Partitioning Evapotranspiration in Semiarid Grassland and Shrubland Ecosystems Using Diurnal Surface Temperature Variation

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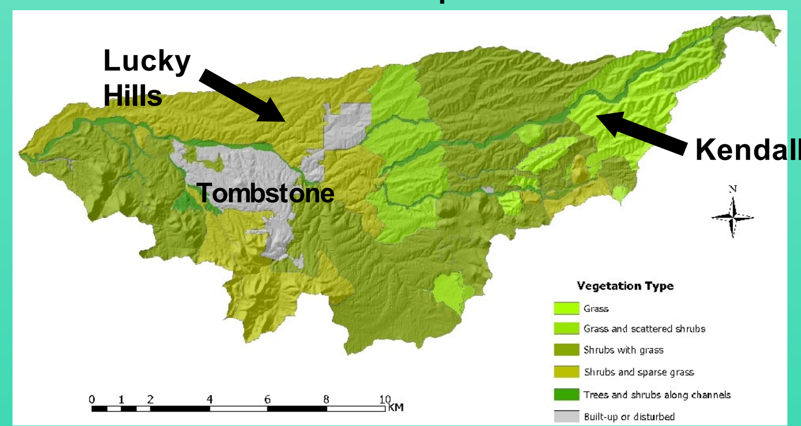
Abstract

The encroachment of woody plants in grasslands across the Western U.S. will affect soil water availability by altering the contributions of evaporation (E) and transpiration (T) to total evapotranspiration (ET). To study this phenomenon, a network of flux stations is in place to measure ET in grass- and shrub-dominated ecosystems throughout the Western U.S. A method is described and tested here to partition the daily measurements of ET into E and T based on diurnal surface temperature variations of the soil and standard energy balance theory. The difference between the mid-afternoon and pre-dawn soil surface temperature, termed Apparent Thermal Inertia (I_A), was used to identify days when E was negligible, and thus, ET=T. For other days, a three-step procedure based on energy balance equations was used to estimate the contributions of daily E and T to total daily ET. The method was tested at Walnut Gulch Experimental Watershed in southeast Arizona based on Bowen ratio estimates of ET and continuous measurements of surface temperature with an infrared thermometer (IRT) from 2004-2005, and a second dataset of Bowen ratio, IRT and stem-flow gage measurements in 2003. Results showed that reasonable estimates of daily T were obtained for a multi-year period with ease of operation and minimal cost.

Instrumentation and Field Sites

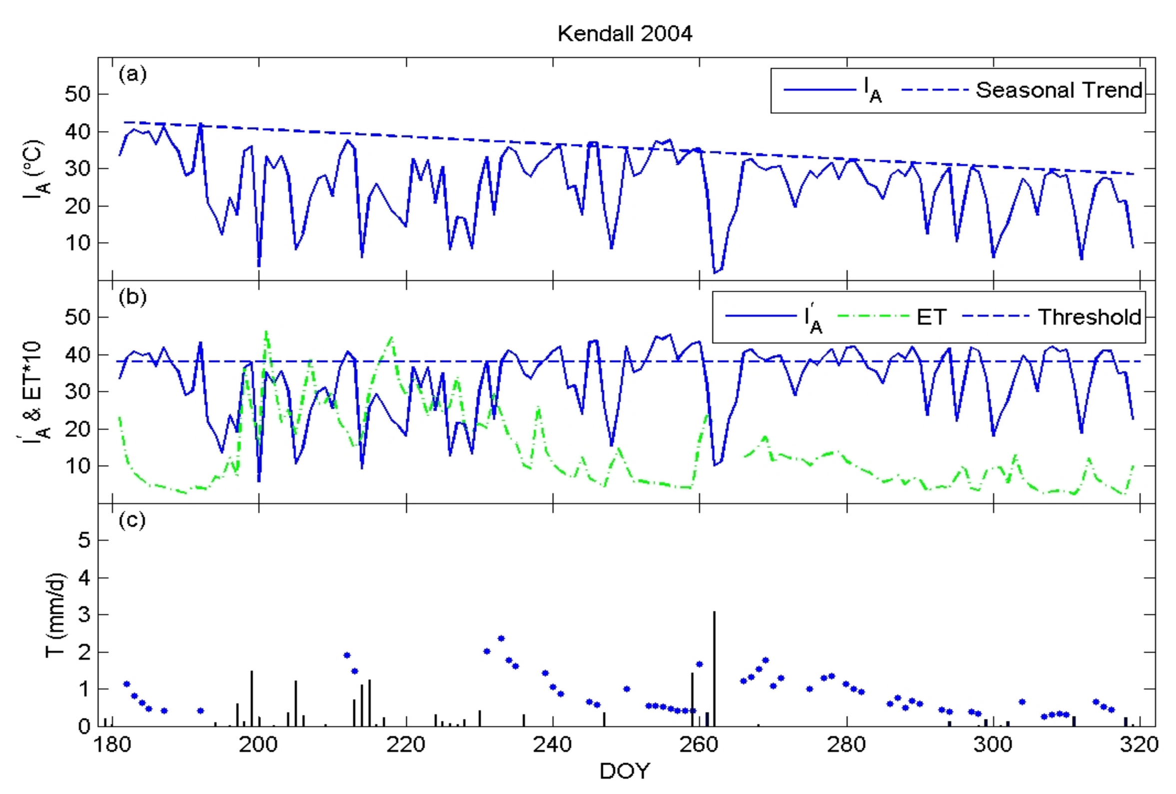
This approach is based on the assumption that conventional eddy covariance or Bowen ratio instrumentation is in place at a site, with coincident measurements of soil surface temperature, making measurements throughout the day at the commonly used 20- or 30-minute time interval.

USDA ARS Walnut Gulch Experimental Watershed



Emmerich, W.E. 2003. J. Ag. and For. Meteorol. 116
Scott, R.L., T.E. Huxman, W.L. Cable and W.E. Emmerich. In press. Hydrological Processes.

Partitioning ET with Thermal Inertia

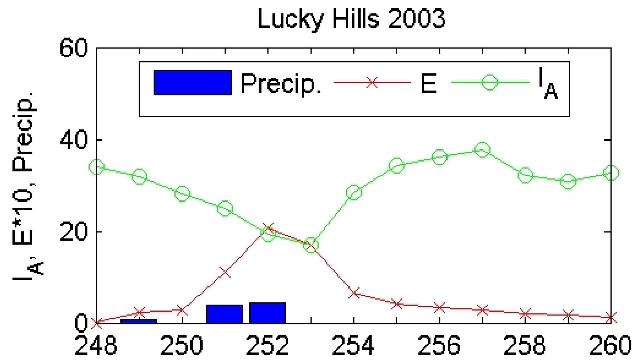


(a) A polynomial was fit to the highest I_A vales. (b) A threshold was set to discriminate the highest detrended I_A values (I_A'). (c) For dates when I_A' exceeded the threshold, then ET_D=T_D. Bars represent daily precipitation (mm).

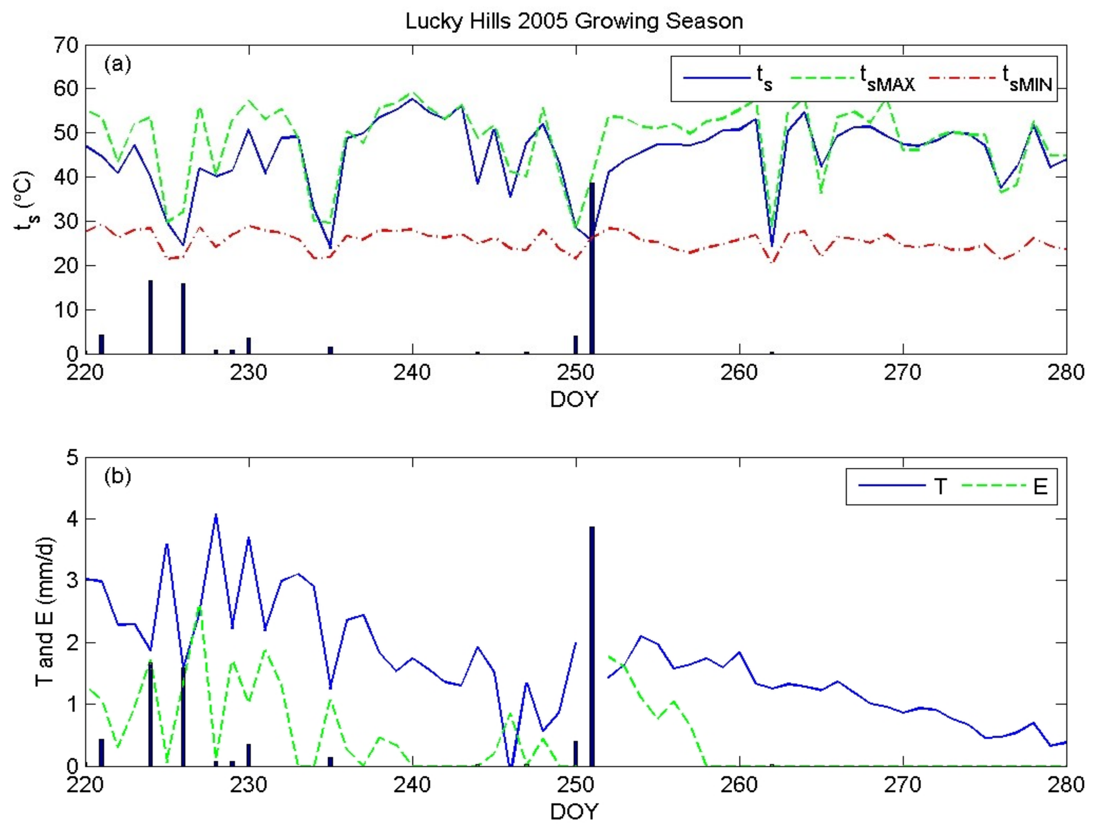
Apparent thermal inertia (I_A) is derived from the difference between mid-afternoon and pre-dawn (or soil) temperatures, where

$I_A = (t_{2pm} - t_{5am})$ [˚C].

The terms t_{2pm} and t_{5am} represent soil surface temperatures measured with a down-looking infrared thermometer (IRT) at times 2:00 pm and 5:00 am, respectively. I_A is related to E (see below).



Partitioning ET with Semi-Empirical Energy Balance Approach



Values of (a) measured, minimum and maximum surface temperature (t_s, t_{sMIN} and t_{sMAX}) and (b) transpiration (T) and evaporation (E) during the growing season (DOY 220-280) at Lucky Hills in 2005.

$$t_{sMin} = \left[\frac{r_a(R_n - G)}{C_v} \frac{\gamma}{(\Delta + \gamma)} - \frac{VPD}{\Delta + \gamma} \right] + t_a$$

$$t_{sMax} = \left[\frac{r_a(R_n - G)}{C_v} \right] + t_a$$

Key: determine r_a empirically when sky is cloudfree and E=0

$$E/E_p = (t_{sMAX} - t_{sMEAS})/(t_{sMAX} - t_{sMIN}) \quad (1)$$

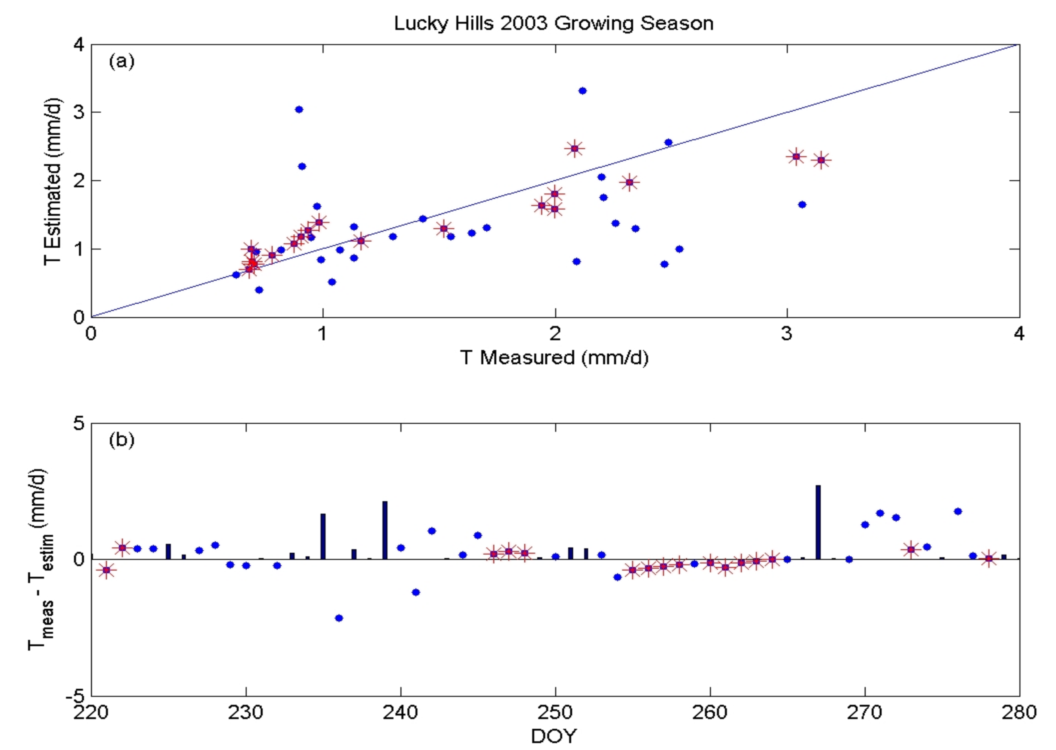
where E_p is potential evaporation (W m^{-2}). Actual E_D can be estimated by multiplying the daily E_p (E_{pD}) by

$$E_D = (E/E_p)E_{pD} \quad (2)$$

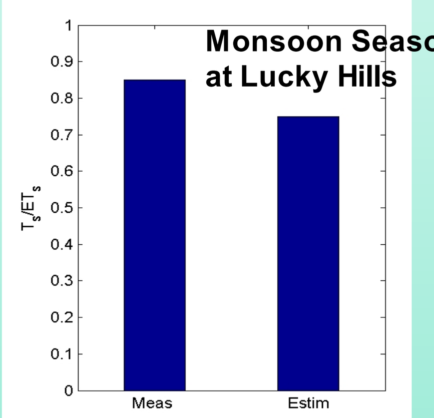
Finally, daily transpiration can be determined

$$T_D = ET_D - E_D. \quad (3)$$

Validation of Estimated Transpiration with Transpiration Measured with Sapflow Technique



(a) Comparison of transpiration (T) estimated with this approach and T measured with a conventional sapflow technique (from Scott et al., in press) and (b) the difference between measured and estimated T (T_{meas}-T_{estim}). The bars represented daily precipitation (mm).



The correlation between T estimated with I_A' and T measured with a sapflow technique was good (asterisks, MAD = 0.29 mm/d). The correlation between T estimated with the semi-empirical energy balance approach was not as successful (circles, MAD = 0.64mm/d). The estimated T_S/ET_S (0.76) was within 10% of the measured value (0.84).

Results and Conclusions

Seasonal T/ET Ratio, Kendall & Lucky Hills

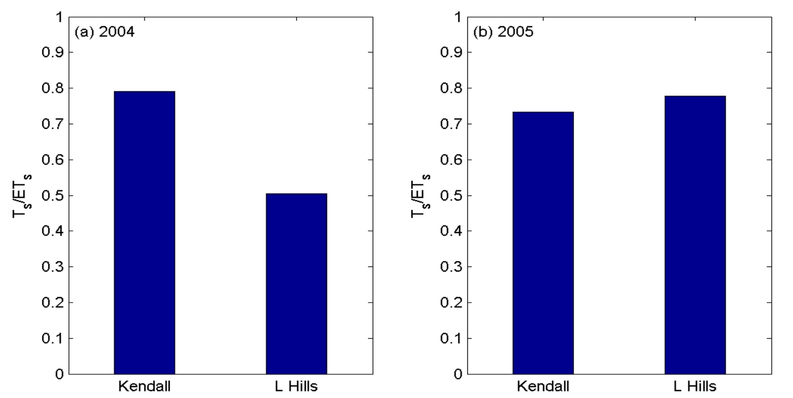


Table 1. Rainfall summary (mm) for the growing season at WGEW during years 2003-2005 at Kendall and Lucky Hills sites.

Site and Year	Annual	Growing Season DOY 220-280	
	Total Precipitation	Total precipitation	# of storms
Lucky Hills 2003	245.9	93.2	15
Kendall 2004	294.9	67.7	12
Lucky Hills 2004	219.4	58.4	12
Kendall 2005	162.3	61.0	16
Lucky Hills 2005	223.2	87.2	13

The main contribution of this work was a new method to partition on-site measurements of ET_D into daily E and T based on the low-cost addition of an IRT to existing eddy covariance and Bowen ratio stations. We showed that reasonable estimates of T_D were obtained for clear-sky days when E_D was found to be zero based on the magnitude of the apparent thermal inertia (I_A). This finding is the most valuable and reliable aspect of this approach.

A theoretical supplement was added to compute T_D on days when the I_A-based approach is not applicable (e.g. cloudy days or when E_D≠0), resulting in season-long estimates of T_D and E_D. The theoretical energy balance approach should be refined to account for days with variable cloud conditions.

Future work should continue to explore the soil water availability in grass- and shrub-dominated ecosystems like Kendall and Lucky Hills to better understand the potential impact of woody plant encroachment in grasslands across the Western U.S. These preliminary results will be combined with results from similar data collected in 2006 (a relatively wet monsoon season) to further study this link between T_D/ET_D and such variations in rainfall at WGEW.