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# Evaluating the Effectiveness of Surface Renewal and other Technologies to Determine Almond Tree Water Use and Stress

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## **A. Summary**

Surface Renewal (SR) technology is now patented and being provided to growers as a commercial product. Over the last several years we have conducted research to evaluate tree water use and stress estimates derived from SR with those from eddy covariance, weighing lysimetry and other stress indicators under field conditions for almonds. We continued to evaluate the following research question: How effective is SR as a cost-effective irrigation management tool that provides growers with information about both the amount and timing of irrigation events for almond orchards? We found that tree water use measured with SR correlates well with other measurements from a weighing lysimeter and eddy covariance methods, but the magnitude of measurements differs. ET data from the 2020 season exhibited a relationship closer to 1:1 compared to previous years comparing outputs from the various methods. During the course of this work a new method was developed to track tree water use with high frequency measurements of canopy temperature from infrared radiometers (IRTs). This method shows great promise for being able to track water use, and provides a potential rugged and relatively inexpensive technique for future groundtruthing of remotely sensed ET and stress.

## **B. Objectives (300 words max.)**

We addressed the following specific objectives: 1) Evaluate the effectiveness of the new stand-alone SR method to accurately quantify almond orchard ET; 2) Compare stress indices from SR with several other methods to determine how effective they are for almonds; 3) Continue efforts to develop IRT based measurements of ET using SR principles.

## **C. Annual Results and Discussion**

Over the course of this work, we continued our ongoing efforts with collaborators to validate the new SR technique for measuring almond ET, and compared our estimates with those from weighing lysimetry (with Ken Shackel) and eddy covariance. We evaluated how well SR works when radiation and ground heat flux are measured directly versus modelled. We also tested how effectively the SR technique works for detecting water stress compared to other methods like water potential measurements, leaf gas exchange and crop water stress indicators derived from measurements of canopy temperature (with Infrared Radiometers- IRT).

Our flux footprint analysis and station location and instrumentation was improved in the 2018 season, and we continued measurements to gather a full season of data in 2019 and 2020 (report Figures below focus on 2020 data). We have collected adequate to make an evaluation of the effectiveness of SR for use in almond orchards. We also developed and evaluated IRT sensors to estimate ET and will continue these efforts based on promising results. We began comparing our results with those of satellite based ET approaches for all years of the study. We are preparing multiple peer-reviewed manuscripts to be submitted in 2021, which will include comparison with other techniques collected by collaborators. See details in figures at the end of the report.

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 wavelet method presented here, IRT sensors could 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. The IRT and SR methods were both able to track seasonal and water stress-induced changes in almond water use.

#### **D. Outreach Activities**

Presented in the virtual Almond Conference December 2020, and was invited to speak virtually to the ABC Irrigation workgroup in the Fall 2020 regarding the new T-REX (Tree crop Remotely sensed Evapotranspiration eXperiment) project. Worked closely with ABC staff to facilitate coordination of irrigation proposal submission from various collaborators at UC Davis and USDA.

#### **E. Materials and Methods (500 word max.):**

A research grade surface renewal station along with an Eddy Covariance system was established in an almond orchard located at the Kearney Agricultural Center. The station is equipped similarly to commercial units. We measured net radiation and ground heat flux directly, and also model net radiation and set daily G to zero to obtain ET estimates to assure commercial sensors perform equally well to research systems. ET estimates obtained from both types of surface renewal station were compared to ET estimates recorded by the weighing lysimeter and eddy covariance located in the orchard. Midday values of water potential were measured with a pressure bomb on weekly or biweekly basis using sun-exposed leaves in the block. Applied water quantity and irrigation frequency were recorded.

## **F. Publications that emerged from this work**

### *Manuscripts in preparation*

Bambach, Parry, Shackel, McElrone (in review). A new method to estimate sensible heat fluxes from wavelet analysis of semi-high frequency radiometric canopy temperature – *AGU Advances*

Bambach, Parry, Shackel, Collatz, Castro-Bustamante, McElrone (in prep). Evaluating a new method that utilizes wavelet analysis of semi-high frequency radiometric canopy temperature to determine sensible heat flux for an almond growing in a weighing lysimeter - *Agricultural and Forest Meteorology*

Bambach, McElrone, Shackel et al. (in prep). Comparison of almond tree evapotranspiration and stress measured with surface renewal, eddy covariance and weighing lysimetry. *Irrigation Science*



Figure 1: Flux tower in the experimental almond orchard containing a mature tree in a weighing lysimeter at the Kearney Agricultural Research center in Parlier, CA.

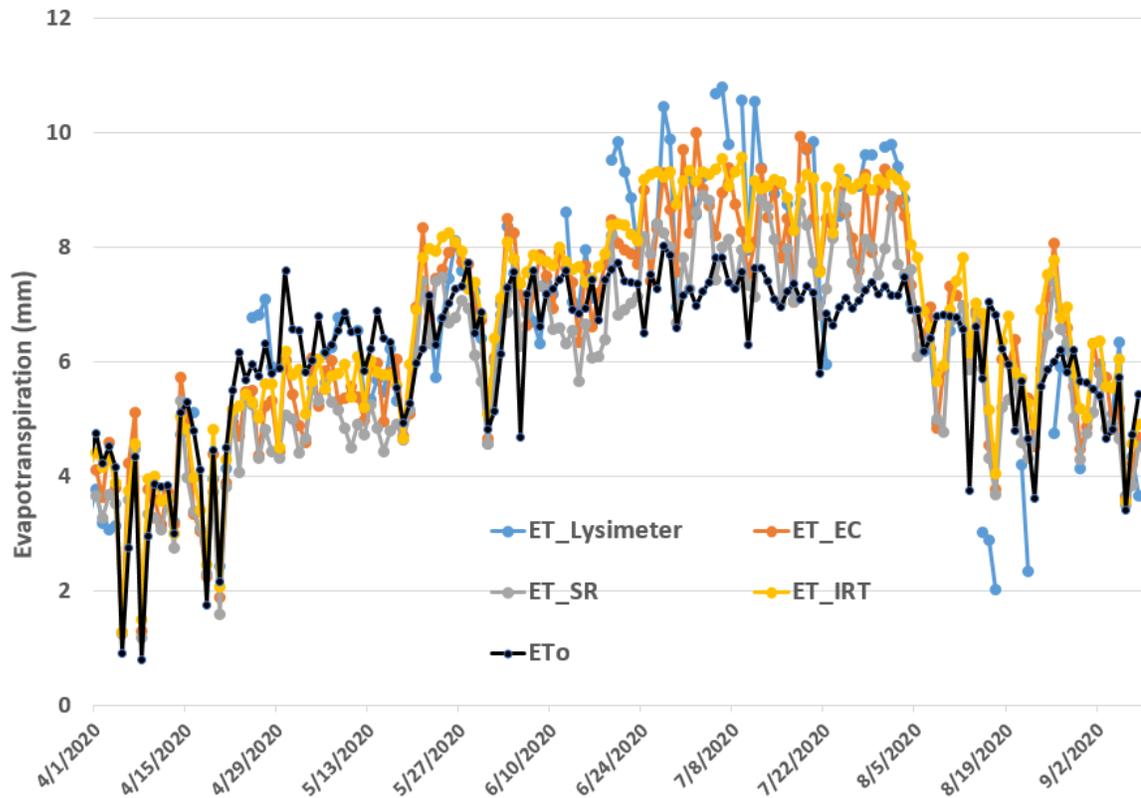


Figure 2: Almond evapotranspiration (ET) estimates from a variety of methods measured in an experimental almond orchard in Parlier, CA during the 2020 field season. A single almond tree is growing in a weighing lysimeter contained within this orchard to measure ET directly. A flux tower was used on site 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 using the new wavelet method described below. These values were also compared with reference ET calculated from a California Irrigation Management Information System station located at the Kearney Ag Center.

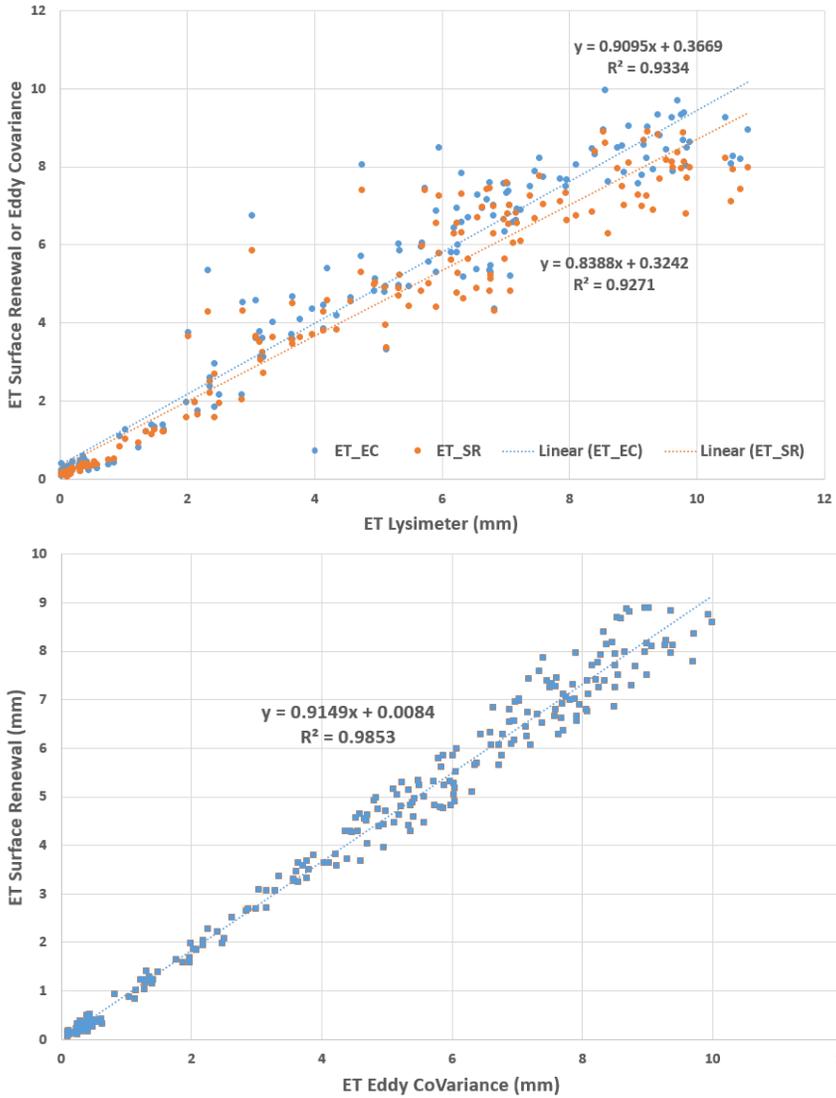


Figure 3: Regression analyses comparing ET estimates from surface renewal, eddy covariance and weighing lysimetry techniques presented in Fig. 2 for the 2020 growing season.

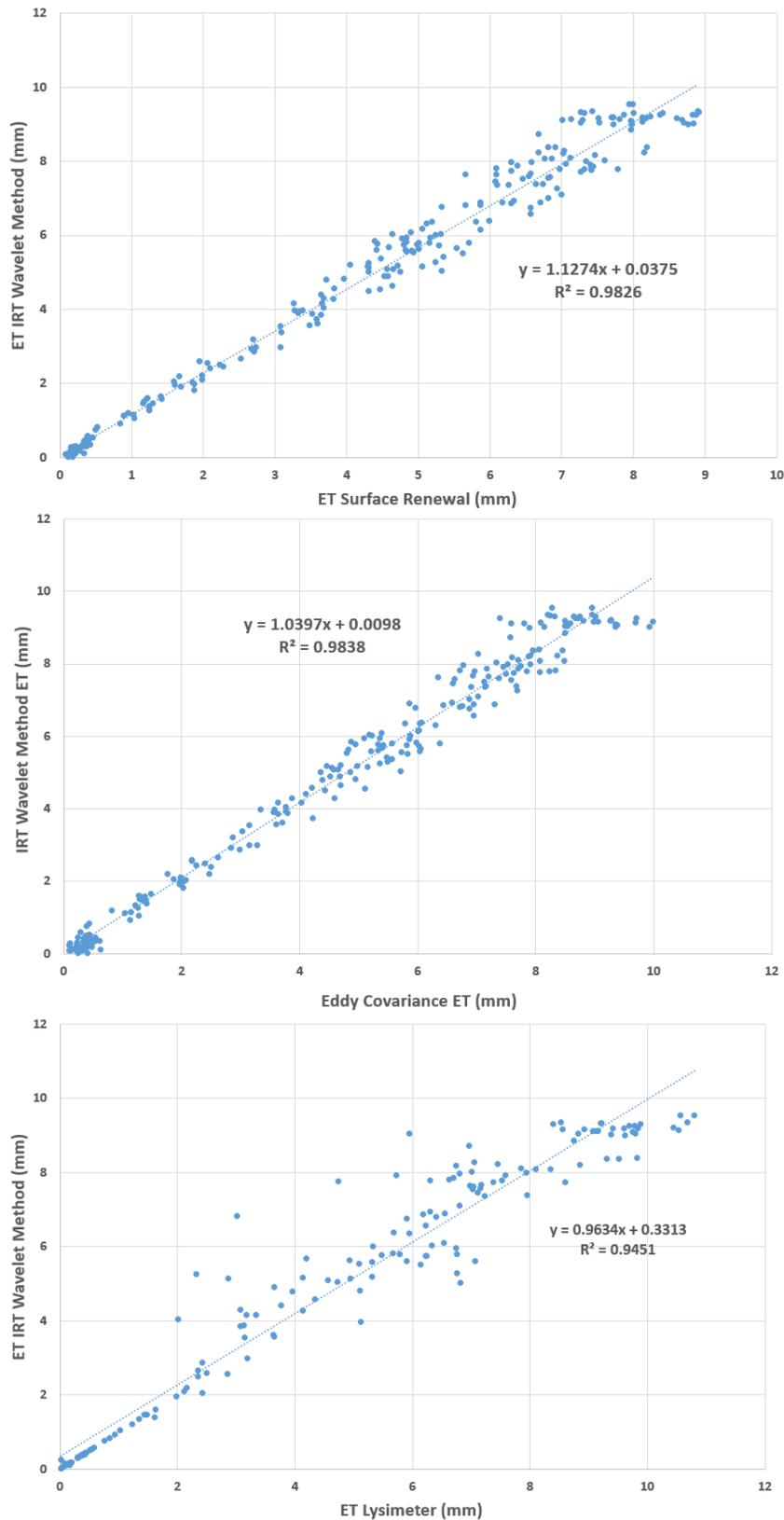


Figure 4: Regression analyses comparing ET estimates from the new IRT wavelet method with surface renewal, eddy covariance and weighing lysimetry techniques presented in Fig. 2 for the 2020 growing season.

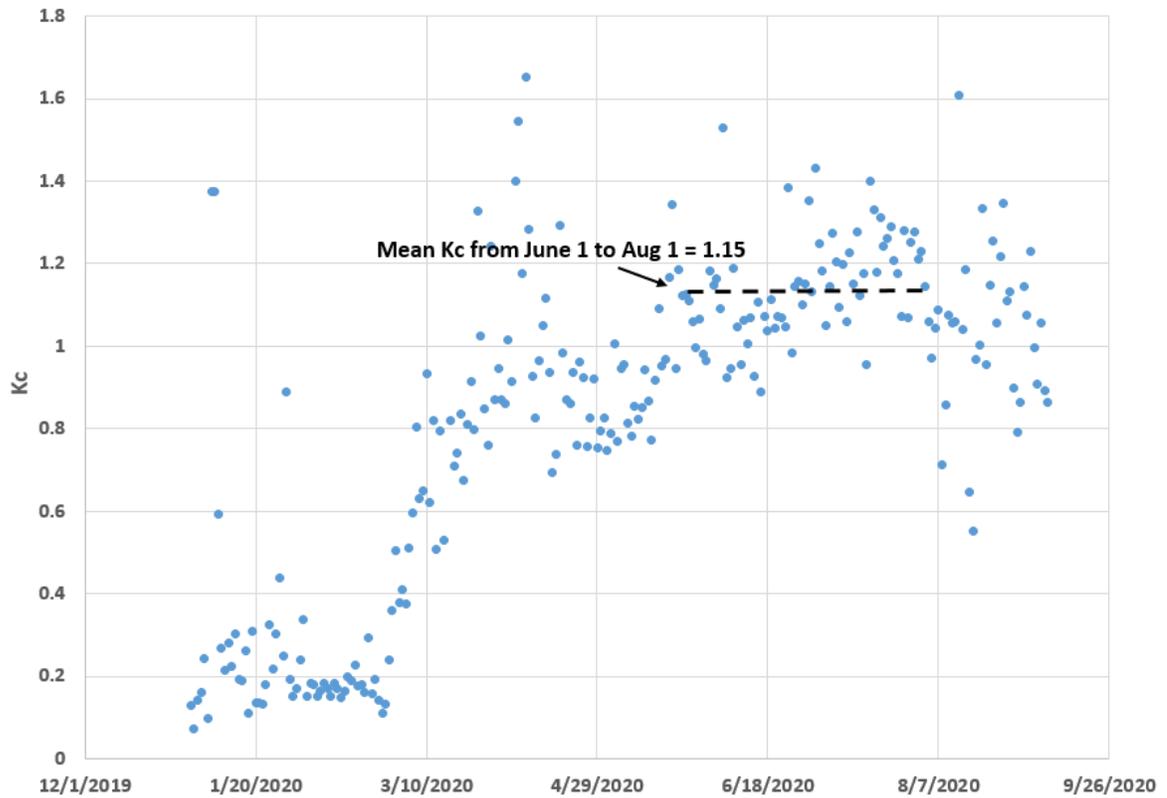


Figure 5: Crop coefficient derived using  $ET_a$  from Eddy Covariance flux measurements and reference  $ET_o$  for this site. The mean Kc value from June 1 to August 1 was 1.15 and commonly exhibited values between 1.2 and 1.3 during this period. The mean value was calculated for this period as the canopy was full by the beginning of this period, and this preceded the water stress treatment initiated in early August.

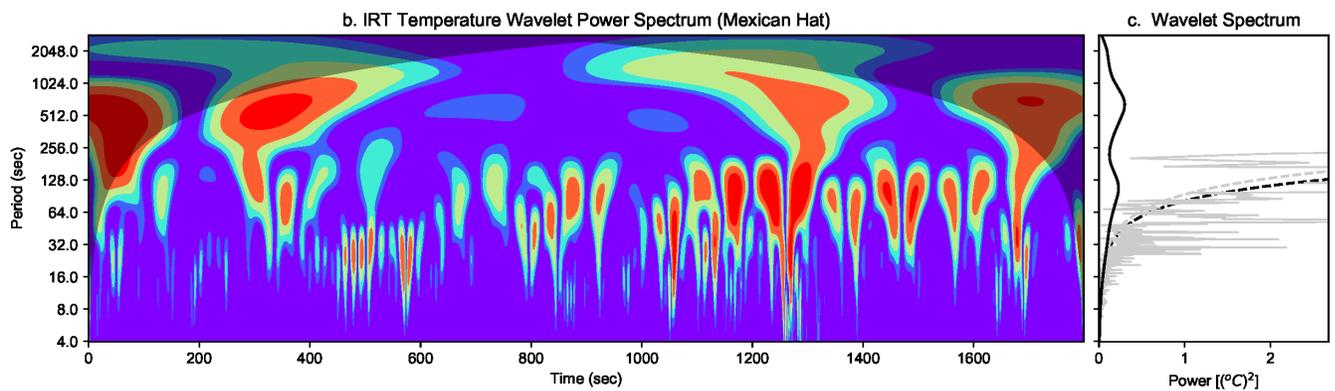
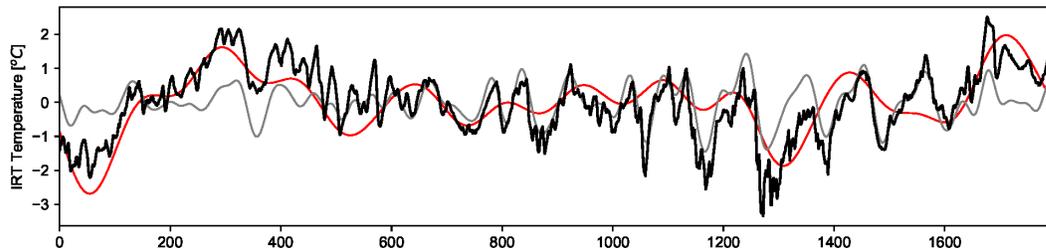
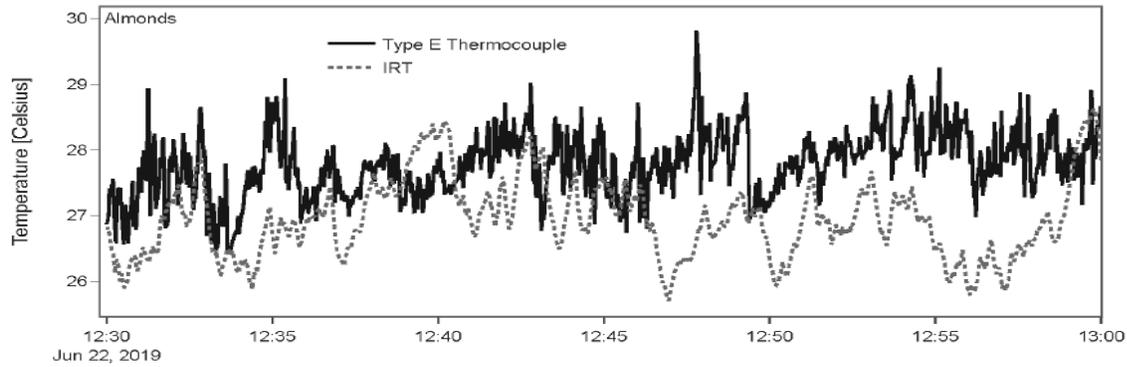


Figure 6: Raw temperature traces from IRT (top-panel dashed grey line) aimed at the plant canopy, and fine wire thermocouple (top-panel black solid line) located above the canopy captured at the almond lysimeter site. Ramp like structures in the fine wire thermocouple data that represent energy exchange between the canopy and air coincide with ramps in the canopy temperature. Wavelet analysis was conducted IRT temperature traces using PyWavelets (middle panel)- an open source wavelet transform software for Python. This analysis identifies the ramp like structures from the IRT canopy temperature data that coincide with sensible heat flux ramps. An example wavelet power spectrum (bottom panel) from the same data in the middle panel illustrates output from the Mexican Hat/Ricker spectrum analysis.

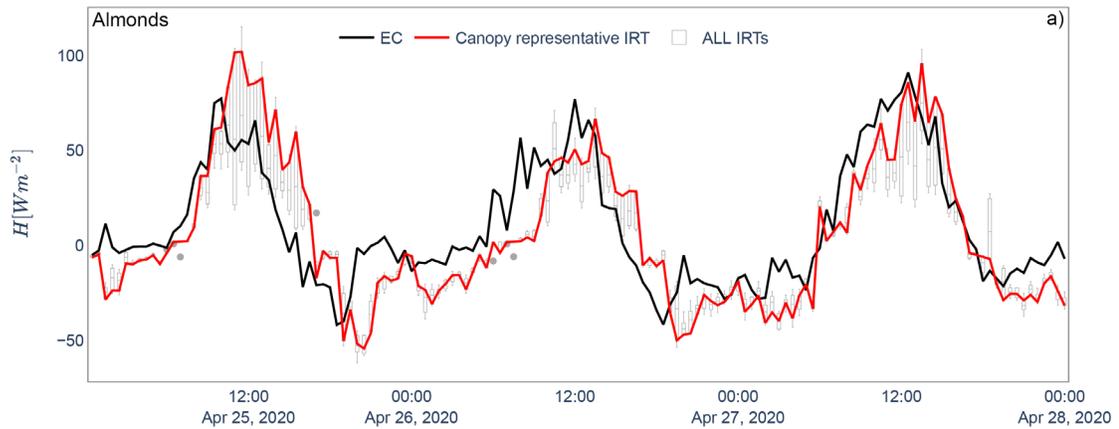


Figure 7: Sensible heat flux ( $H$ ) derived from Eddy Covariance and the new IRT wavelet method. Total daily ET calculated from these values showed excellent agreement between these two techniques (see regression in Fig. 4 with slope of 1.04 and  $R^2$  of 0.98 despite the offset (i.e. sensible heat flux captured with the IRT shows a time delay shifted towards the afternoon). The Red line shows results for the IRT sensor that best represents the canopy, while the grey open boxes represents the range of data seen in sensors pointed in various directions. Additional work is needed to resolve best orientations for sensor data capture.