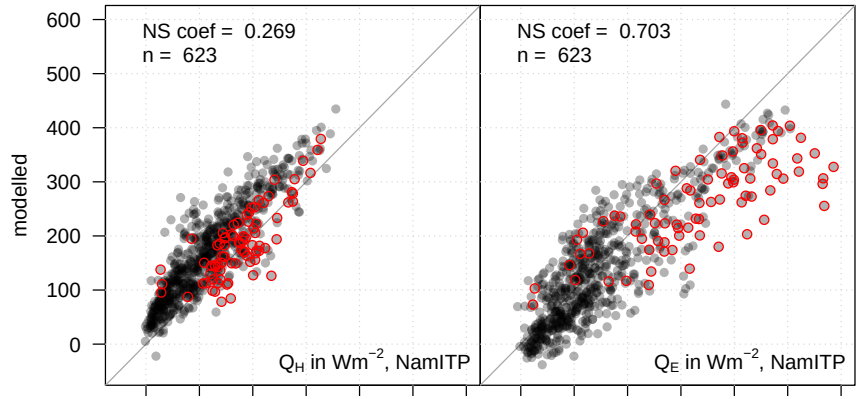
(Babel, Dissertation, 2013; model: SEWAB, Mengelkamp et al., 1999, 2001)

Influence on model validation

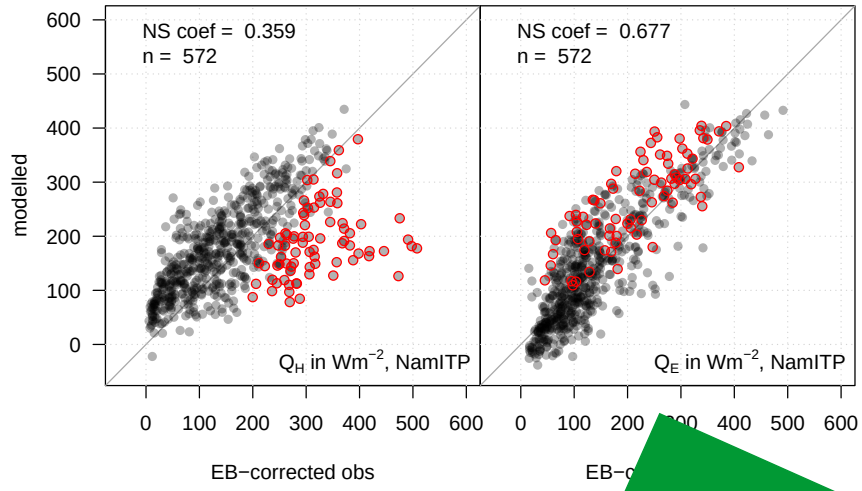
no EBC correction



Bowen ratio correction



buoyancy flux correction



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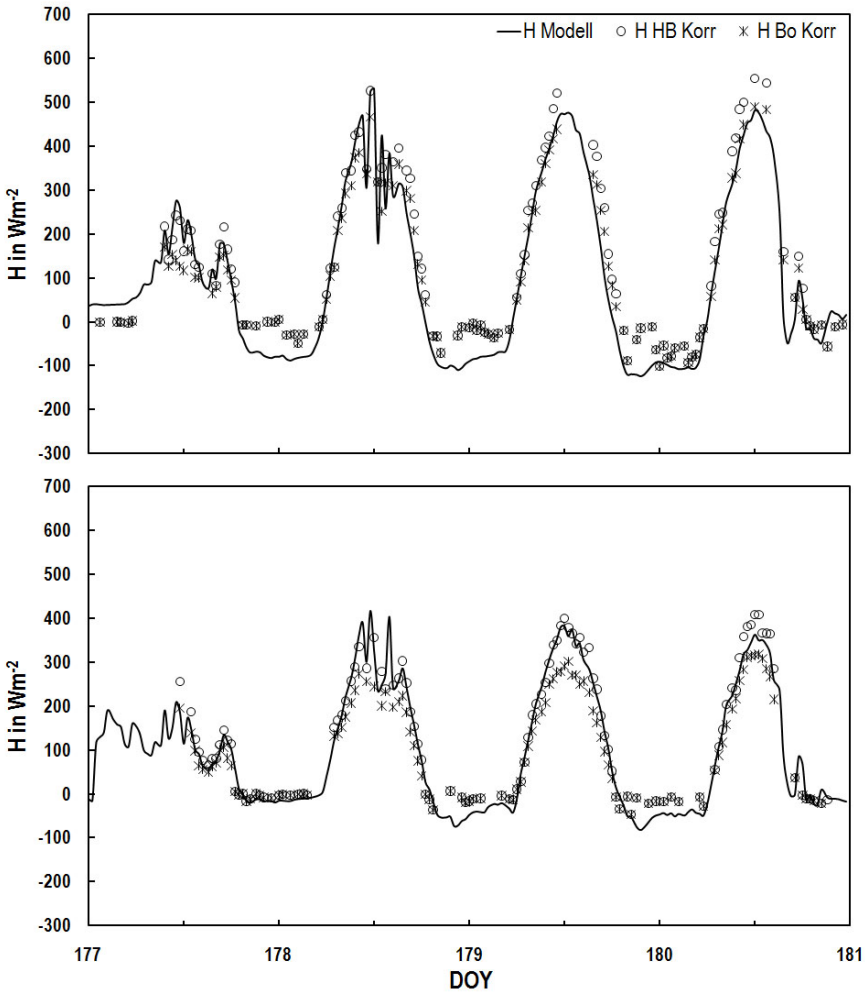
Influence on model validation



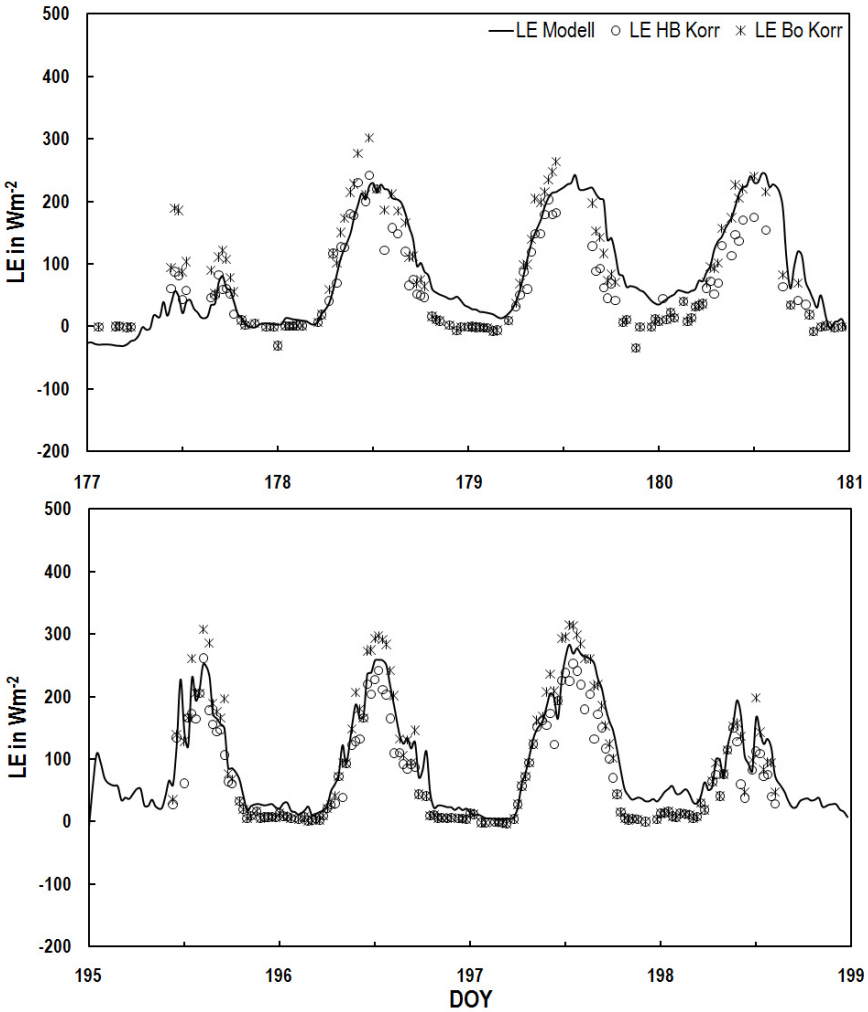
Waldstein, Upper Franconia, Germany

Q_H

upper panel: spruce forest
lower panel: clearing

(Gatzsche, Master Thesis, 2013; model: ACASA, Pyles et al., 2000)

Influence on model validation



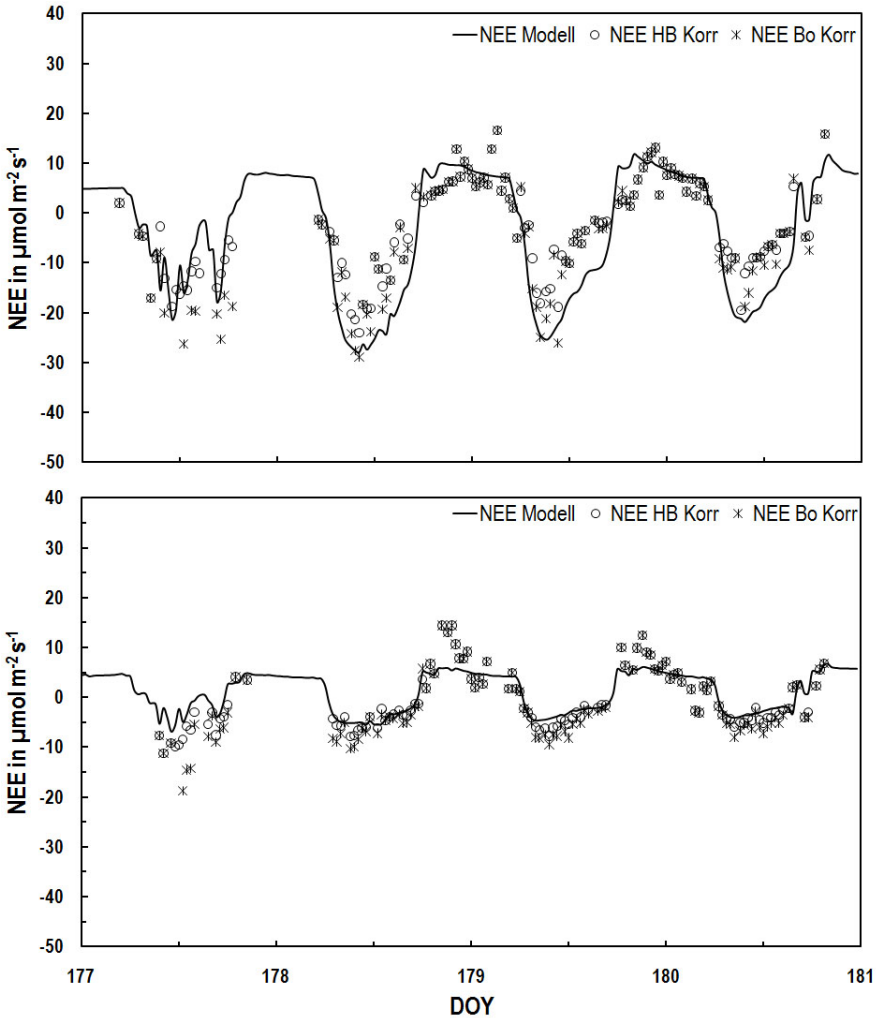
Waldstein, Upper Franconia, Germany

Q_E

upper panel: spruce forest
lower panel: clearing

(Gatzsche, Master Thesis, 2013; model: ACASA, Pyles et al., 2000)

Influence on model validation



Waldstein, Upper Franconia, Germany

NEE

upper panel: spruce forest
lower panel: clearing

EBC correction of *NEE* by a factor

$$k_{Bo,HB} = \frac{Q_E^{EBC-HB,Bo}}{Q_E}$$

(Gatzsche, Master Thesis, 2013; model: ACASA, Pyles et al., 2000)

Conclusions

Besides many site-specific reasons the energy balance closure problem is mainly related to meso-scale circulation systems in a heterogeneous landscape

Because such circulation systems are mainly buoyancy driven, we propose to replace the Bowen ratio correction by a buoyancy correction

Mechanistic model development of turbulent flux parameterisations should recognize the recent hypotheses concerning the energy balance closure rather than fitting just to the uncorrected eddy-covariance data.

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