An Alternative Method to Estimate Atmosphere-Canopy Fluxes from Semi-High Frequency Canopy Infrared Temperature

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Abstract

For precision irrigation management, growers require estimates of crop water use and stress, but few methods can provide both reliably. Infrared radiometers have long been used to estimate crop stress indices based on canopy temperatures. Here, we tested whether semi-high frequency canopy infrared radiometers could be used to derive sensible heat flux density (H) combining eddy diffusivity and surface renewal approaches. We found that plant canopy temperature traces show ramp-like features such as those observed from air temperature measured above canopies. We propose that the mean resistance to heat transfer is implicitly resolved by deriving the magnitude and time of ramp-like canopy temperatures over periods of times commonly used to derived H by other techniques (e.g. about 30 minutes in eddy covariance and surface renewal analysis). We analyzed measurements comparing this new approach with eddy covariance and surface renewal estimations of sensible heat fluxes from bare soil, alfalfa, almonds, and vineyards canopies. This novel approach to estimate H strongly correlates with estimations derived from both eddy covariance and traditional surface renewal using fine wire thermocouple temperature measurements. These results suggest a path for more practical ground-based evapotranspiration for irrigation management with resolution down to individual plants.

Background and Objectives

Agricultural water use, and almond growing in particular, has been severely scrutinized as competition for limited water resources intensifies in seasonally dry growing regions like California's Central Valley. Evapotranspiration (ET) from an orchard or vineyard results from the plant canopy-atmosphere exchange, and represents the primary driver of agricultural water demands. Reliable, real time ET and stress data are needed by growers to precisely match crop water demands and trigger irrigation tied to crop water status. The development and refinement of practical and inexpensive techniques to measure ET are needed. Infrared radiometers have long been used to estimate crop stress indices based on canopy temperatures, but not for estimating crop water use (ET). Here, we aimed to test whether semi-high frequency canopy infrared radiometers (IRTs) could be used to derive sensible heat flux density (H) combining eddy diffusivity and surface renewal approaches. These H estimates from the IRT sensors were then used to calculate the latent heat flux (LE) (and thereafter ET) from the residual of the energy balance equation (i.e. $R_n = H + G + LE$), where R_n is the net radiation and G is the soil heat flux.

Experimental almond orchard containing a mature tree in a weighing lysimeter

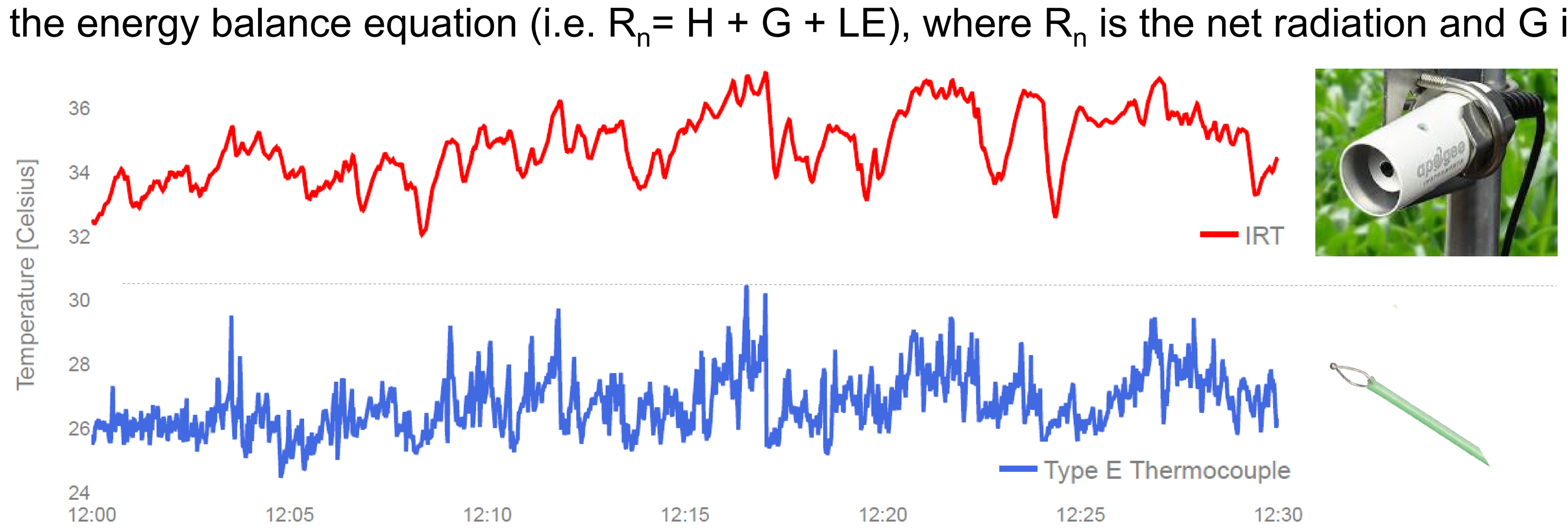
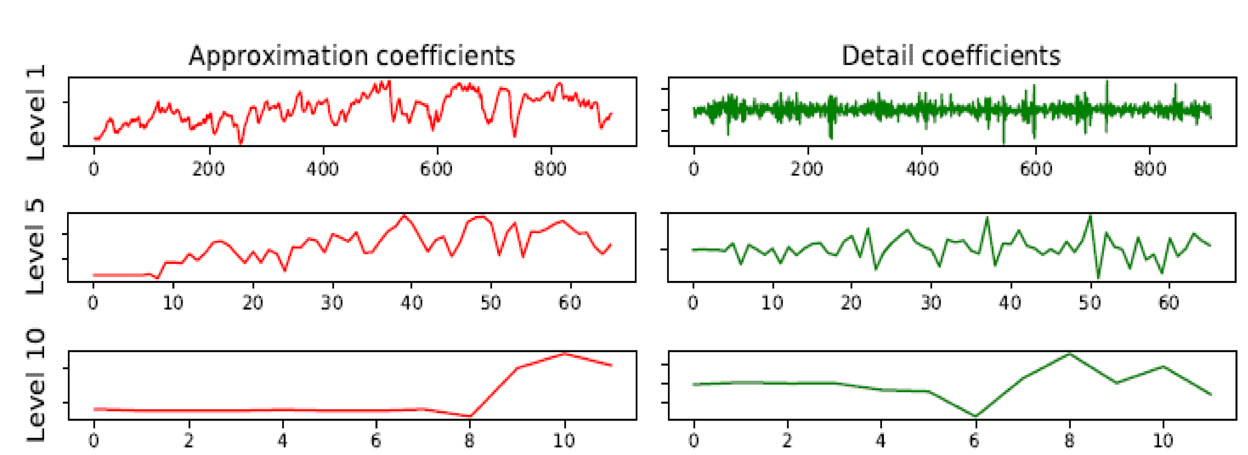


***Figure 1** (above): Raw temperature traces from IRT (top - red) aimed at the tree canopy and fine wire thermocouple (bottom in blue) located above the canopy.*

***Figure 2** (to the right): Wavelet analysis conducted on the same IRT raw canopy temperature traces using PyWavelets- an open source wavelet transform software for Python*



Methods

Measurements were conducted in an experimental almond orchard at the Kearney Agricultural Center (KAC) in Parlier, CA that contains a weighing lysimeter and a flux tower. IRT sensors were installed above the almond tree contained in the weighing lysimeter. The flux tower was located in close proximity to the lysimeter and contained eddy covariance and surface renewal systems (i.e. IRGA, sonic anemometer, net radiometer, soil heat flux instruments, and fine wire thermocouples). ET was estimated from the eddy covariance and surface renewal systems using well-established standard techniques. Sensible heat flux estimated with the IRTs was analyzed using the van Atta approach from surface renewal as well as wavelet analysis.

Results

- We found that plant canopy temperature traces show ramp-like features such as those observed from air temperature measured above canopies (Fig. 1). Wavelet analysis (Fig. 2) was used successfully to process the canopy temperature traces from the IRTs, and the H estimates from this compared favorably with those of other methods (Figs. 3&4). We suspect that the mean resistance to heat transfer is implicitly resolved by deriving the magnitude and time of ramp-like canopy temperatures over periods of times commonly used to derived H by other techniques (e.g about 30 minutes in eddy covariance and surface renewal analysis).

- Our new approach to estimate H strongly correlates with estimations derived from eddy covariance, traditional surface renewal using fine wire thermocouple temperature, and weighing lysimetry measurements. This shows great promise for the use of IRTs for more practical ground-based evapotranspiration for irrigation management with resolution down to individual plants.

Flux tower in experimental almond orchard containing a mature tree in a weighing lysimeter

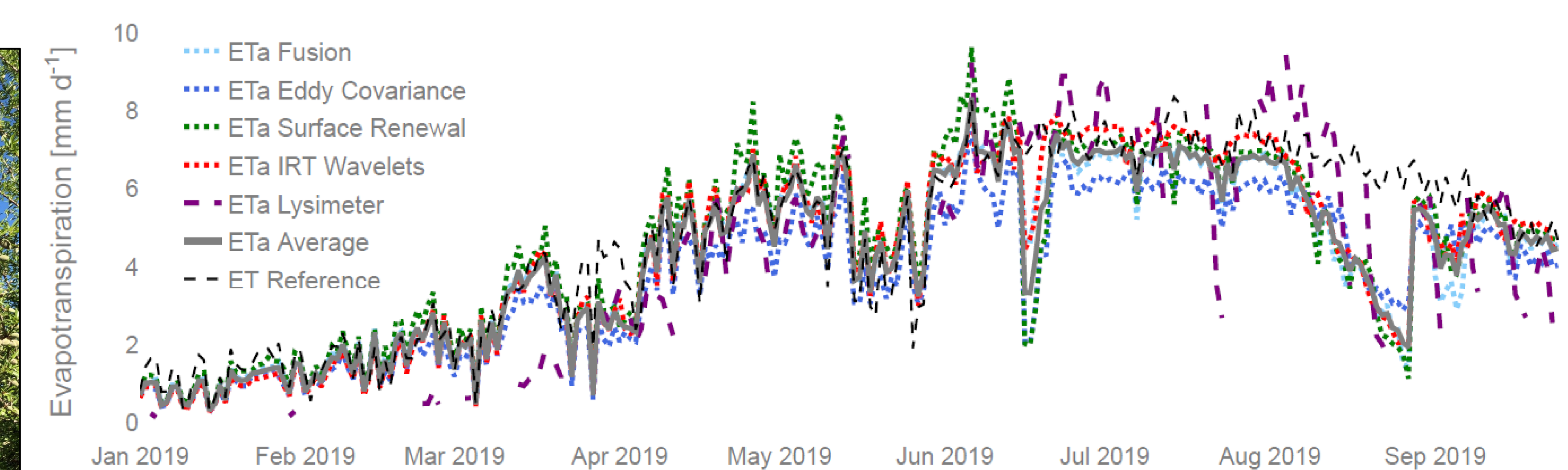


***Figure 3** (above): Evapotranspiration (ET) estimates from a variety of methods measured in an experimental almond orchard in Parlier, CA. A single almond tree is growing in a weighing lysimeter contained within this orchard to measure ET directly. A flux tower was used on site to estimate ET using eddy covariance and surface renewal using a footprint to represent the entire orchard, and the combination of these two techniques was used for a Fusion ET estimate. IRT sensors aimed at the lysimeter tree were used to calculate H. These values were also compared with reference ET calculated from a California Irrigation Management Information System station located at the Kearney Ag Center.*

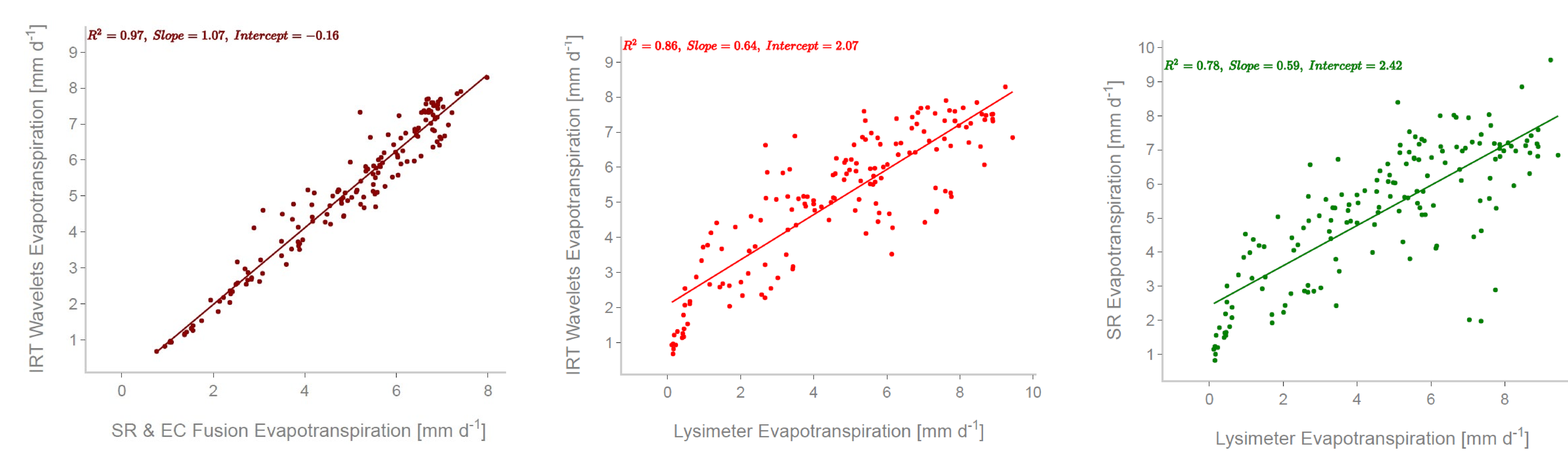


***Figure 4** (above): Regression analyses comparing ET estimates from several of the techniques presented in Fig. 3 for the 2019 growing season. A similar relationship was found between SR and the lysimeter for the 2018 growing season (i.e. the slope was 0.59 in 2018, too).*

Conclusions

- Growers require information on how much, when and where to irrigate. ET estimates can provide data on the quantity of water lost via ET from crop surfaces. Based on the results from the new approach presented here, IRT sensors provide an opportunity to determine ET at the single plant resolution, but also estimates of stress based on changes in canopy temperature with adequate resolution to account for infield variability.

- Such data would also be particularly useful for ground-truthing remotely sensing based estimates of ET from energy balance approaches.

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