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Internet-Based Remote Sensing Calculation of Evapotranspiration Using Energy Balance Algorithm

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1. ABSTRACT

Remote sensing driven evapotranspiration (ET) models are a significant technological improvement to the dynamic management of forests, phreatophytes, rangelands, agricultural water, and invasive pests. However, most remote sensing ET models are not available in an internet-based operational mode. Manually downloading satellite data and processing this data is complicated and time-consuming, requiring as much as 2–6 hrs per satellite scene. If the ET algorithm is to be used by the scientific community or management agencies and farmers, it is imperative that the computer processing be automated and user-friendly. An internet-based ET model combining Moderate Resolution Imaging Spectroradiometer (MODIS) satellite images and local weather station data was developed. The automated calculated daily ET was compared to on-site ET, measured by eddy-covariance under both stressed and non-stressed conditions. The accuracy of the automated model is acceptable.

2. INTRODUCTION

For forest, riparian, rangeland, agricultural water and pest management, local evapotranspiration (ET) amounts and rates are important. However, most remote sensing ET models are not in an operational mode on the internet. The downloading of satellite data and processing of this data are complicated and time consuming requiring as much as 2-6 hrs per MODIS file. Consequently, if the ET algorithm is going to be used by the scientific community it is imperative that the computer processing be automated and user-friendly.

The Surface Energy Balance Algorithm for Land (SEBAL©) presents an operational approach to using satellite derived surface temperature measurements for the calculation of evapotranspiration (ET) (e.g., Remote Sensing ET model in Wang et al. 2009, RSET). The approach requires scaling the satellite estimated surface temperature in each pixel by the temperatures of a nearby cold/wet spot in the same scene where the ET rate is maximized, and by a hot/dry spot temperature, where the ET rate is zero. The scaled surface temperatures are then combined with hourly weather data to estimate ET from the surface energy budget for each pixel in the scene. The energy balance can be written as LE = Rn- G - H, where the available radient energy (Rn) is partitioned into evapotranspiration energy (LE) energy exchange with the soil (G) and energy exchange with the air (H). Rn, G and H are calculated from weather and satellite data and the residual, LE, is ET in energy units. The primary problem with this approach has been picking the hot and cold locations in each scene and adjusting them for the surface cover material, elevation and angle of view. To date this has only been done by analysts examining each scene; thus requiring significant time and variability between analysts.

Wang et al (2009) used this approach and presented an algorithm called Remote Sensing Evapotranspiration (RSET) in a data retrieval and decision system. RSET was developed and validated for ASTER data (Advanced Spaceborne Thermal Emission and Reflection Radiometer) (Wang

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et al., 2009). Although ASTER's spatial resolution is high for ET (90 m by 90 m), the temporal resolution is low (> 16 days) and the data may not be available for a location at a special day unless that location and day were requested by the end user and the request was accepted by the persons controlling the satellite. Landsat data is also available on a low temporal resolution (16 days) and a 90-120 m high spatial resolution. MODIS data has a medium spatial resolution for ET calculation (1000 m by 1000 m) and daily coverage. Therefore, MODIS data is the more practical and operational data for ET calculations over forests, phreatophyte, rangelands, and large scale agricultural lands.

The purpose of this project was to test the hypotheses that the RSET remote sensing algorithms to calculate daily ET with MODIS data could be automated using computer code, including the selection of hot and cold calibration spots in the MODIS scenes. The evaluation involved comparing the automated daily calculated ET to on- site eddy covariance (EC) measured ET under both stressed and non-stressed conditions.

Materials and Methods

Model Theory

Equations of MODIS ET Model

The MODIS RSET model uses the same equations and algorithms that are used in the ASTER RESET model, described in Wang et al. (2009), to calculate ET except for dT at a cold spot, NDVI, and albedo. The dT (temperature difference between air and land/canopy) calculation at a cold spot for MODIS data is different from Wang et al. (2009). Instead, the Mapping Evapotranspiration with Internalized Calibration (METRIC) method in Allen et al. (2007) was adopted for dT calculation at a cold spot. The following will describe the dT at a cold spot, Rn for water bodies, NDVI and albedo calculations.

Surface temperature data needed in the model are acquired from the MOD11_L2 (MODIS level 2 land surface temperature 5-min product). The MOD11_L2 scenes are categorized as level 2 data, having been processed by NASA (Wan, 2007). MOD11_L2 data also provide the cloud cover and water body information and the data quality flags. If a pixel is cloudy, the ET in the model for that pixel is set to -1 mm/day .

MOD021KM (level 1 data, L1B data) are used in the model to calculate NDVI and albedo. MOD03 data in this model provides the correct geo-location data (latitude, longitude, and elevation) for the MOD021KM and MOD11_L2. MOD021KM files. Table 1 lists the corresponding MODIS files, downloading site, and bands used for the model variables.

Reflectances, NDVI, Albedo Calculated from MODIS L1b Data

When using MODIS data (L1 B 1-km data), land surface reflectances (inputs for albedo and NDVI calculation) can be calculated from bands 1, 2, 3, 4, 5 and 7. Bands 1 and 2 are the 250-m aggregated 1-km bands. Bands 3, 4, 5, and 7 are the 500 m-aggregated 1-km bands (MODIS, 2009):

$$r_i = reflectance\_scale\ (SI - reflectance\_offset) \quad (1)$$

where r_i (unitless) is the reflectance of band i, SI (scaled integer) is the L1B data value for the corresponding pixel, and reflectance scale and reflectance offset are the conversion factors to convert SI to reflectances. The L1B data product provides the conversion factors.

The NDVI (unitless) can be calculated using Eq. (4.2) on page 54 in Morse , et al. (2000), i.e.,

$$NDVI=(r_2-r_1)/(r_2+r_1) \quad (2)$$

where r_1 and r_2 are band 1 reflectance and band 2 reflectance, respectively.

The albedo can be calculated as (Liang , et al. 2000):

albedo $=2\ 0.160r_1 + 0.291r_2 + 0.243r_3 +$

$0.116r_4+0.112r_5 + 0.081r_7- 0.0015$ (3)

where r_1, r_2, r_3, r_4, r_5, and r_7 are the corresponding reflectances of bands 1, 2, 3, 4, 5 and 7.

The equation for sensible heat flux into the soil (G) is the same as the ASTER model where:

$$G = c \times Rn \quad (4)$$

According to (Bastiaanssen, et al., 1998),

$$c = -2.70NDVI^4 + 3.98NDVI^3 - 1.64NDVI^2 - 0.11NDVI + 0.41. \quad (5)$$

When a pixel is over water then

$$C=0.65 \quad (6)$$

Cold Spot

Cold spot dT calculation used the METRIC method in Allen et al. (2007).

$$dT_{cold} = \frac{H_{cold} r_{ah-cold}}{\rho_{air-cold} C_p} \quad (7)$$

$$H_{cold} = R_n - G_{cold} - LE_{cold} \quad (8)$$

where H_{cold} is the sensible heat flux at a cold spot, G_{cold} is the soil heat flux at the cold spot, and LE_{cold} is the estimated latent heat at the spot.

$$LE_{cold}=1.1LE_{refernce} \quad (9)$$

where $LE_{refernce}$ is the reference latent heat calculated for tall alfalfa by using the ASCE standard tall alfalfa daily reference ET equation (equation 26 in Walter et al., 2002).

The model searches a hot spot in a 60 km range and a cold spot in a 100 km range. The cold spot must satisfy: NDVI>0.45 (choose vegetation area) and the elevation difference between the cold spot and the point of interest<200 m.

Weather data

The weather data can be read in as an input file needed in the RSET algorithm. The input data includes: daily reference ET (mm/day); relative Humidity(%), Wind Speed (m/s), Solar Radiation(mj/hr), Air Temperature (C°) at satellite overpass time; and Month, Day, Year of inteest.

Model data downloading

C++ programs were created to automatically download the satellite data at the ftp sites daily:

L1B data: ftp://ladsftp.nascom.nasa.gov/allData/5/MOD021KM/

MOD03: ftp://ladsftp.nascom.nasa.gov/allData/5/MOD03/

MOD11: ftp://e4ftl01u.ecs.nasa.gov/MOLT/MOD11_L2.005/

Model Structure and operating system validation

The code has been developed and implemented on a Windows XP computer running the Apache web server and transferred to a Windows Server 2008 operating system running an ISS 7 web server. Consequently, the software can be set up to run under either the ISS or Apache web server. The servers can provide maps of ET and ASCII data files for a specified date and region via standard internet browsers. The general flow chart of the system is presented in Figure 1. The operational system uses a PHP CGI internet interface that allows a user to input the dates (now in Julian day type) and location of interest (Figure 2) (rs.tnstate.edu/rset;remotesensing.nmsu.edu/rset). After the user submits the input information, the server will calculate the ET for the area and dates and send the map and data links to the user. The server will produce a GoogleEarth map that shows the cold and hot spots used in the calculations (Figure 3) along with a GoogleEarth graph of the ET result (Figure 4).

Validation of ET estimates

The technique of EC for measuring field scale fluxes of water vapor into the atmosphere is well described elsewhere (Wang et al., 2007). EC systems were installed in Las Cruces, NM (2005), Chestnut Bridge, TN (2006), and Bakersfield, CA (2008). The measured ET data was used to evaluate the model.

Experimental sites

Daily ET was measured at three experimental sites described as follows.

Las Cruces Site in NM

Las Cruces site is a desert area (latitude: 32.24474, longitude: -106.910619; Figures 3-5). It is classified as an arid, subtropical climate (annual average precipitation: 297 mm/11.7 inch, www.city-data.com). The site has creosote shrubs that was irrigated by waste water from a cheese plant. Because of the low precipitation and insufficient irrigation, the plants were often under water stress (actual ET<reference ET). The daily ET in 2005 from day 40 to day 260 was measured using an One Propeller Eddy Covariance (OPEC) System at the site. The Leyendecker (112) weather station data (Latitude : 32.200261, longitude: - 106.743) was used for the model inputs. The weather data was obtained from New Mexico Climate Center (http://weather.nmsu.edu/data/data.html) website.

Bakersfield Site in CA

Bakersfield (latitude: 35.51045; longitude: -119.666) has a Desert climate (annual average precipitation: 165 mm/6.5 inch, en.wikipedia.org). The site had almond orchards (Figure 6). The orchards were well irrigated and not under water stress. The weather data for Bakersfield was obtained from the California Irrigation Management Information System (CIMIS) (http://wwwcimis.water.ca.gov/cimis/data.jsp) website. Potential ET (ETo) obtained from the CIMIS is multiplied with 1.23 to convert it into ETr (Snyder, 2006). The weather data of Belridge (station number: 146, Latitude : 35.51045 ; Longitude : -119.666) was taken for Bakersfield. The daily ET in 2008 was measured using Surface Renewal (SR) and an sonic EC system. The SR technology was well described in Simmons et al. (2006).

Chestnut Ridge Site in TN

Chestnut Ridge in TN (latitude: 35.9311; longitude: -84.3324;elevation: 286 m) has a Temperate climate (annual average precipitation: 1237 mm/48.7 inch, www.frontdoor.com/). The site has deciduous broad-leaf forest and is one of Ameriflux sites (Figure 7) (http://public.ornl.gov/). ET and weather data in 2006 was measured by a sonic EC system and downloaded from the Ameriflux website. The measured weather data was used for the model inputs.

Results and Discussions

The model now is internet-based and operational. Figures 2-4 are sample input interfaces for dates and location and outputs (searched hot and cold spots and ET output shown on GoogleEarth).

The RSET model has been validated against EC data. Figure 8 shows the ET data processed for the desert shrub area at Las Cruces, NM compared with the measured data in 2005. The site was under water stress that the measured ET was generally much lower the non-stressed ET (ETr). As expected, the ET values were small in winter and spring (days 40-150), and in fall (days 241-260), and higher in summer (151-240). The ET time series and the scatter plot show that the average model values are accurate (slope=0.9) and the variability is moderate, i.e. R^2 is 0.63.

Figure 9 shows the meaured vs.

modeled ET comparision at Bakersfield site in 2008. The site was not under water stress (ET was similar to ETr). SR ET measurments were similar to the EC's. The modeled ET was similar to the measured. In 2008, modeled ET=0.84×Measured (R^2=0.53) by regrassion analysis. At the Tennessee site in 2006 (Figure 10), the plants were also not stressed because the measured ET was similar to the reference ET. Some ETr values were much lower (>2 times) than the measured ET. The possible reason was that the raw weather data for these ETr calculations may be wrong in some days (among 113 to 253) and some the measured ET were wrong in some days (among 20 to 113 and 253 to 365). After removed these outliers, the modeled ET=0.75×Measured (R2=0.60) by regrassion analysis. Because this site had many cloudy days and a hot spot was hard to find in some days (a lot of prcipitaion days made wet grounds), there were many days when ET values were not calculated.

The internet-based ET model accuracy (75-84%) is comparable with the mannual operated ET models. The accuracy of the various SEBAL-like algorithms varies from 67% to 95% for instantaneous ET estimates and from 70% to 98% for 1- to 10-day ET estimates (Bastiaanssen et al., 2005).

The model has been evaluated with limited sites. It needs to be validated with other sites and times. The model needs to be further automated. For example, the weather data now need be preapred mannually. It may be improved by automatically input by th emodel. For example, the model downloads and inputs the National Weather Services weather data for a special location(s) and date(s). Then, the model needs to be compared with the results from mannualy input weather data. Improvents are also needed for hot spot serach for TN and other areas with a high annual precipitation.

Conclusions

The accuracy of the internet based RSET model is acceptable (75-84%). The interfaces of the model are user-friendly. It is in an operational mode. More comparisons will be conducted for more dates and other areas. For example, the model will be tested against EC data from orchards with greater spatial extent. In addition, the model will be improved with automated weather data inputs; and it will be improved for hot spot search at a high precipitation area.

Acknowledgements

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Reference:

Bastiaanssen, W.G.M., M. Menenti, R.A. Feddes, and A.A.M. Holtslag. 1998. A remote sensing surface energy balance algorithm for land (SEBAL): 1. Formulation. *J. Hydrology* 212-213, p. 198-212.

Bastiaanssen, W. G. M., E. J. M. Noordman, H. Pelgrum, G. Davids, B. P. Thoreson, and R. G. Allen. 2005. SEBAL model with remotely sensed data to improve water-resources.
management under actual field conditions. J. Irrig. and Drainage Eng. 131(1): 85-93.

Liang, S. 2000. Narrowband to broadband conversions of land surface albedo I Algorithms. Remote Sensing of Environment, 76, 213-238.

Wan, Z. 2007. Collection-5 MODIS Land Surface Temperature Products Users' Guide.

ICESS, University of California, Santa Barbara. http://www.icess.ucsb.edu/modis/LstUsrGuide/MODIS_LST_products_Users_guide_C5.pdf.

MODIS. 2009. MODIS Level 1B Product User's Guide, For Level 1B Version 6.1.0 (Terra) and Version 6.1.1 (Aqua). MCST Document # PUB-01-U-0202- REV C MCST Internal Memorandum # M1054. Prepared by
Members of the MODIS Characterization Support Team For NASA/Goddard Space Flight Center. Greenbelt, MD 20771.

Morse, A., M. Tasumi, R.G. Allen, and W.J. Kramber. 2000. Final Report. Application of the SEBAL Methodology for Estimating Consumptive Use of Water and Streamflow Depletion in the Bear River Basin of Idaho through Remote Sensing. Idaho Department of Water Resources. University of Idaho, Department of Biological and Agricultural Engineering. Submitted to: The Raytheon Systems Company; Earth Observation System Data and Information System Project.

Simmons, L.J., J. Wang, T.W. Sammis, and D.R. Miller. 2006. An Evaluation of Two Inexpensive Energy-Balance Techniques for Measuring Water Use in Flood-Irrigated Pecans (Carya Illinoinensis). Agricultural Water Management. 88:181-191.

Snyder, R. L. 2006. Daily ETos, ETrs and HS ETo Calculator using the ASCE-EWRI method (revised 2 Feb 2006). UC Davis Biometerology Programm. http://biomet.ucdavis.edu/Evapotranspiration/PMdayXLS/PMday.xls.

Wang, J., Miller, D.R., Sammis, T.W., Gutschick, V.P., Simmons, L.J., Andales, A.A., 2007. Energy balance measurements and a simple model for estimating pecan water use efficiency. Agr. Water Manage. 91 (1-3), 92-101.

Wang, J., T. W. Sammis, V. P. Gutschick, M. Gebremichael, and D. R. Miller. 2009. Sensitivity Analysis of the Surface Energy Balance Algorithm for Land (SEBAL). ASABE Transactions. 52 (3)-801-811.

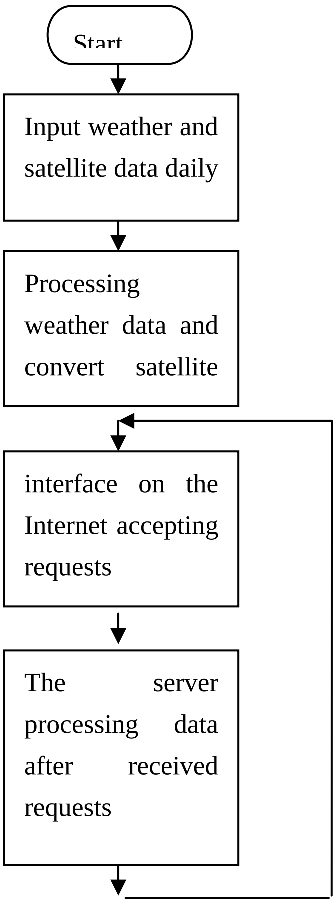


Figure 1. The general flowchart of the whole automated system.

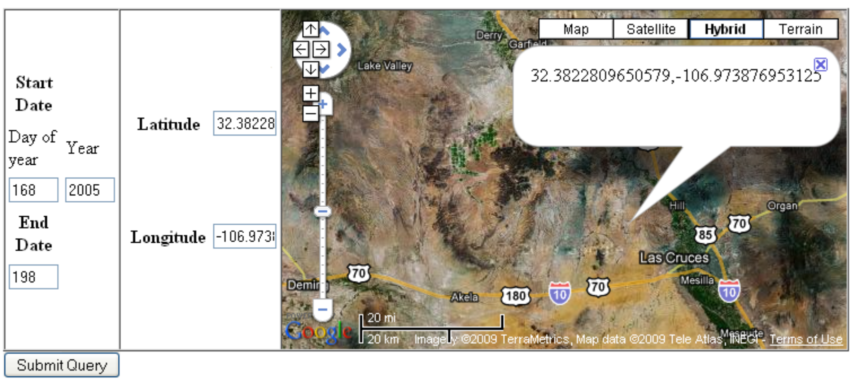


Figure 2. Internet user input interface for computing evapotranspiration rates for any specified region and date, using remotely-sensed data .

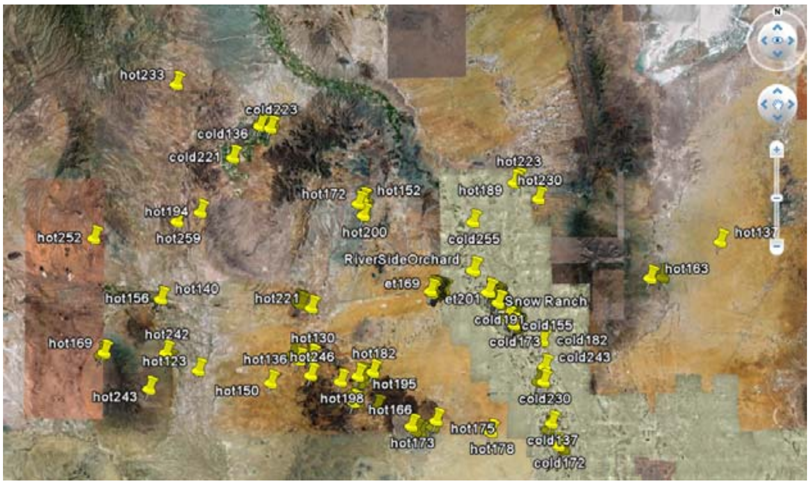


Figure 3 The cold and hot spots used in the ET calculations for Las Cruces, NM.

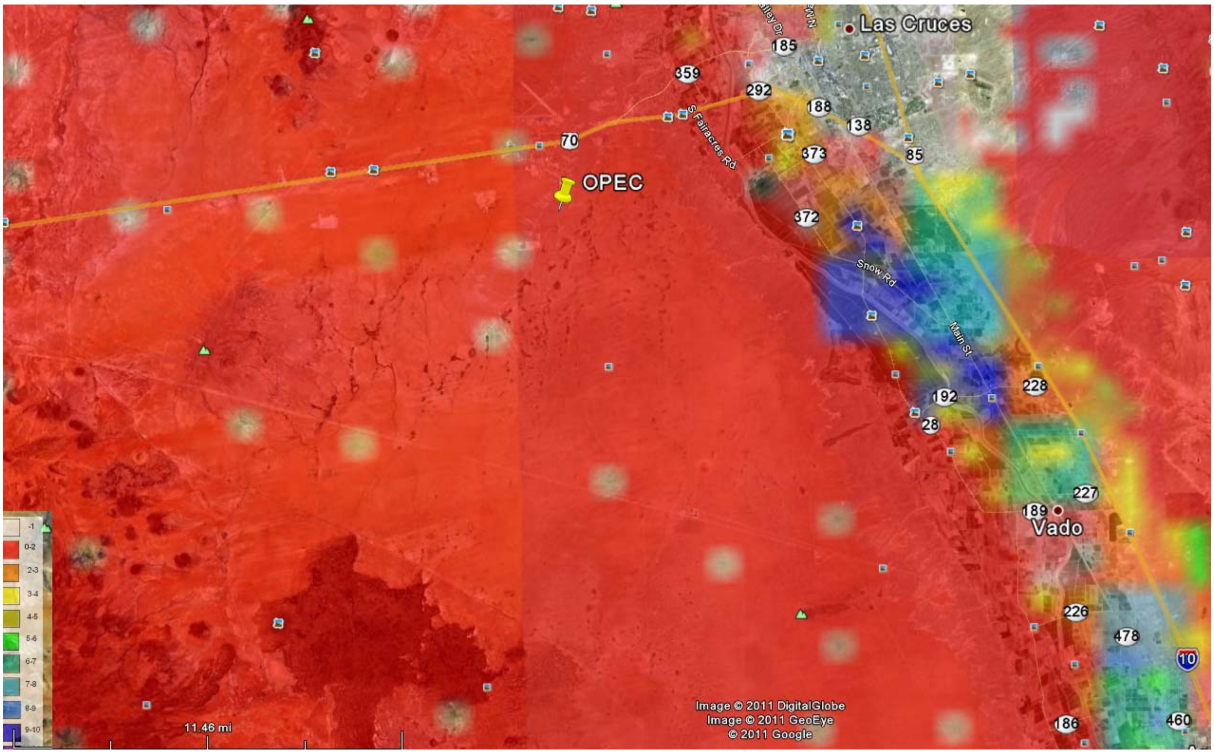


Figure 4. ET GoogleEarth overlay from the model for June 15th, 2005 at Las Cruces, NM. OPEC: One propeller measurement site (the value of -1 represents cloudy areas).

Figure 5. The creosote shrub area irrigated by waste water from a cheese plant, Las Cruces, NM (32°14'44.14"N , 106°55'4.50"W). One eddy covariance system for energy balance measurement was installed in 2005.

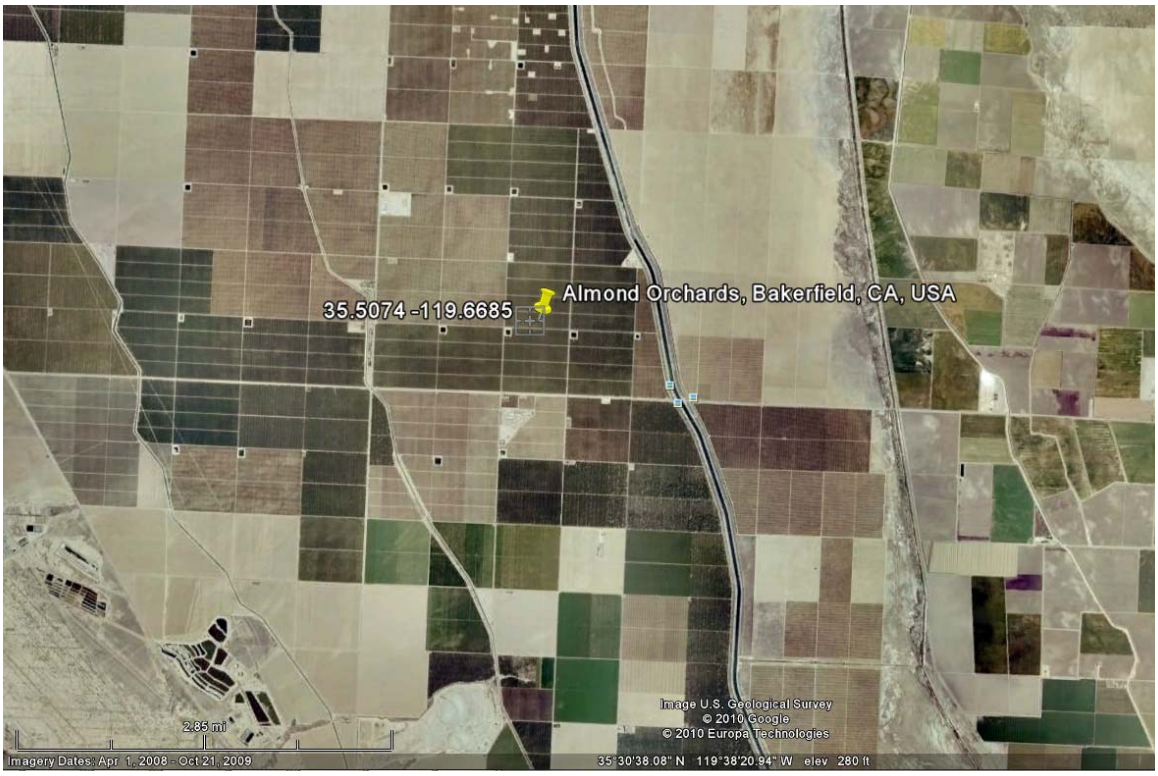
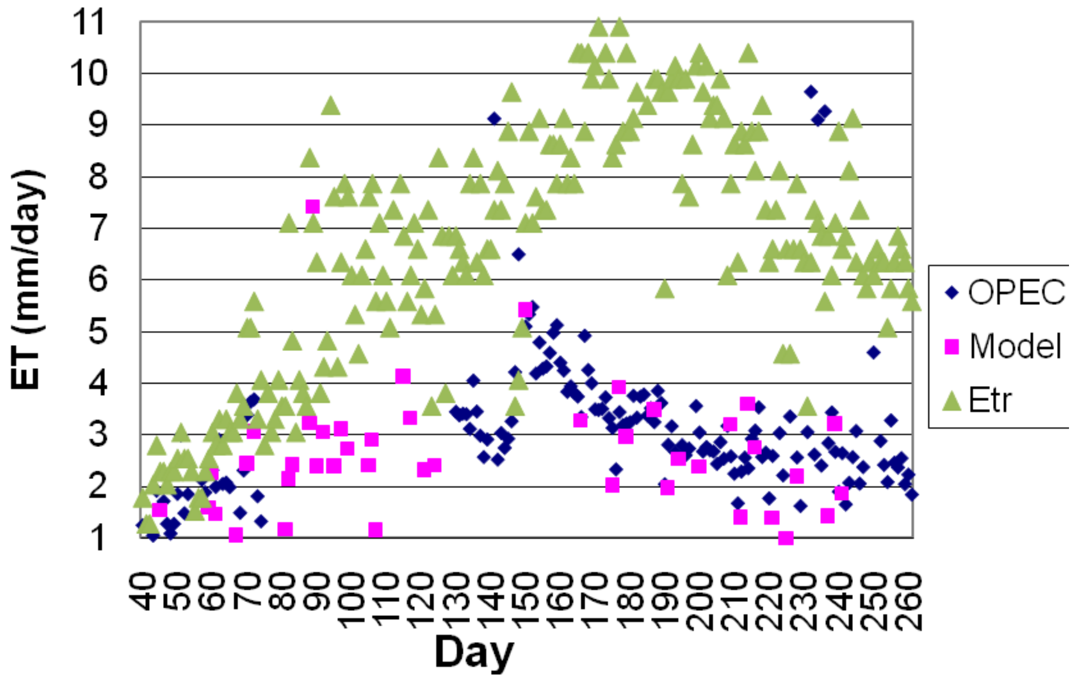


Figure 6. The almond orchard ET measurement site at Bakerfield, CA.

Figure 7. The ET measurement site at Chestnut Ridge, TN.



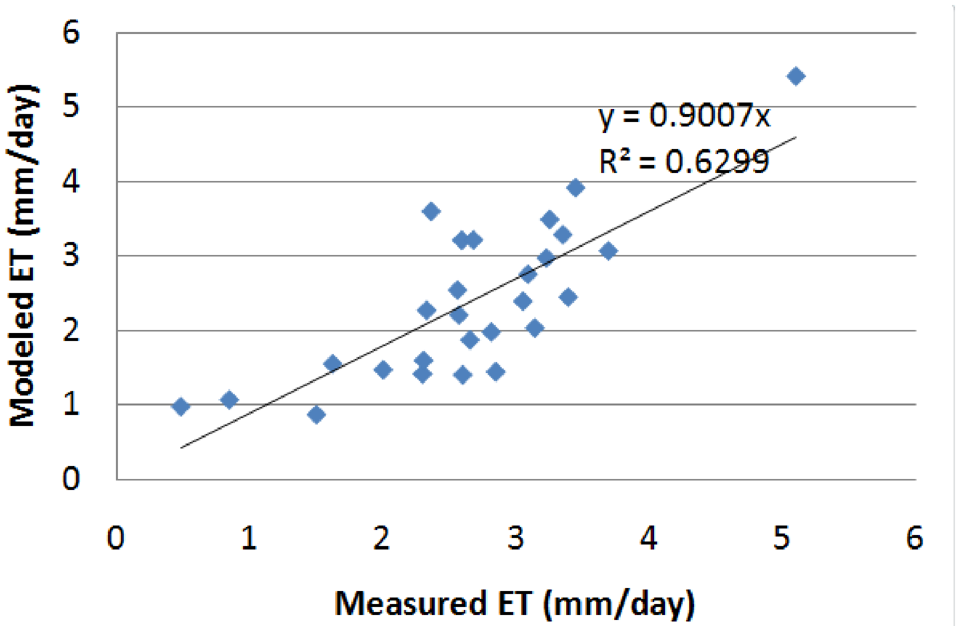


Figure 8. Modeled vs. measured ET at Las Cruces site in 2005. ETr: reference ET; OPEC: one propeller eddy-covariance system. Because of instrument problems, there were missed data during the spring season.

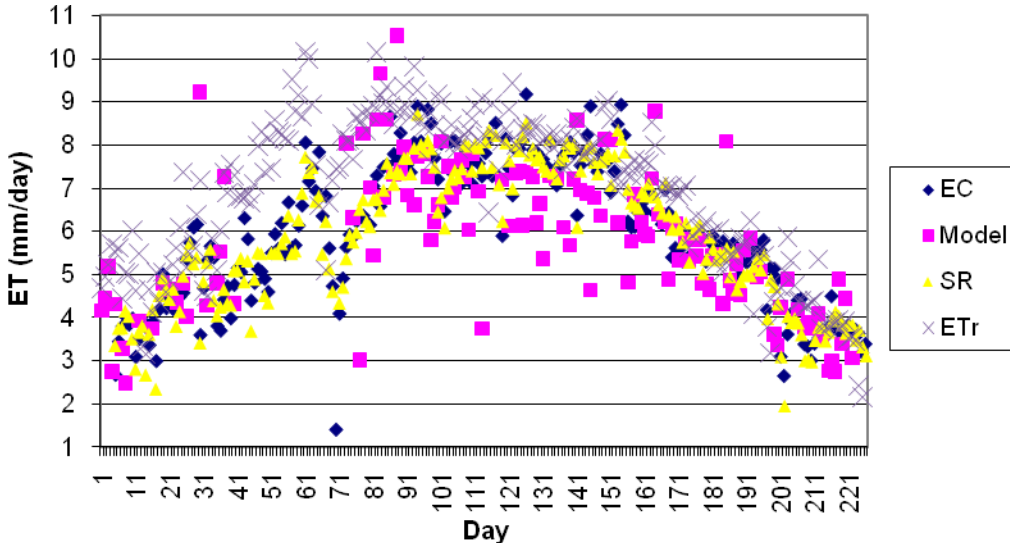


Figure 9. Measured vs. modeled ET in 2008 at Bakerfield, CA. EC: eddy-covariance system measured data; Model: modeled data; SR: Surface Renewal data; ETr: reference ET.

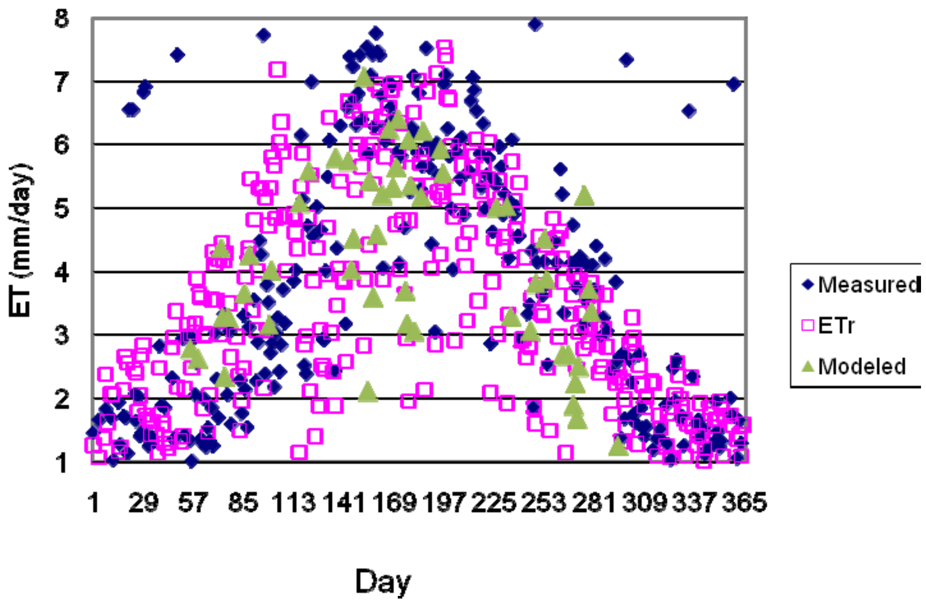


Figure 10. Measured vs. modeled ET in 2006 at Chestnut Ridge, TN. ETr: reference ET.

Table 1. MODIS data information for RSET model

Variable	MODIS File	URL	Band
Reflectance for NDVI and Albedo.	L1B	ftp://ladsftp.nascom.nasa.gov/allData/5/MOD021KM/	1,2,3,4,5,7
Temperature	MOD11_L2	ftp://e4ftl01u.ecs.nasa.gov/MOLT/MOD11_L2.005/	LST
Cloud Cover/QC	MOD11_L2	ftp://e4ftl01u.ecs.nasa.gov/MOLT/MOD11_L2.005/	QC
Latitude	MOD03	ftp://ladsftp.nascom.nasa.gov/allData/5/MOD03/	Latitude
Longitude	MOD03	ftp://ladsftp.nascom.nasa.gov/allData/5/MOD03/	Longitude
Elevation	MOD03	ftp://ladsftp.nascom.nasa.gov/allData/5/MOD03/	Elevation