Sensitivity of TSEB Turbulent Energy Fluxes to Stability Functions

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INTRODUCTION

The Two-Source Energy Balance (TSEB) [1] model is widely used for estimating turbulent heat fluxes and evapotranspiration [2,3]. Atmospheric stability is represented in TSEB using Monin–Obukhov similarity theory [4], which influences the calculation of aerodynamic resistances [1,2]. Multiple stability correction formulations exist [4–8], yet their impact on TSEB flux estimates has not been systematically evaluated, contributing to structural uncertainty in evapotranspiration estimates. This study evaluates the sensitivity of TSEB-derived fluxes to different combinations of stability functions using eddy covariance (EC) observations.

METHODS

The analysis was conducted for the 2023 growing season at an agricultural site near Křešín u Pacova (49.573° N, 15.079° E; 534 m a.s.l.), covering ~20 ha with an average EC footprint of ~3 ha. Meteorological and flux measurements were obtained from two nearby towers, providing air temperature and wind speed at 50 m and near-surface variables at 5 m, while turbulent fluxes of sensible (H) and latent heat (LE) were measured at 2.6 m using EC. Standard quality control included despiking, stationarity tests, footprint filtering, and u* filtering, and only high-quality, non-gapfilled data were used for TSEB evaluation. Surface radiometric temperature was derived from longwave radiation, correcting for reflected atmospheric radiation using NDVI-derived emissivity. TSEB was applied to estimate H and LE, with atmospheric stability represented using Monin–Obukhov similarity theory within a modular framework allowing independent selection of unstable and stable formulations. Common parameterizations (Businger–Dyer [4], Kader–Yaglom [5], Cheng–Brutsaert [6], Beljaars–Holtslag [7], Grachev [8]) were tested using numerical integration of similarity functions and spline-based approximations. Model performance was evaluated against EC observations using both original and energy balance closure (EBC)-corrected fluxes, where the residual was either assigned to LE or redistributed while preserving the Bowen ratio (H/LE). Sensitivity analyses assessed the influence of stability formulation, EBC, forcing height (5 m vs. 50 m), and ±10% perturbations of selected TSEB vegetation parameters, while performance was quantified using R^2, NSE, KGE, error metrics, and regression parameters.

RESULTS AND DISCUSSION

Differences between stability formulations resulted in consistent but moderate variations in model performance. When H and LE were not adjusted to enforce EBC, KGE ranged from 0.4 to 0.7 for H, with the best performance obtained for Kader–Yaglom under unstable conditions combined with Beljaars–Holtslag or Cheng–Brutsaert for stable cases, while Businger–Dyer and Grachev-based formulations showed the lowest performance. For non-adjusted LE, KGE was consistently negative, with Businger–Dyer yielding the highest, yet still inferior, performance. For Bowen ratio-adjusted H and LE, Businger–Dyer yielded the highest KGE (0.83 and 0.45), while Kader–Yaglom-based formulations showed the worst performance (0.75 and 0.44 for H and LE). Assigning LE as the full residual of the energy balance resulted in the highest KGE (~0.51–0.57) among all tested EBC correction approaches, with the best performance obtained for Kader–Yaglom combined with Beljaars–Holtslag or Cheng–Brutsaert, while Businger–Dyer and Grachev-based formulations performed worse (Fig. 1). Despite these differences, variation between stability configurations remained small compared to systematic bias. Compared to non-adjusted EC observations, TSEB tended to overestimate LE by approximately 40–47%, reflecting the magnitude of energy balance non-closure in eddy covariance measurements. Applying EBC correction reduced this discrepancy and improved agreement across configurations, indicating that EBC-related uncertainties dominate over those from stability formulation. Because both H and LE can be affected by EBC assumptions, model evaluation depends on the chosen correction method. The influence of stability formulation exceeded that of ±10% perturbations of most TSEB vegetation parameters; however, canopy height had a stronger effect, particularly on regression slope and error metrics, with impacts comparable to or exceeding those of stability formulation. Importantly, the measurement height of meteorological forcing (air temperature and wind speed) produced even larger variations, highlighting its dominant role in controlling aerodynamic exchange.

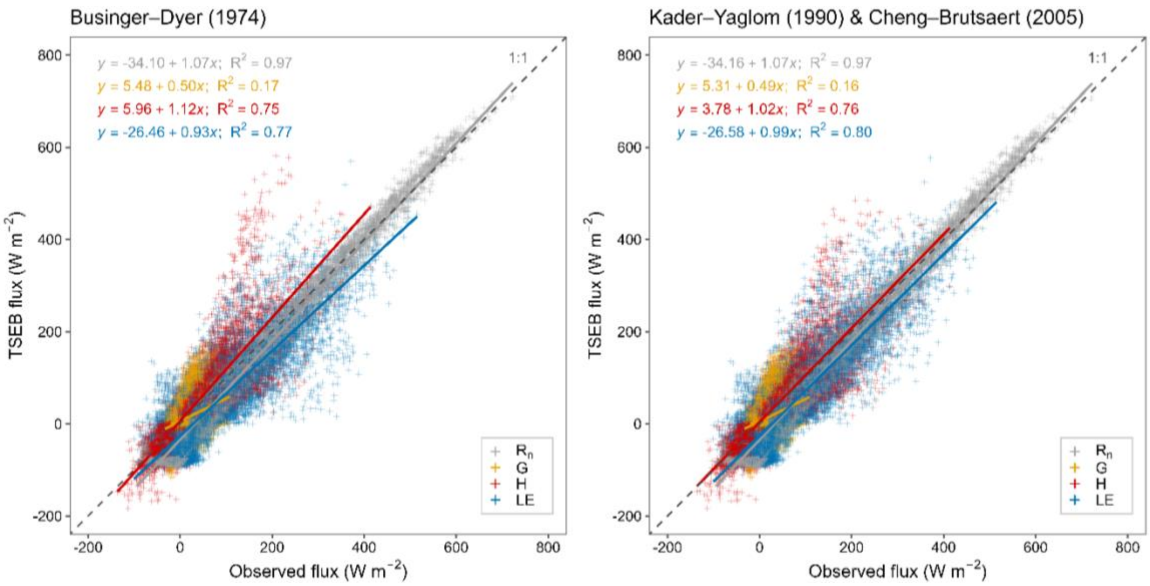

Fig. 1. Comparison of observed and modeled energy fluxes for net radiation (R_n), soil heat flux (G), sensible heat flux (H), and latent heat flux (LE), with LE computed as the residual of the energy balance. Observations are based on in situ measurements, including eddy covariance fluxes, while modeled values are derived from TSEB. The left panel shows results using the Businger–Dyer (1974) stability formulation, while the right panel shows Kader–Yaglom (1990) for unstable and Cheng–Brutsaert (2005) for stable conditions. Linear regression statistics are included to illustrate differences in model performance. Meteorological forcing (air temperature and wind speed) was measured at 5 m. Data represent the 2023 season, including winter barley, harvest, bare soil, and subsequent oilseed rape emergence.

CONCLUSIONS

The results indicate that stability function choice has a systematic but non-negligible influence on TSEB flux estimates. However, its impact is smaller than that of energy balance closure and forcing height, and comparable to canopy height uncertainty, suggesting that forcing conditions and canopy height are more influential than stability parameterization, although this may be site- and stability-specific. Overall, the TSEB model driven by radiometric surface temperature measurements and basic meteorological data was found to be a robust approach for estimating sensible and latent heat fluxes at 30 min resolution.

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