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Failure of correct evapotranspiration measurements by eddy covariance under certain conditions and energy balance closure in open-oak savanna ecosystems

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Separation of evapotranspiration (ET) into its components represents one of the main ecohydrological challenges in heterogeneous ecosystems (i.e. tree-grass savanna), where two main evaporative layers consisting of tree canopy (ET_{above}) and its underlying surface ($ET_{subcanopy}$) dominate ET. The challenge arises from the fact that classical eddy covariance 1) directly only measures total ET and 2) biases in the respective energy balance are often observed. Here, we address these challenges in a Mediterranean savannah tree-grass ecosystem, by synchronous, combined measurements via classical eddy covariance, sub-canopy eddy covariance, sap-flow, and replicated lysimeters.

To this end, half-hourly latent heat fluxes of the grass layer estimated using six novel lower boundary-tension and -temperature controlled lysimeters ($LE_{subcanopy-lysimeter}$)were compared to those measured by a sub-canopy eddy covariance tower placed at 1.8 m ($LE_{subcanopy-eddy}$) over a year. To explain the residuals (*epsilon*) between $LE_{subcanopy-lysimeter}$ and $LE_{subcanopy-eddy}$, we trained a random forest model (RF) using soil moisture (SM), ground-heat fluxes (G), net radiation (R_n), air relative humidity (RH) and friction velocity (u*) as main predictor variables. The degree of energy closure was evaluated by comparing residual LE ($LE_{residual}$, estimated as Rn-H-G; H denotes sensible heat flux) against total LE measured by a tall tower installed above the canopy at 15 m (LE_{eddy}). In parallel, we contrasted this using independent, upscaled LE ($LE_{upscaled}$= $LE_{subcanopy-lysimeter}$ + $LE_{above-sapflow}$; being $LE_{above-sapflow}$ the tree component derived from sap-flow measurements) to test whether failures in LE_{eddy} explain the lack of energy balance closure. In such a case, we test the use of RF as a generalized approach to estimate *epsilon* and correct for LE_{eddy} ($LE_{eddy-corrected}$ = LE_{eddy} + *epsilon*).

As main results, the comparison of independent $LE_{subcanopy-eddy}$ and $LE_{subcanopy-lysimeter}$ evidenced that eddy covariance tends to underestimate LE under certain conditions. To assess the relative importance of the most important predictor variables, a permutation-based test was carried out. In order of importance, SM and G showed to be the most determinant in predicting *epsilon* in our site. More in details, results from a partial dependence analysis showed that highest disagreements hold at high SM, G, Rn and RH and low u*. Errors in LE_{eddy} explained the lack of closure in the surface energy balance (slope=0.79, R2=0.64). In fact, a better agreement was obtained with $LE_{upscaled}$(slope=0.92, R2=0.70), which support such hypothesis. Consistently, an even better result was obtained by using $LE_{eddy-corrected}$ (slope=1.01, R2=0.70) and points over the generalization of the RF model to correct for LE_{eddy}. Promising results were also obtained by predicting *epsilon* in similar sites with similar instrumental set-up. The implication of such results, together with the importance of other source of uncertainties (i.e. spatial and temporal cross-scale issues among methods, footprint analyses, and surface heterogeneity) in determining the degree of closure in the surface energy balance will be further discussed.