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Surface Energy Balance System for Estimating Daily Evapotranspiration Rates in the Texas High Plains

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Abstract. Numerous energy balance (EB) algorithms have been developed to use remote sensing data for mapping evapotranspiration (ET) on a regional basis. Adopting any single or a combination of these models for an operational ET remote sensing program requires thorough evaluation. The Surface Energy Balance System (SEBS) was evaluated for its ability to estimate daily ET rates of summer crops grown in the Texas High Plains using Landsat 5 Thematic Mapper data acquired on 10 July 2007. Performance of SEBS was evaluated by comparing estimated daily ET with measured weighing lysimeter ET data from four large lysimeters at the USDA-ARS Conservation and Production Research Laboratory, Bushland, Texas. SEBS estimated daily ET values measured with the weighing lysimeter measurements indicated that the SEBS model may provide good ET estimates for both irrigated and dryland fields.

Keywords. Surface energy balance, SEBS

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Introduction

Remote sensing has been recognized as the most feasible means to provide spatially distributed regional evapotranspiration (ET) information on land surfaces (Park et al., 1968; Jackson, 1984). Since ET requires a large amount of energy to change water from a liquid to a vapor in the environment (Su et al., 2005), remote sensing based energy balance (EB) models can convert satellite sensed radiances into land surface characteristics such as albedo, leaf area index, vegetation indices, surface emissivity, and surface temperature to estimate ET as a "residual" of the land surface energy balance equation:

$$LE = R_n - G - H \qquad (1)$$

where, R_n is the net radiation resulting from the energy budget of short and long wave radiation, LE is the latent heat flux from ET, G is the soil heat flux into the ground, and H is the sensible heat flux (all in W m^{-2} units) to the atmosphere. LE is converted to ET (mm h^{-1} or mm d^{-1}) by dividing it by the latent heat of vaporization (λ_v; ~2.45 MJ kg^{-1}), density of water (ρ_w; ~1.0 Mg m^{-3}), and an appropriate time constant (e.g. 3600 s hr^{-1} for hourly ET).

Numerous remote sensing algorithms are available for estimating magnitude and trends in regional ET. These models included the Two-Source Model (TSM; Norman et al., 1995; Kustas and Norman, 1996), where the energy balance of soil and vegetation are modeled separately and then combined to estimate total LE, Surface Energy Balance Algorithm for Land (SEBAL; Bastiaanssen et al., 1998a,b) and Mapping Evapotranspiration with Internalized Calibration (METRIC™; Allen et al., 2007a,b) that both use 'hot' and 'cold' pixels to develop an empirical temperature difference equation, and Surface Energy Balance System (SEBS; Su, 2002) based on the contrast between wet and dry areas. Other models include Simplified Surface Energy Balance Index (SEBI; Menenti etal., 2001; Roerink et al., 2000); the aerodynamic temperature parameterization models proposed by Crago et al. (2004); Beta (β) approach (Chehbouni et al, 1996); and most recently ET Mapping Algorithm (ETMA; Loheide and Gorelick, 2005).

Surface energy balance system (Su, 2002) was developed using the SEBI concept. It uses a dynamic model for thermal roughness (Su et al., 2001), Bulk Atmospheric Similarity (BAS) (Brutsaert, 1999) and Monin-Obukhov Similarity (MOS) theories for regional ET estimation, and Atmospheric Surface Layer (ASL) scaling for estimating ET at local scale. SEBS requires wet and dry boundary conditions to estimate H. Under dry conditions, the calculation of H_{dry} is set to the available energy AE as evaporation becomes zero due to the limitation of water availability and H_{wet} is calculated using the Penman-Monteith parameterization (Monteith, 1965; 1981) as:

$$H_{wet} = AE - \frac{\left(\frac{\rho_a C_p}{r_{ah}}\right)\left(e_s - \frac{e}{\gamma}\right)}{\left(1 + \frac{\Delta}{\gamma}\right)} \qquad (2)$$

where e is the actual vapor pressure (kPa), e_s is the saturation vapor pressure (kPa), γ is the psychrometric constant (kPa °C^{-1}), Δ is the rate of change of saturation vapor pressure with temperature (kPa °C^{-1}) and r_{ah} is the bulk surface external or aerodynamic resistance (s m^{-1}) estimated under the assumption that the bulk internal resistance is zero. Finally, relative evaporative fraction (Λ_r), evaporative fraction (Λ) and LE for each pixel in the remote sensing image is calculated as:

$$\Lambda_r = 1 - \frac{H - H_{wet}}{H_{dry} - H_{wet}} \tag{3}$$

$$\Lambda = \frac{\Lambda_r (R_N - G - H_{wet})}{R_N - G} \tag{4}$$

and

$$LE = \Lambda (R_N - G) \tag{5}$$

The evaporative fraction [$\Lambda = LE/(R_n - G)$] is used in the estimation of LE because it is assumed to remain constant through out the day and can be obtained for short periods and be used for LE extrapolation to daily values. Brutsaert and Sugita (1992) presented the assumption that the partitioning of available energy (AE) into H and LE is constant (self-preservation of the available energy partitioning) or that the evaporative fraction remains almost constant during the daytime. Zhang and Lemeur (1995) added that the evaporative fraction indicates how much of the available energy is used for ET and that the assumption that the instantaneous Λ is representative of the daily energy partitioning, is an acceptable approximation for clear-sky conditions. Crago (2000) concluded that the Λ has the tendency to be nearly constant during daytime, permitting the estimation of daytime evaporation from one or two estimates of the evaporative fraction during the middle of the day at the satellite overpass time.

Su et al. (2005) evaluated SEBS with two independent, high quality datasets that were collected at a field scale during the Soil Moisture–Atmosphere Coupling Experiment (SMACEX) in the Walnut Creek agricultural watershed near Ames, IA. Meteorological and EC measurements from 10 locations within the watershed were used to estimate and compare fluxes during a period of rapid vegetation growth and varied hydrometeorology. Results indicated that ET estimates from the SEBS were close to 85-90% of the measured ET values from EC systems for both corn and soybean surfaces. In the same study, regional fluxes were calculated using Landsat Enhanced Thematic Mapper Plus (ETM+) data for a clear day during the field experiment. Results at the regional scale showed that ET prediction accuracies were strongly related to crop type with improved ET estimates for corn surfaces compared to those of soybean. Differences between the observed and predicted ET values were approximately 5%. Further, McCabe and Wood (2006) used thermal data from Landsat ETM+ (60 m), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER; 90 m), and Moderate Resolution Imaging Spectrometer (MODIS; 1020 m) sensors to independently estimate ET using SEBS. A high degree of consistency was observed between flux retrievals from ETM+ and ASTER data while MODIS data was unable to discriminate the influence of heterogeneity in land use at field scale. Overall, SEBS is a more robust energy balance algorithm as it doesn't requires selection of hot and cold pixels as in the case of SEBAL and METRIC. However, this method has never been evaluated with lysimetric measurements. Therefore, the main objective of this study was to evaluate SEBS for its ability to estimate daily ET for the Texas High Plains using lysimetric data.

Methods and Materials

This study was conducted at the USDA-ARS Conservation and Production Research Laboratory (CPRL) located in Bushland, TX (Fig. 1). The geographic coordinates of the CPRL are 35° 11' N, 102° 06' W, and its elevation is 1170 m above mean sea level. For this study, a 30-m resolution Landsat 5 TM scene was used to derive energy fluxes at the land surface. The scene path/row

was 31/36 and was acquired at 17:27 GMT on 10 July 2007 (DOY 191). The TM band 6 image was captured at a coarser resolution of 120 m, and was resampled to 30 m by the image supplier. Soils around Bushland are described as slowly permeable Pullman clay loam soils. The major crops in the study area were corn, sorghum, winter wheat, and cotton.

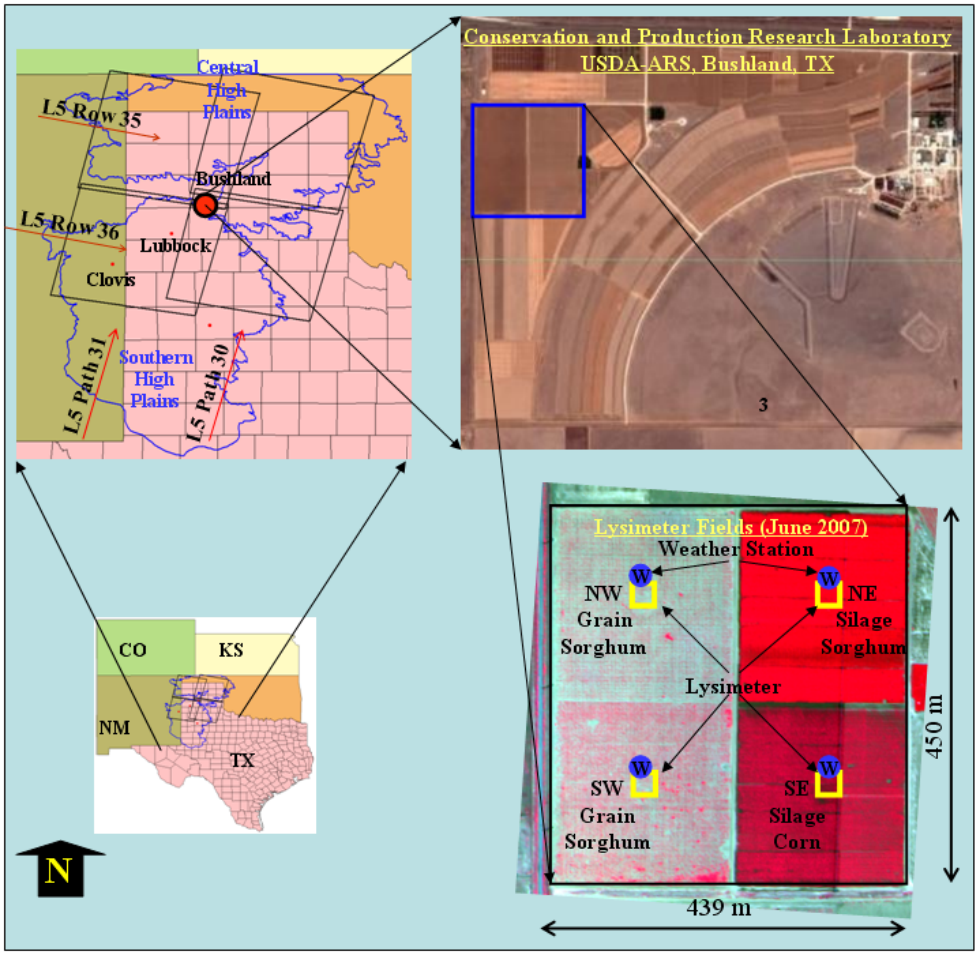

Figure 1. Location of Texas High Plains and four large weighing lysimeters in the USDA-ARS Conservation and Production and Research Laboratory, Bushland, TX, USA.

SEBS-estimated ET values were verified by comparison with soil water mass change-based daily ET values from four large monolithic precision weighing lysimeters located at the CPRL. Each lysimeter (3 m length × 3 m width × 2.4 m depth) was located in the middle of a 4.7-ha field and all four lysimeters were arranged in a block pattern (see Fig. 1). Dryland cropping systems are managed on two lysimeter fields in the west and irrigated cropping systems are managed on two lysimeter fields in the east with a 10-span lateral move sprinkler system. In 2007, SW and NW were planted to dryland grain sorghum in clumps (SW) and rows (NW) as part of another study. The irrigated SE and NE lysimeter fields were planted to forage corn and sorghum, respectively. A grass reference ET weather station field (0.31 ha), which is a part of the Texas High Plains ET Network (TXHPET, 2006) is located in the eastern side of the irrigated lysimeter fields. Finally, SEBS was evaluated by comparing predicted daily ET with observed data. Root Mean Square Error (RMSE) and Mean Bias Error (MBE) statistics were used in the comparison of predicted against measured data.

Results and Discussion

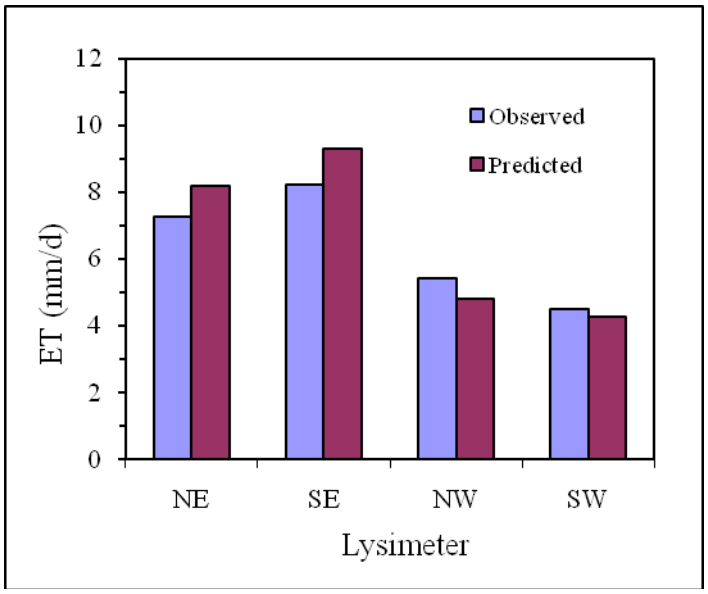

Figure 2. Predicted versus observed daily ET on four large lysimeters in Bushland, Texas on July 10, 2007.

Surface energy balance system (SEBS) was implemented within an ArcInfo environment (ESRI[1], 2008). A computer program was written in Arc Marco Language (AML) to automate the implementation process. SEBS found to be robust as the entire program was run in one step. Further, there was no need for identifying hot and cold pixels as in the case of SEBAL or METRIC. Figure 2 illustrates the comparison of predicted daily ET with measured data on four lysimeters located in Bushland, Texas. Comparison of SEBS-estimated daily ET against observed data indicated that performance of the SEBS was excellent. However, the SEBS slightly over predicted daily ET more than 12 percent for irrigated SE and NE Lysimeter fields. For NW and SW lysimeter fields, the SEBS underpredicted daily ET by 11.8 and 5.8 percent, respectively. The MBE±RMSE for estimated ET for all four lysimeters was 0.4±0.3 mm/day. Accuracy levels with SEBS for estimating daily ET rates in the Texas High Plains were comparable to values reported in the literature (Gowda et al., 2008).

Summary

Surface energy balance system (SEBS) is a single-source model requiring minimal amount of ancillary data. It was applied on a Landsat 5 TM image acquired on July 10, 2007 at 11:27 CST hours. SEBS over predicted daily ET for dryland conditions and under predicted for irrigated Lysimeter fields. Considering the minimal amount of ancillary data required for applying SEBS, and good performance in predicting daily ET on both dryland and irrigated fields, it is a

[1] Disclaimer: Mention of trade names or commercial products in this article is solely for the purpose of providing information and does not constitute recommendation or endorsement by the U.S. Department of Agriculture.

promising tool for operational ET remote sensing program in the semi-arid Texas High Plains. However, a thorough evaluation of SEBS is needed for all major crops in the Texas High Plains under different agroclimatological conditions. At present, efforts are being made to thoroughly evaluate SEBS with 19 Landsat TM images acquired during 2006-2008 cropping seasons with short and tall crops.

References

Allen, R.G., M. Tasumi, and R. Trezza. 2007a. Satellite-based energy balance for Mapping evapotranspiration with internalized calibration (METRIC)-Model. *Journal of Irrigation and Drainage Engineering, 133(4):380-394*.

Allen, R.G., M. Tasumi, A. Morse, R. Trezza, J.L. Wright, W. Bastiaanssen, W. Kramber, I. Lorite-Torres, and C.W. Robison. 2007b. Satellite-based energy balance for Mapping evapotranspiration with internalized calibration (METRIC)-Applications*. Journal of Irrigation and Drainage Engineering, 133(4):395-406.*

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

Bastiaanssen, W.G.M, H. Pegrum, J. Wang, Y. Ma, J. Moreno, G.J. Roerink, and T. Van der Wal. 1998b. The surface energy balance algorithm for land (SEBAL): Part 2 validation. *Journal of Hydrology, 212-213:213-229*.

Brutsaert, W., and M. Sugita. 1992. Application of self-preservation in the diurnal evolution of the surface energy budget to determine daily evaporation. *Journal of Geophysical Research, 97: 18,377–18,382*.

Brutsaert, W. 1999. Aspect of bulk atmospheric boundary layer similarity under free-convective conditions. *Reviews of Geophysics, 37:439-451.*

Chehbouni, A., D. Lo Seen, E.G. Njoku, and B. Monteny. 1996. Examination of the difference between radiative and aerodynamic surface temperatures over sparsely vegetated surfaces. *Remote Sensing of Environment, 58:177–186*.

Crago, R.D. 2000. Conservation and variability of the evaporative fraction during the daytime. *Journal of Hydrology, 180(1 - 4): 173-194*.

Crago, R., M. Friedl, W. Kustas, and Y. Wang, 2004. Investigation of Aerodynamic and Radiometric Land Surface Temperatures. *NASA Scientific and Technical Aerospace Reports (STAR)*, *42(1):201*.

Gowda, P. H., J. L. Chavez, P. D. Colaizzi, S. R. Evett, T. A. Howell, and J. A. Tolk, 2008a. ET mapping for agricultural water management: present status and challenges. Irrigation Sci. 26: 223-237.

Howell, T.A., A.D. Schneider, T.H. Marek, and J.L. Steiner. (1995). Calibration and scale performance of Bushland weighing lysimeters. *Transactions of the ASAE, 38:1019 – 1024.*

Jackson, R.D. 1984. Remote sensing of vegetation characteristics for farm management. *SPIE, 475:81-96*.

Kustas, W.P., and J.M. Norman. 1996. Use of remote sensing for evapotranspiration monitoring over land surfaces. *Hydrology Science Journal, 41(4):495-516.*

Menenti, M., Choudhury, B.J., and Di Girolamo, N. (2001) Monitoring of actual evaporation in the Aral Basin using AVHRR observations and 4DDA results. In *Advanced Earth*

Observation – Land Surface Climate, Su, Z. and Jacobs, C. (Eds.), report USP-2, 01-02, Publications of the National Remote Sensing Board (BCRS), *pp79-83*.

Monteith, J.L. 1965. Evaporation and environment. *Symposium of Society of. Exploratory Biology, 19:205-234.*

Monteith, J.L. 1981. Evaporation and surface temperature. *Quarterly Journal of Royal Meteorological Society, 107:1-27.*

Norman, J.M., W.P. Kustas, and K.S. Humes. 1995. A two-source approach for estimating soil and vegetation energy fluxes from observations of directional radiometric surface temperature. *Agriculture and Forest Meteorology, 77:263-293*.

Park, A.B., R.N. Colwell, and V.F. Meyers. 1968. Resource survey by satellite; science fiction coming true. *Yearbook of Agriculture, pp 13–19.*

Roerink, G.J., B. Su, and M. Menenti. 2000. S-SEBI - A simple remote sensing algorithm to estimate the surface energy balance. *Physics Climate Earth Journal (B) 25(2):147-157*.

Su, Z. 2002. The surface energy balance system (SEBS) for estimation of turbulent fluxes. *Hydrology and Earth Systems Science, 6:85-99*.

Su, H., M.F. McCabe, E.F. Wood, Z. Su, and J.H. Prueger. 2005. Modeling evapotranspiration during SMACEX: Comparing Two approaches Local- and Regional-Scale prediction. *Journal of Hydrometerology, 6(6):910-922*.

Timmermans, W., W.P. Kustas, M.C. Anderson, and A.N. French. 2007. An intercomparison of the surface energy balance algorithm for land (SEBAL) and the two-source energy balance (TSEB) modeling schemes. *Remote Sensing of Environment, 108:369-384*.

Zhang, L., and R. Lemeur. 1995. Evaluation of daily ET estimates from instantaneous measurements. *Agricultural and Forest Meteorology. 74:139-154*.