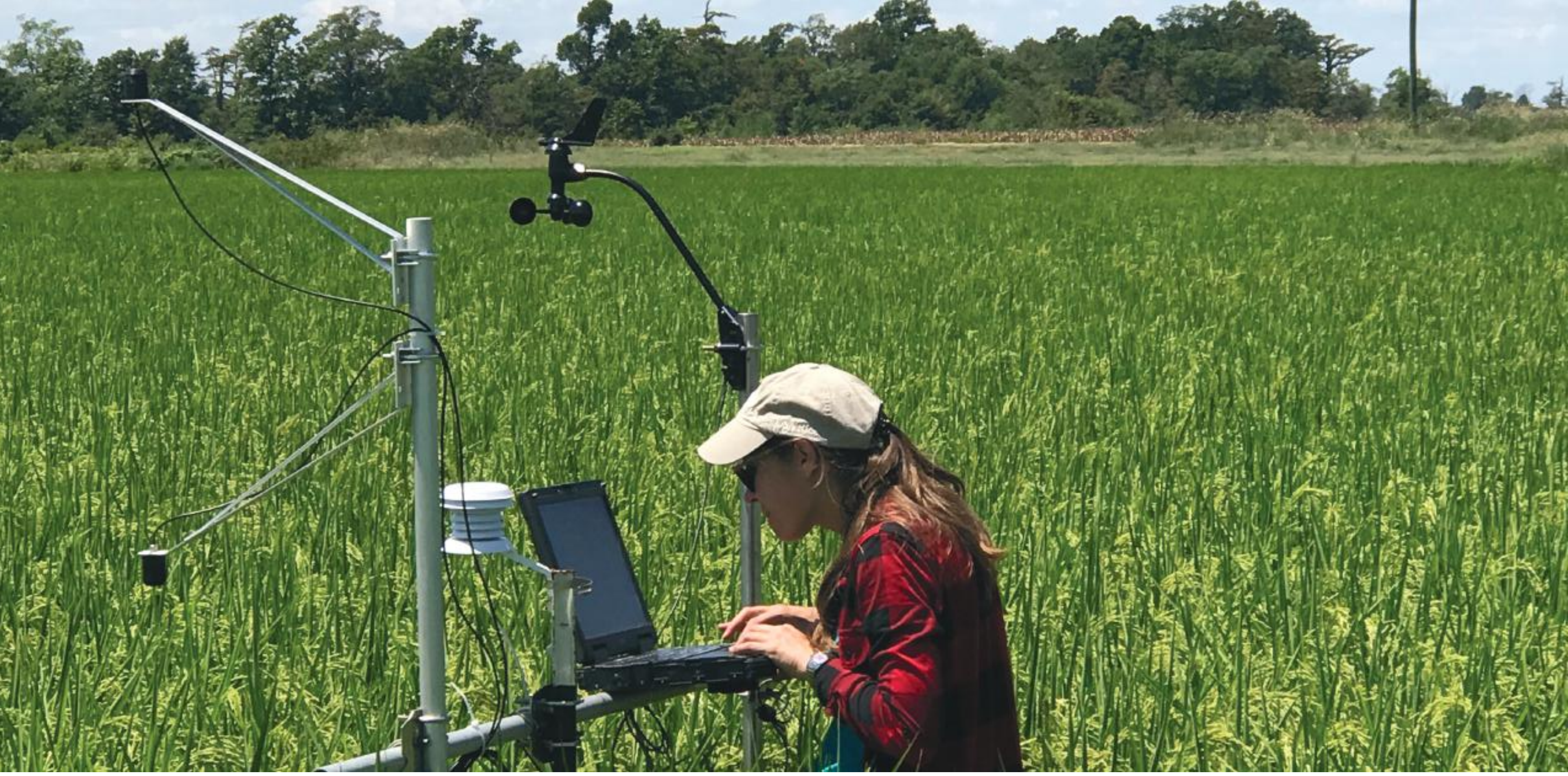

Image caption: Post-doctoral research associate, Beatriz Moreno Garcia, works with the Eddy Covariance equipment in a rice field in the Arkansas Delta. Garcia works for Dr. Benjamin Runkle, University of Arkansas professor of Biological and Agricultural Engineering.

Regionalizing Agricultural Field Evapotranspiration Observations

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Abstract: This project aimed to quantify evapotranspiration (ET) estimates in different agricultural production systems in Arkansas as part of a broader strategy to understand and improve upon the over-consumption of groundwater in the state. The project team directly observes ET in a cotton and several rice fields over different growing seasons. These measurements are taken with the eddy covariance method, compared to the Penman-Monteith model, and are also taken with a more experimental method called "surface renewal". Growing season ET is determined to be 567-636 mm in the rice fields and 555-615 mm in the cotton field. The Penman-Monteith model over-estimated ET, with estimates ranging from 752-835 mm. The surface renewal method was within 10-20% of eddy covariance estimates, encouraging its broader adaptation as a more cost-effective ET observation method. Quantifying ET will be helpful to quantify the dynamics of the crop water use. By knowing the water use dynamics we can follow up with questions about how to save water and associated pumping costs. The project findings are contextualized through inclusion in a growing, multi-institution network named Delta-Flux, which will be used to develop climate-smart and water-saving agricultural production.

Key Points:

- •Growing season evapotranspiration estimates of between 67-636 mm have been made for production-scale rice fields in Lonoke County, Arkansas, for the years 2016-17.
- •Growing season evapotranspiration estimates of 555-615 mm have been made for production-scale cotton production fields in Mississippi County, Arkansas.
- •The surface renewal method, a potentially cheaper and more adaptable strategy of providing direct observations of the evapotranspiration flux, is within 10-20% of more standardized eddy covariance estimates.
- •The surface renewal method performs better after the canopy cover develops, guiding future research directions.

Introduction

Rice and cotton agriculture together use approximately 50% of Arkansas's irrigation water; unfortunately Arkansas's groundwater supplies are being unsustainably applied to irrigate fields (Reba et al., 2013; ANRC, 2014). To understand this water use better and to create targeted water management solutions that preserve both food and water security, estimates of evapotranspiration (ET) are necessary for different Arkansas row crops. ET is the dominant part of the growing season water balance and is directly tied to plant primary production and growth. ET is therefore also an indicator of the landscape's cycling of water, carbon, and energy and a key link between field function and performance. Over-application of irrigation water contributes to groundwater depletion, changing surface water base flow regimes, and has real energy costs due to its pumping requirement. ET is difficult to directly observe, and to determine constrained state-wide estimates of water use. Thus, we need to improve and reduce costs in ET measurement systems in order to have better measurement resolution across different crops and across the whole aquifer-withdrawing region. Using additional and/or alternative observations of ET allows researchers to make predictions of irrigation scheduling that have a scientific basis in how they represent expected crop dynamics.

This work builds on USGS 104B grants in both FY2015 and FY2016 to study the hydrological implications of increased water use efficiency – with a focus in rice production. These projects have generated the intriguing finding (from the FY2015 award) that total evapotranspiration (ET) from an AWD field is similar or even slightly greater than a reference, continuously flooded field. This response may be due to the strong ability of rice roots to pull water from the soil matrix and from the relatively short length of the dry down period (approximately 11 days). The FY2016 award demonstrated the potential of the FAO-56 version of the Penman-Monteith equation for ET to adequately and accurately simulate observed ET. This equation seems to significantly outperform the relatively simpler Hargreaves model currently used in Arkansas's irrigation scheduling tools. We recognized a need to work beyond rice, as it represents less than half the irrigation water used in Arkansas and any solution to water withdrawal issues will come from a concerted, multi-crop effort.

In this work, we therefore measure ET in production-scale rice and cotton fields in Arkansas. We observe and model ET rates, partition ET into its two constituent parts (evaporation and transpiration), and compare ET measured in different years. We also test a novel ET measurement strategy as a step toward implementing a potentially cheaper and more scalable method to observe ET under many different land management regimes. This new strategy is a micrometeorological method called "surface renewal" (Paw U et al., 1995) and is based on detecting and quantifying ramp-like structures seen in the turbulent transport of H_2O or other scalars into the atmosphere. It is compared to the more common and expensive, eddy covariance method (Baldocchi, 2003) whose observations we have presented in the previous years' reports.

We focus on fields already under potentially water-saving irrigation practices. In cotton, pivot irrigation has been shown to halve irrigation water use while increasing yield, relative to more traditional furrow irrigation practices (Reba et al., 2014). In rice, the Alternate Wetting and Drying (AWD) style of irrigation (Lampayan et al., 2015), especially when applied on zero-grade fields, can save 40% of water applications (Hardke, 2015; Henry et al., 2016). AWD can also serve as a carbon-offset credit option (ACR, 2014), and its implementation expenses may partially be paid for through the Natural Resources Conservation Service's Environmental Quality Incentives Program (EQIP).

Methods

We measured water vapor fluxes as observations of evapotranspiration by the eddy covariance (EC) method (Baldocchi, 2003) of deriving the turbulent transport from landscape to atmosphere. These flux terms are then modeled by the Penman-Monteith equation (Monteith, 1981) as implemented in FAO document 56 (Allen et al., 1998). In brief, the measurement procedure uses a sonic anemometer to measure the wind vector components and an infrared gas analyzer (IRGA) to measure CO_2 and H_2O concentrations. We then derive an observational data-stream and gap-filling it using an artificial neural network, as documented in our previous report (Runkle, 2017). As before, the dual crop coefficient method within the FAO56 procedure is used to calculate separate crop coefficients used to convert reference evapotranspiration (ET_o) into transpiration and evaporation: $ET=(K_b+K_e)*ET_o$. The part modified by K_b is the estimated transpiration and the part modified by K_e is the estimated evaporation. These coefficients are adjusted for the higher relative humidity conditions present in the US Mid-South following the FAO56 protocol. The reference evapotranspiration rate was calculated using methods also outlined in FAO56 as part of the Penman-Monteith method.

Surface renewal (SR) estimates of ET were generated using the IRGA's time series of H_2O concentration to detect recurrent ramp structures. The ramp characteristics were detected by structure function analysis (van Atta, 1977). These characteristics are then processed with horizontal wind speed in a calibration-free approach (Castellví, 2004) that iterates a solution by deriving friction velocity, H_2O flux, and atmospheric stability parameters. These ET estimates are gap-filled using the same neural network strategy applied to the EC observations.

Site Description

This research is performed at two privately farmed, adjacent rice fields (34° 35' 8.58" N, 91° 44' 51.07" W) outside of Humnoke, Arkansas, and a cotton field near Manila, Arkansas (35° 53' 14" N, 90° 8' 15" W). The rice fields are zero-graded and their size is approximately 350 m wide from north to south and 750 m long from east to west (i.e., 26 ha each). One field was managed with continuous flooding (CF) during the rice growing season and the other with AWD management practice, facilitating a direct comparison of the two types of systems with minimal spatial separation. The sites are not tilled and are flooded for two months in winter for duck habitat and hunting. The dominant soil mapping unit in this area is a poorly-drained Perry silty clay. In 2016 the fields were drill-seed planted 23 April and harvested 13 September. In 2017 the fields were drill-seed planted on 9-10 April and harvested 26-27 August. The fields are surface irrigated through perimeter ditches; in 2016 an Alternate Wetting and Drying irrigation strategy was used on both fields; in 2017 a continuous flood was established in both fields on 17 May and held until 4 August.

The pivot-irrigated, 63 ha cotton field had a cover crop eliminated by a mixture of Glyphosphate, Dicamba and Firstshot approximately three weeks before planting. The DeltaPine 1518B2XF cotton variety was planted at a rate of 118,610 seeds ha^{-1} (48,000 seeds ac^{-1}). In 2016, cotton was planted on 8 May and harvested 10 October while in 2017, cotton was planted on 19 May and harvested 30 October.

Results and Discussion

The observed ET by eddy covariance (EC) in rice was relatively consistent across the measurement fields and growing seasons (Figure 1; Figure 2). In the northern field at Humnoke, ET ranged from 567-608 mm and in the southern field ET at Humnoke, ranged from 594-636 mm. In all cases, the Penman-Montieth FAO56 model over-estimated ET, with estimates ranging from 752-835 mm. This over-estimation was consistent across the growing season. This over-estimation may result from higher crop coefficients – derived from their global synthesis – than necessary in Arkansas under water-efficient or higher humidity conditions. Following the FAO56 method of partitioning growing season ET into its constituent parts, evaporation and transpiration, transpiration represented 23-35% of the seasonal total ET flux. The partition between these terms follows the seasonal growth cycle, with more transpiration during later vegetative and early reproductive stages.

The cotton field evapotranspiration rates were similar to the rice fields, with measured values of 555-615 mm (Figure 3). ET increased after emergence likely due to higher

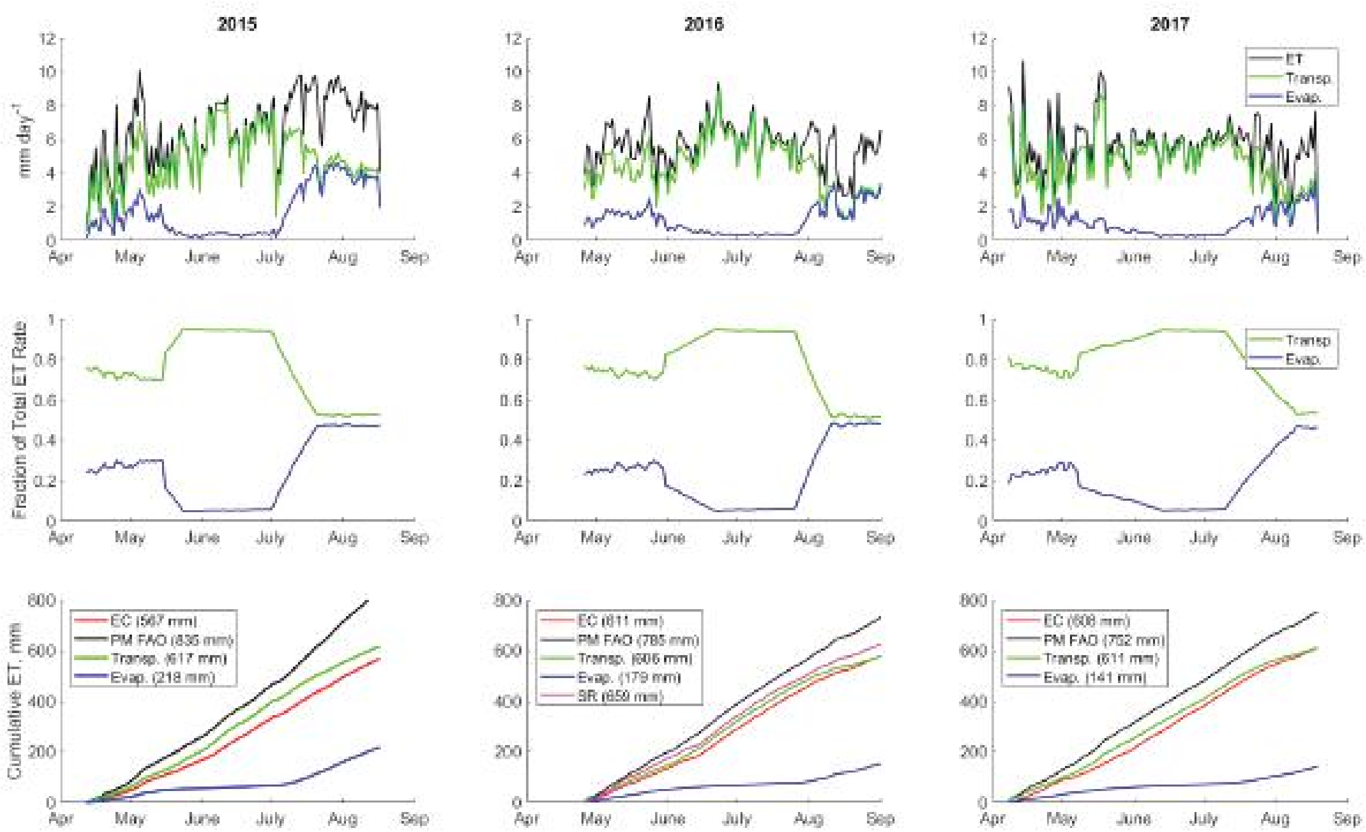

Figure 1: ET measured and modeled at the northern rice field in Humnoke (2015-17). The top six figures use the Penman Monteith model (PM FAO) to estimate ET and its partition into evaporation and transpiration components. Note the surface renewal observations are presented in for 2016 in the lower panels.

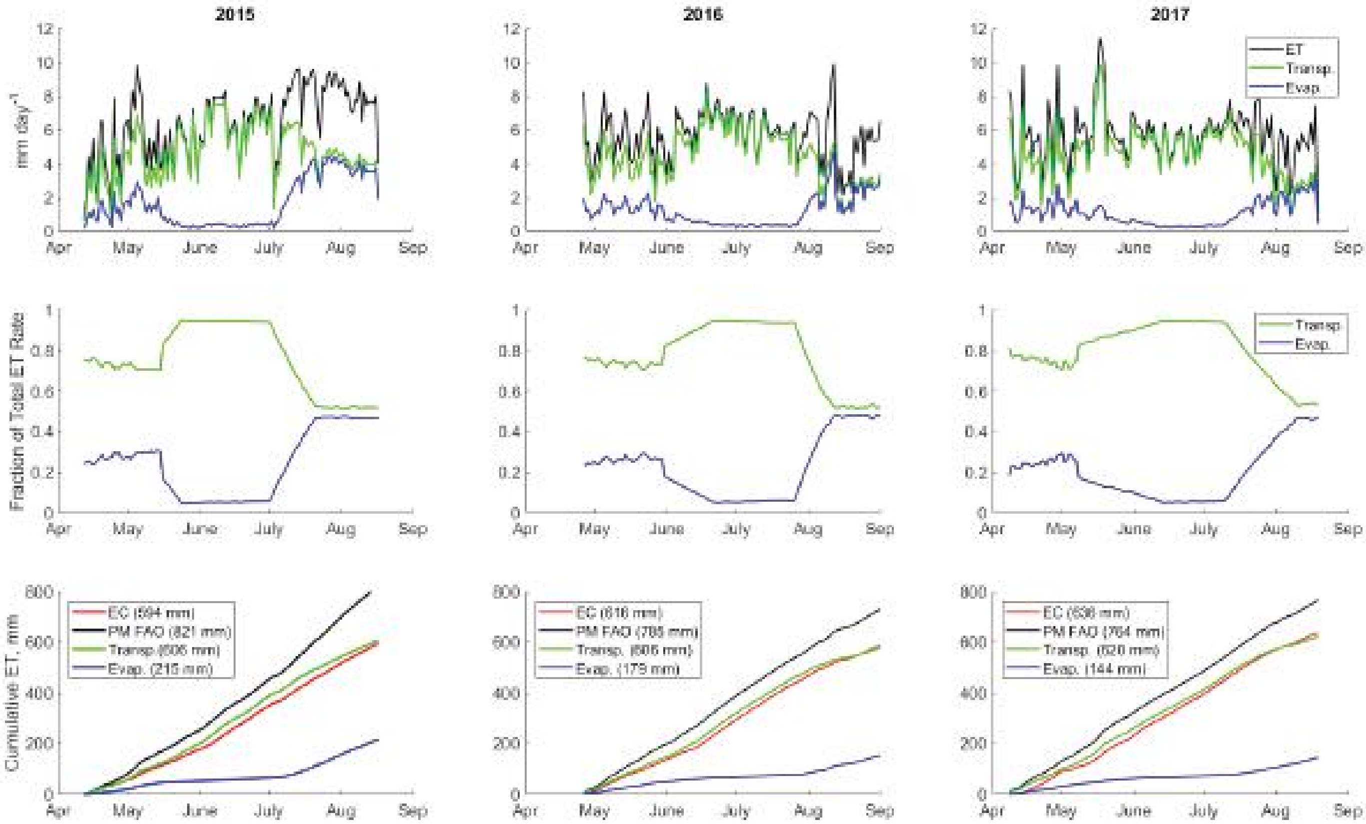

Figure 2: ET measured and modeled at the southern field in Humnoke (2015-17), and otherwise similar to Figure 1, though for this field we do not present the surface renewal data in 2016.

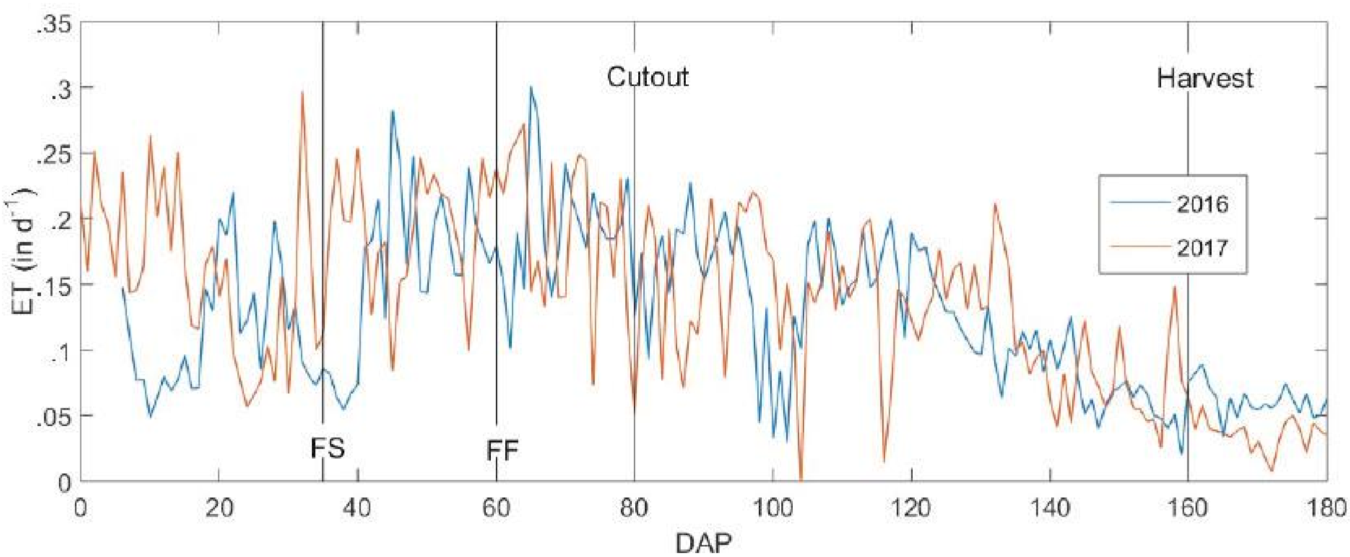

Figure 3: Daily crop evapotranspiration (ET) during 2016 and 2017 cotton growing seasons presented against days after planting (DAP). FS is first week of squaring, FF is first week of flowering, and cutout is physiological cutout or nodes above white flower equal to 5.

transpiration activity, greater water applications or rainfall, and higher air temperatures. ET later decreased after physiological cutout during boll maturation, likely due to lower plant water needs. Likely due to the higher relative humidity and greater cloud cover (reducing incoming solar radiation), these ET estimates are lower than in other regions. For example, a two-year study in Texas using weighing lysimeters found ET of 739-775 mm in full irrigation conditions; compared to 578-622 mm under a deficit irrigation strategy that also reduced field yields by 10-50% (Howell et al., 2004).

The surface renewal estimates are presented for the northern rice field for 2016 as these were the most complete

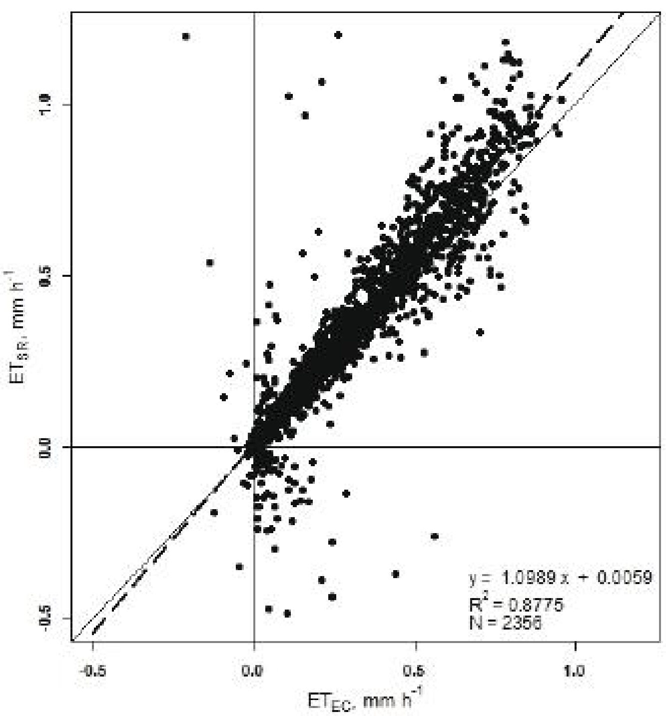

Figure 4: EC measured by surface renewal (SR) as compared to eddy covariance (EC) methods, in the northern rice field in Humnoke (2016).

time series (Figure 4). This method performed well – when gap-filled, its cumulative estimate of ET was very similar to the EC method (660 mm vs. 616 mm). On a one-to-one comparison, the methods agree well. Most of the over-estimation of SR relative to EC is largest earlier in the season, prior to full canopy development. Reasons may include the larger effective measurement height (with less surface roughness and greater effective eddies) and changes in canopy interference with turbulent structures. While corrected for density fluctuations, it may be that the concentration signals under high evaporative fluxes are challenging to interpret with the structure functions that have been more rigorously tested under temperature, rather than water vapor, time series.

Conclusions

The project finds good agreement between methods for estimating ET and more carefully partitions ET between transpiration and evaporation. Total ET shows less year-to-year variability. Similar to our previous work, we find that ET is largely controlled by transpiration during the peak growing season. We see little impact from irrigation style on the magnitude of ET fluxes, indicating minimal potential reduction to crop yield (due to the link between the carbon and water cycles through stomatal transfer of both CO_2 and H_2O). Work is ongoing to enhance the ability of the Penman-Monteith method to adequately represent ET in these land cover types. We will work to determine crop coefficients for rice derived from local measurements rather than the global values found in the FAO56 handbook. The ET measurements from the Arkansas cotton fields support this approach, as these measurements also indicated lower ET than in Texas, in part due to the greater cloudiness and higher humidity of the mid-south vs. other cotton-growing regions.

Local, regional, and national benefits

The site-based data is helpful to guide farmer decisions on water application to their fields. It is also contextualized through inclusion in the growing network named Delta-Flux (Runkle et al., 2017) for climate-smart agriculture. This multi-institution network, is composed of a suite of eddy covariance measurement towers on multiple crop and land cover types. The most representative crops and landscapes of the Lower Mississippi Alluvial Plain will be monitored for their water use, potentials for the decrease in water applications to the fields and carbon sequestration possibilities.

The scientists involved represent the USGS, USDA, and higher education institutions. The group is beginning to work with USGS partners on the MERAS groundwater model to contribute our ET datasets to their regional modeling initiatives. Additionally the locally-calibrated mechanistic relationships we are working to develop will offer predictive strategies upon which to strengthen irrigation planning tools. Being part of the Ameriflux and Fluxnet network, our measurements contribute to the global database for landscape types that have historically not been represented for their ET rates and CO_2 fluxes.

Acknowledgements

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