Improving Evapotranspiration Estimation Using Remote Sensing Technology

By

Zohrab A. Samani, Professor

A. Salim Bawazir, Associate Professor

Ian Hewitt, Graduate Student

Francisco Ochoa, WRRI

Civil Engineering Department and New Mexico Water Resources Research Institute

New Mexico State University

FINAL PROGRESS REPORT

ACCOUNT NUMBER (Index #): **126483**

June 2016

New Mexico Water Resources Research Institute

in cooperation with the

Civil Engineering Department

New Mexico State University

The research on which this report is based was financed by the State of New Mexico through the New Mexico Water Resources Research Institute.

DISCLAIMER

The New Mexico Water Resources Research Institute and **affiliated institutions** make no warranties, express or implied, as to the use of the information obtained from this data product. All information included with this product is provided without warranty or any representation of accuracy and timeliness of completeness. Users should be aware that changes may have occurred since this data set was collected and that some parts of these data may no longer represent actual conditions. This information may be updated without notification. Users should not use these data for critical applications without a full awareness of its limitations. This product is for informational purposes only and may not be suitable for legal, engineering, or surveying purposes. The New Mexico Water Resources Research Institute and **affiliated institutions** shall not be liable for any activity involving these data, installation, fitness of the data for a particular purpose, its use, or analyses results.

ACKNOWLEDGMENT

We appreciate the contribution of graduate student Leba Tiep and the support of NMSU Civil Engineering Department and the New Mexico Water Resources Research Institute (WRRI) staff.

ABSTRACT

Many remote-sensing models have been developed and can be used in calculating ET of a large area but they vary in complexity, accuracy, and require specific expertise and high operational cost. Two satellite-based remote sensing ET models, SSEBop and REEM, were modified for use in calculating ET for a large area. These models were selected specifically for their simplicity and to be used in calculating ET losses in the assessment of New Mexico's statewide water budget. The work is in progress. Preliminary ET calculations by the models are presented. The comparison with historical ground measurements show that the difference in ET between modified model calculations and the measured values can be minimized. The model algorithms are still being tested.

Keywords: Evapotranspiration, remote sensing, satellite, New Mexico, water resources, water management

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION AND BACKGROUND

The work presented here started in 2015 by comparing and evaluating remote sensing models for possible use in New Mexico's statewide water assessment calculation of evapotranspiration or ET (Samani and Bawazir, 2015 WRRI report). A simplified surface energy balance model (SSEBop; Senay et al., 2013) was identified as the model that could be used on operational basis due to its simplicity and did not require costly ground measurements of ET.

The SSEBop model, Regional ET Estimation Model (REEM; Samani et al 2009) and ground measured ET values for MRG (Middle Rio Grande) and LRG (Lower Rio Grande) were compared. The difference in ET estimates by SSEBop and ground measured ET in the MRG and LRG varied from 25% to more than 50%. In general, the SSEBop model underestimated ET depending on the location and vegetation characteristics.

While models such as REEM can provide ET estimate with high resolution and relatively high accuracy, they require ground level ET flux and meteorological measurements for calibration as well as elaborate analysis. The process is time consuming and costly. Currently there is no simple and accurate model for large scale modeling of ET. The SSEBop model, based on high resolution data from Landsat, offers a promising approach for such purpose (Singh et al., 2014) but it is subject to large error when compared with measured and calibrated remote sensing modeled ET values. In collaboration with the Gabriel Senay of US Geological Survey (USGS), we are working on a modified SSEBop model for simplified and low cost estimation of crop water use (or ET) in New Mexico. The thermal and reflective bands used in the remote sensing ET models are available through satellite images and can cover large swath around the globe. The main barrier is the need for local calibration which is costly, labor intensive and subject to error. Progress on the modified SSEBop model is presented in this report.

OBJECTIVE

The specific objectives of this project are:

1. To work jointly with Dr. Gabriel Senay of USGS and modify SSEBop model that can estimate water use (or ET) of crops and other vegetation in New Mexico;

2. To validate the accuracy of the modified SSEBop model by using results from ground ET and micrometeorological measurements, and REEM generated ET values in New Mexico LRG and MRG;

3. Organize a workshop to demonstrate the application of the SSEBop model for regional estimation of ET based on Landsat as well as MODIS images.

MODIFIED SSEBop MODEL

In collaborative effort with the USGS, Gabriel Senay, the SSEBop model was modified for simplified and low cost estimation of crop water in New Mexico based on remote sensing technology. The SSEBop model estimates evaporative fraction (ET_f) as,

$$ET_f = \frac{T_h - T_s}{T_h - T_c} \quad (1)$$

where, T_h is the estimated temperature at hot pixel, T_c is estimated temperature at a cold pixel with sensible heat equal to zero and T_s is the surface temperature at any pixel. The T_c is calculated using an empirical equation as:

$$T_c = c \times T_a \quad (2)$$

where T_a is the near-surface maximum daily temperature and c is an empirical coefficient.

The temperature of the hot pixel in the SSEBop model is then calculated using the following equation:

$$T_h = T_c + dT \qquad (3)$$

and, dT is calculated as,

$$dT = \frac{R_n \times r_{ah}}{\rho_a \times c_p} \qquad (4)$$

where, R_n is daily net radiation, ρ_a is the air density, and c_p is specific heat of the air at constant pressure. The r_{ah} is the aerodynamic resistance for heat flow and is calculated empirically in the SSEBop model.

In collaboration with Gabriel Senay, we developed empirical coefficients to determine both dT as well as T_c using locally measured data from the LRG. The dT was determined as a function of measured daily solar radiation (RSD) as shown in Figure 1. dT is the difference between temperature of hot and cold pixel for conditions where sensible heat fluxes were close to zero. For the same location, the relationship between T_c and maximum daily temperature was developed. See Figure 2.

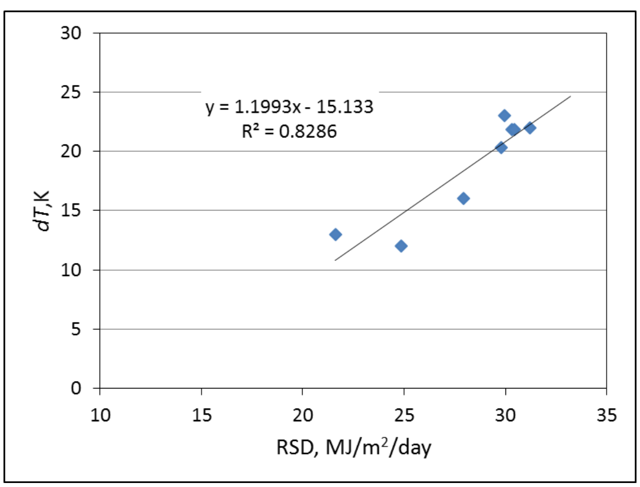

Figure 1. Calibration of dT as a function of daily solar radiation (RSD) for the Lower Rio Grande (LRG)

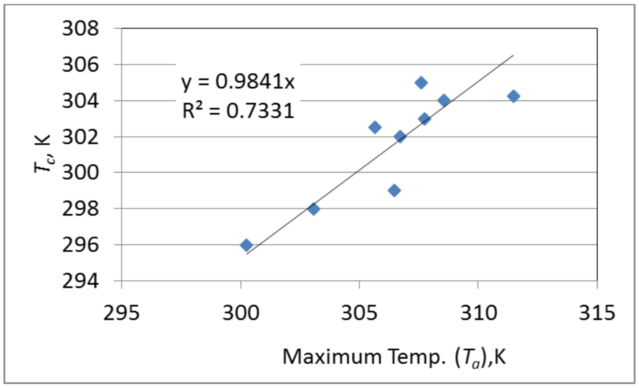

Figure 2. Calibration of T_c as a function of maximum daily temperature (T_a)

In addition to developing the empirical equations shown in Figures 1 and 2, evaporative function was calculated using energy balance instead of equation 1 as follows:

$$ET_f = 1 - \frac{H_i}{Rn_i - G_i} \qquad (5)$$

where H_i, R_{ni}, and G_i are the instantaneous sensible, net radiation and soil heat flux, respectively. Using the above modifications, preliminary comparison of the monthly ET values using three different methods (modified SSEBop, REEM and ground measurements) for a pecan orchard in Las Cruces, NM during 2008 is shown in Figure 3 and in Table 1.

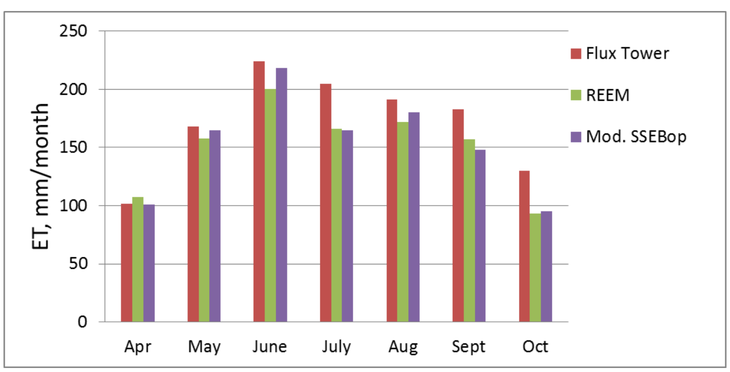

Figure 3. Monthly ET values calculated by REEM and Mod. SSEBop compared to ground measured ET (Flux Tower) of 2008

Table 1. Comparison of monthly ET in mm using three methods: REEM, modified SSEBop and ground measured ET of 2008.

	Ground Measurement (Flux Tower) mm	REEM mm	Mod. SSEBop mm	Difference from Measured	
				REEM	Mod. SSEBop
April	101.7	107.5	100.8	-6%	1%
May	168.3	158	165	6%	2%
June	224.1	200	218	11%	3%
July	205	166	165	19%	20%
Aug	191	172	180	10%	6%
Sept	183	157	148	14%	19%
Oct	130	93	95	28%	27%

With the preliminary modification of SSEBop, the difference in ET between ground measured and the model can be minimized. This comparison, is preliminary and further work is still needed as the values reported in Table 1 are just for one location, crop and elevation.

Using the same calibration process, dT and T_c calibration curves were developed for MRG using data from ET flux tower and a weather station in South Albuquerque. Figures 4 and 5, show the calibration curves for LRG using data 2013 flux tower.

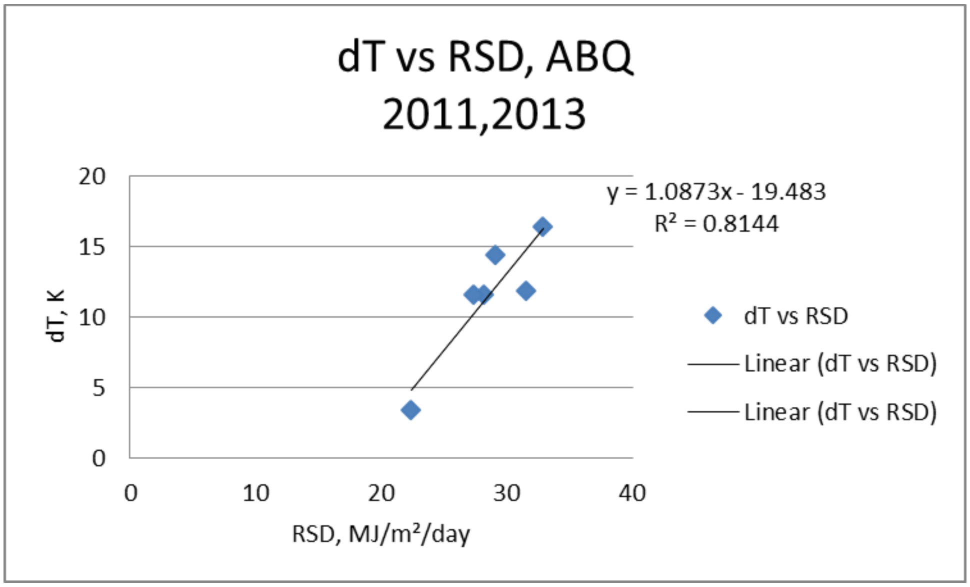

Figure 4. *dT* versus Daily Solar Radiation (RSD) for MRG, using data from 2011 and 2013.

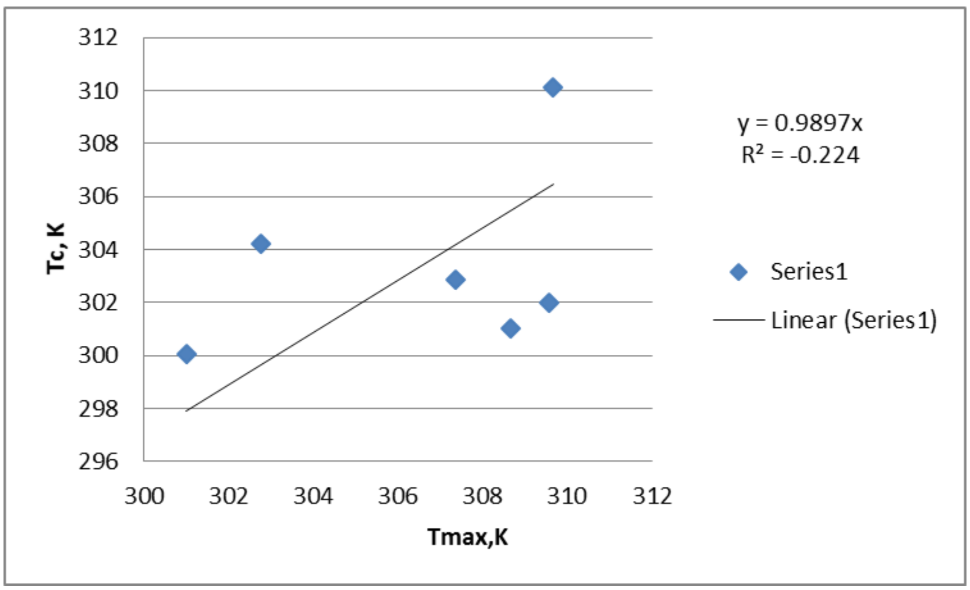

Figure 5. T_c versus maximum daily temperature for MRG using data from 2011 and 2013.

Comparing figures 1 and 4 show that while local calibration curves can be developed for estimating *dT*, the relationship vary with location and the results cannot be extrapolated. Comparing Figures 2 and 5 show that while T_c can be correlated to Tmax (or T_a), the relationship may not be valid in all locations depending on the atmospheric conditions.

Since Figure 5 did not provide a good correlation between T_c and Tmax (or Ta), actual T_c values from the time of satellite overpass were used to calculate ET using Modified SSEBop for South Albuquerque. Figure 6, compares the monthly ET estimates using three methods of flux tower, REEM and Modified SSEBop. The data shown in figure 6, are also presented in Table 2.

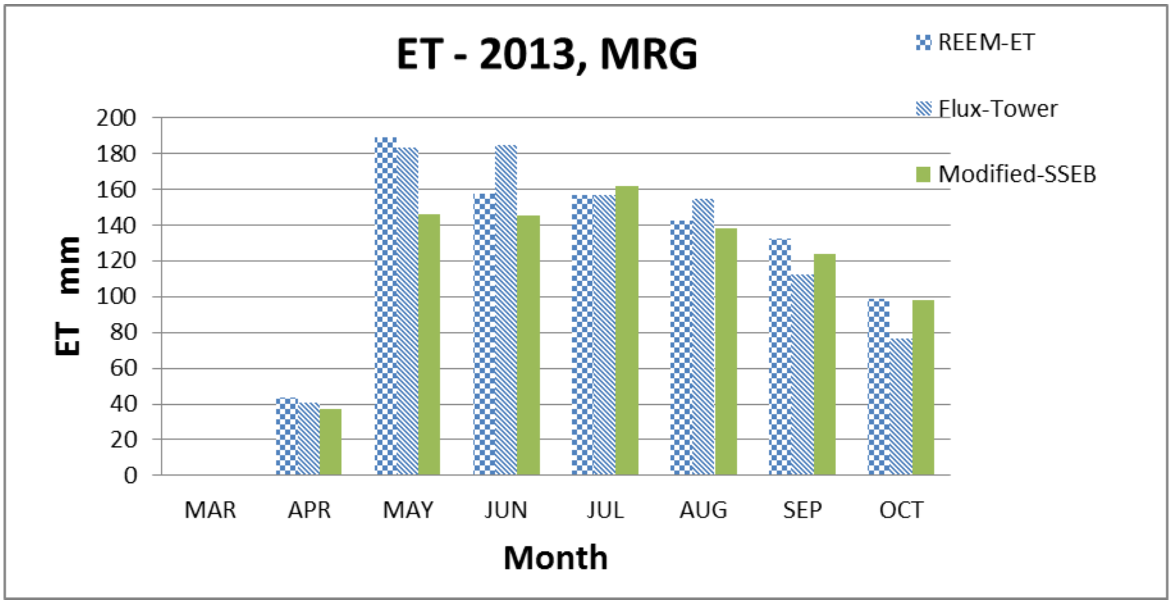

Figure 6. Comparison of Monthly ET values for alfalfa in South Albuquerque during 2013

Table 2. Comparison of annual and monthly ET for Alfalfa using three different methods

	Annual ET, mm	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
REEM-ET	922.7		44	189	158	157	143	133	98.7
Flux-Tower	911.24		41	183.8	185	157.2	154.9	112.34	77
Mod. SSEBop	850		37	146	145	162	138	124	98

MODIFIED REEM

In addition to modifying SSEBop model with local calibration, a modified REEM Model was also being developed. The objective is to modify the REEM model to estimate ET that does not depend on local (ground measured ET) calibration. The modified REEM model uses an actual hot pixel from the satellite image and an imaginary cold pixel using local weather data to calibrate the model. The Modified REEM model is being tested for estimating regionalized ET. It was used to calculate ET values for three locations in Northern New Mexico where point ET was measured using a chamber method by Ian Hewitt. The three locations were Alcalde, El Rito, and Arroyo Hondo. The comparison of modified REEM and the chamber measurements by Ian Hewitt are shown in Table 3. A sample of ET maps generated by the modified REEM model for the Alcalde and for Arroyo Hondo are shown in Figures 7 and 8. Using the modified REEM, a map of ET for the LRG is shown in Figure 9 for June 12, 2015.

	Chamber				REEM			
Category	Mean	Median	Range	Std. Dev.	Mean	Median	Range	Std. Dev.
Alcalde Ag.	4.03	3.87	2.34 - 6.13	1.42	4.14	4.24	1.14 - 6.25	0.94
Alcalde Non-Ag.	1.12	1.02	0.72 - 1.70	0.37	0.00	0.00	0.00 - 0.01	0.00
El Rito Ag.	3.20	3.14	2.12 - 4.41	0.81	3.51	3.45	1.81 - 5.73	0.71
El Rito Non-Ag.	1.69	1.57	1.01 - 2.74	0.57	0.13	0.00	0.00 - 0.92	0.25
Arr. Hondo Ag.	3.96	3.79	2.49 - 5.89	1.21	3.98	3.67	1.57 - 6.33	1.17
Arr. Hondo Non-Ag.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

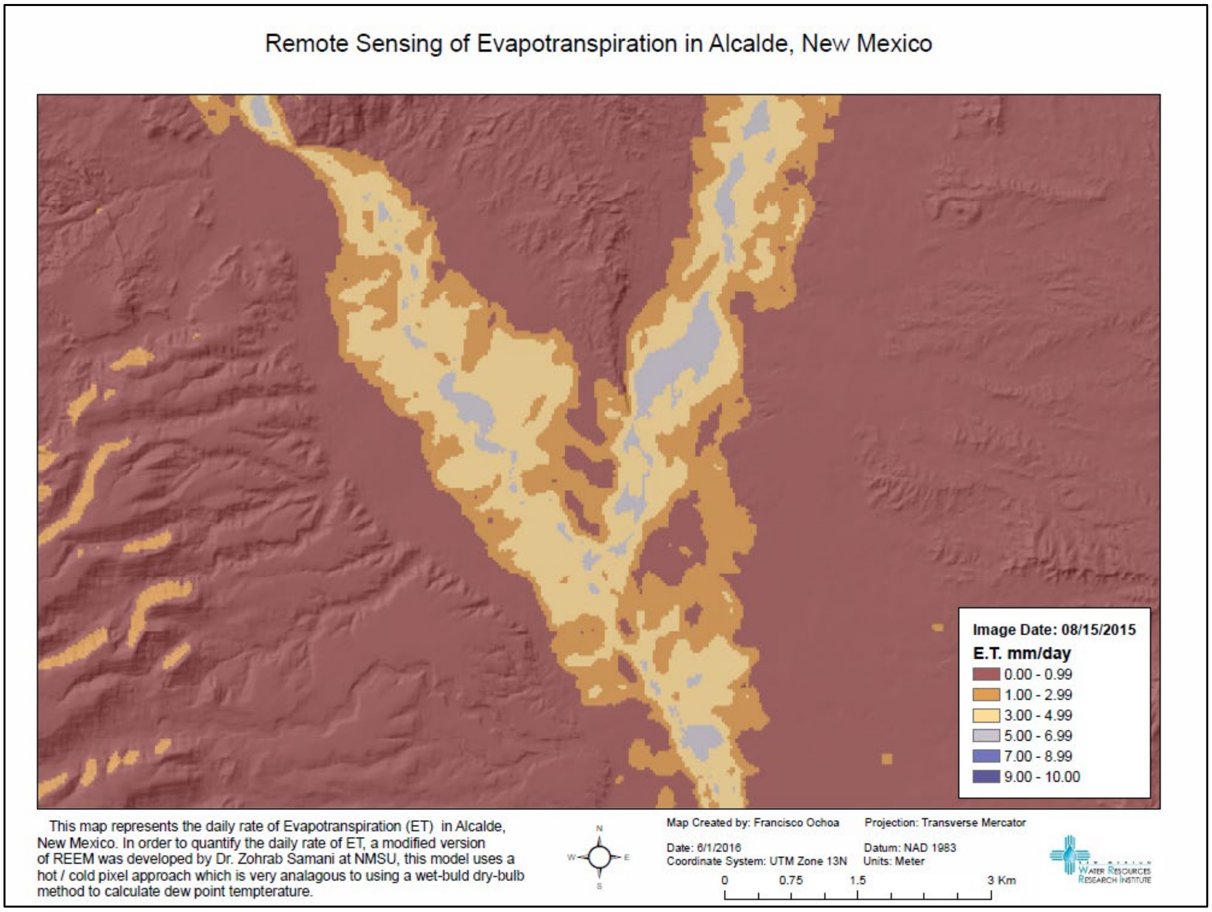

Figure 7. Map of evapotranspiration (ET) for Alcalde, NM for June 15, 2016

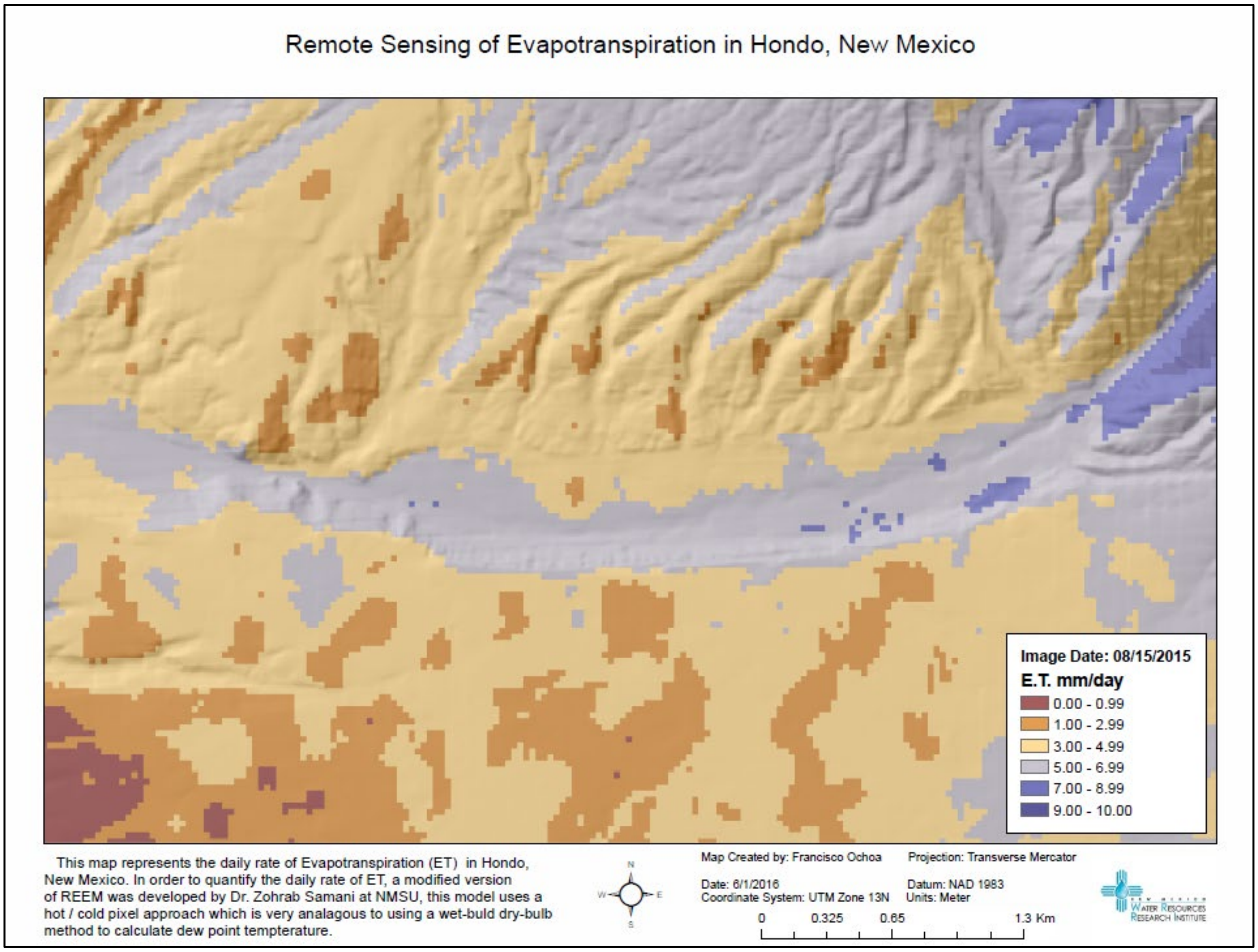

Figure 8. Map of evapotranspiration (ET) for Arroyo Hondo, NM for June 15, 2016

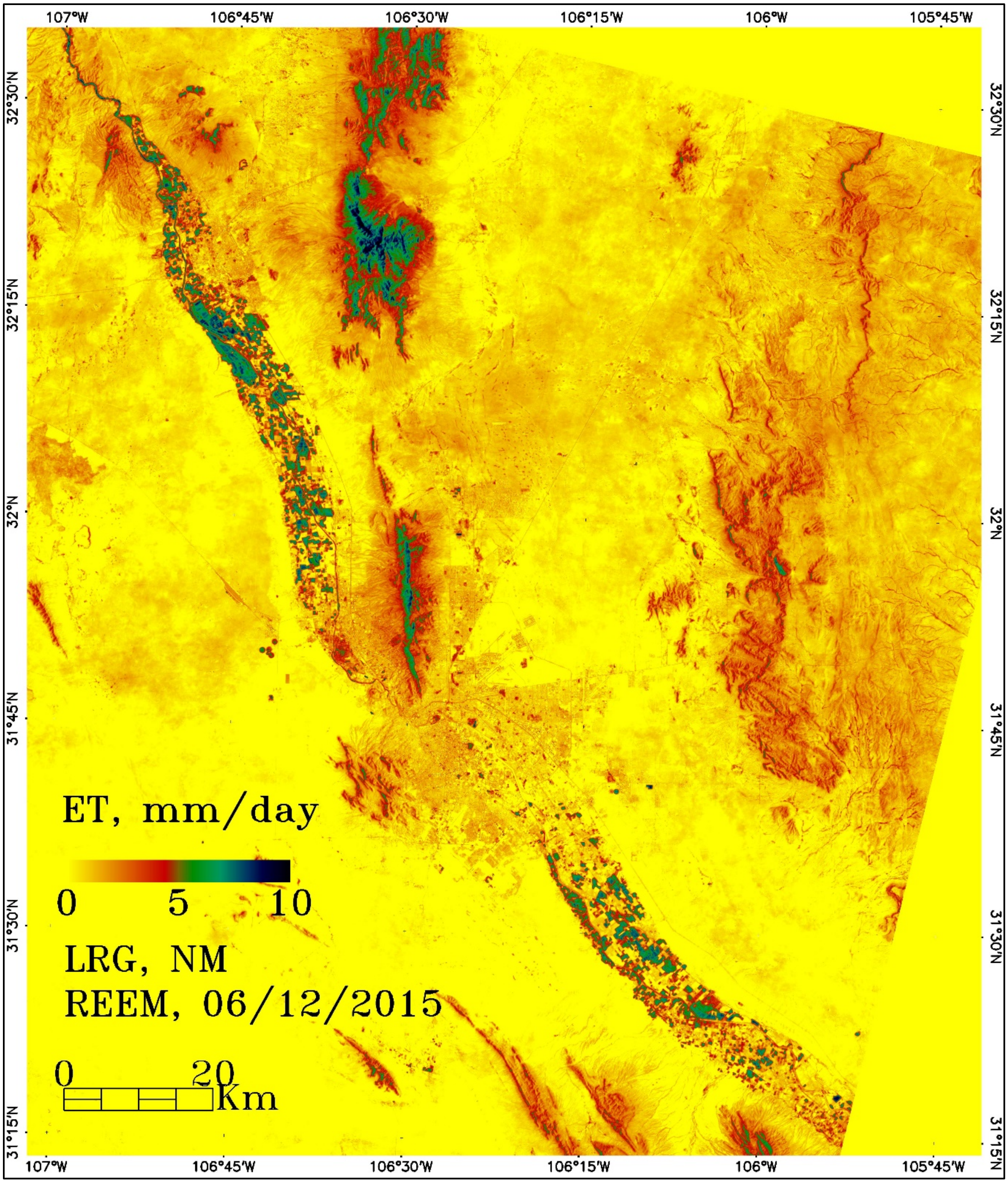

Figure 9. A map of evapotranspiration for the lower Rio Grande (LRG) calculated by modified REEM model.

CONCLUSION AND RECOMMENDATION

Two satellite-based remote sensing ET models, SSEBop and REEM, were modified for use in calculating ET for a large area. The two models were selected specifically for their simplicity and to be used ultimately in calculating ET losses in the assessment of New Mexico's statewide water budget. Preliminary ET calculations by the models are presented. The comparison with historical ground measurements show that the difference in ET between model calculations and the measured values can be minimized. The model algorithms are still being tested and is in progress. To validate the models however will require ground ET flux measurements.

WORKSHOP/PRESENTATION

A workshop titled "High-efficient Water Use in Agriculture Project (111 Plan) Workshop: Water and Energy Innovation for Food Security and Environmental Sustainability" was offered on Jun1-7, 2016 in China. It was organized by the Center for Agricultural Water Research in China, China Agricultural University and the NMSU-CAU Water Science and Engineering Join Research Center. Dr. Zohrab Samani presented on two topics: i) "Updated presentation on the recent advances in remote sensing" and ii) "Calculating and managing agricultural water requirement"

REFERENCES

Samani, Zohrab, A. Salim Bawazir. June 2015. Improving Evapotranspiration Estimation Using Remote Sensing Technology. NM WRRI project report

Samani, Z, S. Bawazir, Max Bleiweiss, Rhonda Skaggs, J. Longworth, Vien Tran, and Aldo Pinion. 2009. Using remote sensing to evaluate the spatial variability of evapotranspiration and crop coefficient in the lower Rio Grande Valley, New Mexico. *Irrig. Sci.* 28:93 – 100.

Senay, G.B., S. Bohms, R.K. Singh, P.H. Gowda, N.M. Velpuri, H. Alemu, and J.P. Verdin. 2013. Operational evapotranspiration mapping using remote sensing and weather datasets: A new parameterization for the SSEB approach. *J. Am. Water Resourc. Assoc*. 49: 577 – 591.

Singh, R., G. Senay, N. Velpuri, S. Bohms, R. Scott, and J. Verdin. 2014. Actual Evapotranspiration (Water Use) Assessment of the Colorado River Basin at the Landsat Resolution Using the Operational Simplified Surface Energy Balance Model. *Remote Sensing*. *6*(1): 233 – 256.