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Remote sensing-based soil water balance to estimate Mediterranean holm oak savanna (dehesa) evapotranspiration under water stress conditions

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SUMMARY

This paper aims to present the use of a remote sensing-based soil water balance to estimate holm oak woodland evapotranspiration (ET). The model is based on the assimilation of MODIS reflectance-based vegetation indices in the dual crop coefficient methodology. A daily water balance was performed on the root zone soil to estimate plant water stress. The methodology was evaluated with respect to the actual ET measured by eddy covariance in Mediterranean holm oak savanna (dehesa) for five consecutive years (2004–2008).

The model adequately reproduced the absolute values and tendencies measured at daily and weekly periods. Root mean square error (RMSE) was 0.50 mm/day for daily values and 2.70 mm/week for weekly accumulated values. The analysis demonstrated the presence of a long period of water stress during the summer and at the beginning of fall. Measured ET dropped during these periods, and the model replicated this tendency accurately, reaching a stress coefficient value close to 0.2.

To be operative, the proposed method required low ground data (reference evapotranspiration and precipitation) and the results indicated a simple, robust method that can be used to map ET and water stress in the dehesa ecosystem.

1. Introduction

A common interest area for research has been quantifying natural vegetation evapotranspiration (ET) and water deficit in the root zone due to their relation to stomatal conductance and thus CO_2 assimilation and primary production. Moreover, ET is a relevant component of the water cycle and, consequently, it must be estimated in groundwater recharge and basin discharge studies (Zhang et al., 2008; Toews and Allen, 2009). Additionally, water stress and plant water status are biophysical factors related to fire hazards (Vidal et al., 1994; Guangxiong et al., 2007), although a complete potential fire hazard assessment should consider other abiotic and human factors (Chuvieco et al., 2010).

Algorithms linking biophysical variables to remotely sensed data allow for the quantitative operational monitoring of vegetation (Calera et al., 2004). Estimating these biophysical indicators by remote sensing is a good first step toward mapping ET estimates on crops or natural vegetation (Glenn et al., 2011). A variety of methods based on remote sensing data has been developed for ET assessment in natural ecosystems. These methods have been evaluated in a wide variety of landscape types, several time periods and various spatial scales. Nagler et al. (2005a,b) used a multivariate regression equation for ET estimates in riparian vegetation based on an Enhanced Vegetation Index plus canopy temperature. Some physical models attempt to determine the variables by using the Penman-Monteith equation, compounding the Remote Sensing Penman-Monteith algorithms (RS-PM). Cleugh et al. (2007) proposed the inclusion of remote sensing inputs in the Penman-Montheith equation, specifically by using NDVI and leaf area index estimates for surface resistance assessment. Further improvements have been proposed by adding constraints to potential surface evapotranspiration due to water stress (Mu et al., 2007, 2011; Leuning et al., 2008; Zhang et al., 2008, 2009a,b). Other methodologies rely on the use of thermal signals obtained from remote sensors as inputs for energy balance models to estimate surface evapotranspiration (Moran et al., 1994; Kustas and Norman, 1996; Gillies et al., 1997; Bastiaanssen et al., 1998; Allen et al., 2007a,b).

In a more direct approach, the Vegetation Indices (VIs) obtained from multispectral imagery can be related to the ratio of ET under optimal conditions over reference crop evapotranspiration (ETo), which is functionally the same as the crop coefficient (Kc) in the

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method known as FAO-56 (Allen et al., 1998). VI can be related to a transpiration coefficient for ET estimation. Crop coefficient assessment by using VI has been widely evaluated and applied in herbaceous crops (Bausch and Neale, 1987; Choudhury et al., 1994; Hunsaker et al., 2003; Duchemin et al., 2006; González-Piqueras, 2006; Er-Raki et al., 2007; Jayanthi et al., 2007; González-Dugo and Mateos, 2008) and in woody crops (Samani et al., 2009; Campos et al., 2010b). Kc estimates based on VI for natural vegetation under no water stress conditions have been provided by Groeneveld et al. (2007). In a more complex approach Guerschman et al. (2009) proposed a model that accounts for all sources of ET, plant transpiration and soil and canopy evaporation, combining MODIS-derived Global Vegetation Moisture Index and Enhanced Vegetation Index. A review of Kcb-VI relationships by Glenn et al. (2011) indicates both the limits of this relationship as well as the need for further research in the case of natural vegetation.

In this paper, we present our results and compare them to experimental data in the application of a water balance remote sensing based approach for ET estimation in Mediterranean holm oak savanna, a typical landscape in Mediterranean areas traditionally called "dehesa", as shown in Fig. 1. The Mediterranean climate often causes water shortage during the warm summer period and so vegetation could undergo water stress conditions. Therefore, one of the main goals of this paper is to determine and quantify water stress during several annual cycles. The proposed method provides comparable results with respect to actual ET measured in dehesa over five consecutive years (2004–2008) using the eddy covariance method.

2. Materials and methods

2.1. Remote sensing-based soil water balance model description

The soil water balance (SWB) applied in this paper is a single-layer soil water balance (performed in the plant root zone) with additions to simulate soil evaporation from the surface layer. The

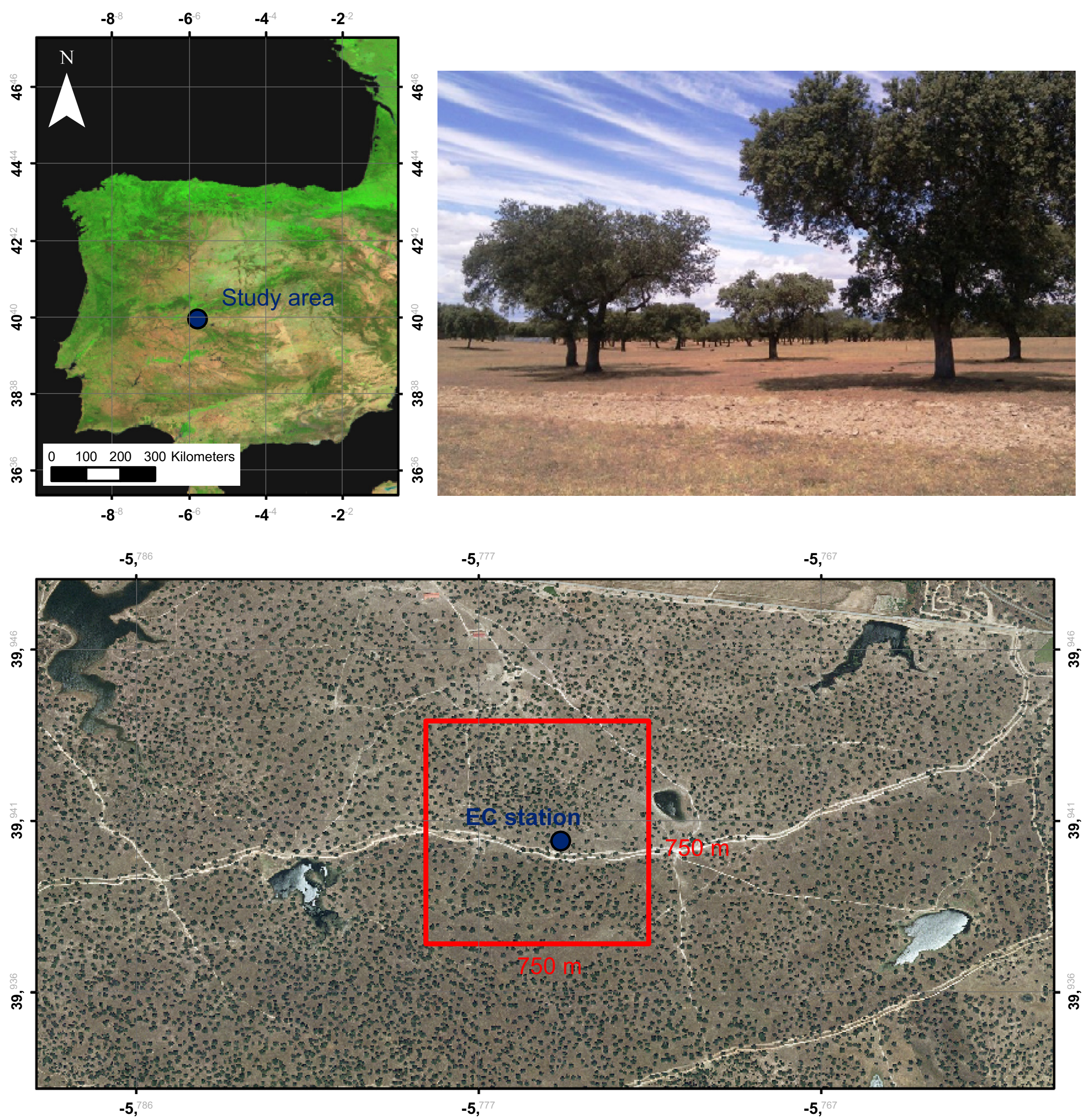

Fig. 1. Study site location, overview and aerial photograph of the "Majadas del Tietar" dehesa ecosystem.