INCORPORATION OF HOURLY DATA INTO COTTON2K

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Abstract

The COTTON2K (C2K) model is a simulation model that is well adapted to simulate cotton growth and development and lint yield in dry climates in part due to the algorithm used to calculate crop evapotranspiration (ET). However, earlier versions of C2K interpolated hourly values of air temperature (T_a), humidity (RH), wind-speed (U_z) and shortwave irradiance (R_g) from corresponding measured daily values of T_a, RH, U_z and R_g. Given the increasing number of weather networks and stations that record hourly values of T_a, RH, U_z and R_g it is now possible to use these variables directly as input in models such as C2K. An updated version of C2K was modified to handle hourly input values of T_a, RH, U_z and R_g decreasing the amount of weather parameterization with the expectation that it will be suited and more readily adopted by users in the Southern High Plains of TX. Specific examples of modeling efforts using the updated version of C2K are presented and compared with results from the previous version of the model.

Introduction

The C2K model was derived from the GOSSYM model in 1997 by Dr. Avi Marani. This model, originally named CALGOS, was modified to more accurately represent cotton grown under arid irrigated conditions (Baker et al., 2010). One of the main differences between C2K and GOSSYM is the hourly time-step used to interpolate weather data in C2K in contrast to the daily values used in GOSSYM. These hourly weather parameters are derived from daily weather input using diurnal curves to calculate the corresponding hourly values for T_a, RH, U_z, and R_g in C2K v. 4.0 (CTK4). Within the model, the calculations are based on typical weather patterns for only a few regions in the world where the parameters were evaluated extensively such as Arizona and California in the U.S.A., and in Israel. These calculations are based on the measured daily T_a, wind run, dew point (T_d), and R_g, but additional assumptions are made based on the simulation area's time of solar noon, expected T_{max}, and typical cloud cover.

There are five geographic locations within the CTK4 model to select for interpolating the hourly weather data. These include Phoenix, AZ, West San Joaquin Valley, CA, and 3 locations in Israel. Weather data from these locations were compared to average weather data from Lubbock, TX (Figure 1). These comparisons showed that while some variables (T_a) may be similar to the prediction locations, other variables that have a significant effect on ET like RH and U_z are different. In fact, one of the most obvious differences between the Phoenix and Lubbock climate is the number of clear days, which affects the amount of solar radiation reaching the plants (Figure 1).

We have recently renewed our interest in this cotton growth model due to our work with the Precision Agriculture Landscape Modeling System (PALMS). The PALMS model was developed in the upper Midwestern U.S.A. and its purpose is to model crop growth based on how the landscape affects the water and nutrient balance in a field (Morgan et al., 2003). It currently uses crop models for corn and soybean, i.e., primary crops where the model was developed; however, our application of the model makes it important to include a cotton crop. Further, our interest in PALMS stems from the landscape focus including soil water storage and runoff components of the model, which have been evaluated in the Texas High Plains (THP) for the past 4 years (Nelson, 2010). To use PALMS, a cotton model must be included and evaluated for the conditions of the THP. The model PALMS requires hourly weather input and thus our interest in evaluating hourly vs. daily input weather to C2K.

In 2010, we worked with Dr. Yoni Ephrath, Ben-Gurion University of the Negev, Israel, while he was a visiting scientist with the USDA-ARS Wind Erosion and Water Conservation (WEWC) unit in Big Spring, TX. Ephrath is a former student of Marani and an expert on the C2K4 model developing and testing many of the algorithms used to interpolate the hourly weather values used in C2K (Ephrath et al., 1996). During his visit, we discussed the variability of weather in West Texas especially in regard to wind during the day and the higher daily RH compared with the more arid regions where the model was originally tested. With advances in technology to collect and store weather data, hourly weather datasets are more readily available than in the past. Ephrath agreed that weather patterns of the THP posed a challenge to the methods used in C2K4, leading to discussions with Marani as to the feasibility of incorporating measured hourly data to the model. In November, 2010, Dr. Robert Lascano, Research Leader of WEWC, USDA-ARS, met with Marani in Israel and discussed changes to C2K4, yielding COTTON2K v. 6.0 (C2K6). This paper compares simulated results of C2K4 and C2K6 to measured cotton lint yields in Lamesa, TX and evaluates the incorporation of hourly weather variables compared to hourly values obtained from interpolation from daily values.

Materials & Methods

Data was collected in 1999-2001 in Lamesa, TX (32.77 Latitude and -101.94 Longitude) on an Amarillo fine sandy loam soil as a part of a precision agriculture study. The datasets contained soil and plant data relative to the model providing useful validation data for comparison of the two versions of the C2K model.

In 1999, soil samples were collected and analyzed on an acre grid pattern for particle size; however, to ensure the accuracy of this dataset for the area of the field where cotton lint samples were gathered, additional soil samples were collected in Fall 2010 for soil texture analysis. There was a good agreement between the textural analyses from the two sampling times, confirming the applicability of the dataset. Particle size was measured using the Bouyoucos method (Klute, 1986) and this information was used as input to the pedotransfer function Rosetta (USDA, 1999) to calculate the required van Genuchten input parameters for use in the C2K hydrology files.

Soil chemical properties were measured in the spring of each year of the study and this data was used to create the initial soil input parameter files needed for the C2K models. Additionally, records of irrigation application times and amounts, cultivation events, fertilizer applications and other cultural practice information was compiled into agronomic input files for both models.

The C2K model requires four types of input files including plant-mapping information if available. The four required file types are: weather, soil hydrology, initial soil data, and agronomic data. The weather file for C2K4 requires only daily weather information on T_{max}, T_{min}, R_g, daily wind run, T_d, and precipitation. The weather file for C2K6 allows for the input of hourly weather variables including T_{max}, T_{min}, U_z, R_g, RH_{max}, RH_{min}, and rainfall in addition to the daily parameters required by CTK4 listed above. The daily weather information is included in C2K6 because it can interpolate hourly data, but this feature was not used.

Finally, the "profile" file in C2K is the compilation file containing general information about the field or study, refers to all of the input files for the run, and provides output options including specific dates to run the model. In this profile, one must select the location that is most similar to the simulation location so that in the case of C2K4 the weather parameters process according to the most similar diurnal weather patterns to the area of interest, and in the case of C2K6 it is only used if the daily weather data is used to fill in missing hourly data. It is important to note that the cotton variety grown must be selected in this profile as well, and that this is a likely source of parameterization error within the C2K model. The varieties available are older, e.g., Delta and Pineland 77 and 61, which are upland cotton varieties rarely grown in the THP. Other available varieties are Pima and Chinese cotton varieties that are also not used in the THP. For our simulations, we selected and used DP61 because it was the upland variety that provided the most comparable results to the actual yield data. However, the variety planted in 1999-2001 was Paymaster 2326 that likely has growth patterns and traits that differ from the variety we selected as input from the C2K model. Furthermore, the plant-mapping portion of C2K can be use to improve the variety parameterization process if the data is available. In addition, C2K provides access to the variety files that can be modified based on known traits of newer varieties. However, this information is difficult to find and costly to measure and thus no attempt was made to modify.

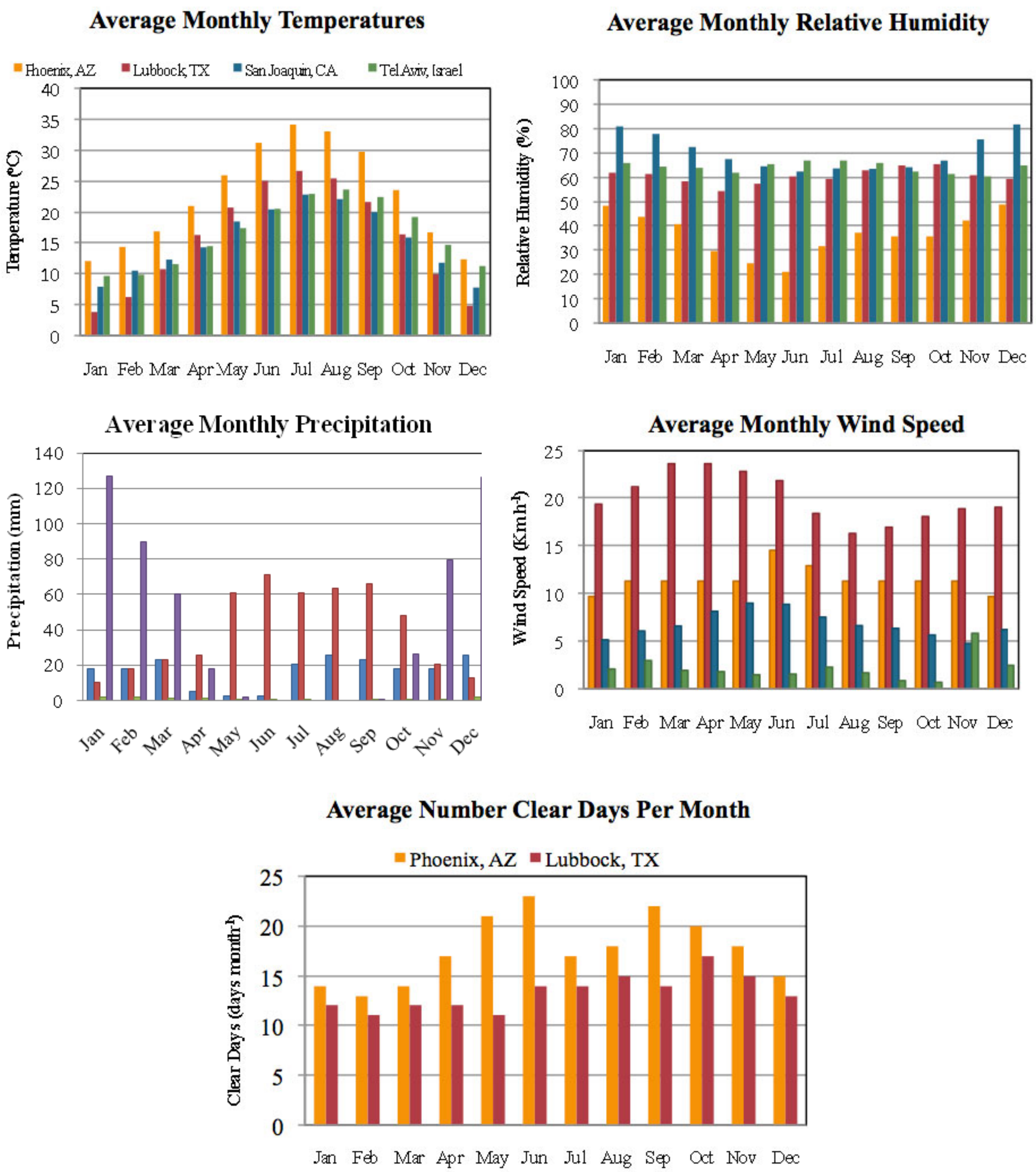

Figure 1. Average weather for the locations available in C2K and compared to weather from Lubbock, TX.

Results & Discussion

Comparing the output of weather variables from C2K4 and C2K6, shows considerable differences especially in the U_z and RH variables. In Figure 2, differences of U_z between measured (C2K6) and interpolated (C2K4) values for August, 2001 are shown. Results show that interpolated values of U_z typically underestimated the measured values. Similarly, a comparison of measured and interpolated values of RH for August 2001 show that the interpolated values are also underestimated (Figure 3). An hourly comparison of measured and interpolated values of U_z for a two-day period reveal that the underestimation is mostly during daytime hours which directly impacts the calculation of all the energy and water fluxes from the crop (Figure 4). While it is not surprising that the interpolated U_z data is underestimated, the magnitude of the discrepancy provides a compelling case to use measured hourly data and supports our hypothesis that the use of measured data will provide a better lint yield estimate.

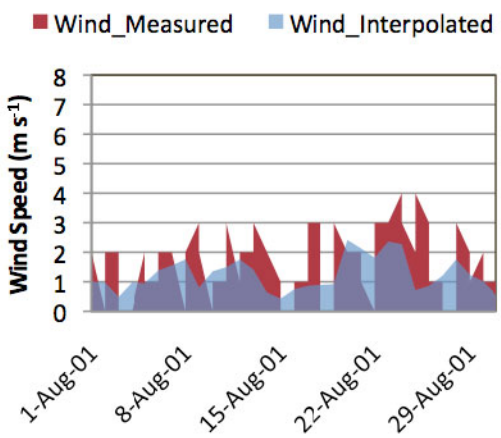

Figure 2. Differences between measured (C2K6) and interpolated (C2K4) U_z data.

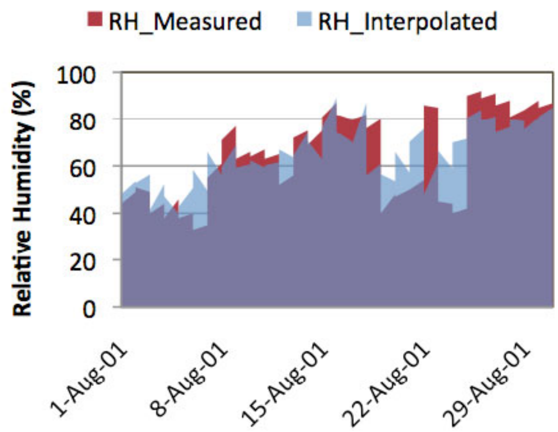

Figure 3. Differences between measured (C2K6) and interpolated (C2K4) RH data.

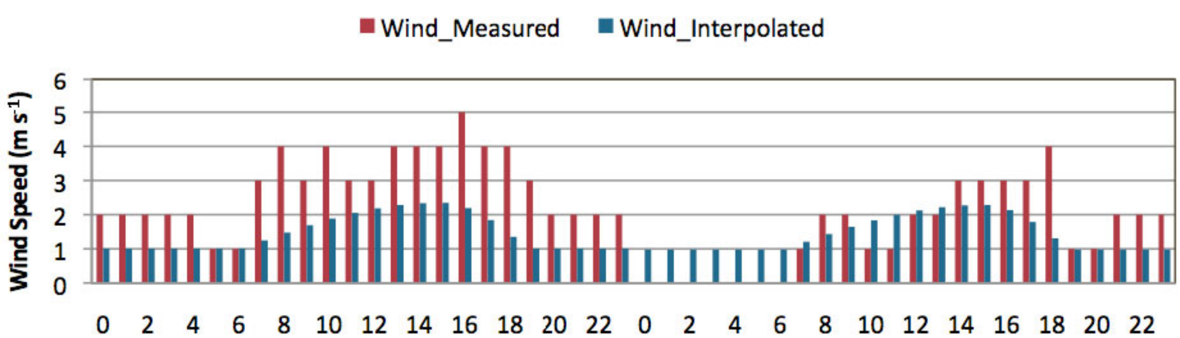

Figure 4. Comparison of measured and interpolated wind speed for a 2-day period.

As expected, results of cotton lint yield using interpolated (C2K4) compared to measured (C2K6) weather variables for Lamesa, TX in 1999-2001 showed that using measured weather data improved the simulated estimates of lint yield (Figure 5). In 1999, simulated relative lint yield was 1.4 for measured weather and 1.7 for interpolated weather, i.e., a 21 % improvement compared to measured lint yield. In 2000, the improvement was 16% and 37% in 2001. The average 25% improvement, on the calculated values of cotton lint yield by simply using hourly measured weather variables, lead us to conclude that in our application the C2K model must use hourly input weather values.

Relative cotton lint yield estimates from C2K6 showed a decrease compared to the yield estimates from C2K4 (Figure 5); however, in all three years calculated cotton lint yield was overestimated compared to measured values. The agreement between measured and calculated values of lint yield ranged from 10% in 2001 to 90% in 2000. Variations in the effectiveness of the model between years can be partially explained by comparing the estimations of ET between the models (Figures 6-10).

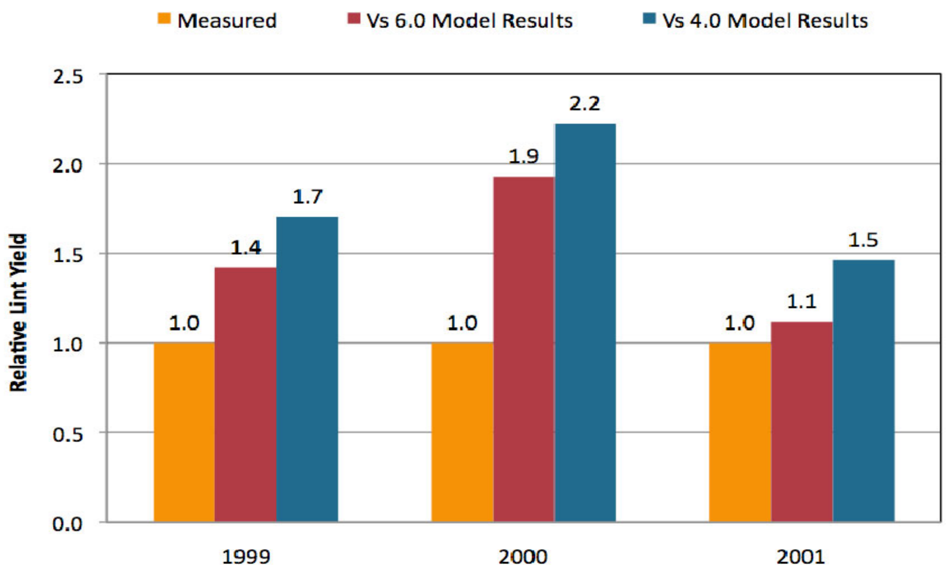

Figure 5. Relative lint yield comparison using simulated and measured weather variables in C2K4 and C2K6 (respectively) for 1999-2001.

In our discussion, we selected the month of August as a time-period that represents high water use to illustrate differences in how the two versions of C2K calculate evaporative losses of water from the soil (E_s) and from the plant as transpiration (T_p). The interpolated values refer to C2K4 using daily weather input and C2K6 using hourly input of weather. These results are shown in Figure 6 – 10.

In August, 1999, daily E_s increased using measured data as compared to interpolated values. Conversely, calculated T_p was clearly lower using measured weather values as compared to the interpolated data (Figure 6). This is an expected result considering that more E_s should result in less water for the plant to transpire. However, adding E_s and T_p, i.e., evapotranspiration indicates that the differences in the components of ET were offset with no difference between the two model versions (Figure 7). However, crop water use is directly proportional to lint yield and thus less T_p will yield less lint as shown in Figure 5. Thus, the partition of evaporative losses from the soil and the plant are an important indication of model accuracy.

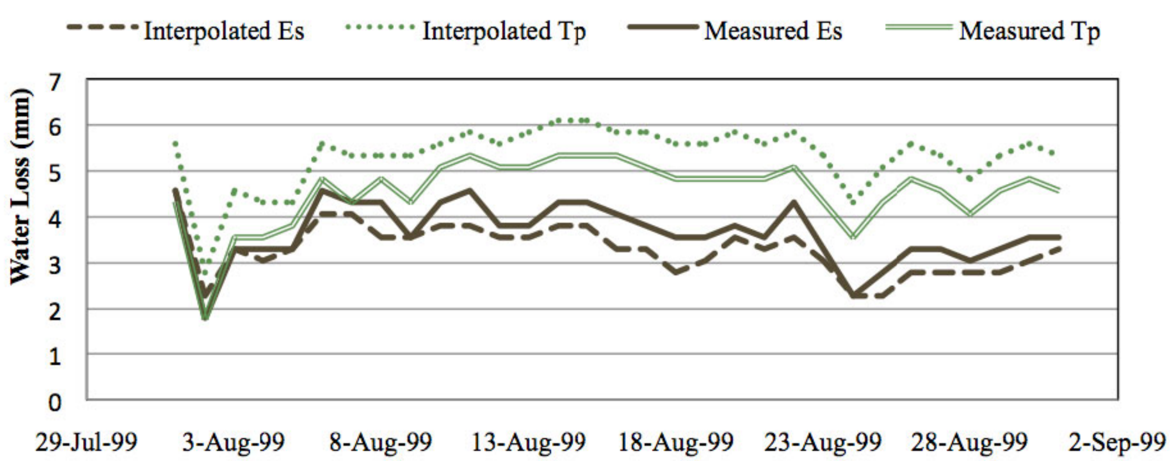

Figure 6. 1999 estimates for E_s and T_p using C2K4 (interpolated) and C2K6 (measured) output.

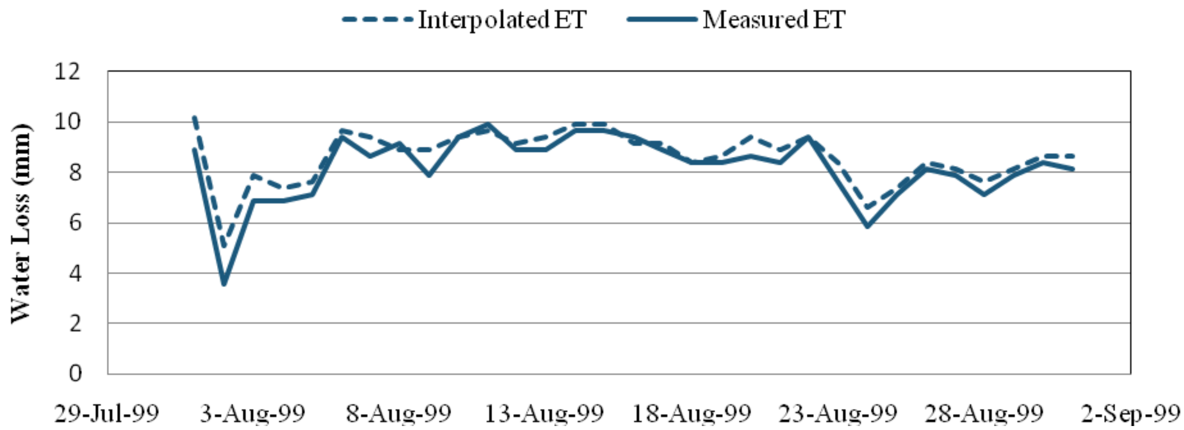

Figure 7. Water loss in 1999 after summing the individual components of ET (E_s and T_p) for each model.

In 2000, the difference between the measured and interpolated values of E_s and T_p was minimal (Figure 8), suggesting that C2K4 did an adequate job of providing weather parameterization using the diurnal curve algorithms. This translated into only slight differences between the relative lint yield estimates for C2K4 and C2K6 (Figure 5).

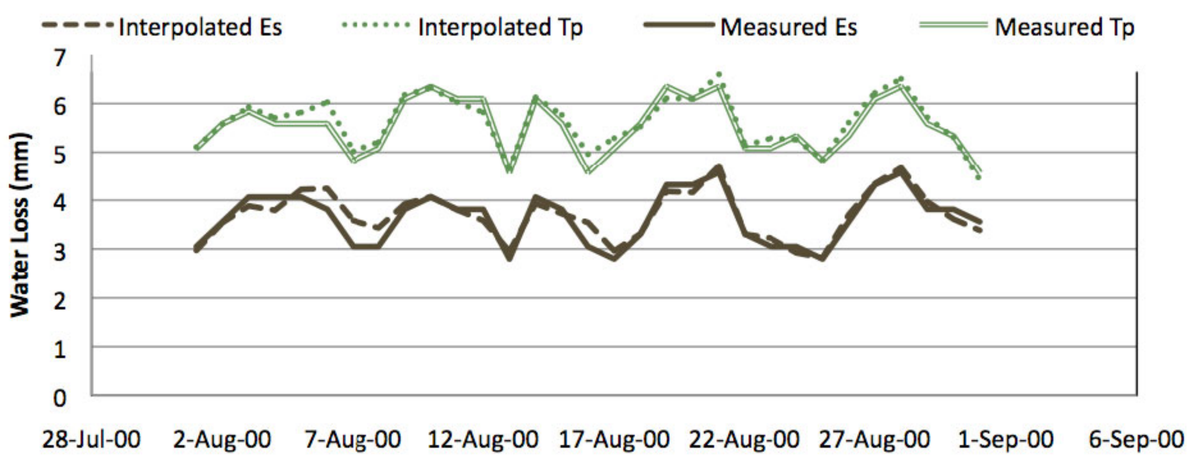

Figure 8. 2000 estimates for E_s and T_p using C2K4 (interpolated) and C2K6 (measured) output.

However, in 2001, where we see the greatest change in relative lint yields between the two model versions (Figure 5), there were also greater differences in E_s and T_p (Figure 9). Both measured E_s and T_p were greater when using the measured data rather than when using the interpolated data from C2K4. This resulted in an overall increase of ET during August, 2001 (Figure 10). Despite higher E_s over this time period, more water was transpired through the plants. This effect could be due to greater water storage in the soil in 2001 as compared to 1999 and needs to be further evaluated to understand the dynamics of this outcome, pointing to the use of this model as a research tool.

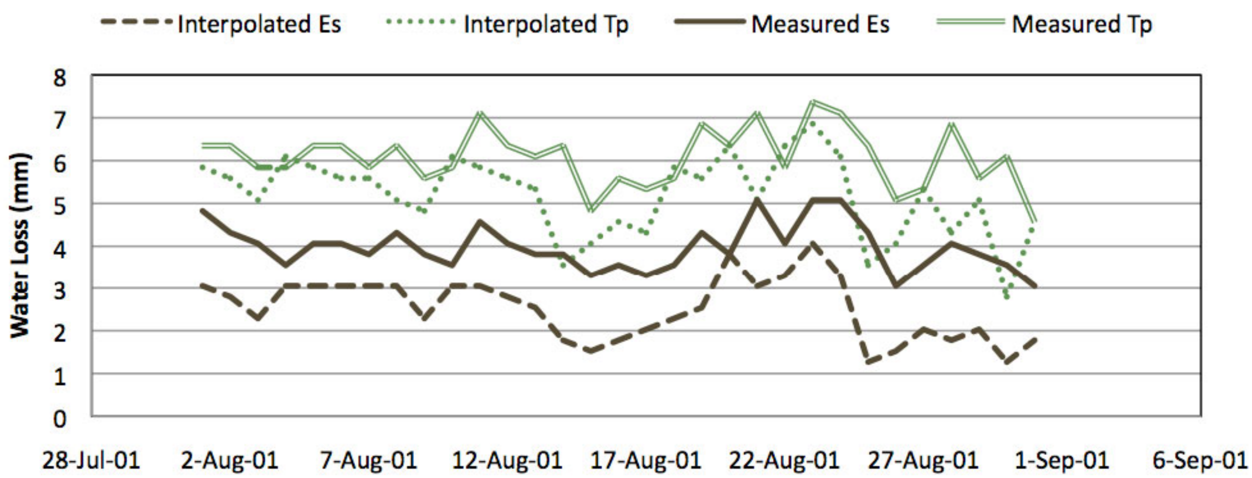

Figure 9. 2001 estimates for E_s and T_p using C2K4 (interpolated) and C2K6 (measured) output.

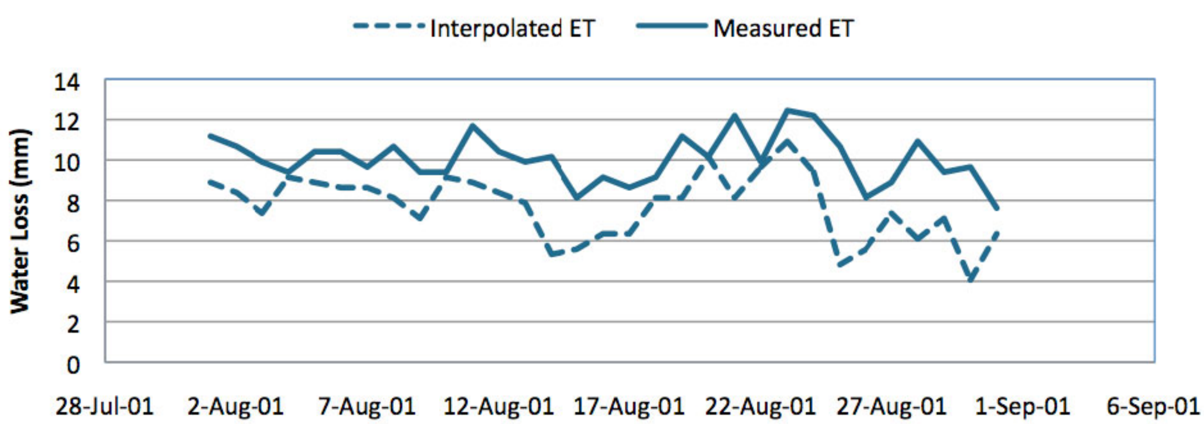

Figure 10. Water loss using measured hourly values of weather data revealed greater total water loss than estimates provide by C2K4 using interpolative methods.

Summary

It is clear that relative lint yield estimates were improved using measured hourly data in the C2K6 model. It is also clear that additional work is needed to improve the cotton lint yield estimates. By removing the parameterization of hourly data, error in the model was reduced, but there are other factors at play that continue to impact the model results. The primary focus of these errors is likely in the variety parameterization considering the use of older, rarely used varieties and the lack of modern variety choices within the model. However, the improvements achieved by the inclusion of measured weather data has set us on the right path to further evaluate the COTTON2K cotton growth model in combination with PALMS to more accurately depict field-scale water use and potential lint yield in the THP.

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