Monitoring cotton crop evapotranspiration based on satellite data

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Abstract. The water demand to meet seasonal and long-term water needs in Thessaly, central Greece, is related to historical semi-arid conditions in the region, which is the main agricultural area of the country. In this paper irrigation water requirements are assessed through the estimation and monitoring of crop evapotranspiration ET_c for cotton fields in Thessaly. Remotely sensed data are used to delineate the spatial and temporal variability of crop coefficient K_c and crop ET_c. Cotton crop production is examined for the years 2007, 2008, 2009 and 2010. Weekly ground based measurements carried out throughout the growing season and satellite images (Landsat TM) were processed for the corresponding time period. Satellite data provide the cover capability of large scale areas and monitoring of crop during growth stages. Methodology can be applied in large scale areas for the calculation of K_c and extend to other crops using satellite data. The results are in good agreement with ground- truth observations.

Keywords: Remote Sensing, K_c, ET_c

1 Introduction

Agriculture of any kind is strongly influenced by water availability. In semi-arid regions, such as Mediterranean, agriculture is already the largest consumer of water resources. Actual and/or potential evapotranspiration (ET) estimation and monitoring is important in irrigation scheduling by contributing in rationalizing water needs during the growing season (Pereira et al, 1999). Monitoring of ET becomes even more significant when water scarcity combined with drought events cause more difficulties to agricultural production. Evapotranspiration (ET) is one of the most significant parameters in agriculture, since it can justify whether water is used effectively or not. Moreover, ET spatial and temporal variability, in different land uses can be considered to provide adequate and reliable assessment of water use. Nevertheless, it is difficult to obtain accurate measures or estimates of ET due to the

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complexity and variability of meteorological and biophysical components involved in the process.

Remote sensing methods have already reached a significant level of accuracy and reliability over the last forty years, thus becoming attractive for ET estimation, since they have a very high resolution and cover large areas. Remotely sensed models are currently considered suitable for crop water use estimation at fields as well as regional scales (Bastiaanssen et al., 1998; D'Urso and Menenti, 1996). In this paper, evapotranspiration ETc is estimated and monitored in cotton fields in Thessaly, central Greece, using remotely sensed data. In particular, LANDSAT images are processed and analyzed in order to compute the Normalized Difference Vegetation Index (NDVI) and then the crop (cotton) K_c coefficient, which is used in evapotranspiration ETc equation. The method is validated by comparing ET_c estimation using ground-truth conventional meteorological data. The paper is organized as follows: section 2 describes the study area and the data base, which includes meteorological and satellite data, as well as agronomic, geographic and phenological information from selected cotton plots. In section 3 the methodology is presented including data processing and ET_c estimation. Section 4 and 5 shows an analysis and discussion of results.

2 Study area and Database

2.1 Study area

For the experimental layout the pilot area that was selected is the Pinios river basin, Thessaly, central Greece, a high agricultural productivity area that produces high quality products. The region of Thessaly overtakes the central - Eastern department of continental Greece. It is constituted by the Prefectures Karditsa, Larissa, Magnesia and Trikala and overtakes total extent of 14036 Km2 (10.6% of total extent of country). The 36.0% of ground are in a plain, the 17.1% semi-mountain, while the 44.9% is mountainous. High mountains surround the plain of Thessaly, which constitutes the bigger plain of country that divided westwards to Eastern from the river Pinios that is the third bigger river of country. The study area is under drought conditions. Agriculture is affected by limited availability of water resources. In this area, intense and extensive cultivation, mostly with water demanding crops, leads to overexploitation of groundwater. Crop selected is cotton which composes the main cultivation and is one of the most water demanding crops in the study area. During spring and autumn the climate is usually not stable and this has great influence on cotton, as both seasons are very critical for the crop (planting-harvesting periods). Precipitation is very low during the cotton growing period (April – September) so that irrigation is needed for the crop water requirements. The irrigation water comes from rivers by about 46% and from underground water by about 54%. When rainfall during winter of the previous year is limited, shortage of irrigating water is apparent.

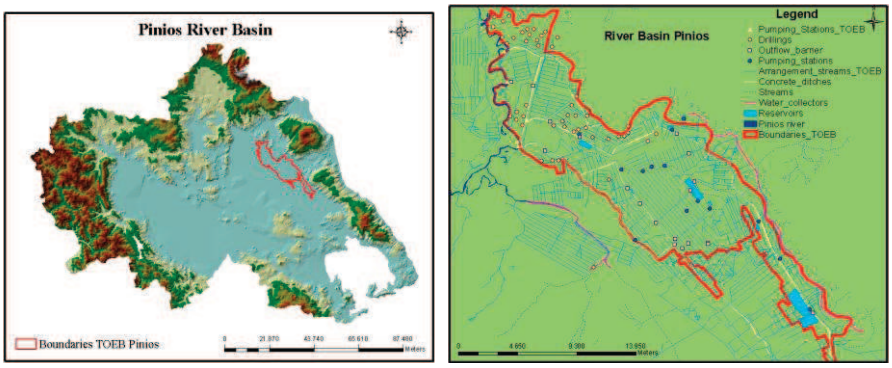


Fig. 1. Study area

Table 1. Irrigated extents in Thessaly

Extents in (thousands hectares)	Thessaly
Agricultural ground	3.152
Total of cultivations	3.130
Irrigated	1.672
Percentage %	53

2.2. Database

Monitoring water needs for agriculture in Thessaly requires a combination of field observations in pilot area, micro-meteorological data and analysis of satellite data. In this paper the process is described for the computation of crop coefficient Kc, and crop evapotraspiration ETc for cotton fields in central Creece, a high agricultural productivity area that produces high quality products.

Conventional data: Ground based micro-meteorological measurements of reporting period for the pilot area include air temperature, wind speed, humidity, and precipitation on daily basis, in order to extract reference evapotraspiration (ET_o), crop evapotranspiration ETc, and Kc, for cotton crop for years 2007, 2008 2009 and 2010.

Satellite data: Remote sensing data are used for agriculture monitoring. The spatial distribution of evapotranspiration is assessed using satellite imagery (Landsat-5 TM) covering the region of Pinios river basin, which was available during the campaign for years 2007, 2008 2009, 2010 at the following dates:

2007	2008	2009	2010
07/05, 24/06, 10/07, 26/07, 27/08, 28/09	30/03, 15/04, 01/05, 17/05, 02/06, 18/06, 04/07, 20/07, 05/08, 21/08, 06/09	02/04, 20/05, 05/06, 21/06, 07/07, 23/07, 24/08	21/04, 07/05, 08/06, 27/08, 28/09, 03/10

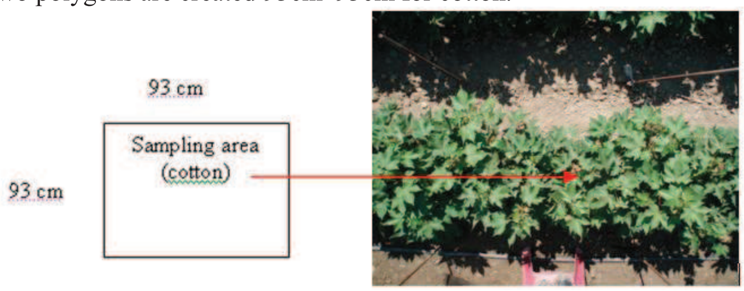
Field data: With regards to field observations, fractional cover and phenological stages for cotton crop for years 2007, 2008, 2009 and 2010 are recorded. Sampling started on May and repeated twice per week for the months of May, June, July August and September. In all pilot areas recorded and measured the followings: photographs, localization of the fields, crop height, irrigation data and meteorological data.

3 Methodology

The paper involves monitoring water needs for crop yield through estimation of evapotranspiration using also satellite data. Methodology includes crop fractional cover and crop classification, estimation of crop evapotranspiration ETc and crop coefficient Kc.

3.1 Crop fractional cover and crop classification

Crop fractional cover: One of the factors that determine the crop coefficient Kc is the crop growth stages. As the crop develops, the ground cover, the height and the leaf area change. The growing period can be divided into four distinct growth stages: initial, development, mid-season and late season (FAO, 1998). The initial stage runs from planting date to approximately 10% ground cover. The development stage runs from 10% ground cover to approximately 70%. The mid-season stage runs from effective full cover to the start of maturity. The late season stage runs from maturity to harvest (FAO, 1998). For the determination of initial and development stages of cotton for the study area one experimental station is set up. In each experimental station two polygons are created 93cm*93cm for cotton.



Using ArcGIS software estimated the percentage of ground cover and hence the initial and development stages.

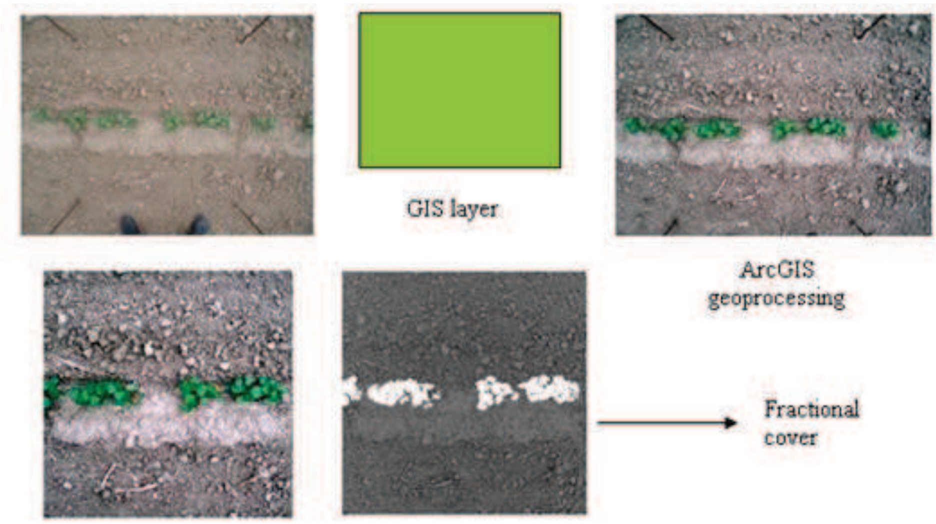


Fig. 2. The process applied to field based on canopy characteristics.

Crop classification: Fifty control points (GCPs) were used for crop classification for main and most cultivated crops in area as signatures for supervised classification that was done to ERDAS IMAGINE 9.1. The GCPs were distributed in a uniform manner along the area of interest. The most common cultivations in Pinios river basin are cotton, alfalfa, corn, winter wheat (fig 3).

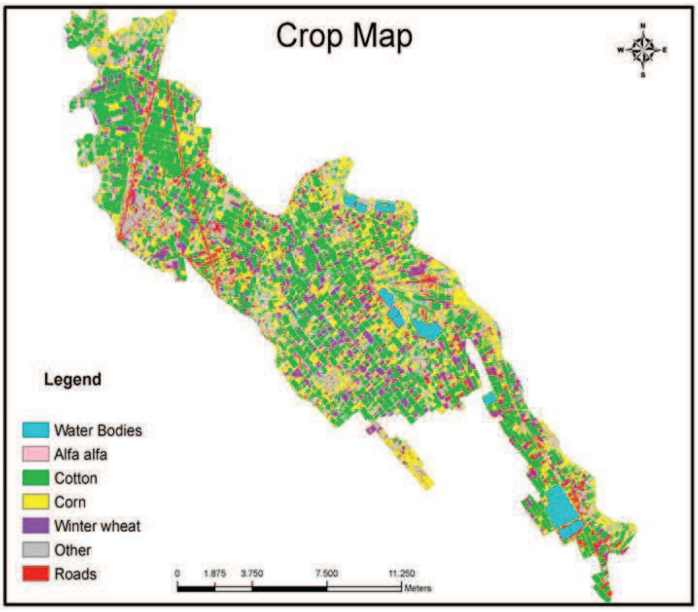


Fig. 3. Crop classification of study area.

3.2 Estimation of Crop Evapotranspiration ET_c

3.2.1 Computation of Reference Evapotranspiration ETo

Reference evapotranspiration is the rate from a reference, not short of water (FAO, 1998). ETo calculated for years 2007, 2008 2009 and 2010 with ground based meteorological data of study area according to Penman-Monteith equation:

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma \frac{37}{T_{hr} + 273} u_2 (e^\circ(T_{hr}) - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

where ET_o: reference evapotranspiration (mm day^{-1}), R_n: net radiation at the crop surface (MJ m^{-2} day^{-1}), G: soil heat flux density (MJ m^{-2} day^{-1}), T: mean daily air temperature at 2 m height (^0C), u_2: wind speed at 2 m height (m s^{-1}), e_s: saturation vapour pressure (kPa), e_a : actual vapour pressure (kPa), e_s-e_a : saturation vapour pressure deficit (kPa), Δ: slope vapour pressure curve (kPa $^0C^{-1}$), γ: psychrometric constant (kPa $^0C^{-1}$)

3.2.2 Estimation of crop coefficient K_c

K_c calculated for years 2007, 2008 2009 and 2010 with ground based meteorological data and field data of study area. K_{cinit}=0.14 (for cotton) taken from table. Kc for development stage derived by linear regression using the last value by initial stage and the first value of mid-season for all years. An indicative equation of linear regression is y=0.0208*-3.1095.

According to Penman-Monteith equations:

$$K_{cmid} = K_{cmid(Tab)} + [0.04(u_2 - 2) - 0.004(RH_{\min} - 45)]\left(\frac{h}{3}\right)^{0.3} \quad (2)$$

where

$K_{cmid(Tab)}$: value for K_{cmid} taken from table, u_2:mean value for daily wind speed at 2 m height over grass during the mid-season growth stage, RH_{min}: mean value for daily minimum relative humidity during the mid-season growth stage, h: mean cotton height during the mid-season growth stage.

The same procedure followed for the estimation of K_{cend} using the daily wind speed at 2 m height over grass, mean value for daily minimum relative humidity and mean cotton height for the corresponding late season growth stage.

3.2.3 Estimation of crop evapotranspiration ET_c

Crop Evapotranspiration under "standard" condition ETc is the evapotransiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water condition and achieving full production under the given climatic conditions (FAO, 1998). In FAO ET_c is calculated as follows:

$$ET_c = K_c * ET_0 \quad (3)$$

where K_c and ET_o calculated by ground based observations.

3.2.4 Estimation of crop evapotranspiration ET_c and crop coefficient K_c based on satellite data

Selection of satellite images, correction and extraction of reflectance, NDVI, ETc, Kc maps were produced for years 2007, 2008, 2009 and 2010.

Preprocessing of satellite data: The satellite data pre-processing includes the atmospheric and geometric correction of the Landsat data. The Landsat-5 TM satellite images acquired almost every 15 days (2 images per month) for the cultivation period (May to September) for years 2007, 2008, 2009 and 2010.The pixel size of images is 30 x 30 m. The atmospheric correction was done using ATCORE2 model in ERDAS IMAGINE 9.1. Geometric correction of satellite images performed to software ArcGIS with the use of 12 digital georeferred 1:50000 scale maps that cover spatial the wide area of satellite images. Over eighty ground control points (GCPs) were used for each image with a third degree polynomial equation for the geometric transformation. The GCPs were distributed in a uniform manner along the area of interest. All images were co-registered into the Hellenic Geodetic Reference System (EGSA'87) using ArcGIS software package.

Image processing: The image processing includes extraction of reflectance, NDVI, Kc and ETc maps.

Extraction of Reflectance: Reflectance in agriculture describes interaction of light with soil and crops. Satellite images provide reflectance from the various components of a crop canopy.

Extraction of NDVI: The development of vegetation indices from satellite images have facilitated the process of differentiating and mapping vegetation by providing valuable information about structure and composition. NDVI is exoressed by the folowing equition:

$$NDVI=(NIR-RED)/(NIR+RED) \quad (4)$$

For Landsat channel 3 (0.63-0.69) and channel 4 (0.76-0.90) are utilized to calculate NDVI.

Extraction of Crop Coefficient (K_c): The Kc coefficient integrates the effect of characteristics that distinguish a typical filed crop from the grass reference, which has a homogenous appearance and covers completely the ground. The values of Kc are influenced by crop type, climate, soil evaporation and crop growth stages (Allen et al., 1998; Bailey, 1990). In the framework of the PLEIADES project, an equation for Kc estimation was developed for the study area:

$$K_c = 1.15NDVI + 0.17 \tag{5}$$

Extraction of Crop Evapotranspiration (ETc): Crop Evapotranspiration under "standard" condition ETc is the evapotransiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water condition and achieving full production under the given climatic conditions (FAO, 1998). In FAO ETc is calculated as follows:

$$ET_c = K_c * ET_0 \tag{6}$$

where K_c remote sensing and ET_o ground based.

3.2.5 Error statistics

The accuracy of the remotely sensed ETc and Kc estimated series is evaluated by comparison with the corresponding ground-truth ETc and Kc estimations through four error statistics. The following statistics are employed:

$$Eff = 1 - \frac{\sum_{i=1}^{n}\left(ET_{cg} - ET_{cs}\right)^2}{\sum_{i=1}^{n}\left(ET_{cg} - \overline{ET_{cg}}\right)^2} \tag{7}$$

where equation (7) is the efficiency coefficient, ET_{cg}: ground based values of ETc, ET_{cs}: satellite based values of ETc, ET_{cg}(uperliing):mean ground based values of ETc.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{k}\left(ET_{cg} - \overline{ET_{cg}}\right)^2}{K}} \quad \textbf{(8)}$$

where equation (8) is the root mean square error (RMSE), ETcg: ground based values of ETc, $\overline{ET_{cg}}$: mean ground based values of ETc, K: number of cases.

$$BIAS = \frac{1}{N}\sum_{i=1}^{N}\left(ET_{cg} - ET_{cs}\right) \quad \textbf{(9)}$$

where equation (9) is the statistical BIAS, ET_{cg}: ground based values of ETc, ET_{cs}: satellite based values of ETc, N: number of cases.

$$r^2 = \left(\frac{\sum_{i=1}^{n}\left(ET_{cg} - \overline{ET_{cg}}\right)\left(ET_{cs} - \overline{ET_{cs}}\right)}{\sqrt{\sum_{i=1}^{n}\left(ET_{cg} - \overline{ET_{cg}}\right)^2}\sqrt{\sum_{i=1}^{n}\left(ET_{cs} - \overline{ET_{cs}}\right)^2}}\right)^2 \quad \textbf{(10)}$$

where equation (10) is the coefficient of determination r^2, ET_{cg} are ground based values, ET_{cs} are satellite based values, $\overline{ET_{cg}}$ are mean ground based values, $\overline{ET_{cs}}$ are mean satellite based values.

4 Results and Discussion

The results are summarized in Table 2 and Figures 4 and 5. Table 2 presents the error statistics results, namely efficiency coefficient (Eff), RMSE, BIAS and r^2. The results are considered satisfactory ranging within acceptable levels. Figures 4 and 5 present sample images of the analysis of Kc and ETc, respectively.

The methodology is based on new technologies (GIS combined with satellite data) for water management. Satellite data provide the cover capability of large scale areas and monitoring of crop during growth stages. Methodology can be applied in large scale areas for the calculation of Kc and extend to other crops using satellite data. New technologies provide easy access to information for all stakeholders (farmers, Irrigation Advisory Services, Local Organizations of Land Reclamation) while active participation will be effective with by spatial information and innovative networking tools.

Table 2. Results of error statistics for K_c and ET_c

Statistics	Kc		ETc	
	field 1	field 2	field 1	field 2
Eff	0.12	-0.24	0.64	0.74
RMSE	0.35	0.29	0.91	1.15
BIAS	0.08	0.01	0.06	-0.03
R^2	0.31	0.16	0.8	0.88

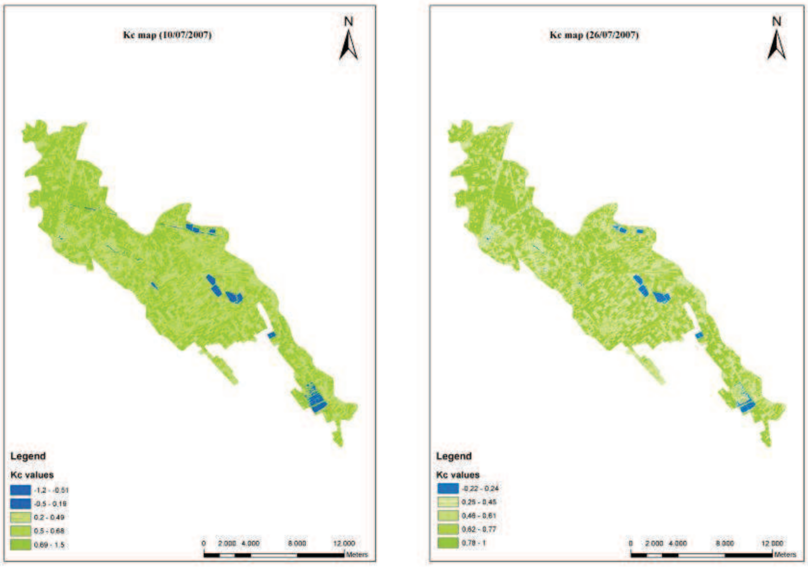


Fig. 4. Kc map of study area (10/072007 and 26/07/2007).

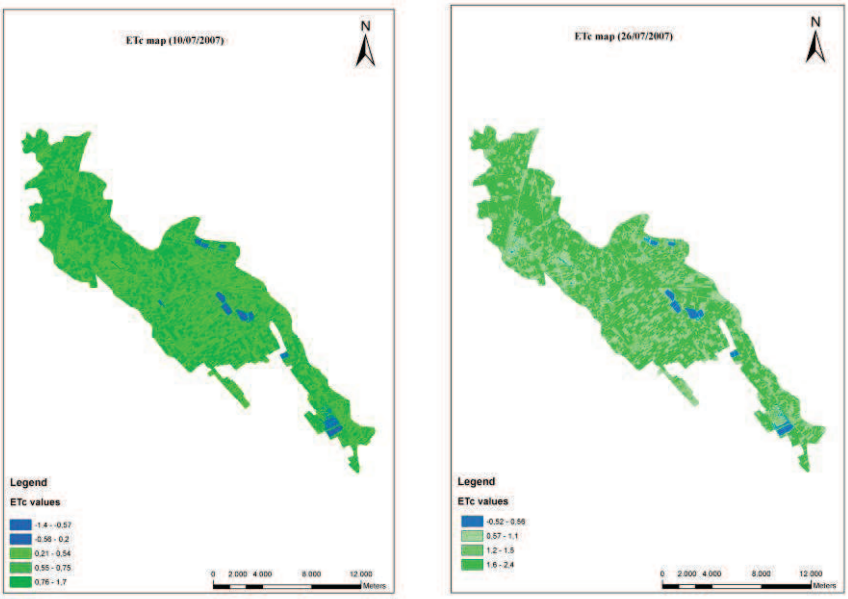


Fig. 5. ETc map of study area (10/072007 and 26/07/2007).

5 Conclusions

Crop evapotranspiration ETc is estimated and monitored in cotton fields in Thessaly, central Greece, using remotely sensed data. In particular, LANDSAT images are processed and analyzed in order to compute the Normalized Difference Vegetation Index (NDVI) and then the crop (cotton) K_c coefficient, which is used in evapotranspiration ETc equation. The method is validated by comparing ET_c estimation using ground-truth conventional meteorological data. The results are in good agreement with ground-truth observations. The results of the error statistics are considered satisfactory ranging within acceptable levels.

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