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The irrigation advisory plan of Campania Region: from research to operational support for the water directive in agriculture

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Abstract. The Irrigation Advisory Plan of Campania Region is an initiative of the Assessor for Agriculture and Productive Activities, through the Research and Development Service (Se.S.I.R.CA); it consists of an innovative advisory service for irrigation, based on the combined use of Earth Observation data, GIS and Information Technology to provide crop water requirements information from the field scale (>1 ha) to the irrigated basin scale (3000 ha). This initiative, which is perfectly aligned with the recommendations of European Union through the Water Directive n. 60/2000 has been tailored to improve the water use efficiency not only at farm level, but also at the district scale, with tangible benefit for the economy of primary sector and environmental protection. The personalized information provided to farmers and irrigation managers consist of the maximal irrigation volumes to be applied on a weekly basis and the duration of irrigation. This information is sent within 36 hours from the satellite acquisition to each farmer via SMS, MMS and E-mail; in addition a dedicated Web-GIS has been developed to monitor irrigation advice at district level.

Keywords. Crop water requirement – Earth Observation – Advisory service in irrigation.

Plan d'Assistance de l'Irrigation dans la Région Campania : exemple de transfert des résultats de la recherche pour supporter l'application de la Directive Européenne sur l'Eau en agriculture

Résumé. *Le Plan d'Assistance de la Région Campania est une initiative du Secteur de l'Agriculture et des Activités Productives du gouvernement régional. Il s'agit d'un service d'assistance au pilotage de l'irrigation, utilsant des donnés d'Observation de la Terre, le SIG et les Technologies de l'Information. Ces instruments sont appliqués pour obtenir la demande en eau des cultures à l'échelle de la parcelle (>1 ha), jusqu'au niveau du secteur de distribution collectif (3000 ha). Ce projet, qui s'aligne aux indications de l'Union Européenne – Directive n. 60/2000, a été conçu pour améliorer l'efficacité de l'irrigation, avec effets positifs sur l'économie de l'entreprise agricole et l'environnement. L'information fournie est personnalisée et indique la quantité maximale d'eau à appliquer en une semaine et la durée de l'application. Cette information est distribuée par SMS, MMS et E-mail dans 36 heures après le passage satellitaire.*

Mots-clés. *Evapotranspiration – Observation de la Terre – Assistance à l'irrigation.*

I – Introduction

During recent years, Earth Observation techniques are more and more transferred to applications for supporting land and water management. In this paper, we present an operational procedure for improving the efficiency of irrigation at farm and district level, built on the integrated use of Earth Observation data and Information Communication Technologies (I.C.T.). By using irrigation advices based on the actual development of the canopy, it is possible to monitor the maximum water demand for irrigation and to achieve an improvement in the application efficiency. The prototype of this methodology has been developed by a consortium of European research institutions in three irrigated areas in Spain, Italy and Portugal within the EU-funded project "DEMETER" (http://www.demeter-ec.net/) and further extended to other areas within the "PLEIADeS" project (http://www.pleiades.es).

Since 2007, the procedure has been implemented operationally in 4 irrigation districts in the Campania Region, Italy; during 2008, it has reached 150 farmers with an irrigated surface of over 3000 ha. This project represents a further step for the implementation of E.U. Directive n.60/2000 in the agricultural sector of this region.

II – Modeling approach

The theoretical background for the estimation of crop water requirements from satellite data adopted in this study is based on the standard method of F.A.O.-Paper 56 (F.A.O., 1998), i.e. the so-called “one-step” approach. This method calculates the maximum evapotranspiration of ETp of a canopy under stardard conditions i.e. unlimited soil water availability, pest and disease-free crop, by using appropriate values of canopy variables such as the surface albedo α and the Leaf Area Index (LAI). In this c ase, assuming a minimum stomatal resistance of 100 sm-1 (Monteith *et al.*, 1990; Kelliher *et al.*, 1995) the value of ETp can be calculated from the following equation:

$$ET_p = \frac{86400}{\lambda}\left[\frac{s\left(1-0.4e^{-0.5LAI}\right)\left(1-\alpha\right)\left(K^{\downarrow}+L^{*}\right)+c_p\,\rho_a\left(e_s-e_a\right)U/124}{s+\gamma\left(1+U/0.62\,LAI\right)}\right]\text{(mm/d)} \quad (1)$$

where $K^{\downarrow}$ is the incoming solar radiation and U the wind speed. The other variables, namely L^* (net longwave radiation), c_p (air specific heat), ρ_a (air density), (es−ea) (vapour pressure deficit), λ (latent heat of vaporisation of water) and γ (thermodynamic psychrometric constant) are calculated from measurements of air temperature and humidity at a ground-based meteo station. Equation is valid under conditions of high solar irradiance (typical summer condition in Mediterranean climate) and for LAI>0.5; adaptations might be needed under different climatic conditions. This equation can be applied by using ground-based meteorological data and satellite-based estimation of the two canopy parameters needed for the calculation, namely the surface albedo α and Leaf Area Index (D’Urso *et al.*, 1995; 2006).

Simplified methods are available to estimate surface albedo α and Leaf Area Index from satellite-based surface reflectance with satisfactory accuracy for the present application. Broad-band sensors in the visible and near-infrared, i.e. Landsat, SPOT, IRS, Terra-Aster, have been intensively used for deriving maps of α and *LAI*. A combination of different satellites can be found to define a “virtual constellation”; so doing it is possible to achieve a revisit time of 7-10 days, in order to adequately follow the phonological development of crops during the irrigation season.

For the estimation of α from Earth Observation data we need to solve three main problems: the directional integration of spectral radiance detected by the sensor, the spectral integration to obtain the planetary albedo, that is at top-of-atmosphere height, and the correction of atmospheric effects in each spectral band for deriving the surface albedo. The current sensor capabilities (broad-band, near-nadir view) impose several simplifications. Considering that radiance measurements are performed at different wavelengths, the spectral integration is approximated in discrete form, as expressed by the following relationship (Menenti *et al.*, 1989):

$$\alpha = \pi\int_0^{\infty}\frac{K^{\uparrow}(\lambda)}{K^{\downarrow}(\lambda)}d\lambda \cong \pi\sum_{\lambda_1}^{\lambda_n}\frac{K_{\lambda}\left(d^0\right)^2}{E_{\lambda}^0\cos\vartheta^0} \quad (2)$$

In Eq. (2) the spectral radiance reflected from the surface, $K^{\uparrow}_{\lambda}$ (W m^{-2}), and the extraterrestrial solar irradiance, E^0_{λ} (xW m^{-2}), are integrated values over the width of each spectral band λ_i; θ^0 and d^0 are respectively the solar zenith angle and the sun-earth distance in Astronomical Units. By grouping these quantities in a set of band-coefficients (which are sensor-dependent), Eq. can be simplified in the following expression:

$$\alpha = \sum_{\lambda} w_{\lambda} \rho_{\lambda} \qquad \lambda = 1,2,....,n \tag{3}$$

where $\rho\lambda$ represent the spectral reflectance (corrected for atmospheric effects) in the generic band. The coefficients $w\lambda$ can be calculated for each sensor type and applied to calculate α for the given image acquisition (D'Urso *et al.*, 2006).

Simple and feasible approaches based on empirical relationships between *LAI* and nadir-viewing measurements in the red and infrared bands has been have been defined by several authors. These methods implicitly assume that all other factors, except *LAI*, influencing the spectral response of canopy are fixed. In the DEMETER and PLEIADES projects, we have used the model CLAIR (Clevers, 1989), based on the *Weighted Difference Vegetation Index* (*WDVI*) which is defined as follows:

$$WDVI = \rho_i - \rho_r \frac{\rho_{si}}{\rho_{sr}} \tag{4}$$

where ρ_r and ρ_i indicate the reflectance of observed canopy in the red and infrared bands respectively, while ρ_{sr} and ρ_{si} are the corresponding values for bare soil conditions; the ratio ρ_{si}/ρ_{sr} can be takes as a constant, in analogy with the "soil line concept" (Baret *et al.*, 1993). The WDVI index has the advantage to reduce to a great extent the influence of soil background on the surface reflectance values; diversely, it is quite sensitive to the atmospheric effects, thus it requires a reliable radiometric correction. The LAI is related to WDVI of the observed surface through the expression:

$$LAI = -\frac{1}{\omega} \ln \left(1 - \frac{WDVI}{WDVI_{\infty}} \right) \tag{5}$$

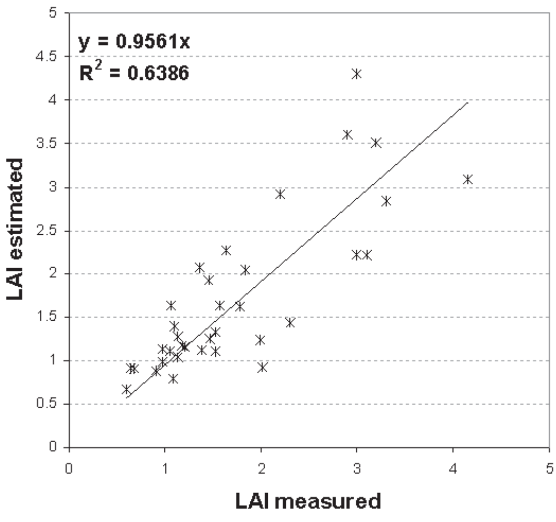

Figure 1. Validation of empirical estimation of LAI on the basis of field measurements on different crop types, Sele River Plain, Italy. Eq.(6) has been applied with ω =0.33; $WDVI_{\infty}$ =0.55 and ρ_{si}/ρ_{sr} =1.11.

In Eq.(5), ω is an extinction coefficient to be determined from simultaneous measurements of LAI and WDVI; $WDVI\infty$ is the asymptotical value of WDVI for $LAI\rightarrow\infty$. This approach has been validated by field measurements and by means of numerical models simulating the reflectance of leaf and canopy in a wide range of conditions in different sites (D'Urso *et al.*, 1995). By using independent measurement data-sets collected during several field campaigns, calibration and validation of Eq.(6) has been carried out (fig.1).

When a more complete radiometric information is available, i.e. by using TERRA-ASTER data or new generation of satellite with super-spectral capabilities, it is possible to apply physically-based model of vegetation radiative transfer to estimate canopy albedo and LAI, without strong restricting assumptions as in the semi-empirical models. A possibility is offered by a fast and robust inversion techniques based on the construction of a look up table (LUT) (Weiss *et al*., 2000) from the widespread SAIL – model (Verhoef, 1984) combined with PROSPECT (Jacquemoud & Baret, 1990) to "PROSAILh" (e.g., Baret *et al.*, 2007; Weiss *et al.*, 2000). This combined model takes into account the effect of soil background, the optical properties of the leaves, which are related to pigments and leaves water content. As such, diversely from Eqs. throug , an higher amount of spectral information is required to achieve a satisfactory level of accuracy in the results (Richter *et al.*, 2007). A remarkable difference between the empirical methods and the physically-based PROSAILh model is the possibility of considering the influence of illumination and observation geometry on the canopy reflectance, otherwise considered as a Lambertian reflector.

The approach described here, based on the combination of canopy parameters estimated from E.O. data and the Eq.(2), has been validated by using independent measurements of ET_a obtained from micro-meteorological instrumentations during different field campaigns. For example, in the case of corn and alfalfa plots under well-watered conditions, the comparison between ET_a and ET_p derived from satellite-based data has evidenced a very high correlation (fig.2).

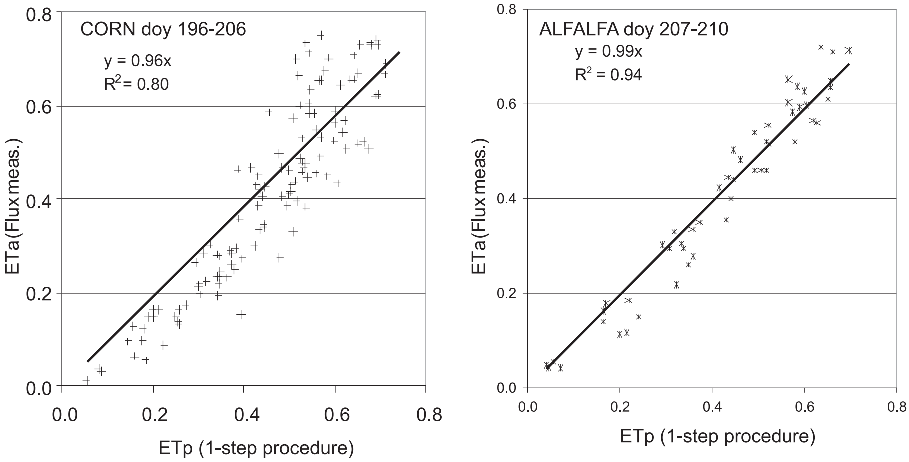

Figure 2. Comparison between ET_p values based on Eq. and field measurements of ET_a obtained by means of Eddy-Covariance techniques on corn and alfalfa plots fully irrigated; values are mm/h. Measurements refers to experiments carried out in the context of PLEIADeS project in the Nurra irrigation district.

Since the concept of crop coefficients K_c is still widely used in irrigation practice and it represents an information which can be easily transferred to final users, we can derive an analytical expression of K_c based on Eq., applied twice, a first time with canopy standard parameters for ET_0 and successively with the actual values for ET_p.

III – Processing and I.C.T. delivery of information to final users

Semi-automatic procedures have been developed in order to elaborate ET_p maps from E.O. data in the minimum possible time. The key-points of this procedure are: a) personalised irrigation advice; b) timely delivery of the information. Once the data are acquired by the satellite, i.e. at 10:00 a.m. day 1, the raw image is available via FTP within 12 hours at the processing center. The following processing steps are then applied: geometric correction (based on Ground Control Points), atmospheric correction, calculation of canopy parameters (albedo, *LAI*, K_c).

This processing is generally completed within 24 hrs from image download, i.e. at 12:00, day 2. At the end of this processing phase, the following products are ready: 1) color combination maps, 2) Crop Coefficient maps – from both approaches, 3) meteorological data (Precipitation, Reference Evapotranspiration) and 4) crop water requirements data. These products are directly delivered to each farmer by using I.T. in two ways: (1) simple text report by using SMS; (2) standard report, by MMS and e-mail, including images of the fields in false colors combination and a Kc map. The entire process is completed around 15:00 hrs, day 2. An example of the derived product is shown in figure 3.

The total cost of the advisory service, based on weekly reports, has been evaluated on the basis of 6 images from Landsat-5 and SPOT per irrigation season (60 days), over an extension of approximately 10 000 ha of irrigated land. The resulting cost is on the order of 40 € per hectare per year, including personnel cost for data processing and product generation; however, this value is strictly dependent on the density of irrigated area within the image acquisition.

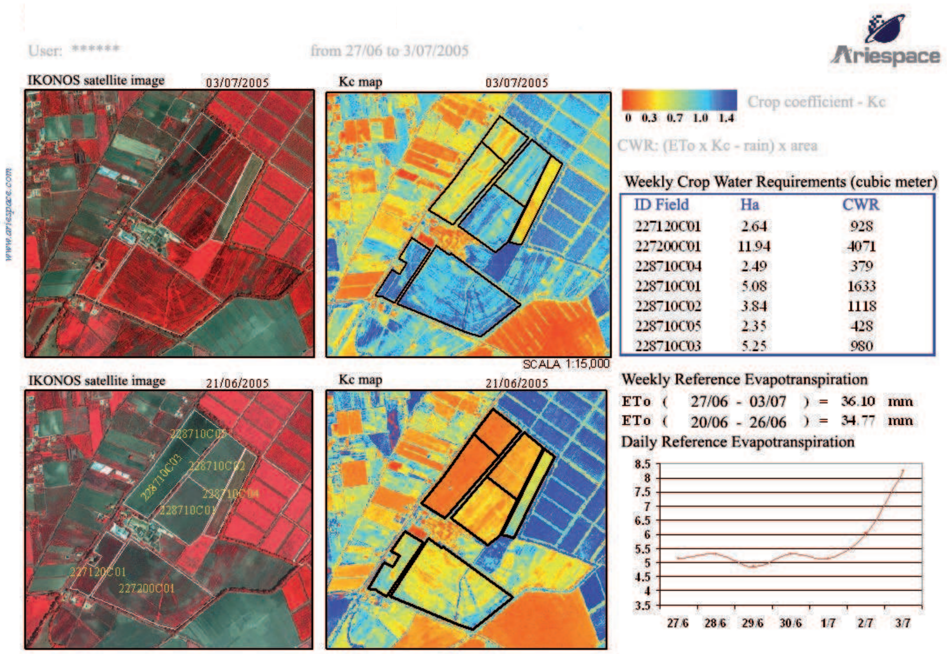

Figure 3. Example of information distributed to farmers via MMS (mobile phones) and E-mail: colour composite derived from high resolution satellite images and K_c map for a period of 4-7 days.

We have also carried out an evaluation survey among the final users. From this investigation, it has resulted that farmers have been able to recognize without difficulties their parcels on the images and they have scheduled the irrigations by taking into account the information provided. The crop heterogeneity captured by the high resolution images has been considered as a valuable add-on information to identify the variability of soil texture and fertility, plant nutrition, or different performance of irrigation systems.

If the actually given water volumes are known, it is then possible to evaluate the irrigation efficiency at different spatial and temporal scales. In a better way, crop water requirement information can be distributed to farmers in order to avoid the application of excessive amounts of irrigation water (and increase efficiency). An example is shown in Fig.4, where the suggested volumes are compared with the actual applied ones.

All the farmers evaluated positively the usefulness of the information provided, especially when it was made readily available by means of the MMS or e-mail weekly reports, and in most cases an increase of irrigation efficiency was achieved, because of the reduction of water volumes.

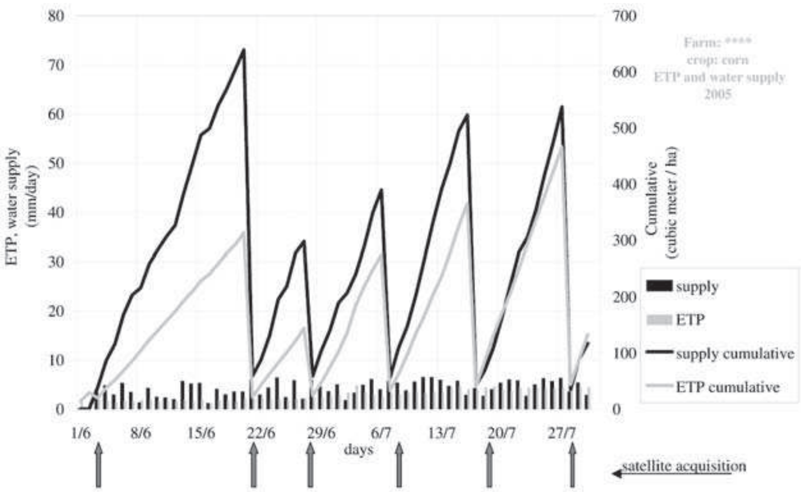

Figure 4. Comparison between the water volume supplied with irrigation and the crop water requirement estimated from E.O. data (bars:daily; lines: cumulate values). Data refer to a corn field with sprinkler irrigation. The farm has received weekly reports, for scheduling irrigation from the information provided.

IV – Conclusions

From the experience briefly presented here, it is possible to conclude that satellite remote sensing represent a mature technology ready to be transferred to operational applications in real-time (Calera *et al.*, 2005). Basic and advanced products, such as evapotranspiration and crop water requirements maps, based on satellite images and personalized for each farm and each parcel are delivered by using new Information Technology media (D'Urso *et al.*, 2006).

In the near future, thanks to improvements in the spatial and radiometric accuracy of new sensors, a more accurate estimation of this type of applications can be achieved. Due to the development of fast-access to Web resources, the time lag between satellite acquisition and availability of data to the final user has sharply decreased.

It is not difficult to positively assess the "cost-benefit" effectiveness of using E.O.data in operational contexts, with tangible benefits for a better management of water resources in irrigated areas.

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