Spatial characterization of evapotranspiration. A study at a field scale

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Abstract. This work present a methodology to estimate spatially-distributed crop evapotranspiration (ETc) using field data and fused satellite images with very high spatial resolution. This goal is based on a fundamental hypothesis: Fused satellite images, with high spatial resolution, and field data allows the estimation of spatially-distributed ETc and the characterization of crops water demand at a farm scale. Experimental results carried out on a cherry orchard during 2011-2012 irrigation season, using multispectral and panchromatic fused images from WorldView-2, confirm the effectiveness of the proposed methodology and the useful to determine water demand at a field scale.

Keywords. Fusion Image, evapotranspiration, crop coefficient, vegetation index.

1. Introduction

Evapotranspiration (ET_c) is the total amount of water lost via transpiration and evaporation from plant surfaces and the soil in an area where a crop is growing. Their correct estimation allows an improvement irrigation management in agriculture [1]. Although ET_c could be calculated with some accuracy, estimations are local and do not consider the spatial variability of the land cover normally present at a field scale. Nowadays, information gathered from aircraft and satellite platforms can be used to estimate ET_c for different crops, delivering information spatial and temporarily distributed over a wide area. However, their use has been limited due to the low spatial and temporal resolution that difficult its utilization at a field scale. Traditionally, ET_c has been estimated using the two-step approach by multiplying the weather-based reference evapotranspiration ET_r by crop coefficients (K_c), to make approximate allowance for crop differences. Crop coefficients are determined according to the crop type and the crop growth stage [2]. However, there is typically some question regarding whether the crops grown compare with the conditions represented by idealized K_c values [3]. In addition, it is difficult to predict the correct crop growth stage dates for large populations of crops and fields [4]. Other method is to make a estimate of ET_r based on the Penman-Monteith equation [5], with crop to crop differences represented by the use of crop specific values of surface and aerodynamic resistances. Although different degrees of success have occurred, the model has generally performed more satisfactorily when the leaf area index (LAI) is large (LAI > 2). All of the previous mentioned methodologies to model ET_c estimate latent heat fluxes locally and do not provide a spatially-distributed estimation. Satellite data are ideally suited for deriving spatially continuous fields of ET_c based on the energy balance equation [4] $LE = R_n - G - H$; where LE is the latent heat flux (evaporation to the atmosphere) calculated as the product of the evaporative flux, E, and the latent heat of vaporization, L; R_n is net radiation; G is soil heat flux; and H is sensible heat flux (all terms taken as positive when flux is leaving the surface, and in W/m^2). Several energy balance models have been coupled with spatially distributed information obtained from remote sensors (satellites and airborne) to mapping ET_c. In general land surface energy balance models uses remotely sensed surface reflectance in the visible and near-infrared portions of the electro- magnetic spectrum and surface temperature (radiometric) from an infrared thermal band [6] (e.g. METRIC [4], SEBAL [7] and ALEXI [8], among others). Another approach to estimate ET_c using remote sensing images are methodologies that relate remotely sensed vegetation indexes (V Is) as Normalized Difference Vegetation Index (NDV I) with crop coefficients (K_c) [9]. This approach does not requires a thermal band as the previous methods based on the energy balance, this is an advantage since most of the satellites platforms do not include measurements on the thermal spectrum. Crop coefficient (K_c) has been related to NDVI, SAVI and PVI [6]. In general, previous experiences have demonstrated that reflectance base crop coefficient is a practical and accurate indicator of the actual crop ET_c.

Although today it is possible to estimate spatially distributed values of ET_c, their application at a field or farm scale has been limited due to calibration and validation process required for different canopy covers and by the low spatial resolution of remote sensed images. To estimate ET_c at a field scale is desirable images with high and very high spatial resolution [10]. The new generation of remote sensed images with high spatial resolution offers the possibility to consider detailed characteristics of the canopy in spatially distributed ET_c models. Here, the use of strategies of satellite image fusion that integrate information from different sensors, offers an opportunity to achieve a characterization with more detail that consistently can be used at a field scale.

2. Material and Methods

2.1. Material Study site and satellite images

The study site (figure 1) is an irrigated Cherry field of 120 ha, located in the central irrigated valley of Chile (34º 6’ 43” S; 70º 41’ 9” O). The Cherry orchard field variety Bing, has been planted with 4 m between rows and 3 m between plants, it has a drip irrigation system with two emitters of 4 L/h per plant. The soil of this site is clay loam. The climate Mediterranean template with a long dry season and average precipitations of 370 mm per year

The Images acquired (Table 1) are Level 1A, characterized by a basic radio- metric normalization (for detector’s calibration) and geometric correction. The atmospheric correction algorithm is the FLAASH model.

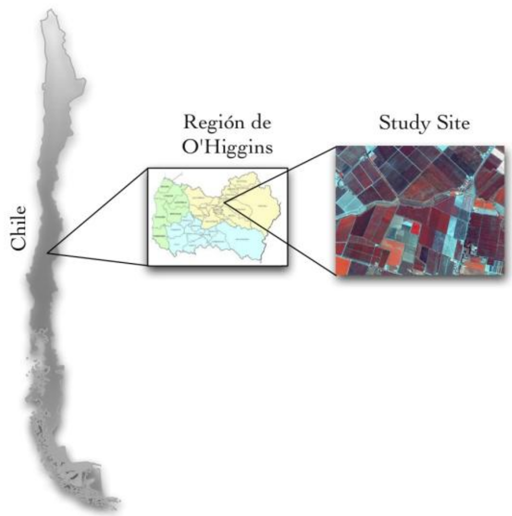

Figure 1. Study site

Table 1. Images available on the study site

Irrigation Season	Satellite	Spatial Resolution (m)	Nº of Images
2011-2012	WorldView-2 (Original)	2.08	3
	WorldView-2 (Fused)	0.52	3
	Landsat 7 ETM+	30	7

2.2. Workflow to Workflow to estimate spatially-distributed ET_c

The methodology proposed consists of four main steps (figure 2):

1. To determining the NDV I-K_c relationship at a field scale. This relation require to estimate the ET_c using Surface Energy Balance (SEB) model. In this work was used METRIC [4]. The input data to the METRIC correspond to seven Landsat 7 ETM+ images (Table 1) and in situ data, coming from a nearby weather station to the study site to estimate references evapotranspiration (ET_r), by FAO Penman-Monteith method. The output of this process is a medium spatial resolution crop coefficient map (K_c) (30 m), obtained from the relation $K_c = ET_c/ET_r$
2. To improve the spatial resolution of ET_c maps, optical multispectral (2.08 m) and panchromatic (0.52m) images, from WorldView-2, are fused by WATFRAC methodology [11]
3. Then, using the previous relationship K_c-NDVI and NDVI map from fused image, a very high spatial resolution K_c map are obtained
4. Finally, using $ET_c = K_c \times ET_r$ equation, map of ET_c, with a 0.52 m spatial resolution is obtained.

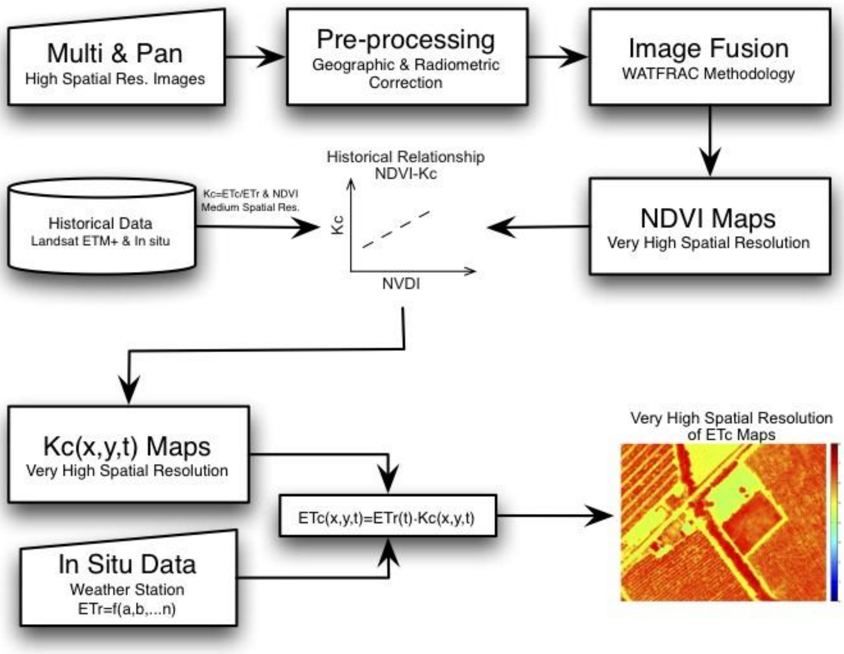

Figure 2. Workflow to estimate ETc

2.3. ET_c measurements and model performance

At study site, Eddy covariance measurements of latent heat, sensible heat, and momentum fluxes were made using a three-dimensional sonic anemometer (CSAT3 Campbell Scientific, Logan, UT) and an open-path infrared CO_2/H_2O gas analyzer system (Model EC150, Campbell Scientific, Logan, UT). To evaluate the performance of the model, evapotranspiration predicted by the proposed methodology will be compared (RMSE) with eddy covariance measurements (mean value) into the square area (90 × 90 m), centered on the instruments tower.

3. Results

The NDVI-Kc relationship obtained is a linear regression function that de- scribes the increase in Kc with NDVI from initial crop growth (NDVI=0.15) through the beginning of maximum cover (NDVI=0.70). Resultant regression coefficients was a = 0.61 and b = 0.64 and their r2 = 0.14.

The model output is a crop evapotranspiration map with very high spatial resolution (0.52 m), their units are mm-day. In the Figure 3 the fused image WorldView-02 on 09/01/12, is showed. This image was used to generate an NDVI map (Figure 4); and using the NDVI-Kc relationship, an ETc map (figure 5) was obtained. In order to compare visually an ETc map, determined by METRIC model and using Landsat 7 ETM+ image is showed in Figure 6. Finally, a synthesis values measured and estimated of ETc, for three days is presented in the Table 2. Even though the RMSE obtained through the NDVI-Kc relationship show an increasing respect to the METRIC model, the ETc values have an acceptable error level, with the a very high spatial resolution, allowing the spatial characterization of ETc at a field scale. From the model point of view, the results shows that it is necessary an improve of the NDVI-Kc relation using a non-parametric model and considering other variables as T^{o}, agricultural management, among others.

Table 2. Estimated and measured ETc values and their RMSE

WorldView-02 NDVI-K_c model (mm-day)				Landsat 7 ETM+ METRIC model (mm-day)		
Date	**Original**	**Fused**	**Measured**	**Date**	**Original**	**Measured**
09/12/11	7.32	7.30	4.90	10/12/11	7.21	5.35
09/01/12	6.68	6.67	4.93	12/01/12	6.49	6.47
05/02/12	7.53	7.52	5.67	13/02/12	5.75	4.43
RMSE	2.03	2.01		**RMSE**	1.32	

Figure 3. Color composition of the fused image WorldView-02, registered on 09/01/12

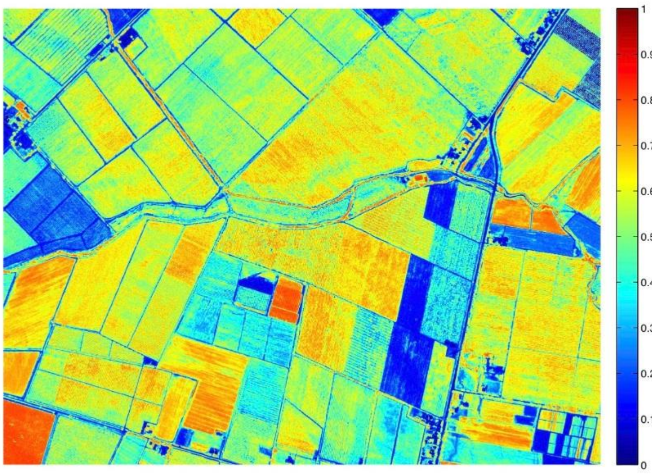

Figure 4. NDVI map using fused image WolrdView-02

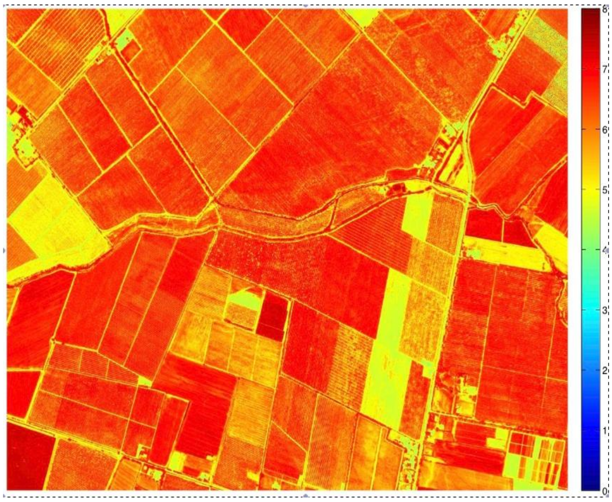

Figure 5. ETc map using fused image WolrdView-02

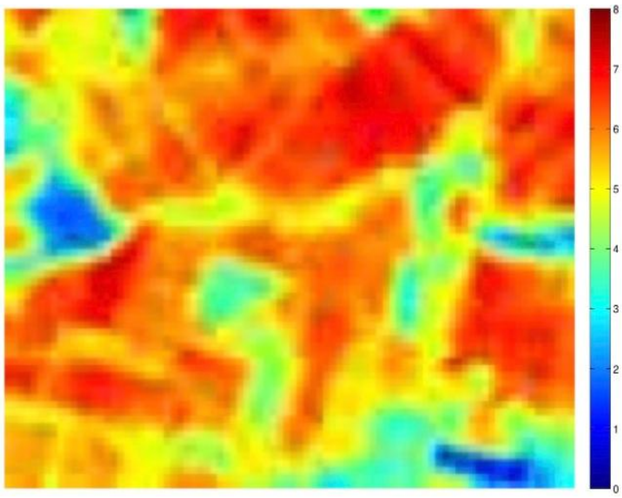

Figure 6. ETc map using Landsat 7 ETM+ image and METRIC model

4. Conclusions

In this work, NDVI-Kc model to estimate spatially distributed ETc at a field scale, has been applied. The obtained results show a acceptable performance of this model, allowing an ETc characterization at a field scale. The behavior of WorldView-02 fused image is similar compared with the original images, and increase four times the spatial resolution of the maps. Further- more, this results confirm the useful of the WATFRAC [11] algorithm in the ETc estimation; and can be a powerful tool in agriculture water management, at a farm scale. The next step must be to improve the estimation of the Kc using other variables involved in the crop growing, and non-parametric models.

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