Response to Anonymous Reviewer #1 – comment on "Divergence of reference evapotranspiration observations with windy tropical conditions"

We thank reviewer 1 for their review of our manuscript. Here, we respond to their highly critical review by addressing their two major critiques and then focusing on their other comments at the end along with a reference list for citations in this reply. Our comments and responses will be in this font (Times New Roman, bolded blue text), and the original comments from reviewer one will be in a different font (Arial, regular black text**).**

Major critique 1 focused on the accuracy of the evapotranspiration observations from the Eddy Covariance tower. Specific overall comments included:

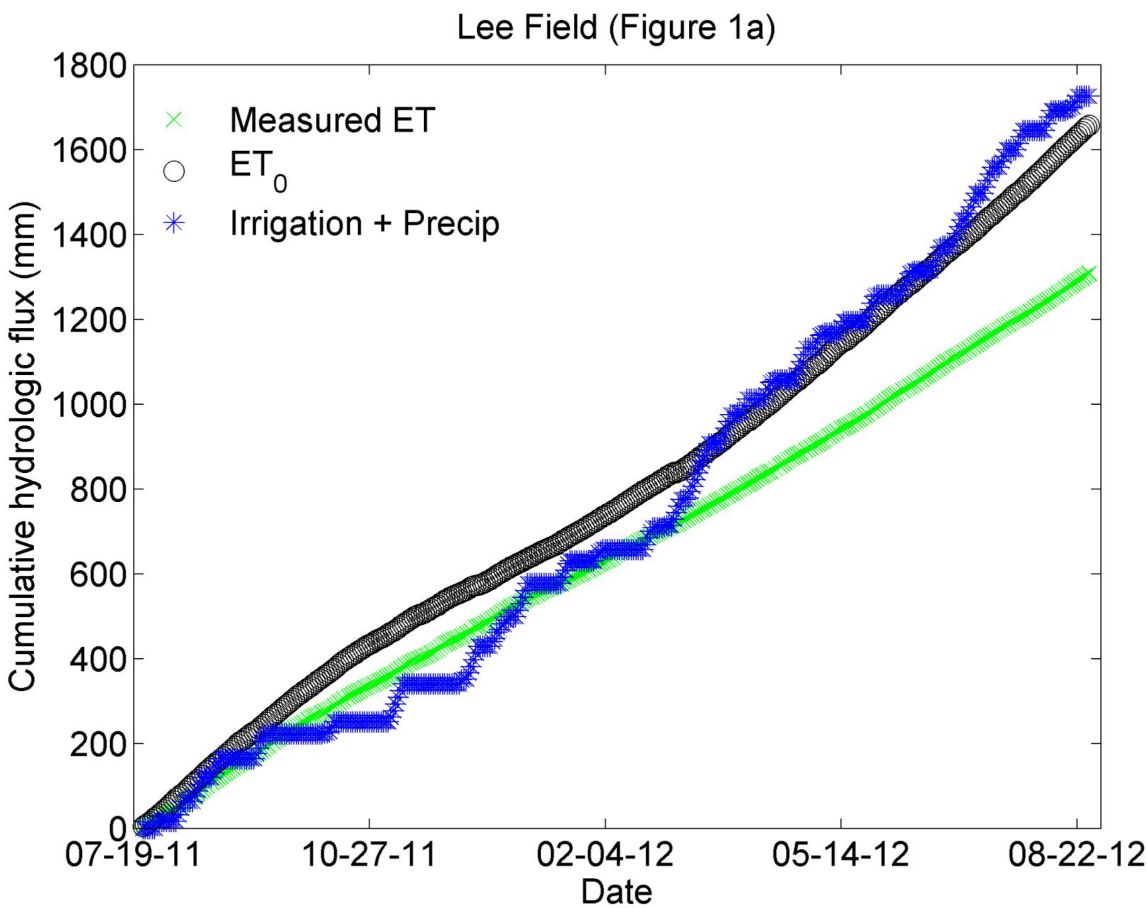
"1. Authors do not have an independent measurement of sugarcane ET to disprove or to confirm the measured ET with the EC system.

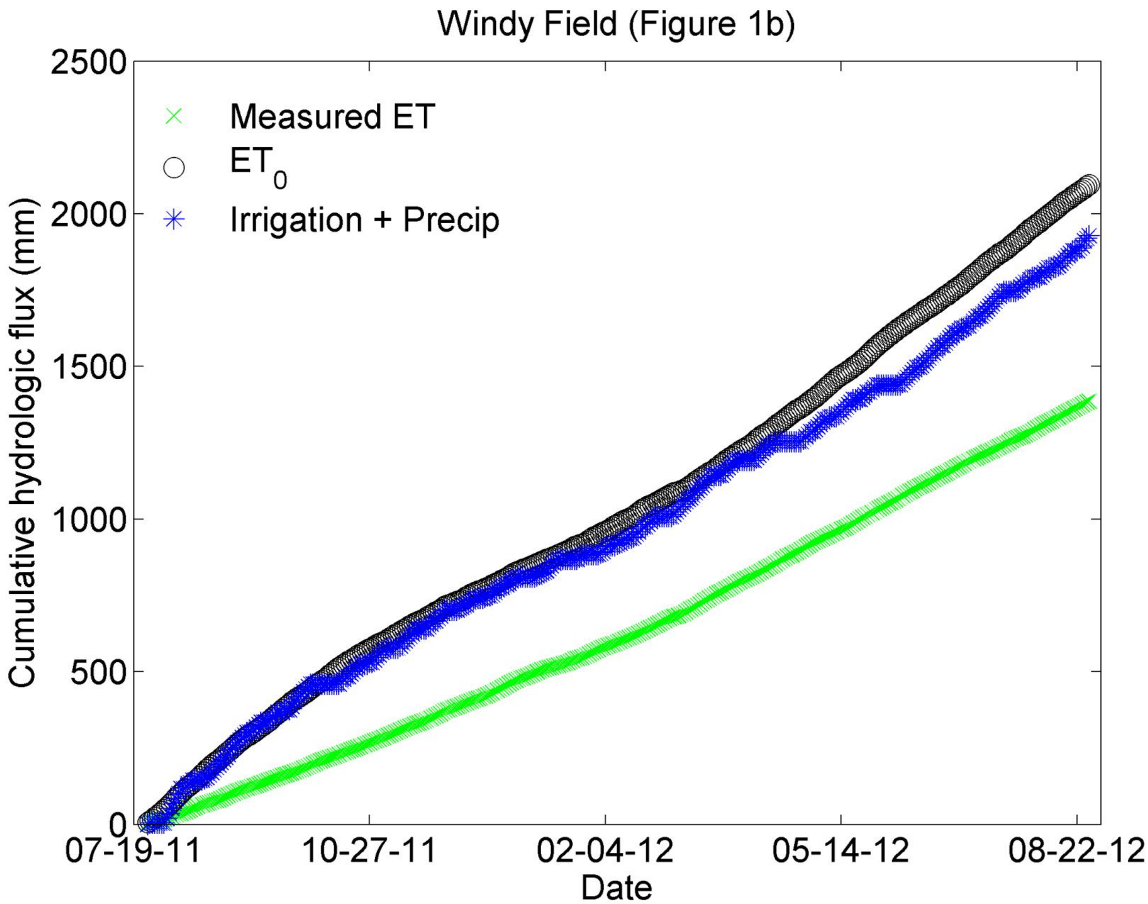
2. They do not have a water balance data (input and output) to at least confirm the seasonal sugarcane ET. For this purpose they need a record of the input (rain and irrigation) and a measurement of the water content in the soil profile.

3. It is well know that EC measurements tend to underestimate ET and thus the calculation of bulk canopy resistance by inverting the Penman-Monteith equation is irrelevant given the large discrepancy of measured and calculated ET."

With respect to applied water, we do have a record of irrigation and precipitation in relation to ET as we discussed on pg. 6492, lines 18-23. The cumulative irrigation and precipitation plots are presented below for both fields (Fig. 1). ET_0 is the ASCE ET_0 (short reference) equation. "Irrigation" on plot refers to total irrigation and precipitation for fields. When combined with the high root zone soil moisture shown in Figure 2d, the irrigation data illustrate fields that are relatively well watered. Furthermore, the cumulative ET_0 exceeds cumulative irrigation plus precipitation throughout most of the study period and the full canopy period. If both the meteorological evaporative demand (ET0) and commonly used crop coefficients (>1) for sugarcane are correct, we should have seen significant water stress in the root zone. We note that previous observations of Hawaiian sugarcane have shown the greatest root density in relatively shallow depths (less than 50cm – Evensen et al., 1997) so if there was significant plant water stress in the sugarcane field (particularly at the Windy field), we should see depletion of root zone soil moisture below field capacity at a depth of 20cm in line with the sugarcane row. We do not see this depletion given that calculated field capacity is at 24% VWC (Table 1) and minimum root zone soil moisture is 23% VWC (Figure 2d). Finally, we note that water and mass based techniques like soil water balance and lysimetry can have large within field variation (e.g. Alfieri et al., 2012; Allen et al. 2011). In particular for the water balance method, independent (non-residual) observations of percolation, which would be needed to estimate ET, are often highly uncertain and dependent upon simplifications of soil water transport (e.g. Gee and Hillel, 1988; Willis et al., 1997). With respect to lysimetry, it was

logistically prohibitive for this project and it also has significant uncertainties due spatial variability because only a small area can be measured (e.g. Alfieri et al., 2012). The Eddy Covariance (EC) method incorporates energy balance along with direct mass exchange observations and it integrates larger field areas for crop ET assessment. The technique has been well documented in the literature (see responses below with respect to EC), and it is not the focus of this study to validate the eddy covariance method.





We now turn to the Eddy Covariance (EC) method and our instrumentation. Reviewer 1 states that EC underestimates actual ET. In our view, this is only true if one ignores the well-established and widely-used energy budget corrections for EC observations (Leuning et al. 2012; Stoy et al. 2013). When corrected for energy budget closure, EC observations have had good agreement with lysimeters, catchment scale precipitation and stream flow observations, and/or soil water balances in forests (Barr et al., 2000; Wilson et al. 2001) and multiple agricultural studies globally (Alfieri et al., 2012; Chávez et al., 2009; Ding et al. 2010). Recent work by Leuning et al. (2012) indicates that much of the apparent imbalance is due to closing energy fluxes on a 30 minute time scale, which can ignore heat fluxes stored in the canopy; using a daily time scale significantly improved closure. Furthermore, energy balance closure at our sites in Maui, particularly Windy, is substantially better (Anderson and Wang, 2014) than the average of EC sites (Wilson et al. 2002), which is due to the stronger turbulence at our sites. At Windy, the energy balance correction was under 5%.

Another related issue that the reviewer indicated was with the instrumentation. Specific comments on this issue include:

"Page 6479 line 8. This does not mean that the values obtained with the EC system are correct. The authors have made the implicit assumption that because all instruments were factory calibrated the results must be correct. An instrument can be calibrated but still give the wrong value for the parameter being measured."

And

"Page 6483. The measurement of leaf stomatal resistance with the Decagon SC-1 instrument has been shown to have problems under field conditions."

Factory calibration was one of multiple cross checks we conducted with the instrumentation. However, given the research-grade equipment used and independent standards to which the instruments are calibrated, noting the factory calibration is a useful detail as mentioned by a reviewer of Anderson and Wang (2014). In particular, the vendor of all of our Eddy Covariance (EC) equipment, Campbell Scientific Inc., has ISO certification (ISO9001:2008 – see https://s.campbellsci.com/documents/us/miscellaneous/iso_certificate.pdf), which provides further assurance on the quality of our third party calibrations.

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.

The Decagon SC-1 porometer underwent a major design change since its introduction with the addition of a desiccant chamber, increases the humidity gradient between sensors, reducing small gradients that may lead to unrealistic conductance calculations. We also note that the SC-1 has been successfully used to measure stomatal conductance in field settings with trees (Barnard and Bauerle, 2013; Gotsch et al., 2014; Polacik and Maricle, 2014), grasses and shrubs (Bijoor et al., 2014), and in agricultural fields. In agriculture, the SC-1 has been used to assess stomatal responses to deficit irrigation across a range of crops and regions (Ballester et al., 2013; Hirich et al., 2014; Mabhaudi et al., 2013; Mendez-Costabel et al., 2014). The SC-1 has also been used by multiple investigators to parameterize and evaluate remote-sensing approaches to assessing crop water stress (Zarco-Tejada et al., 2013; Zia et al., 2013; Zipper and Loheide II, 2014).

We now turn to the 2nd major critique the reviewer raised concerning the high ET_0 and ET_r calculations at the Windy field. Specific comments from the reviewer on this issue include:

"Further, based on the results of the calculated ET using the ASCE method, it appears that perhaps the authors have made a mistake in their calculations as some of the values given in Fig. 4 of 10 – 12 mm/d of ET are too high for the environmental conditions of their site. I suggest that the authors revisit these calculations and make sure that the correct input is used, particularly for global shortwave irradiance [MJ/m2 d]. As an example, I calculated the daily reference ET using the ASCE method (15 July) Site ETgrass [mm/d] ETalfalfa [mm/d] Lee 4.3 4.8 Windy 4.8 6.1. Input values used were taken from Table 1, except for irradiance, dewpoint and pressure, for the Lee site for the middle of July: Latitude: 20.784664 Longitude: 156.403869 Elevation: 203 m Tmax, air: 27.3 _C Tmin, air: 17.8 _C Average daily dewpoint temperature: 19.4 _C (from NOAA) Average daily rh: 65 Average daily wind speed: 2.0 m/s Average daily barometric pressure: 100 kPa (from NOAA)".

And

"Upon inspection of the calculated values of reference ET it seems that some of the values reported are too high. Values of reference ET of 10 mm/d seem too large for the experimental site. Values of reference ET > 10 mm/d are normally associated with high air temperature (> 30 _C), low air humidity (< 10 _C Tdew), large daily shortwave irradiance (> 30 MJ/m2 d), and windy conditions (> 5 m/s). These are conditions of the semiarid High Plains of US in the middle of the summer. These are not the conditions at the experimental site. Tropical environments, because of proximity to equator and a 12-hour day usually have daily ET values in the 4 –8 mm/d range.”

The reviewer seems to believe these results are impossibly high for the field site. The reviewer cites data for a day using an unidentified NOAA product for which the daily wind speed is less than half that of the average for the Windy site (Table 1 of Anderson and Wang, 2014). As an example, we present data from a day with high calculated ET_0 and ET_r (August 16, 2011) from our Windy field site and completely independent data from the Federal Aviation Administration’s ASOS weather station at Kahului Airport (hourly data and station information available http://mesonet.agron.iastate.edu/request/download.phtml?network=HI_ASOS – station ID PHOG). This station is ~ 10 km from our Windy EC tower and has a similar, but weaker, wind field. The good fidelity between the Kahului station and our tower under the typically strong northeasterly trade winds further increases our confidence in our reference ET observations and further illustrates that high reference ET rates are indeed realistic and relatively common in this location. We note that on the high reference ET days, the advective component contributes more than twice as much to the total ET_r than the radiative component.

Table 3: Meteorological and reference ET comparison for August 16, 2011.

Variable	Windy EC tower	Kahului ASOS
Maximum Air T (ºC)	28.3	30
Minimum Air T (ºC)	22.3	22.2
Mean[1] U_2[2] (m/s)	6.05	4.88
Mean Dewpoint T (ºC)	18.1	18.5
Mean RH (%)	63.4	63.0
Mean pressure (kPa)	100.8	101.6[3]
Rn-G (MJ/day)[4]	16.85	13.93
Rs (MJ/day)[5]	N/A	23.91
ET_0 (mm/day)	7.2	7.0
ET_r (mm/day)	9.9	10.2

We now move onto address specific comments from reviewer 1.

[1] All mean values in table are daily averages.
[2] Adjusted from 3m observational height and 10m observational height following ASCE profile wind equation (eq. 67 in Allen et al. 2005.
[3] Adjusted from measured mean sea level pressure following very small elevation correction (10 m).
[4] Measured at Windy EC site. Calculated from geometry and sky conditions, using ASCE approach, at Kahului airport. We used an actual sunshine duration of 75% based on quantitative calculation of cloud cover (5-25%) for the “Few Clouds” category of the ASOS observations.
[5] For comparison, the mean typical solar irradiance for this date is 23.5 MJ/day per the National Solar Radiation Database normal for Kahului (http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2010/)

“This paper deals with ET of sugarcane and as such the authors include information that is not relevant to the topic. For example, the data plotted in Fig. 2 is not relevant and should be deleted. The data of measured soil water content (Fig. 3d) is of no importance for this work.”

We believe the plant canopy data in Fig. 2 is critical for independently determining the start of the mid-period (when the crop ET coefficient (Kc) of unstressed sugarcane should be greater than 1). This enables a more conservative determination of the start of the mid-period compared to using a crop table and reduces the likelihood of our results being due to incomplete crop cover. The soil moisture data in Fig. 3d shows moisture content near the center of the sugarcane root zone. These data can independently assess potential water stress in the crop.

“1. It would be helpful if the authors used the same symbols for terms as given by the ASCE for reference ET. This is one of the reasons the ASCE introduced a “standard” equation and symbols to avoid confusion.”

As far as we can tell, the only difference in symbols between equation 2 of our manuscript and equation 1 in Allen et al. 2005 is one subscript ($ET_{r,0}$ in our manuscript versus ET_{SZ} in Allen et al., 2005). This change was made as a result of an editorial request. We would be very willing to change our nomenclature to ET_{SZ}.

“2. Page 6475 line 25. The ASCE and FAO-56 are essentially same calculation.”

We agree with this and note this similarity in our methods. We discuss both in the introduction to increase relevance for international readers who may not be as familiar with the American Society of Civil Engineers. We can rephrase this part of the introduction to make this similarity more clear.

“3. Page 6476 line 18. All irrigation is supplemental.”

We intended the word “supplemental” to indicate regions where, due to climatic conditions, a much greater percentage of consumptive crop water use is derived from precipitation on the farm and less comes from irrigation. We can remove “supplemental” in a revision.

“4. Page 6477 line 15. Essentially they only have one objective. The objectives read as an afterthought, i.e., the measured and calculated ET differed and therefore we need another objective. Objectives 2 and 3 are not objectives.”

We view testing methods, identifying mechanisms for discrepancies, and proposing improvements to correct discrepancies as separate, but related, objectives. We agree that the reference ET discrepancy was an unexpected discovery, but the additional work beyond the discovery constituted separate objectives, with the far better performance of the Priestley-Taylor approach illuminating the root cause of the discrepancy and the path forward.

“5. Page 6477 line 25. A common mistake is to refer to the measured value of “radiation” with a pyranometer as solar radiation. This is incorrect it is solar irradiance, a property of the receiver. Radiation is a property of the source.”

We agree with the reviewer, and we will correct “solar radiation” to “solar irradiance” in future revisions. We used solar radiation for ease of reading and comparison against net radiation.

“7. Page 6479. Was shortwave global irradiance measured?”

We did not measure irradiance at the tower sites, and instead used net radiation for reference ET calculations as discussed in the manuscript. We did compare our net radiation observations to parameterized net radiation as shown above in Table 2

“8. Page 6479 line 10. What is the purpose of measuring soil water content at one depth?”

The purpose of measuring at one depth was to look at lateral moisture flow in the center of the root zone (~20cm depth). As discussed earlier, the soil water content observations in the cane line are at the heart of the cane root zone and provide an independent measure of potential plant water stress.

“9. Page 6482 – section 2.4. This section is irrelevant to the topic of this paper.”

As we mentioned above, the plant canopy data is important for showing that the discrepancies we observed were not due to variations in crop ET coefficient. As such, we believe this section is highly relevant to this manuscript.

“11. Figures. In some of the figures it is difficult to discern what values are plotted and what corresponds to what site.”

We would be extremely willing to revise figures to improve readability and ease of interpretation. However, it would be highly useful for us to know what specific figures or elements of figures (symbols, colors, size, etc.) are causing difficulty. Without this information, we do not know what presentation elements need revision and which are fine as they are.

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