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Title: Satellite-Based Estimation of Actual Evapotranspiration of Golf Course Cool-Season Turf

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Objectives: The general goal of this study is to acquire a high-quality data set for ET of turfgrass on a golf course, and use it to test several remote sensing based ET models, as well as improve understanding of how turf ET responds to changes in climate conditions. Specific objectives are:

1. Conduct eddy covariance measurements of the flux of water vapor and energy balance of a golf course over multiple years, to get hourly, daily and seasonal water use values. Use findings to test currently used simplistic ET approaches such as reference ET.
2. Apply several remote sensing approaches to estimate ET, and validate their performance against ground-based measurements. These include the Triangle Method and USDA-ARS Data Fusion approach. Examine their utility to estimate irrigation requirements.
3. Combine the surface energy balance measurements with theoretical knowledge to determine the relative importance of available radiation energy, atmospheric humidity and advection of heat from drier surrounding lands on the water use of turf.

Start Date: 2017
Projects Duration: Three years
Total Funding: $89,861.72

Summary Text:

Rationale

Turfgrass is the most widely irrigated managed plant system in the U.S. Irrigated turf landscape provides benefits such as sports surfaces, visual design, and mitigating urban heat islands. Golf courses in particular offer recreation, design aesthetics, and environmental cooling. Population growth and recent droughts amplified by climate change pose a critical need for more efficient irrigation in urban landscapes, particularly, but not exclusively, in the West. Golf courses have historically been proactive in addressing efficient irrigation in terms of amount and timing. But a robust and rigorously validated system for assessing actual turf water use and requirements has not been developed. The historical "black box" approach to estimate water use or evapotranspiration (ET) involves estimating a "reference ET" value (ET0), which is then multiplied by an empirical factor (kc). However, these empirical "black box" values are not extensively studied nor validated for turfgrass, so turf water use estimates from ETo ⍰ kc are not robust and rigorous. Limited water resources and more precise management of irrigation requires a more robust approach to quantifying actual water used by turf in golf courses as well as other turf surfaces.

Current State of Knowledge

Operational satellite imagery and recent advances in remote sensing-based ET models provide an opportunity to determine spatial distribution of daily ET for turf surfaces such as golf courses. Much of this began with the Triangle Method described in Carlson (2007), which uses data from several wavebands of radiation including thermal. This approach was tested in a preliminary study by USU for a region that included the Eagle Lake golf course near Layton, UT. ET estimates for the golf course were compared with measurements of actual ET made at the site by USU. Results were excellent, agreeing with ground-based values to within about 5%. Notice the 30 m elements display spatial variability on the golf course. However, more evaluation is needed to assess the operational utility and accuracy of the method.

Recently, the USDA-ARS developed a suite of algorithms comprising a satellite "data fusion" ET model, described in for example, Semmens et al. (2015). Data sources include hourly data from the GOES satellite, daily data from the Modis platform, and Landsat overpasses at 8 or 16 day intervals. Physically based models simulate ET at the course scales. These are then downscaled to 30 m ET values. It has been tested and validated for a number of land surfaces, but not yet for urban landscapes nor turfgrass.

Methods

ET Measurements

The State of Utah funded USU to install an eddy covariance system on the Eagle Lake golf course in Layton, UT. The station has a sonic anemometer, an open path sensor for water vapor and CO2 densities, net radiometer, and soil heat flux sensors. The resulting ET flux estimates come from a footprint ~ 250 to 300 m of turf upwind of the sensors. Few trees are located upwind, and none near the station.

Eddy Covariance ET Measurements

This is the "gold standard" for determining the exchanges of mass and energy between surfaces and the atmosphere, and based on the definition that turbulence flux is the covariance of any property with the vertical wind. For example, the water vapor flux is the covariance of vertical wind and humidity.

$$E = Covariance(vertical\ wind, water\ vapor\ density) \qquad (1)$$

Similarly, heat flux is covariance of vertical wind and air temperature. Small turbulence structures require measurements at a high frequency (~20 times per second). Additional analyses are later required. Spikes, bad, and missing data must be identified, removed and gap filled. Other corrections are listed in Massman and Lee (2002). In addition, various time series analyses are used to find appropriate averaging periods, and verify measured turbulence conforms to known laws. Finally, the energy of heat and water vapor fluxes is compared to available energy (net radiation minus soil heat flux). When the ratio is too low (under ~85%) established scientific practice adds to fluxes to match available energy. This is an independent check of the reliability of the flux estimates. The above methodology will result in ET values for the golf course for the appropriate averaging periods, usually about one hour. These can be summed to yield daily, weekly and seasonal totals. The proposed graduate student for this project will conduct the eddy covariance measurements and perform the additional analyses under advisement of Dr. Hipps.

The final ET values will be used to check the reliability and quantify errors of the commonly used reference ET and empirical kc approach over a range of conditions. Also, analyses will determine the relative importance of radiation vs. atmospheric humidity and transport of heat from the surroundings on the ET of the turf. This will document how the turf ET responds to variations in weather and climate.

Remote Sensing

The Triangle Method shown above, will be further tested these studies. It can only yield high spatial resolution data every Landsat overpass, but uses nearly daily Modis data, but at 1 km resolution.

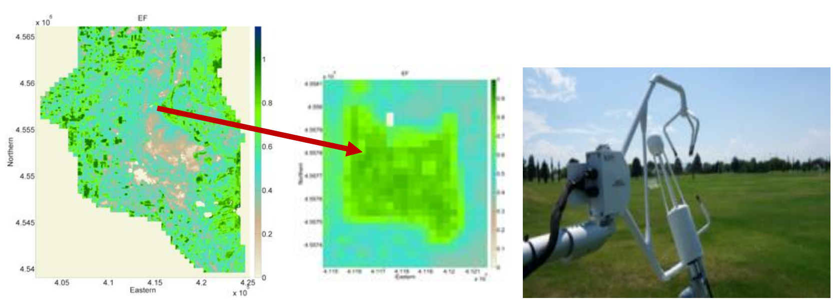
The other more substantial approach will be the suite of data fusion models by the USDA-ARS Hydrology and Remote Sensing Laboratory (Semmens et al., 2015). Starting with hourly data from the GOES satellite, the models use surface temperature changes and atmospheric thermodynamics to calculate ET at 4 km resolution. Higher spatial resolution is achieved combining Modis (daily, 1 km thermal) and Landsat (16 days, 100 m thermal) platforms. A downscaling algorithm increases the resolution of the Modis down to the Landsat value, later sharpened to 30 m. Then a two source model simulates transpiration and soil evaporation. The ET value is then integrated to a daily value using several well-known methods. The PI has a long relationship with the ARS developers, and they have already formally agreed to help USU utilize the models for this study.

Both the triangle method and data fusion approach will be tested during the irrigation seasons for the region shown earlier that includes the golf course. Models will be run for a set of days spanning the season. The ET values for days with no satellite data (2-4 overpass days of data per week), will be filled in using known physical relationships that are refined for the region. The results will then be compared to the eddy covariance measurements, and examined to observe any relationships between the fidelity of the model estimates and various environmental conditions. The graduate student will work with Dr. Torres-Rua to especially on the image processing, and with both PIs on the validation.

References

Massman, W.J. and X. Lee. 2002. Eddy covariance flux corrections and uncertainties in long-term studies of carbon and energy exchanges. Ag. For. Meteorol. 113: 121-144.

Semmens, K.A., Anderson, M. A., Kustas, W.P., Gao, F., Alfieri, J.G., McKee, L.,Prueger, J., Hain, C., Cammalleri, C., Yang, Y., Xia, T., Sanchexz, L. Mar Alsina, M and M. Velez. 2015. Monitoring Daily Evapotranspiration Over Two California Vineyards Using Landsat 8 in a Multi-Sensor Data Fusion Approach. Remote Sensing of Environment. Ttp://dx.dopi.orh/10.1016/j.rse.2015.10.025



ET SLC Suburbs | Golf Course Daily ET = **0.16 in day^{-1}** | Measured ET = **0.17 in day^{-1}**

Figure 1. A preliminary study by USU for a region that included the Eagle Lake golf course near Layton, UT. ET estimates for the golf course were compared with measurements of actual ET made at the site by USU. Results were excellent, agreeing with ground-based values to within about 5%. Notice the 30 m elements display spatial variability on the golf course. However, more evaluation is needed to assess the operational utility and accuracy of the method.