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# Estimating high resolution evapotranspiration from disaggregated thermal images

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ABSTRACT

Accurate evapotranspiration (ET) estimations based on surface energy balance from remote sensing require information in the thermal infrared (TIR) domain, normally provided with an insufficient spatial resolution. In order to estimate ET in heterogeneous agricultural areas, we inspect in this paper the use of disaggregation techniques applied to two different sensors, such as MODIS (daily revisit cycle and 1 km spatial resolution in the TIR domain) and Spot 5 (5 days revisit cycle and 10 m spatial resolution in the VNIR bands but no TIR band). Spot 5 images were used as a proxy for upcoming Sentinel-2. The Simplified Two-Source Energy Balance (STSEB) model was used for the estimation of ET. Since no Sentinel-2 images were available yet, images from the Spot 5 Take 5 experiment were used for testing this approach. Results assessment was conducted at two different levels: field scale (using ground data), and scene scale (using Landsat 7-ETM + images as a reference). Validation of both disaggregated land surface temperature (LST) and derived surface energy fluxes was performed. Mean absolute deviations of ~2 °C in disaggregated LST were observed at both field and scene scales. At field scale, relative errors of 22% and 19% were obtained for ET at instantaneous and daily scales, respectively. At scene scale, the four components of the surface energy balance equation were obtained with relative errors of 3, 14, 11 and 8% for net radiation, evapotranspiration, sensible heat flux and soil heat flux, respectively, compared to Landsat. The results obtained were compared to the use of the MODIS LST at its original resolution (1 km), which was used also to obtain the surface energy fluxes. As the surface heterogeneity increases the errors in both MODIS LST and ET become more and more significant, compared to the use of the disaggregated images. Although reference images at 10 m spatial resolution were not available at this stage for a more robust comparison, this paper shows the potential of the use of disaggregated LST to estimate ET at 10 m spatial resolution, which is especially attractive in highly heterogeneous areas.



## 1. Introduction

Evapotranspiration (ET) is a key component in hydrological and energy balances models. It is essential for water resources management, as well as in many other disciplines such as hydrology, ecology and climate change (Anderson et al., 2007; Wang and Dickinson, 2012; Katul et al., 2012). Good knowledge of ET can improve the water resources management at different scales; in particular, detailed ET estimations in agricultural areas can improve detection of water stress and help in the irrigation scheduling (French et al., 2015). There exist several techniques to measure in situ ET: eddy covariance systems, weighing lysimeters, Bowen stations, etc. All these are punctual data on a specific location and the extrapolation to large regions is difficult; moreover the instruments needed require an important economic investment. Remote sensing offers a suitable alternative for regional to global scale applications. Different approaches have been developed for ET estimation from satellite images and meteorological variables. The Penman-Monteith equation is used in the MODIS (Moderate Resolution Image Spectroradiometer) ET product MOD16 (Mu et al., 2007; Mu et al., 2011). The inputs used in this product include: land cover, fraction of vegetation cover, albedo and meteorological variables. Other methods estimate the ET based on the surface energy balance (SEB) equation. Approaches based on the energy balance usually obtain the ET as a residual of the SEB equation. These methods require information in the thermal infrared (TIR) domain, and are then limited by the availability and accuracy of these data. Some other approaches do not use TIR data, although several studies have shown that the use of TIR data can better monitor the short-time changes in the canopy conditions and consequently in ET, than the use of only visible and near infrared (VNIR) data (French et al., 2015). A wide variety of studies have shown the feasibility of using the SEB approach together with thermal remote sensing to estimate surface energy fluxes, including ET (Norman et al., 1995;

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Anderson et al., 1997; Bastiaanssen et al., 1998; Allen et al., 2007; Sánchez et al., 2008a; French et al., 2015).

The estimation of ET in agricultural areas from remote sensing data is mainly limited by the sensors spatial resolution. This is especially remarkable when using TIR data, because the images in the TIR domain are provided with a lower spatial resolution than in the VNIR domain onboard the same sensor. In order to solve this problem, several fusion and disaggregation techniques have been proposed to downscale the TIR data to the VNIR spatial resolution within a particular sensor (Kustas et al., 2003; Agam et al., 2007). Beyond this, some recent works have explored the possibility to downscale TIR data from low resolution sensors (SEVIRI, MODIS, AATSR, or the coming Sentinel-3) to the spatial scale of medium-high resolution sensors (ASTER, Landsat, Sentinel-2) (Bindhu et al., 2013; Bisquert et al., 2016). Bisquert et al. (2016) analyzed several disaggregation methods applied to Landsat and MODIS images in central Spain. The assessment included methods using classical approaches (linear and quadratic regression), data mining and neural networks; a simple method based on the linear adjustment between land surface temperature (LST) and NDVI (Normalized Difference Vegetation Index) led to the best results. An analysis per land cover occupation was also performed. The Landsat TIR bands were used as the reference data for the validation. The use of disaggregated temperature to estimate ET has been analyzed in several works (Bindhu et al., 2013; Corbari et al., 2015). However, the disaggregation method used in Bindhu et al. (2013) is better suited for areas with high vegetation cover, which is not the case of our study area. This method was already tested in Bisquert et al. (2016) leading to poor results. In Corbari et al. (2015) the disaggregation was applied to MODIS and SEVIRI sensors separately, so the disaggregated images had spatial resolutions of 250 m and 1000 m, respectively. These spatial resolutions are not suited for agricultural areas with small plots.

An alternative to the use of disaggregation techniques are the fusion methods, such as the widely used Spatial and Temporal Adaptive Reflectance Fusion Model (STARFM) (Gao et al., 2006). STARFM is based on the spectral and spatial relationship between an existing high/low resolution image pair. This relationship is later used to complete the time series of high resolution images for dates when only low resolution images are available. This method has been widely used for fusing VNIR images (Senf et al., 2015; Schmidt et al., 2015; Doña et al., 2015). Recently, Cammalleri et al. (2013) investigated the use of the STARFM for fusing daily ET retrieved from multiple TIR sensors. The performance of this methodology was further assessed in different fields, distinguishing between irrigated and rainfed fields (Cammalleri et al., 2014). The same methodology was applied to two vineyards in Semmens et al. (2015). Results from these studies were validated at daily timescale using ground data.

An optimum remote sensing system for agricultural applications would provide data as often as twice per week for irrigation scheduling and once every two weeks for general crop damage detection or crop production (Moran et al., 1997; Moran, 2000). Many authors have dealt with this issue in recent literature (Zarco-Tejada et al., 2005; Dorigo et al., 2007; Roy et al., 2008; Amorós-López et al., 2013; Inglada et al., 2015; etc.). The recently launched Sentinel-2a enhances the temporal and spatial resolution of the current satellites, offering a 10-day revisit cycle with 10–30 m spatial resolutions. With the coming Sentinel-2b the combination of both sensors will offer a 5-day revisit cycle. The constraint is that no thermal sensor is present in this satellite. Thus, the fusion methods cannot be applied to this satellite; contrarily it is possible to apply the disaggregation techniques, as shown in Bisquert et al. (2016). The main objective of this paper is to assess the use of disaggregated LST combining two different satellites to estimate ET from a high resolution sensor provided with no thermal band. There is interest in the scientific community in the application to Sentinel-2 because of its temporal and spatial resolution. While waiting for the availability of Sentinel-2 scenes, images from the Spot-5 Take 5 experiment simulating Sentinel-2 during summer 2015 were used in this work. A first assessment of the disaggregated LSTs obtained from MODIS and these Spot-5 images was performed at field scale by means of ground data measured in different plots. Also, a comparison between MODIS LST and ground data was performed to see the improvement of the disaggregated LST face to the use of MODIS LST. Then, a scene scale assessment was conducted using Landsat TIR data as a reference. Subsequently, the ET was estimated using the disaggregated LSTs on one hand, and using the MODIS LST on the other hand, and results were validated with ground data from two different plots at field scale, and using Landsat ET images as a reference at scene scale.

## 2. Materials and methods

### 2.1. Study site and measurements

The study area is located in Barrax, central Spain, including "Las Tiesas" experimental farm (39°03′35″N, 2°06′W). This is a traditional ESA (European Space Agency) test site used in different international campaigns: SEN2FLEX (SENtinel-2 and Fluorescence Experiment, Sobrino et al., 2008), SPARC (SPectra bARrax Campaign, Moreno et al., 2004), ImagineS (Implementing Multi-scale Agricultural Indicators Exploiting Sentinels, Latorre et al., 2014), and DAISEX (Digital Airborne Imaging Spectrometer EXperiment, Berger et al., 2001). This is a patchy agricultural flat area and is frequently used in agriculture water management studies (López-Urrea et al., 2006; López-Urrea et al., 2009; Sánchez et al., 2011; López-Urrea et al., 2012; Sánchez et al., 2014). Two weighing lysimeters are available in this experimental farm, installed in a grass plot and in a vineyard, with continuous data acquisition. The grass plot is used to monitor the reference evapotranspiration and is maintained in optimum growth conditions (López-Urrea et al., 2006). A meteorological station is set up in the grass plot, recording air temperature, relative air humidity, long and short wave radiation and atmospheric pressure. More details on the study area, the plot, the lysimeter and the meteorological station can be found in López-Urrea et al. (2006). The second lysimeter used in this work was installed in a nearby vineyard, where an additional meteorological station was assembled, together with a Hukseflux NRO1 sensor measuring net radiation at 4-m height. All data were collected and stored in 15-min averages. Ground radiometric temperatures were measured in the grass and vineyard fields, besides three additional test plots (poppy, barley and maize), concurrently with daytime, cloud-free MODIS overpasses during the summer of 2015 (Fig. 1) (DOYs: 127, 132, 134, 141, 173, 182, 189, 198, 214 and 237). Overpass time for all dates is around 11 am (UTM). A resume of the meteorological conditions for each date is shown in Table 1. The barley and maize plots occupy a 40 ha pivot field covering each crop 50% of the area. The vineyard, grass and poppy fields cover areas of 3, 1 and 0.6 ha, respectively. LST transects were carried out at the five different plots (Fig. 1). A set of portable infrared thermal radiometers (IRTs) Apogee MI-210 were used. These are single band (8–14 μm) instruments with an accuracy of $\pm 0.3$ °C and a field of view of 22°. In order to capture the spatial variability of the surface within each field, the radiometers were carried back and forth along transects covering large areas within each plot, and finally the average LST and its standard deviation are obtained for each field. In the vineyard field, which is a row crop, special care was taken in the measurements, pointing the radiometer to an area including both, vine plants and soil surrounding. As expected, higher standard deviations are observed in the vineyard LST measurements. Measurements were made at a rate of >5 measurements per minute and data were collected during periods of 15–20 min centered at the satellite overpass time to assure a good stability of the IRTs response. Measurements of the downward sky radiance, required for the atmospheric correction, were performed with each radiometer at the start and end of the temperature transects. Also, information on irrigation events was registered.