A three-source energy balance approach for estimating surface energy fluxes in heterogeneous crops with remotely sensed imagery

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Accurate estimation of surface energy fluxes in perennial cropping systems remains challenging due to the thermodynamic heterogeneity introduced by the coexistence of tall crop canopies, bare soil, and cover crop canopies. Existing two-source energy balance models, such as TSEB, parameterize complex perennial systems into two components (tree canopy and soil), making it difficult to explicitly account for additional dynamic vegetation layers, such as interrow cover crops, during periods of significantly increased vegetative biomass. Accurately quantifying cover crop water use is particularly important in California's Central Valley, where water scarcity has heightened scrutiny implementing cover crops despite their well-documented soil health benefits.

We developed a drone-based Three-Source Energy Balance model (3SEB) that expands the original TSEB framework by incorporating an additional canopy layer for interrow vegetation, enabling separate partitioning of radiative and turbulent fluxes among the tree canopy, cover crop, and bare soil. High-resolution thermal and multispectral drone imagery were used to directly retrieve component radiometric temperatures, fractional cover, canopy height, and leaf area index (LAI) from each source. We evaluated multiple 3SEB model formulations: a Priestley-Taylor approach (3SEB-PT), a dual-temperature approach (3SEB-2T), and a triple-temperature approach (3SEB-3T). Additionally, the TSEB Priestley-Taylor (TSEB-PT) and dual-temperature (TSEB-2T) formulations were also compared against 3SEB model results. The 3SEB model was applied across twelve drone flights spanning 2019–2026 at three commercial perennial cropping systems, winegrapes, almonds, and olives, that span a climatic gradient across California's Central Valley. Model outputs were spatially validated against the eddy covariance footprint at each site.

Preliminary results suggest that explicitly representing cover crops with an additional vegetation layer can improve surface flux estimation compared to TSEB during the cover crop growing season (generally February – May). Additionally, the high spatial resolution of drone imagery offered the greatest flux estimation improvements from the source-level temperature partitioning, which is not currently achievable with satellite-based observations. Ongoing analyses are evaluating 3SEB model performance across conditions with varying LAI and water stress conditions of the tree canopy and interrow vegetation.