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Management and optimization of the water resources in irrigated agriculture through the use of remote sensing, agrometeorological data and information technologies

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SUMMARY – In this work we show the GEA prototype (an environmental information manager) in order to assess water deficits over the irrigated crops of large areas. The proposed solution consists of evapotranspiration and water deficit estimations from remote sensing and agrometeorological information. The designed prototype is composed of three modules: (i) a geostatistical module, which generates precipitation and reference evapotranspiration maps from measurements collected in agrometeorological stations; (ii) an image processing module, which processes remote sensing images (Landsat) in order to derive canopy parameters and real evapotranspiration following the "two-steps" FAO method, where the crop coefficient is obtained from remote sensing data and an empirical relationship proposed by the Instituto de Desarrollo Regional IDR of the Universidad de Castilla-La Mancha; and (iii) a module which uses information technologies to develop the GEA on-line application, which allows the user to define regions of interest, real-time consulting of water deficits, elaboration of reports and image downloading, as well as a creation of a historical database or the configuration of alarms for situations of water stress. This prototype has been funded by the GESTA program of IMPIVA (Comunitat Valenciana) and FEDER funds.

Key words: GEA, remote sensing, water resources, water management, water deficit, evapotranspiration, irrigation advisory service.

Introduction

Management and optimization of the water resources in agriculture has been recognized as a technical problem in the Community of Valencia (Spain), which is a vulnerable region to drought. Irrigated agriculture is the main consumer of freshwater in large parts of the world. Therefore, it is the key strategic focus for efficient water use. Accordingly, the concept of irrigation modernization has evolved over the years from the mere introduction of new technical infrastructure and equipment towards a more holistic concept including measures to optimize water application. Such a system now includes also tools to generate information on most efficient water use and mechanisms to transmit this information to farmers and water manager (Osann Jochum *et al.*, 2006). Earth Observation data in combination with Geographical Information Systems (GIS), is naturally destined to fill such need. In parallel, last-generation Information and Communication Technologies (ICT) open vast possibilities to transmit spatialized information to users in a personalized way using internet (Calera *et al.*, 2005; Martín de Santa Olalla *et al.*, 2003). An operational irrigation advisory service has been developed in the context of DEMETER project (Osann Jochum *et al.*, 2006), using a relationship between vegetation indices and the crop coefficient (González-Piqueras, 2006).

The Earth Observation Laboratory (EOLAB) is a spin-off from the University of Valencia (Spain), which is involved in the operational production of biophysical products from remote sensing, and it has developed a new system denoted as GEA. The key feature of GEA is the operational generation of remote sensing products related to vegetation and water needs and their delivery to users in near-real-time using leading-edge online analysis and visualization tools. The products delivered by GEA are water deficit (in mm), obtained as a balance between precipitation and evapotranspiration. GEA also provides additional remote sensing products of interest in agro-environmental studies (fractional vegetation cover, leaf area index). We describe in the following the procedures, products and results obtained in the development of the GEA system.

Description of GEA

GEA prototype has been developed to derive crops agronomical parameters and water requirements, following the Kc-ET_0 "two-steps" methodology proposed by the Food and Agriculture Organization of the United Nations (FAO), where Kc is the crop coefficient and ET_0 the reference evapotranspiration. GEA is composed by three modules, all together providing efficient solutions to the problem of operational estimation of crops water requirements from space over large areas. A scheme of the prototype is illustrated in Fig. 1, and a description of each module is given bellow.

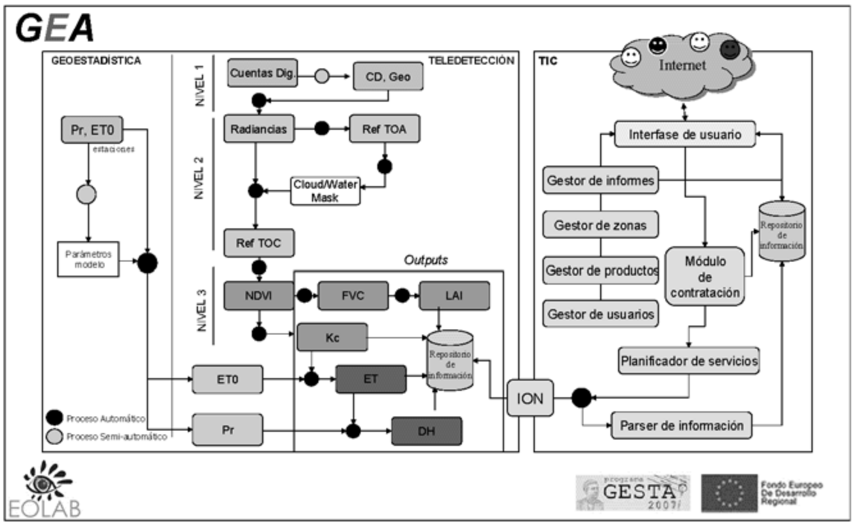

Fig. 1. Flowchart of the GEA prototype.

Module 1: Geostatistical techniques

This module spatializes rainfall (Pr) and ET_0 data collected in agrometeorological stations (operated by the Agrarian Institute of Valencia, IVIA), with the proper resolution and projection to be used in the remote sensing module (Module 2). These maps are obtained applying the geostatistic technique denoted as kriging (Martínez, 2006). Figure 2 shows the different agrometeorological stations included in the study area and examples of Pr and ET_0 maps obtained with the kriging technique at a spatial resolution of 30 m.

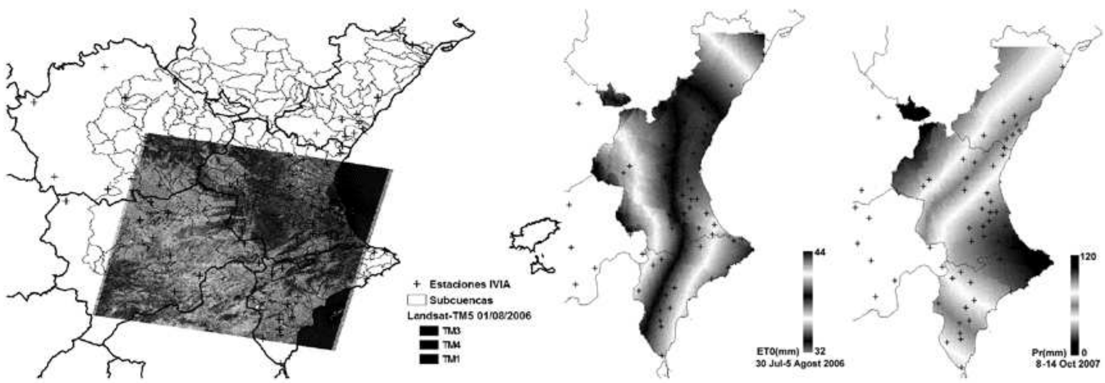

Fig. 2. Agrometeorological stations provided by the IVIA overplotted to a Landsat TM-5 image acquired the 1st of August, 2006 (left), and examples of ET_0 (center) and Pr (right) maps obtained with the kriging technique at a spatial resolution of 30 meters.

Module 2: Remote sensing and image processing

This is the main module of GEA, since it processes the satellite image to obtain evapotranspiration (ETc) and water needs (DH) products, jointly with other agronomical products of interest (NDVI, Fractional Vegetation Cover, Leaf Area Index, Crop Coefficient). The module transforms the satellite image in digital counts (level 1) into cloud-free Top-Of-Canopy Reflectance (level 2). After that, level 2 data is used to generate level 3 biophysical products (NDVI, FVC, LAI, Kc) and finally level 4 hydrological products (ETc and DH) are derived combining level 3 products with the agro-meteorological information. Figure 3 shows some examples of the different products obtained from remote sensing data acquired with the Landsat TM5 sensor.

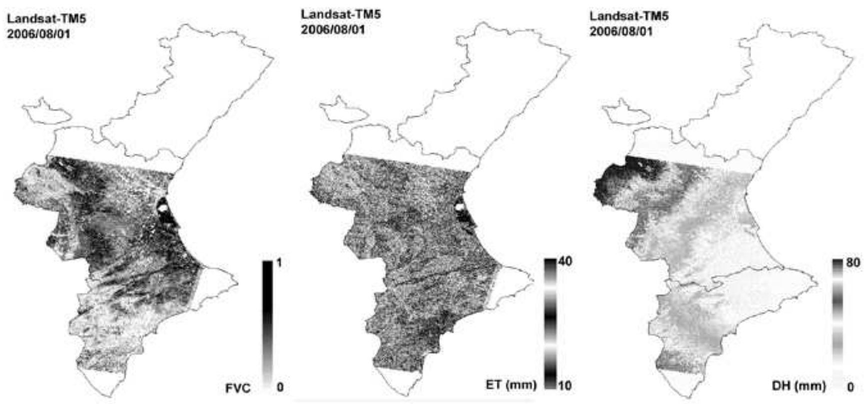

Fig. 3. Examples of the different products derived by GEA based on remote sensing data (Landsat TM5): Fractional Vegetation Cover (FVC), Crop Coefficient (Kc), Evapotranspiration (ETc) and Water Needs (DH). The example of Water Needs is generated using a precipitation map for the first week of October, with important rainfalls in Valencia and Alicante.

The processing chain implemented into the GEA system to estimate level 2, level 3 and level 4 products have been obtained using operational algorithms published in the scientific literature. Details of level 2 and level 3 algorithms will not be given in this communication for simplicity (see Camacho *et al*., 2008 for further details). To estimate water needs from space, the critical step is the estimation of the Crop Coefficient from optical remote sensing data. González-Piqueras (2006) found a linear relationship between the NDVI and Kc, which is the base for monitoring Kc from space. The linear relationship was calibrated over more than 1300 samples of irrigated crops located in Albacete. This relationship has been found suitable for different crops, over the full phenology cycle, and with different vegetation coverage. Once the Kc has been obtained, the FAO56 (Allen *et al*., 1998) method is used. The evapotranspiration (ETc) is then computed as the product of Kc and ET_0, where the ET_0 is the reference evapotranspiration obtained from the agrometeorological stations. ETc is the crop evapotranspiration in optimal conditions. Finally, the water need is obtained using a simplified hydrological balance, considering an effective precipitation, which is the 70% of the total precipitation (López-Urrea, 2004).

Figure 4 shows some results obtained in the evaluation of the accuracy of the different products. One of the most critical steps in the image processing is the atmospheric correction of the remote sensing data, which has been proved to be satisfactory when comparing with other sophisticated methods as the one used by the IDR in the framework of the DEMETER project (RMS<0.07). Errors on Fractional Vegetation Cover (FVC) and Leaf Area Index (LAI) are around 0.1 and 0.2 respectively, which agrees with accuracies published in scientific journals, and demonstrate the reliability of the processing chain.

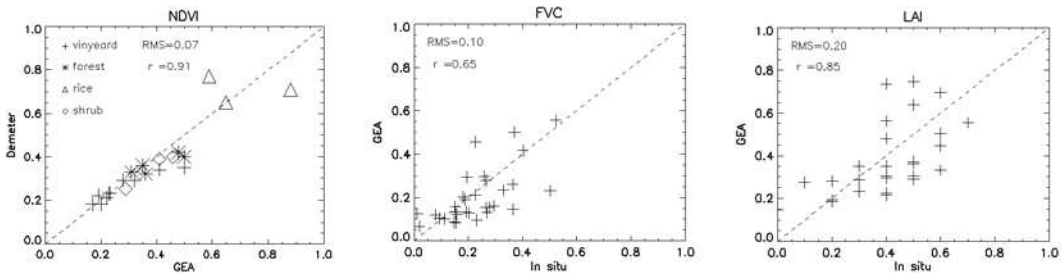

Fig. 4. Evaluation of the atmospheric correction in terms of NDVI (left). Comparison between Fractional Vegetation Cover (FVC) (middle) and Leaf Area Index (LAI) (right) GEA products and in-situ values.

Module 3: Information and communicaton technologies

The ICT module in GEA is called GeNeW, and it provides a management of the information and offers to the user the possibility of selecting regions of interest, contracting the services and acceding to the information. GeNeW is developed according to WEB 2.0 standards, using AJAX as the tool for the development and integration. For visualizing GIS information, the Google Maps API has been used. Figure 5 shows how GEA application looks like via web.

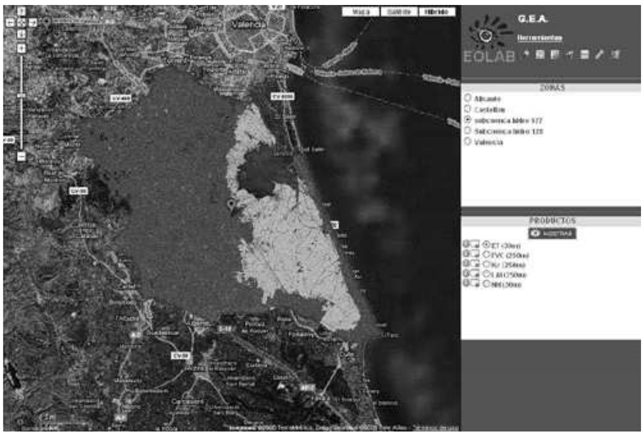

Fig. 5. GEA interface. The user can select a region of interest based on Google Maps or introducing a shape file (in the figure the Jucar hydrological sub-area 128 is shown). The menu on the right allows to the user selection of the product (see examples of products in Fig. 3). In the figure the ETc product is shown. Rice fields at La Albufera show the highest values.

Summary and conclusions

Management and optimization of the water resources in irrigated agriculture has become an important concern for local and regional authorities. The use of remote sensing data certainly provides a significant contribution to estimate water deficits for large agricultural areas. In this framework, EOLAB has developed the GEA prototype, capable of providing near real time information to users. At this moment Landsat TM5 images are being used as input data, which provides a spatial resolution of 30 meters, suitable for local studies. EOLAB is also developing and implementing into the GEA system the processing chain for MODIS data, with a spatial resolution of 250 meters, suitable for regional applications.

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