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A mobile platform to constrain regional estimates of evapotranspiration

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ABSTRACT

Regional estimates of evapotranspiration (ET) are needed for environmental analysis and management purposes, yet can be difficult to obtain. Current methods for determining regional ET have spatial, temporal, methodological, and/or logistical limitations that affect their usefulness. To address these gaps, we developed a surface mobile measurement technique, the Regional Evaporative Fraction Energy Balance platform (REFEB), which measures evaporative fraction (EF) and water use efficiency (WUE) using a truck operating on a public right of way. REFEB can measure EF and WUE at 25 or more locations per day, which allows for rapid, dense, and spatially distributed sampling of fields across a region. We assessed the accuracy of the field measurements of EF and WUE with REFEB by comparing them to an Eddy covariance (EC) and Bowen ratio energy balance (BREB) tower. This site validation showed that REFEB has error and uncertainty similar to previous BREB approaches. We then used empirical relationships between field measurements and remote sensing vegetation indices to derive regional maps of EF. We combined these EF maps with satellite observations of net radiation to derive monthly and annual calculations of ET at a 250 m resolution during calendar year 2004 in the Imperial Valley, California, a major agricultural region that is dependent upon irrigation and which has a well constrained water budget. We then summed ET for the Imperial Valley and compared the result to a surface water budget based on irrigation and drainage measurements, which showed good annual and seasonal agreement. These results indicate REFEB produces accurate field measurements of EF and WUE, which can be scaled to estimate regional ET at time scales ranging from less than a week to annual sums.

1. Introduction

Regional estimates of ET are needed for a variety of ecological, environmental, climatological, and agricultural monitoring and modeling applications. In agriculture, regional ET estimates are critical for managing irrigation supplies and practices to increase agricultural productivity with increasingly scarce water supplies (e.g. Er-Raki et al., 2007; Akbari et al., 2007). Numerous methods exist for determining evapotranspiration (ET) and water use efficiency (WUE); however, gaps remain in the spatial and temporal range of existing approaches, especially at a regional scale.

Micrometeorological methods such as Eddy covariance (EC) (Law et al., 2002), Bowen ratio energy balance (BREB) (Held et al., 1990), and surface renewal (Paw and Brunet, 1991), use in situ observations that can provide direct, site-specific estimates of ET at high temporal resolution. However, spatial heterogeneity and the relatively few number of sites prevent direct scaling of these calculations to regional estimates. EC can assess regional scale (~100 km^2) fluxes from an aircraft

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platform at short temporal scales (Barr et al., 1997), but the cost is prohibitive for wide use.

Most approaches to estimating regional ET use a model combined with remote sensing observations and ancillary meteorological measurements. Commonly used semi-empirical models include Priestly–Taylor, Blaney–Criddle, Pruitt–Doorenbos, and Penman–Monteith (Temesgen et al., 2005). These models have been combined with satellite observations of temperature (Kustas et al., 2003), evaporative fraction (Isaac et al., 2004), changes in surface and subsurface water storage (Rodell et al., 2004), and vegetation indices (Cleugh et al., 2007). Regional irrigation networks can estimate ET by applying a model at a network of meteorological sites (Amatya et al., 1995; Temesgen et al., 2005). Depending on the input data, uncertainties arise from errors in approximating model parameters (Rana and Katerji, 1998), estimating necessary parameters from available remote sensing data (Kustas et al., 2003), discrepancies between regional field conditions and the conditions under which the model was developed (Rana and Katerji, 2000), coarse spatial and/or temporal resolution (Rodell et al., 2004) and/or a lack of ancillary meteorological measurements (Rana and Katerji, 2000). Many farmers and irrigation managers use crop specific coefficients (K_c) that estimate field ET based on empirical estimates of reference ET from surface meteorological observations (Temesgen et al., 2005). Regional ET estimates can then be constructed using estimates of reference ET combined with estimates of area averaged K_c derived from land cover estimates (Allen et al., 2005). Accurate estimation of K_c is laborious at a regional scale and requires current surveys of crop acreage and mean planting and harvesting dates, which are often based on extensive ground surveys (Allen et al., 2005). Currently accepted methods such as the FAO-56 protocol (Allen et al., 1998) can overestimate K_c by up to 20% (Allen, 2000).

In this paper, we describe a strategy for assessing regional ET. We developed a mobile micrometeorological measurement technique, the Regional Evaporative Fraction Energy Balance platform (REFEB), which can make point measurements of field evaporative fraction (EF: the fraction of available surface energy contained in latent heat) and (WUE: here defined as the ratio of instantaneous net carbon uptake over ET) using a truck that operates on public right of ways. REFEB can measure EF and WUE at 25 or more locations per day, which allows for a dense and spatially distributed sampling of fields across a region. We tested REFEB theory against Eddy covariance at an agricultural site in an irrigated region, the Imperial Valley, California (hereafter referred to as ''IV''). We then demonstrate an application of REFEB by using it to make field-scale measurements of EF in the IV. Field measurements of EF are regressed against remotely sensed vegetation indices for the fields measured. We then use these empirical relationships to construct regional, medium-resolution (250 m) maps of EF and ET. Finally, we sum these gridded results to calculate regional ET, which we compare to the observed water budget for the entire IV.

2. Methods

2.1. Measurement theory and instrumentation

REFEB combines two established methods, the temperature (T)–specific humidity (q) regression Bowen ratio method (De Bruin et al., 1999) and the Bowen ratio energy balance method (BREB) (Held et al., 1990; Verma and Rosenberg, 1975). The T–q regression Bowen ratio method can be used to assess the Bowen ratio (B: the ratio of sensible heat over latent heat), using high-speed temperature and specific humidity measurements at a single height.

Assuming similarity of transfer coefficients for heat and water vapor, B can be found with Eq. (1), as applied to a T'–q' plot (an example is shown in Fig. 1a). EF can be found through a conversion of B as shown in Eq. (2).

$$B = \gamma\left(\frac{T'}{q'}\right) \quad (1)$$

$$\mathrm{EF} = \frac{1}{1 + B} \quad (2)$$

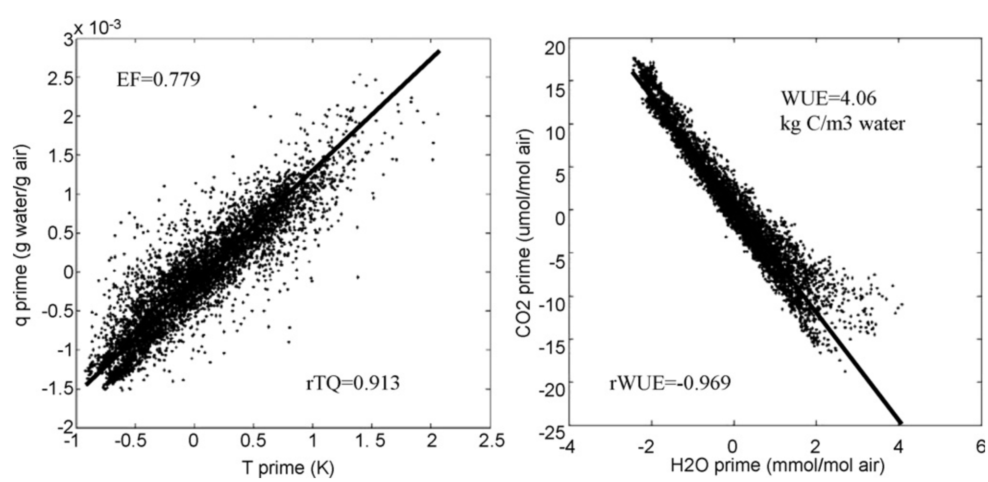

Fig. 1 – Example data plots to illustrate how evaporative fraction and water use efficiency are obtained from raw measurements. Data were recorded at 10 Hz for 10 min downwind of a sudan grass field (location: 32.73736°N, 115.32265°W; time: 18 May 2007 from 9:36 to 10:46 a.m. PDT). (a left) T'–q' plot. (b right) WUE plot of the stop.