# EARTH OBSERVATION TECHNOLOGIES TO IMPROVE IRRIGATION ADVISORY SERVICES

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**Abstract**

*Irrigation Advisory Services (IAS) are the natural management instruments to achieve a better efficiency in the use of water for irrigation. IAS help farmers to apply water according to the actual crop water requirements and thus, to optimize production and cost-effectiveness.*

*The project DEMETER (DEMonstration of Earth observation Technologies in Routine irrigation advisory services) aims at assessing and demonstrating how the performance and cost-effectiveness of IAS is substantially improved by the incorporation of Earth observation (EO) techniques and Information Society Technology (IT) into their day-to-day operations. EO allows for efficiently monitoring crop water requirements of each field in extended areas. The incorporation of IT in the generation and distribution of information makes that information easily available to IAS and to its associated farmers (the end-users) in a personalized way.*

*This paper describes the methodology and first results.*

# 1 INTRODUCTION

Irrigation agriculture is the main water consumer in Europe (88% in Greece, 72% in Spain, 59% in Portugal) and in large parts of the world. Therefore, it is the key strategic focus for efficient water use. Policy directives (Water Framework Directive, National Water Plans, National Irrigation Plans) and the corresponding administrations are calling for tools to aid in sustainable water management and for operational monitoring systems to assist in planning and control of water resources.

Irrigation Advisory Services (IAS) are the natural management instruments to achieve a better efficiency in the use of water for irrigation. IAS help farmers to apply water according to the actual crop water requirements and thus, to optimize production and cost-effectiveness. Member States and the Commission have recognized the strategic importance of IAS in sustainable water management and have initiated a process of generalized creation of IAS in Europe.

IAS provide the farmers with irrigation scheduling information, expressed in crop water requirements for different crops. The current methodology used by IAS for this purpose is generally based on the standards recommended by the FAO (Allen et al., 1998). This method, also called the crop coefficient approach, consist of two parts. Firstly, reference evapotranspiration ($ET_0$) is obtained from measurements of the IAS agrometeorological station. Secondly, the crop coefficient is determined from calibrated look-up tables and field observations of the crop pheonological state across the IAS area. Potential evapotranspiration is then obtained from multiplication of these two quantities. In the final step, crop water requirement is calculated as the difference between observed precipitation and potential evapotranspiration (Allen et al., 1998).

The irrigation scheduling information is then transferred to the end-user, the farmer, in various ways (Martín de Santa Olalla et al., 1999; Calera Belmonte et al., 1999).

Current IAS are labor- and cost-intensive, yet unable to cover each field in extended areas at regular short time intervals. Earth observation (EO) is naturally destined to fill such a gap. In parallel, the new information technologies offer possibilities to improve the information flow from the IAS to the farmers, using internet and mobile telephones. The introduction of these new technologies also helps to create value-added employment opportunities in rural environments.

This work aims at assessing and demonstrating how the performance and cost-effectiveness of IAS is substantially improved by the incorporation of Earth observation (EO) techniques and Information Society Technology (IT) into their day-to-day operations. It is based on the project DEMETER (DEMonstration of Earth observation TEchnologies in Routine irrigation advisory services), which is simultaneously implemented in pilot zones in Spain, Italy, and Portugal.

Current IAS is based on traditional (non-remote-sensing) data sources, although the use of land-use maps derived from remote sensing has become rather common. But the day-to-day estimates of crop water requirements are still performed on the basis of agrometeorological station and field data. Various studies have demonstrated the feasibility and the potential of using EO data in irrigation advisory (Montesinos and Castaño, 1999). Yet, EO has not been used operationally in that area for three main reasons and limitations:

* the lack of adequate time-space resolution of satellite imagery for IAS needs;
* the lack of mature EO-derived products that match directly the IAS operations,
* aspects related to the adequate and easy-to-use information for the farmer.

As expressed by Bastiaanssen et al. (2000), these limitations arise from the fact that “remote sensing is essentially a research tool and is rarely applied in the management of irrigated agricultural systems either at a local scale or nationally. Two main reasons for this gap may be identified: first, it is 'supply driven' by the research community which basically implies that researchers have influence on the sensor design and flight characteristics (e.g. revisit period, spatial resolution). These decisions not necessarily respond to the needs of practitioners in the field of water resources. Second, discussions with water managers and policy makers have revealed that this community is quite often unaware of the new technical possibilities, partly because the discussion about remote sensing remains within remote sensing community”.

The objective of the project DEMETER (DEMETER, 2002) is to develop and demonstrate innovative solutions to overcome each of these three obstacles, while establishing mechanisms of permanent dialogue between scientific-technical system developers and representative users. This paper describes briefly the corresponding solutions (sections 2-4) and summarizes the overall concept and expected improvements.

# 2 METHODOLOGY TO OBTAIN THE REQUIRED SPACE-TIME RESOLUTION

The IAS user requirements were assessed in the precursor project LISSE (Land Irrigation Support SErvice) (Moreno et al., 2002). The results clearly indicate the need for time-series of maps of various parameters (crop coefficient, etc., see section 3) at a spatial resolution of 10-30 meters. This resolution allows for identifying plots of 1000-10000 $m^2$, which cover the size ranges most frequently found in irrigated agriculture. Irrigation advisory cycles of one week determine the required temporal resolution.

The currently available high-resolution satellites (Landsat, Spot, IRS, and ASTER) offer a spatial resolution of 15-30 m, which matches very well the resolution requirements of IAS

(Table 1). Recently launched very-high-resolution satellites (like Ikonos and Quickbird), with their resolution of 1-5 m, offer the potential of monitoring smaller size fields and within-field structures for the purpose of precision agriculture.

Each high-resolution satellite has a repeat cycle of 14-25 days (Table 1). Taking into account the potential presence of clouds, the resulting revisit time of any given area would be clearly insufficient for operational IAS purposes.

The key to obtaining adequate temporal resolution is in using the full set of all currently available high-resolution satellites. The joint use of data from different satellites requires inter-satellite cross-calibration. A multi-temporal data synthesising procedure was developed by Calera et al. (2001) for this purpose. It uses synchronous or near-synchronous imagery from different sensors over the same area, such that directional effects are small and can be neglected. Calera et al. (2001) have shown that reflectances and, especially, vegetation indices, obtained from different spectral bandwidth bands of different sensors, set to different spatial scales, can be compared with high reliability by means of linear relationships.

Another important aspect in the treatment of time-series of images from different satellites is the atmospheric correction. The current procedures often use data from numerical weather prediction models (NWP) for that purpose. However, the vertical profiles of water vapor are frequently affected by errors introduced by the moisture assimilation process, especially in semiarid mountainous landscapes and areas close to coastlines (Jochum et al., 2002). These errors propagate into the derived parameters, causing errors of up to 15% in the surface reflectance, for example. Therefore, a combination of data from operational radiosondes with a high-resolution numerical model is used here.

Changes in the solar illumination geometry and the observation angle of the sensors are another likely source of error. In order to maintain this error small (and to avoid dealing with BRDF), the admissible ranges of illumination and observation angles are defined such as to minimize these effects and EO-derived parameters are selected, that are most insensitive to these effects.

Table 1. Sampling characteristics of EO satellites used in this work. VIS: visible; NIR: near-infrared; SWIR: short-wave infrared; TIR: thermal infrared.

| *Satellite* | *Repeat cycle* | *Image size* | *Bands (number)* | *Spatial resolution* |
|---|---|---|---|---|
| ASTER | 16 d | 60km x 60km | VIS (2)<br>NIR (1) | 15 m |
| | | | SWIR (6) | 30 m |
| | | | TIR (5) | 90 m |
| IRS-C | 24 d | 142km x 142km | VIS (2)<br>NIR (1) | 23 m |
| | | | SWIR (1) | 70 m |
| IRS-D | 25 d | 148km x 148km | same as IRS-C | |
| Landsat 7 | 16 d | 185 km x 185 km | VIS (3)<br>NIR (1)<br>SWIR (2) | 30 m |
| | | | TIR (1) | 60 m |
| Spot 1, 2, 3 | *) | 60km x 60km | VIS (2)<br>NIR (1) | 20 m |
| Spot 4 | *) | 60km x 60km | VIS (2)<br>NIR (1)<br>SWIR (1) | 20 m |

*) The orbit pattern of SPOT1, 2, 3 and 4 is repeated every 26 days. The frequency varies with latitude.

# 3 PRODUCT LINE AND METHODOLOGY TO DERIVE PRODUCTS FROM EARTH OBSERVATION

Selecting the right EO products may sound trivial, but strategic EO product definition is the second key to successfully introducing EO operationally in IAS.

Current IAS are based on the FAO methodology. One important step to propagate the use of EO in IAS is obviously to match the EO-derived products to the exact needs of the IAS. Thus the basic EO-derived products are maps of crop coefficient, $K_c$, which can be incorporated directly into the day-to-day operational irrigation advisory procedure, requiring only minimal adjustments of the current operational procedure. It brings the advantage of better spatial coverage (extent of the area, spatial resolution) at less cost and effort. Note that field work is still considered necessary, but the amount can be greatly reduced and the gain of spatial resolution and coverage is substantial.

The simplest approach to derive the crop coefficient $K_c$ from EO data is straightforward to implement. It uses a linear relationship between NDVI (Normalised Differences Vegetation Index) and $K_{c..}$ NDVI is obtained from bands of red and near infrared reflectances, which are available from all high-resolution satellites (Table 1). Moran et al. (1997) conclude that this approach is one of the most promising ways for operational application. Furthermore, the use of NDVI supports the cross-calibration between different satellites, since NDVI values from the different sensors show the best correlations (Calera et al., 2001; Teillet et al., 2001)

A field validation campaign for this method was performed in maize during the entire growing cycle in 2001. The spectral response was measured by means of a spectroradiometer GER3700 with a range of 300-2300 nm. The NDVI was derived from the simulated Landsat7-ETM+ bands. The basal crop coefficient, Kcb, was measured regularly in the field. Kcb is defined as the ratio of crop evapotranspiration and reference evapotranspiration in dry soil conditions, according to the FAO methodology (Allen et al., 1998). Thus Kcb represents the crop coefficient component that corresponds to transpiration. Figure 1 shows the temporal evolution of Kcb and NCVI and their very similar behavior.

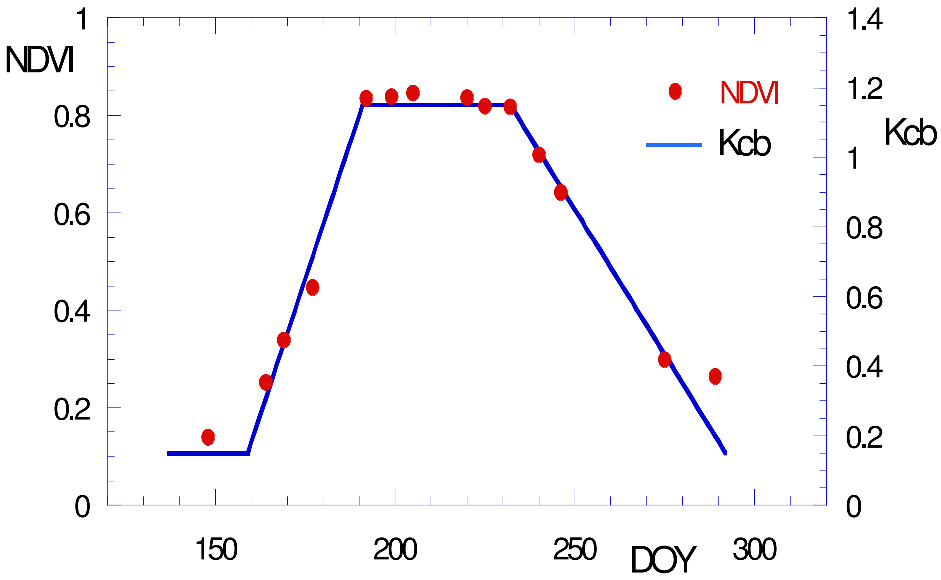


Figure 1. Temporal evolution of crop coefficient Kcb and of NDVI in maize during 2001 growing season. DOY denotes day of year.

In a second step, DEMETER provides EO-derived advanced products, which are considered useful by many IAS and which may be incorporated in next-generation IAS. Table 2 gives a list of parameters considered and classifies them into three levels (basic, advanced, and potential), depending on the maturity of the corresponding EO methods on one hand and on the readiness of IAS to introduce them on the other. Most of these products can be derived from NDVI, using mature EO methodology (d'Urso, 2001). The irrigation performance indicators were developed for the purpose of monitoring the efficiency of water use (Menenti, 2000). Their application to pilot catchments in Spain and Portugal has show great promise (Montesinos y Castaño, 1999). The potential products, like crop water content, are aiming at fine-tuning the irrigation scheduling and thus at achieving a maximum efficiency of water use. The users have shown high interest in them, although the methodology is still in the research and development stage.

Table 2. Specification of DEMETER products.

| ***product level*** | ***parameter*** |
|---|---|
| Basic | Crop coefficient Kc (from NDVI) |
| Advanced | Kc (analytical approach)<br>Green ground fractional cover<br>Leaf area index (LAI)<br>Fraction of absorbed photosynthetically-available radiation (fAPAR)<br>Accumulated (dry) biomass<br>Irrigation performance indicators (IPI):<br>IPI1 water vs. cropped area<br>IPI2 water vs. crop water requirement<br>IPI3 marginal benefit of water |
| Potential | Water stress indicator (water index)<br>Canopy water content<br>Evaporative fraction |

# 4 INFORMATION TRANSMISSION

The basic mission of IAS is to generate maps of crop water requirements for irrigation scheduling and to distribute that information to the users, either in personalized mode or of free access to the general public. A fully developed current IAS has a telecommunications component, which operationally distributes and disseminates the information to the farmers, using printed and other media as well as telephone and increasingly internet (see, e.g., http://www.itap.es).

The use of EO products in IAS, integrated into a Geographical Information System (GIS), allows for generating digital maps of crop water requirements, as discussed in the previous section. Now, these maps can be used to distribute irrigation scheduling information in the traditional way. Yet at the same time, they offer the opportunity to modify the entire system and procedures of information generation and distribution at the IAS, opening the door to a wide range of improvements.

Considering the IAS as the key "information broker", a new IT component has been defined, again based on the user requirements obtained from the LISSE and similar projects (Moreno et al., 2002). Two areas of improvement are especially emphasised. Firstly, there is great interest in increasing the information content (at the IAS and to the farmer) by including, e.g., a wide range of meteorological and climatological information. Secondly, more flexible and comprehensive distribution and dissemination tools are considered vital. The new IT component consists of three modules.

The first module ("EO-data Integration Module") takes care of the integration of the EO-derived data products into the GIS of the IAS area and from there into the operational input data stream of the IAS, where crop water requirements are calculated and irrigation scheduling information is generated.

The second module creates a novel "Information-Decision Interface" at the IAS. This tool serves as an information connector, capable of acquiring spatial and non-spatial data from networked sources and of integrating these into an advanced information visualisation display. In addition to the classical IAS information (agrometeorological station data, phenological data from field work), the data and information sources considered here include all kinds of meteorological data, like local station data, weather satellite images, reference climate data, rainfall radar data, last 24-hours rainfall, seasonal accumulated precipitation maps, and short- and medium-term weather forecast maps.

The third module ("Information Distribution Module") addresses the distribution and dissemination of the information to the farmers (end-users). Two ways are considered here: one a personalised service to each associated or registered farmer (as a customer receiving information specifically tailored to his fields and needs) and the other of general access to the public. Internet is conceived as one alternative. For a more flexible service, the use of wireless communications is envisioned, e.g., to mobile phones or PDAs with specifically designed front-end for quick and easy information visualisation and retrieval. The new technology provides an opportunity to redefine the interface between the IAS and its users. The concept of "local premium users" is introduced here, which can be either Irrigation Users Associations or other local farmers' associations or farm cooperatives. These users would receive personalized information tailored to their needs and training on best farming practices to use that information.

# 5 THE IT-AND-SPACE-ASSISTED IRRIGATION ADVISORY SERVICE (E-SAIAS)

Figure 2 shows schematically the flow of data and information in the new IT-and Space-assisted Irrigation Advisory Service (e-SaIAS) model. The incorporation of state-of-the-art information technology gives rise to a qualitative and quantitative jump in the information supply to the farmer. It allows for transmitting not only the traditional irrigation scheduling information in improved and personalized form, but also a wide range of additional information, e.g. on past, present, and future weather, that is of relevance to the farmer. Table 3 summarizes the main aspects of improvement.

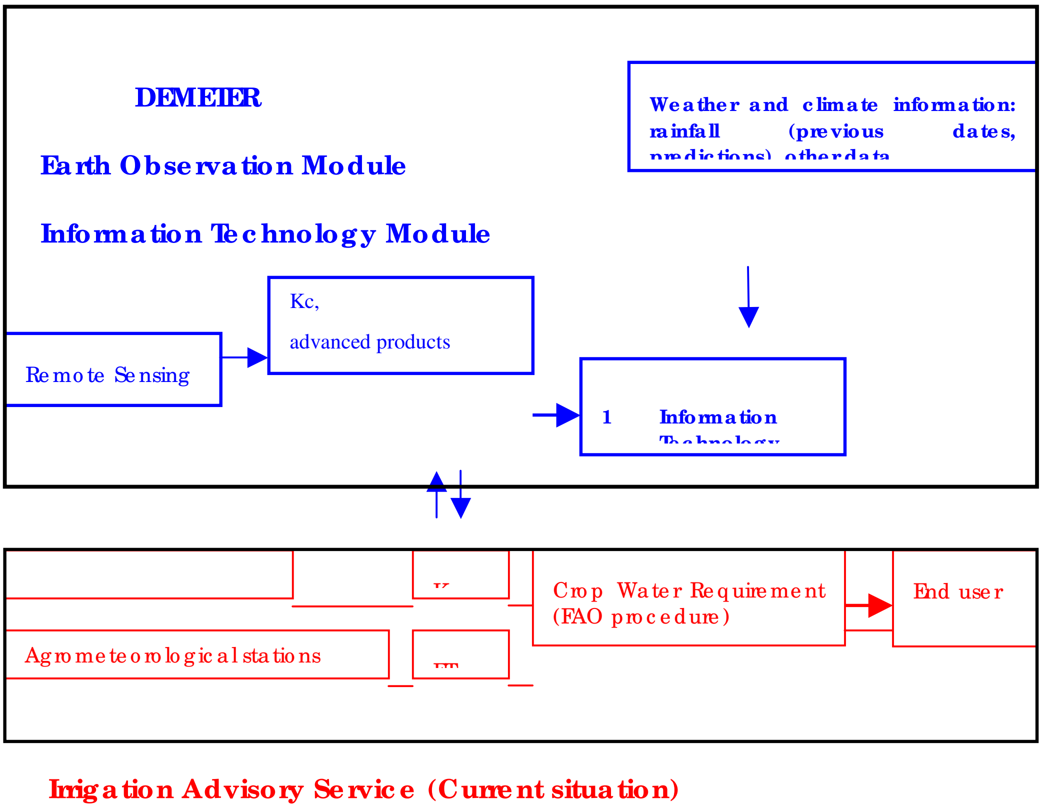


Figure 2. Concept and functioning of the new IT-and-Space-assisted Irrigation Advisory Service (e-SaIAS).

Table 3. Areas of expected improvement in IAS after integration of IT and EO technologies.

| | *Current IAS* | *e-SaIAS* | *Improvement* |
|---|---|---|---|
| Generation of products | Monitoring of selected pilot plots by means of expensive field work. | Monitoring and mapping of extended areas.<br>Monitoring of all individual plots or even within plots. | Personalized information for each farm at no extra field work effort;<br>Allows for irrigation monitoring and control in water-scarce areas. |
| Product line | Crop water requirements. | Crop water requirements;<br>Green vegetative fraction, LAI, fAPAR, Biomass;<br>Irrigation performance indicators;<br>Crop water status | Enhanced quality and quantity of products;<br>Advanced geo-referenced products for precision agriculture;<br>Improved water use efficiency. |
| Information transmission | Bulletins, Media, Telephone, and Internet | Bulletins, Media;<br>Emphasis on Internet, mobile phones, and PDAs;<br>Local "premium users". | Integrates value-added information from other sources (meteorology, pests, treatments...);<br>Creates employment opportunities for qualified professionals in rural environments. |

# 6 CONCLUSIONS AND PERSPECTIVES

Earth observation technology has attained a level of maturity that allows for integrating it into the day-to-day operations of Irrigation Advisory Services (IAS). The expected improvements include a more efficient use of water for irrigation, which is the main water consumer. IAS are considered to be one of the key instruments for water management in a sustainable agriculture.

Accordingly, a prototype of the new IT-and-Space-assisted IAS is being implemented in three pilot zones in Spain, Italy, and Portugal, in the framework of the project DEMETER (DEMETER, 2002). These pilot zones have different climate, crops, irrigation infrastructure and administration, cultural, and socio-economic conditions. Together they are highly representative of Mediterranean agriculture. The first pilot campaign is conducted in the growing season of spring-summer 2003.

# 7 ACKNOWLEGMENTS:

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