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Divergence of actual and reference evapotranspiration observations for irrigated sugarcane with windy tropical conditions

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Supplement: Technical details on soil moisture calibration and Eddy Covariance cross checks.

1. Soil moisture calibration and water retention characteristics

To calibrate the Water Content Reflectometry probes, three ~19 L (5 U.S. gallon) water coolers (Internal height 46.6 cm, internal diameter 32.8 cm) were used to calibrate each soil. We inserted the probe rod vertically in the center (middle) of the experimental coolers into the soil ensuring full contact with the soil. Then, the coolers were closed with their respective lids to allow the system to equilibrate before taking account of the period readings for each VWC. For the upper 40 cm of soil in each field, we determined bulk density, porosity, and soil texture (Bouyoucus, 1962) and soil water retention characteristics (Windy field only) with samples from 3 locations within the tower footprint. Soil water retention characteristic (from saturation point to 1 bar) were determined for the Windy soil using Tempe Cells (1400 Series, Soil Moisture Equipment Corp, Santa Barbara, California, USA). Permanent wilting point (PWP) was determined using a dew point potentiometer (WP4C, Decagon Devices, Inc., Pullman, Washington, USA). Soil water depth was determined for the upper 40 cm by converting soil VWC with porosity and subtracting PWP

2. Eddy Covariance instrument cross-checks and validations

We conducted two major cross-checks with our Eddy Covariance instrumentation. One major cross-check was with our net radiometer. Net radiation is perhaps the most significant single observation for ET accuracy with Eddy Covariance since it controls the scale of the energy balance correction. Because of the known sensitivity of the domeless radiometer (NR-Lite) to wind (Cobos and Baker, 2003), we conducted two quality assurance evaluations to evaluate potential biases in the net radiation observations. First, we plotted our daily, wind corrected, net radiation observations against mean daily wind speed to see if there was any residual relationship between wind speed and observed net radiation. Second, we compared our net radiation observations to net radiation as parameterized from nearby weather stations (Table 1), inputting solar insolation, air temperature, and relative humidity observations following the ASCE formulations for net radiation (see Appendix B in Allen et al. 2005). We compared the ASCE-weather station net radiation parameterizations to observed net radiation during the mid-period to ensure that the crop surface measured by the net radiometer was most similar to the ASCE reference surface characteristics.

Intercomparison of the net radiometers at the EC towers with the ASCE net radiation parameterization did not show a greater underestimation of Rn at the Windy field compared to the Lee field (Table 2). Both slopes were within 12% of unity, with Windy's weather station having a slope within 5% of unity. Bias at both stations was less than 0.5 MJ/day. We also compared the residuals of daily Rn (radiometer Rn-ASCE parameterized Rn) to mean daily wind speed. For both weather station – EC tower pairings, the slope of the relationship was not significantly different from 0 ($p>0.10$). Finally, we note that, since we used the radiometer-observed net radiation in both our EC correction and reference ET calculation, any (unlikely) bias would bias measured and calculated reference ET in the same direction.

Table 1

This table contains weather station information for weather stations used in net radiation intercomparison. Station instrumentation consists of an anemometer (Wind Monitor Jr., R.M. Young, Traverse City, Michigan, USA), rain gauge (TE525, Texas Electronics, Dallas, Texas, USA), downwelling (incoming) pyranometer (LI200X, LI-COR, Inc.), and air temperature and relative humidity probe (HMP35C or 45C, Vaisala). Most stations are mounted at ~10 m above ground elevation on wooden poles near sugarcane fields. Operation, maintenance, annual instrument calibration, and data processing for the network are contracted to an independent, commercial company. We paired two of the weather stations (hereafter referred to as WindyWS and LeeWS) with the EC towers in the Windy and Lee fields respectively (Table 2). The two weather stations are within 1500 m of their paired EC tower, and there are no significant topographic barriers between the weather station and EC tower.

Name	LeeWS	WindyWS-close
Operator	Farm/contractor	Farm/contractor
Latitude (°N)	20.795361	20.813333
Longitude (°W)	156.406444	156.496694
Elevation (m)	142	24
Distance between WS and associated EC tower (m)	1220	1360

Table 2: Comparison of EC tower net radiometer observations with ASCE net radiation parameterizations from weather station observations

	Slope	Intercept	r^2	RMSE (MJ/day)	Bias (MJ/day)
WindyWS	0.99	0.33	0.89	1.16	-0.21
LeeWS	0.89	0.79	0.89	1.09	0.39

A second major cross check was our routine calibration and swapping of instruments. We calibrated our infrared gas analyzers (IRGA) against EPA protocol, primary gas standards for zero and span (400 ppmv) concentrations (Airgas, Kahului, Hawaii). We also calibrated the IRGA for water vapor against a dewpoint generator (Licor 610, Lincoln, Nebraska). During our multiple calibrations during the experiment, we swapped the IRGA in each field with a spare instrument in our laboratory. We also swapped the sonic anemometer heads in both fields, replacing the anemometer in Windy with a new instrument following a transducer failure. Finally, we replaced the temperature and humidity probes with freshly calibrated probes midway through the experiment following manufacturer's recommendations. After all of these instrument swaps, we did not find any observational discontinuities (with fluxes or meteorological values) that would indicate a badly calibrated instrument. Also, the instrument exchanges and recalibrations eliminate the possibility of a single bad instrument or calibration biasing the measurements.

References

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