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Impact of the spatial resolution on the energy balance components on an open-canopy olive orchard

J.M. Ramírez-Cuesta[a,b,*], R.G. Allen[c], P.J. Zarco-Tejada[d], A. Kilic[e], C. Santos[b], I.J. Lorite[b]

[a] Centro de Edafología y Biología Aplicada del Segura (CEBAS), Consejo Superior de Investigaciones Científicas (CSIC), Campus Universitario de Espinardo, 30100, Murcia, Spain
[b] IFAPA, Centro "Alameda del Obispo", Avda. Menéndez Pidal s/n. 14004, Córdoba, Spain
[c] Kimberly Research Center, University of Idaho, Kimberly, ID, USA
[d] Instituto de Agricultura Sostenible (IAS), Consejo Superior de Investigaciones Científicas (CSIC), Avda. Menéndez Pidal s/n., 14004, Córdoba, Spain
[e] Department of Civil Engineering School of Natural Resources, University of Nebraska-Lincoln, Lincoln, NE, USA

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ABSTRACT

The recent technical improvements in the sensors used to acquire images from land surfaces has made possible to assess the performance of the energy balance models using unprecedented spatial resolutions. Thus, the objective of this work is to evaluate the response of the different energy balance components obtained from METRIC model as a function of the input pixel size. Very high spatial resolution airborne images (≈50 cm) on three dates over olive orchards were used to aggregate different spatial resolutions, ranging from 5 m to 1 km. This study represents the first time that METRIC model has been run with such high spatial resolution imagery in heterogeneous agricultural systems, evaluating the effects caused by its aggregation into coarser pixel sizes. Net radiation and soil heat flux showed a near insensitive behavior to spatial resolution changes, reflecting that the emissivity and albedo respond linearly to pixel aggregation. However, greater discrepancies were obtained for sensible (up to 17%) and latent (up to 23%) heat fluxes at spatial resolutions coarser than 30 × 30 m due to the aggregation of non-linear components, and to the inclusion of non-agricultural areas in such aggregation. Results obtained confirm the good performance of METRIC model when used with high spatial resolution imagery, whereas they warn of some major errors in crop evapotranspiration estimation when medium or large scales are used.

1. Introduction

An accurate assessment of irrigation requirements results crucial to improve water productivity, especially where water scarcity prevails (Allen et al., 1998; Pereira et al., 2002; Lovarelli et al., 2016; Winter et al., 2017). These irrigation requirements must counteract water losses due to evapotranspiration (ET), which includes plant transpiration and soil evaporation. The evapotranspiration process is dependent on meteorological variables (air temperature, relative humidity, solar radiation and wind speed), and crop parameters (vegetation status, height and density, vegetation fraction cover (F_c), etc.) (Brutsaert, 1982).

The large number of factors controlling crop evapotranspiration (ET_c), along with their interactions, make ET_c estimation a complex procedure. However, numerous methods are intended to estimate ET_c, differing between those based on field methods (soil water balance, eddy covariance (EC), lysimeters, bowen ratio, surface renewal, scintillometry, sap flow…) and those based on remote sensing, RS, techniques (surface energy balance, SEB, models; and vegetation index, VI, based models).

Field methods provide valuable continuous and nearly fully automated ET estimates. They are nondestructive methods that can measure ET over both reference (ET_o) and non-reference (ET_c) surfaces (Allen et al., 2011). Nevertheless, these methods based on field sensors show some drawbacks. Most of them require fragile and expensive equipment, and with some methodologies such as EC, a sizable fetch (and then, large field size) to achieve an equilibrium boundary layer deeper than the instrument installation height (Rana and Katerji, 2000; Allen et al., 2011; Kool et al., 2014). Additionally, field methods provide discrete measurements that may not be representative of the surrounding area (Idso et al., 1975a; Moran et al., 1989; Rana and Katerji, 2000; Allen et al., 2011). Thus, especially for measurements carried out

* Corresponding author at: Centro de Edafología y Biología Aplicada del Segura (CEBAS), Consejo Superior de Investigaciones Científicas (CSIC), Campus Universitario de Espinardo, 30100, Murcia, Spain.
E-mail address: ramirezcuesta.jm@gmail.com (J.M. Ramírez-Cuesta).

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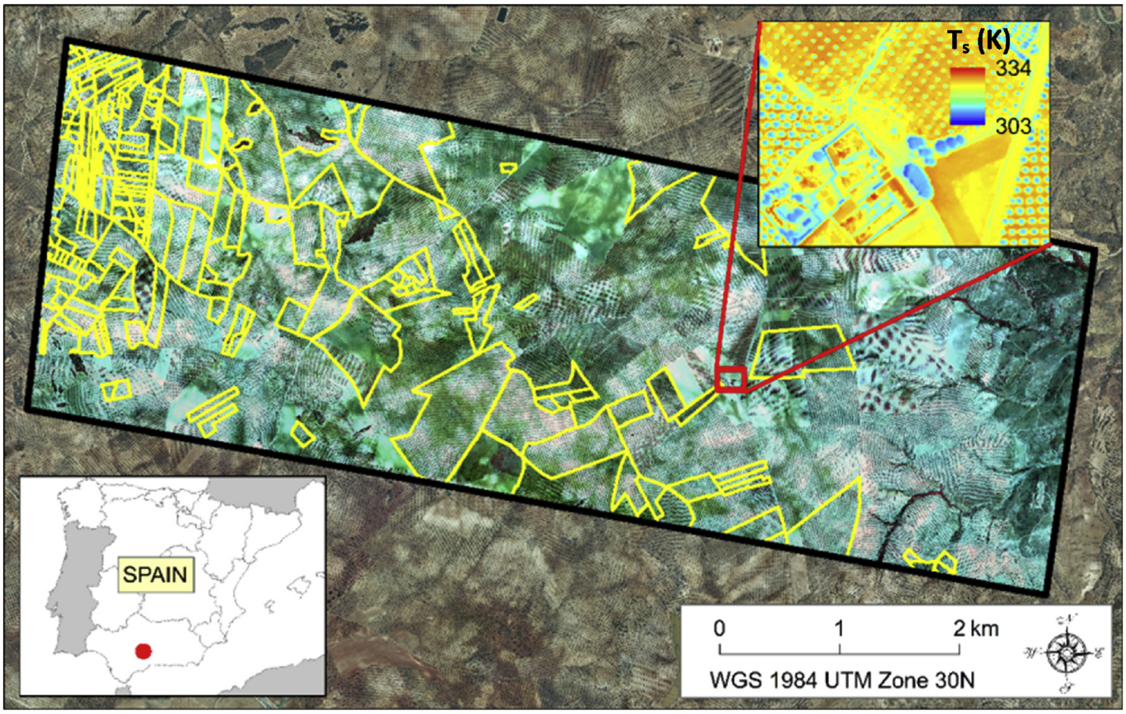

Fig. 1. False color composition (NIR-Red-Green) of the study area. Solid black line includes the area covered by the flights. The small rectangle in the upper-right corner shows an example of the thermal image. The fields considered in the analysis are represented by solid yellow lines. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

in orchards, heterogeneity hinders the characterization of field water-related properties, requiring dense sensors networks.

Techniques based on RS are generally more economic than field sensors measurements. Actual ET estimations of large areas may be provided by RS, allowing the assessment of the spatial ET variability (Norman et al., 1995; Bastiaanssen et al., 1998a; Allen et al., 2001; Su, 2002; Anderson et al., 2003; Allen et al., 2007a). The spatial resolution of these techniques varies according to the selected sensor, ranging from kilometers (e.g. MODIS, MVIRI, SEVIRI, GERB) to a few centimeters (e.g. sensors on-board Quickbird, Ikonos or aircrafts). Despite the advantages of RS techniques, these have similar limitations than field methods for orchard characterization and in fields with limited size. Thus, although the spatial resolution from satellites in the visible and near infrared (VNIR) has improved significantly in the last years, the thermal domain remains at the same (or even lower) spatial resolution than the one provided by the satellites in the early eighties. Furthermore, the physical processes within crop orchards, as the energy or water balance in the soil, become more complicated than in homogeneous crops due mainly to the structural complexity inherent in such heterogeneity.

The consideration of the previously described satellites such as Landsat or TERRA providing medium-high spatial resolution data, has allowed developing and validating models for ET assessment. These models include Surface Energy Balance Algorithm for Land, SEBAL (Bastiaanssen et al., 1998a, b); Mapping Evapotranspiration at High Resolution using Internalized Calibration, METRIC (Allen et al., 2007a, b); Surface Energy Balance System, SEBS (Su, 2002); SIMDualKc model (Rosa et al., 2012), Simplified Surface Energy Balance Index, S-SEBI (Roerink et al., 2000); operational Simplified Surface Energy Balance model, SSEBop (Senay et al., 2013), among others. However, it may be necessary to evaluate these models to other spatial scales different from those targeted in their development (Yang et al., 2014;Zipper and Loheide, 2014; Bisquert et al., 2016; Ortega-Farias et al., 2016, 2017), as the change in the spatial resolution could impact on the turbulent heat fluxes calculation, resulting in a spatial scale discrepancy (Su et al., 1999).

Several authors have studied the effect of the spatial resolution of input satellite data on ET_c estimation. Thus, Su et al. (1999), Hong et al. (2009), Gebremichael et al. (2010), Long et al. (2011) and Tang et al. (2013) analyzed spatial resolution effect on SEBAL model. McCabe and Wood (2006), Ershadi et al. (2013) and Sharma et al. (2016) performed studies with the same objective than the previous ones, but based on SEBS model, whereas Tian et al. (2012) focused on the effect on METRIC model. Kustas et al. (2004) performed a similar research by using a two-source SEB model (Norman et al., 1995). All these studies were mainly focused on the range from Landsat to MODIS spatial resolutions and found that a good agreement exists between ET estimated from these satellites, especially when simple averaging approach is used for spatial input aggregation. In addition, these authors also pointed out the critical role that extreme pixels selection and land surface heterogeneity play, which can cause significant errors in the ET estimation. However, they did not assess the effect of the image pixel size on the ET_c estimation, especially when non-homogeneous crops are evaluated.

Therefore, the objective of this study was to assess the effect of spatial resolution on ET_c estimated in open-canopy olive orchards using METRIC model (Allen et al., 2007a). To achieve this objective, the study encompassed a wide range of pixel sizes (from meters to kilometers) representing the first attempt to run the METRIC model at very high spatial resolution. This objective was addressed for each component of the energy balance, assessing their corresponding sensitivities to changes in spatial resolution and evaluating the impact on the assessment of water requirements.

2. Materials and methods

2.1. Airborne campaigns

Three airborne campaigns were carried out during 2012 on 6th July (Day of Year, DOY, 188), 23rd August (DOY 236) and 8th September (DOY 252) over a large olive region (2600 ha) located between Córdoba, Málaga and Sevilla provinces (southern Spain) (37.25 °N, 4.70 °W) (Fig. 1). The area has a Mediterranean climate, with an