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## Software application for real-time $ET_o/ET_c$ calculation through mobile devices

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Received: date / Accepted: date

**Abstract** In the southeast of Spain, farmers usually resort to the Agricultural Information Service of Murcia (SIAM) to get the data needed for an estimation of their water use and needs. Through 48 automatic stations, the SIAM provides data about temperature, wind speed, solar radiation or humidity, on a not very user-friendly web page which is not adapted to mobile devices and shows some shortcomings in downloading data. In addition, the key reference parameter in irrigation, the daily reference evapotranspiration ( $ET_o$ ), is not provided on the current day and the hourly  $ET_o$  and the crop evapotranspiration ( $ET_c$ ) are not offered either. This paper presents a new software application for mobile devices capable of providing the required data by an easy-to-use and friendly app. This tool employs the GPS co-ordinates of a place under study to get the data required from the closest SIAM stations and interpolates station data to increase accuracy. The hourly and daily  $ET_o$  are automatically calculated using the Penman-Monteith equation, declared by the FAO in 1990 as the only valid method for calculating evapotranspiration. The  $ET_o$  computation entails the calculation of the net solar radiation, the heat soil flux or the psychrometric constant. A new extension of the tool also allows calculation of the  $ET_c$  for a set of typical crops of the southeast of Spain. All the computed data can be stored and edited, as well as those geographical positions of interest. To the best of the authors' knowledge, this is the first application of this kind available.

**Keywords** Evapotranspiration · FAO · Penman-Monteith · mobile application · Android · GPS

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## Introduction

In arid and semi-arid climates, water is the first limiting factor of agricultural development. Irrigation is undoubtedly the most important practice and requires an effective use. Farmers need to estimate the water needs of the crops, to validate the data supplied by agricultural weather stations or to know the free water surface evaporation in dams or lakes. These data were done crudely, until recently. First, a technician had to move to the place under study and measure the variables of interest, e.g. temperature, humidity or wind speed. After that, using a desktop PC and taking some bibliographic resources (Allen et al. 1998), the technician had to calculate the parameters involved to take decisions regarding these tasks, that is, equivalent evaporation, net solar radiation or reference evapotranspiration. Since a decade ago, new techniques have been proposed to improve the way in which the above parameters are obtained. An example of this is the Agricultural Information Service of Murcia (SIAM 1996), that most of the farmers in the southeast of Spain use to get the data needed to estimate their water use and needs. The SIAM is considered as the richest source of meteorological information in Murcia Region equipped with 48 automatic stations around the Region (see Fig. 1). Although data like wind speed, rainfall, humidity and temperature are periodically collected, they are shown in a non-easy to use and unfriendly web page, which is not adapted to mobile devices and shows some shortcomings in downloading data. Moreover, not all the stations maintain real-time information and the key reference parameter in irrigation, the daily reference evapotranspiration ( $ET_o$ ), is not calculated in the current day but only for previous days. The hourly  $ET_o$  and the crop evapotranspiration ( $ET_c$ ) are not offered either. The SIAM seems not to meet the current needs of farmers, who demand easy and affordable access to all that information.

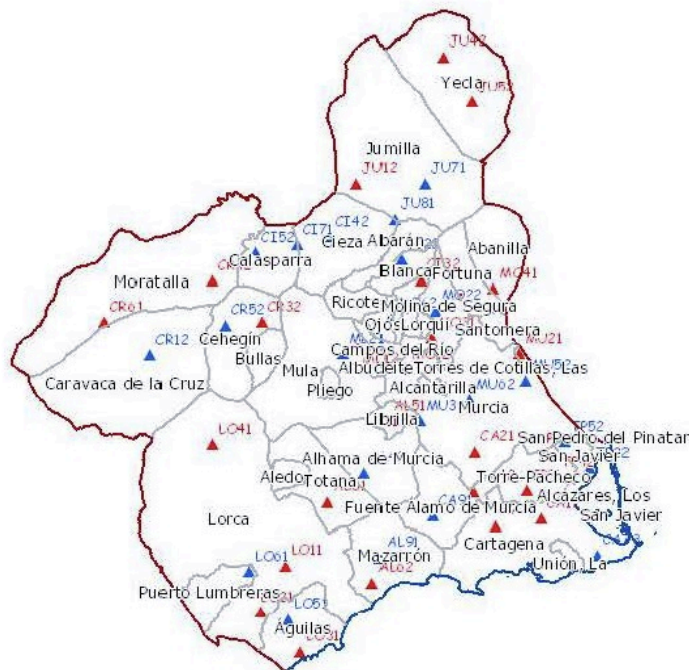


Fig. 1: Placement of SIAM stations in Murcia Region (Spain) (SIAM 1996).

Fortunately, the emergence of smartphones has increased exponentially in the last decade (Device Atlas 2016), and most farmers use them daily for diverse professional and personal purposes, as supported by the scientific literature on mobile applications developed for agriculture (Molina-Martinez et al. 2011; Jonoski et al. 2012, Bueno-Delgado et al. 2015). This suggests that smartphones could be a good tool to obtain the data required to know the water needs or water use in a place of interest or for a specific crop. Thus, this paper presents a new software application (*aka* app) for mobile devices that allows calculation, storage and management of the hourly and daily  $ET_o$  as well as the  $ET_c$  for a set crop, in an easy-to-use and friendly tool. With this aim, the app allows the user to indicate the place under study through its co-ordinates using the GPS integrated in the mobile device through Google Maps tool (Google 2005) or by hand. After that, the app downloads the data required from the SIAM stations closest to these co-ordinates transparently to the user. If the co-ordinates are close to two or more stations, the app interpolates the data to increase accuracy. Then, the hourly and daily  $ET_o$  are automatically calculated using the Penman-Monteith equation, declared by the FAO in 1990 (Allen et al. 1998) as the only valid method for calculating evapotranspiration. Note that the calculation of  $ET_o$  involves computing other necessary parameters that the SIAM does not offer, such as the net solar radiation, the soil heat flux, the psychrometric constant or the vapor saturation pressure curve. The app also allows calculation of  $ET_c$  for a set of crops. All data computed can be stored and edited in the app, as well as those geographical positions of interest. The app is executed in Android Operating System (OS) (Android 2009) because Android devices compose 82.8 % of all smartphones and tablets on the market (IDC corp., 2016). This new app has details like elements in the screen designed to be compatible with tablets and other mobile devices; graphics are included to increase application usability and information of interest can be sent by text messages, bluetooth, whatsapp, e-mail or social networks. To the best of the authors' knowledge, this is the first application of this kind available.

## SIAM

As stated in the Introduction section, the Agricultural Information Service of Murcia (SIAM 1996) is considered as the largest source of meteorological information in Murcia Region, with 48 automatic stations spread over the region (Fig. 1). The stations have been installed progressively, from 1996, when the first 11 stations were activated. Two years later, up to 26 stations were working and, in turn 45 in 2000. All stations are continuously measuring temperature, relative humidity, radiation, wind speed and direction. These data are recorded every ten minutes in a data-logger powered by a solar panel (Fig. 2). The control and measurement module is responsible for conducting the measurement sensors, integrating data via a telecommunications system, and sending data via GSM /GPRS. Once the data reach the central server of SIAM, they are validated, stored and served in a free-access website (SIAM 1996). The website offers a description of the SIAM stations network, including their physical location and their sensors. The data collected by the stations are served by the website in three different ways:

- Checking every single station in real-time: the user searches the station of interest, and a pop-up window is displayed with the data stored in the last reading. Although the SIAM apparently offers these data in “real-time”, in fact the data are delayed by two or three hours.



Fig. 2: An automatic station of the SIAM network (SIAM 1996).

- Plotting the current day: this option displays a table with the average, maximum and minimum values of the data stored by all stations in the current day (until the last read). Every row is a single station, and every column is a meteorological parameter: average, maximum and minimum values of temperature and humidity, rainfall, and the average and maximum wind speed.
- Plotting any previous day: the SIAM offers the possibility of plotting a table similar to the previous one for any previous day since January 1996. This table also includes absolute maximum and minimum values of temperature and humidity, average wind direction, hours of sun, average radiation, reference evapotranspiration, and maximum and average rainfall.

The SIAM also offers irrigation and fertilization schedulers for the most common varieties of fruit and vegetable crops in Murcia Region, that is, lemon, orange, mandarin, grapefruit, apricot, peach, nectarine, almond, apple, pear, olives, grapes, artichokes, broccoli, lettuce, melon, pepper and tomato.

Although the SIAM discloses a lot of information, it does not supply solar radiation or the daily/hourly  $ET_o$  in the current day. In fact, daily  $ET_o$ , and the maximum and minimum radiation are provided only for previous days. Besides, the SIAM server does not provide a responsive web page to be displayed on mobile devices. Another important flaw on the SIAM web page is the way in which data are displayed. All data are recorded in a non-intuitive table or in a pop-up window, which usually takes a long time to load, being not possible to get data in a fast, comfortable and friendly way. In addition, the SIAM forces export of data as a .csv, .xls, .rtf or .pdf file, and most of the times the download fails and the data are not well recorded. Finally, the SIAM does not allow sharing the data by email, whatsapp or social networks.

### Parameters formulation

The theoretical base of the formulas to estimate the water needs of crops considers, among others, the daily/hourly  $ET_o$ , the net solar radiation and the  $ET_c$ . These are computed by the application presented in this work, transparently to the user, simply applying some data recorded by the SIAM or extracted from the GPS coordinates.

A brief description of the equations computed by the application is given in the following sub-sections.

## Evapotranspiration

After rainfall, evapotranspiration is the process with the highest contribution in the water budget. It is estimated that 70% of the received water is returned to the atmosphere by this effect. Evapotranspiration varies depending on location and season, and is affected by climatic factors such as vegetation and soil. Penman (1948) proposed a formula to calculate the evaporation of an open water surface, combining the energy balance with mass transfer from standard climatic data, such as hours of sun, temperature, humidity and wind speed. This method was extended some years later by Monteith (1965), including the surface resistance of the vegetation cover, giving the following equation:

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma(1 + \frac{r_s}{r_a})} \quad (1)$$

where  $R_n$  is the net radiation,  $G$  the soil heat flux,  $\rho_a$  the average density of air at constant pressure,  $c_p$  the specific heat of air,  $e_s$  the average saturation vapor pressure (kPa),  $e_a$  the current vapor pressure (kPa),  $(e_s - e_a)$  the deficit pressure of vapor air,  $\Delta$  the slope of the saturation vapor pressure curve,  $\gamma$  the psychrometric constant, and  $r_s$ ,  $r_a$  the aerodynamic and surface resistance.

In 1990, the FAO (Allen et al. 1998) conducted a meeting with the collaboration of the Inter-national Commission on Irrigation and Drainage and the World Meteorological Organization, where experts and researchers were gathered in order to review the methodologies proposed to calculate the water requirements of crops. The conclusion was to declare the combined Penman-Monteith method as the unique valid method for calculating the reference evapotranspiration ( $ET_o$ ). Moreover, the FAO also advised on the calculation of other parameters involved in the formula. They assumed a reference crop with a 0.12 m height, a surface resistance of  $70 \text{ ms}^{-1}$  and an albedo of 0.23 m, which is similar to the evaporation experienced by an extensive surface of green grass of uniform height, actively growing and well-watered. The recommended equation is:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_{hr} + 273} u_{h2} (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_{h2})} \quad (2)$$

where  $ET_o$  is measured in  $\text{mm} \cdot \text{d}^{-1}$ . Note that  $T$  is the average daily air temperature at 2 m height ( $^{\circ}\text{C}$ ) and  $u_2$  the average wind speed at 2 m height ( $\text{m} \cdot \text{s}^{-1}$ ). Eq. (2) gives successful results if the weather variables do not change quickly. However, in those areas where there are fast changes in wind or cloudy sky, eq. (2) cannot be used. When the weather varies quickly in a short period of time, the hourly evapotranspiration formula allows more precise measurements. Hourly  $ET_o$  is calculated as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_{hr} + 273} u_{h2} (e_s(T_{hr}) - e_a)}{\Delta + \gamma(1 + 0.34u_{h2})} \quad (3)$$

where  $ET_o$  is measured in  $\text{mm} \cdot \text{hour}^{-1}$ ,  $T_{hr}$  and  $u_{h2}$  are the average hourly temperature and wind speed respectively, and  $e_s(T_{hr})$  is the saturation pressure vapor at  $T_{hr}$  temperature.

As can be seen, the hourly and daily  $ET_o$  depend on some parameters that can be obtained by the automatic stations in real time, or daily, such as wind speed or air temperature. However, other parameters such as  $R_n$ ,  $G$ ,  $\gamma$ ,  $e_a$  or  $e_s$ , must be calculated through the equations reviewed in the following subsections.

### Net solar radiation

The net solar radiation ( $R_n$ ) is the balance between that absorbed, reflected and emitted by the earth's surface energy, which is calculated as  $R_n = R_{ns} - R_{nl}$ , that is, the difference between the net radiation of short wave ( $R_{ns}$ ) and long wave ( $R_{nl}$ ). Its value is positive during the day and negative overnight. Its daily value is usually positive except in cases of extreme latitude.

The net radiation of short wave lengths is formulated as  $R_{ns} = (1 - \alpha) \cdot R_s$ , where  $\alpha$  is the albedo parameter (0.23 for a hypothetical crop) and  $R_s$  is the solar radiation, commonly calculated with the Angstrom formula (Angstrom 1924) as follows:

$$R_s = R_a \left( a_s + b_s \frac{n}{N} \right), \quad (4)$$

where  $R_a$  is the extraterrestrial solar radiation and  $\frac{n}{N}$  the relative sunshine duration, where  $n$  is the current duration of sunshine and  $N$  is the maximum possible duration of sunshine or daylight hours, both measured in number of hours.  $a_s$  and  $b_s$  are constants which depend on the climate and location. If there are no solar radiation data available and no calibration has been carried out to get  $a_s$  and  $b_s$  values, then  $a_s=0.25$  and  $b_s=0.50$  values are recommended. The equations to get these parameters depend mainly on the latitude and the Julian day (Julian calendar). All of them were reviewed by the authors in Bueno-Delgado et al. (2015). Note that the solar radiation can be calculated day-to-day or hourly to be applied in eq. (2) and eq. (3) respectively. The net radiation of long wavelengths ( $R_{nl}$ ) is formulated as:

$$R_{nl} = \vartheta \left[ \frac{T_{max,k}^4 + T_{min,k}^4}{2} \right] (0.34 - 0.14\sqrt{e_a}) \left( 1.35 \frac{R_s}{R_{so}} - 0.35 \right), \quad (5)$$

where  $\vartheta$  is the Stefan-Boltzmann constant. If the radiation is measured daily,  $\vartheta=4.903 \cdot 10^{-9} MJK^{-4} m^{-2} day^{-1}$ . By hours,  $\vartheta=2.0412 \cdot 10^{-10} MJK^{-4} m^{-2} h^{-1}$ .  $T_{max,k}$  and  $T_{min,k}$  are the maximum and minimum temperature in a 24 h period ( $^{\circ}K$ ), respectively.  $\frac{R_s}{R_{so}}$  is the relative radiation of short wave, widely explained by Bueno-Delgado et al. (2015).

### Soil heat flux

The soil heat flux ( $G$ ) is the energy used to heat the ground, being positive when the ground is heated and negative when cooled. Although its value is not really high, and it will not affect the evapotranspiration value too much, it must be subtracted from the radiation to achieve accurate results. There exist different formulae to model the soil heat flux, but the following one is used in this work for its simplicity:

$$G = c_s \frac{T_i - T_{i-1}}{\Delta_t} \Delta_z, \quad (6)$$

here  $c_s$  is the soil heat capacity,  $T_i$  the air temperature at time  $i$ ,  $T_{i-1}$  the air temperature at time  $i - 1$ ,  $\Delta_t$  time interval to consider (day, hour), and  $\Delta_z$  the effective soil depth.

Since the variation of the ground temperature is delayed in comparison with the air temperature changes, a period of time longer than a day should be considered in order to determine  $G$ . The depth of penetration of the temperature wave is determined by the time interval. Then,  $\Delta_z$  is 0.10–0.20 m for an interval of one or a few days or may be greater than 2 m for monthly periods.

As a consequence, for daily and shorter periods, the FAO suggests different approaches: for one day period or a few days  $G_{day} = 0$ , whereas for hourly periods of light,  $G_{hr} = 0.1R_n$ , and during night periods,  $G_{hr} = 0.5R_n$ .

### Psychrometric constant

The psychrometric constant, at reference atmospheric conditions (20°), depends on the atmospheric pressure  $P$ , as the following equation shows:

$$\gamma = \frac{c_p P}{\varepsilon \lambda} = 0.665 \cdot 10^{-3} P, \quad (7)$$

being  $c_p = 1.013 \cdot 10^{-3} (MJkg^{-1}C^{-1})$ , the specific heat at constant pressure,  $\varepsilon = 0.622$  the molecular weight ratio of steam dry air, and  $\lambda = 2.45 (mgkg^{-1})$  the latent heat of vaporization. Applying a simplification of ideal gases to Earth's atmosphere at 20°C,  $P$  can be computed in  $kPa$  units as follows:

$$P = 101.3 \left( \frac{293 - 0.0065z}{293} \right)^{5.26}, \quad (8)$$

where  $z$  is the elevation above sea level in meters. This data is computed by the app, using the Google Maps Elevation API (Google 2005).

### Slope of the vapor saturation pressure curve

The slope of the vapor saturation pressure curve is a necessary parameter to calculate evapotranspiration, computed as follows:

$$\Delta = \frac{2504 \cdot e^{\left(\frac{17.27T}{T+273.3}\right)}}{(T+273.3)^2}, \quad (9)$$

As shown, eq. (9) depends on the average air temperature ( $T$ ) for 24 h periods, a variable that can be obtained from the SIAM stations.

### Saturation pressure vapor

The amount of water vapor in the air is directly related to the partial pressure of water

vapor in the air, and through it, its concentration can be measured. When a volume of air is retained on the evaporating surface water, a balance among the water molecules incorporated into the air and returned to the water source is reached. Then, the air is considered to be saturated, because it is not able to store more water molecules.

That pressure is called saturation vapor pressure ( $e^o(T)$ ), and its value is directly proportional to the temperature:

$$e^o(T) = 0.6108 \cdot e^{\frac{17.27T}{T+273.3}}, \quad (10)$$

Due to the non-linearity of the saturation pressure with temperature, if the average saturation pressure vapor must be computed for hour periods, it is necessary to get the average of the saturation pressure vapor ( $e_s$ ) at maximum and minimum temperature during the observation period, using the following equation:

$$e_s = \frac{e^o(T_{max}) + e^o(T_{min})}{2}, \quad (11)$$

On the other hand, the real (or current) vapor pressure ( $e_a$ ) must be also known in order to compute hourly and daily  $ET_o$ . It is calculated as follows:

$$e_a = \frac{e^o(T_{min}) \frac{HR_{max}}{100} + e^o(T_{max}) \frac{HR_{min}}{100}}{2}, \quad (12)$$

Note that  $HR_{min}$  and  $HR_{max}$  is the minimum and maximum relative humidity, respectively. These values are obtained from the SIAM stations.

### Crop evapotranspiration

The crop evapotranspiration ( $ET_c$ ) is computed under standard conditions, that is, it is assumed that there are no restrictions on crop development due to water or salt stress, density cultivation, pests and diseases, presence of weeds or low fertility. The equation is as follows:

$$ET_c = K_c \cdot ET_o \quad (13)$$

where  $K_c$  is the crop coefficient and  $ET_o$  the evapotranspiration reference, explained in depth in the previous subsections. The combined effects of crop transpiration and soil evaporation are integrated in the crop coefficient  $K_c$ , which includes the features of the crop and the average effects of evaporation on the soil, while  $ET_o$  adds the effects of weather conditions.

For normal irrigation planning and management purposes, defining basic irrigation schedules, and according to most studies of water balance, average crop coefficients are appropriate and more convenient than those coefficients  $K_c$  that are calculated daily, considering soil and crop coefficients separately (Allen et al. 1998).

The steps for calculating the crop evapotranspiration for a specific crop in the app are summarized as follows:

- To determine the duration of each stage of crop development (beginning, crop



development, mid-season, end season) and to select the corresponding values of  $K_c$ .

- To adjust the value of  $K_c$  according to the stage, identifying  $K_{c,ini}$ ,  $K_{c,mid}$  and  $K_{c,end}$ .
- To calculate  $ET_c$  following eq. (13), using the  $K_c$  value obtained in the previous steps.

The reference values of  $K_{c,ini}$ ,  $K_{c,mid}$  and  $K_{c,end}$  are available in Allen et al. (1998) for more than sixty types of crops. They are only approximations so it is advisable that they are used for estimating  $ET_c$  only during preliminary studies or crop planning. The following equations are required to obtain a more accurate estimation of  $K_{c,ini}$ ,  $K_{c,mid}$  and  $K_{c,end}$ :

$$K_{c,ini} = f_w \cdot K_{c,ini(DB)} \quad (14)$$

where  $f_w$  is the fraction of the soil surface wetted by irrigation or rain, with values between 0 and 1; for drip irrigation systems,  $f_w = 0.4$ ; for furrow irrigation systems,  $f_w$  may vary between 0.3 and 0.8.  $K_{c,ini(DB)}$  is the value that the FAO recommends for the crop under study at initial stage. The values of both variables are available in Allen et al. (1998), for different types of irrigation and crops.

$$K_{c,mid} = K_{c,mid(DB)} + [0.04(u_2 - 2) - 0.004(HR_{min} - 45)] \left(\frac{h}{3}\right)^{0.3}, \quad (15)$$

where  $K_{c,med(DB)}$  is the value that the FAO recommends for the crop under study at crop development in mid-season,  $u_2$  the daily average wind speed at 2 m height in the mid-season stage,  $HR_{min}$  the daily average relative humidity at mid-season stage, and  $h$  the average plant height at midseason stage.

$$K_{c,end} = K_{c,end(DB)} + [0.04(u_2 - 2) - 0.004(HR_{min} - 45)] \left(\frac{h}{3}\right)^{0.3}, \quad (16)$$

where  $K_{c,end(DB)}$  is the value that the FAO recommends for the crop under study at end season,  $u_2$  the daily average wind speed at 2 m height in the end season stage,  $HR_{min}$  the daily average relative humidity at end season stage, and  $h$  the average plant height at end season stage. Note that eq. (16) is only applicable when  $K_{c,end(DB)} > 0.45$ . Otherwise,  $K_{c,end} = K_{c,end(DB)}$ .

## Software Application

The software tool developed in this work is a mobile app, designed with the aim of offering farmers and technicians a friendly and easy-to-use tool that allows computation of key parameters in many tasks of water management in agriculture, by using their mobile phones or tablets and in just a couple of *clicks*. Specifically, this tool allows (i) to obtain weather data in a place of interest, taking these data from a network of weather stations strategically installed in Murcia Region (Spain); (ii) to calculate the daily and hourly evapotranspiration reference for a given location; (iii) to calculate the crop evapotranspiration for a crop of interest; and (iv) to store, edit, delete or share the data computed. All these features are executed almost automatically and transparently to the user.

The app has been designed to be executed only on devices with Android OS (Android 2009) and GPS, but the latter is not mandatory. Android was selected as OS because it dominated the global mobile market in 2015, being installed in 82.8% of all smartphones worldwide and it is expected to follow the same tendency till 2018 (IDC corp., 2016). The app has been designed to be compatible with most Android versions from 9 API level, that is, Android 2.3. This means that the app works in 99.7% of mobile devices using Android OS worldwide. It has been also designed with an adaptive design, to be compatible with any tablet or smartphone.

The app is installed in a couple of *clicks*. When the app is executed, it detects the language configured in the mobile device. The main screen displays two buttons to select the user's language, although in the current version only Spanish and English are available. The main screen also displays the logo of the company that will exploit the app in the near future (Fig. 3(a)). After selecting a language, the app shows a main menu that allows the user to choose the task to run. These are explained in the following sub-sections.

### Geolocation data

The geolocation data (latitude, longitude and altitude) are entered by using one of the four options: GPS, Google Maps tool, manually, or loaded from a database (see Fig. 3(b)). The first one is used if the user is placed in the location under study but requires that the mobile device incorporates GPS. The second option is only available if the mobile device has internet connection. The users search the place of interest using the Google Maps tool, they can zoom to show the desired point and get its coordinates. A confirmation screen will show the data before downloading. The third one is offered for those users who prefer to insert location data manually (see Fig. 3(c)). The last option is used when the user has the data stored in the database available in the app (see Fig. 4(a)). The app also allows saving, uploading and sharing the location data through the three icons placed at the bottom of the screen. The first one allows storing the location data in the database. The second one gives access to the database where the user can edit, delete or share any of the stored locations (Fig. 4(b)). The third icon allows sending the location data through social networks, whatsapp, email or bluetooth, among others.

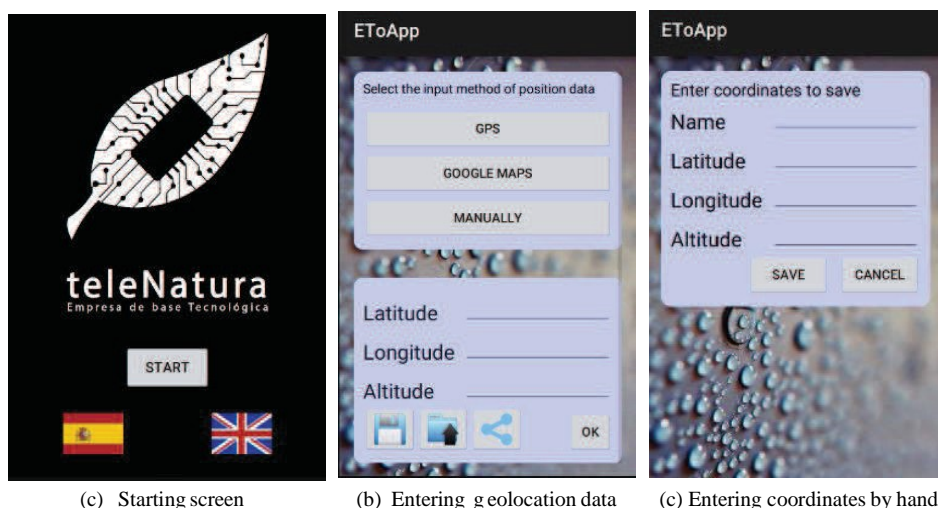


Fig. 3: ETo/ETc app: snapshots of the application (I)

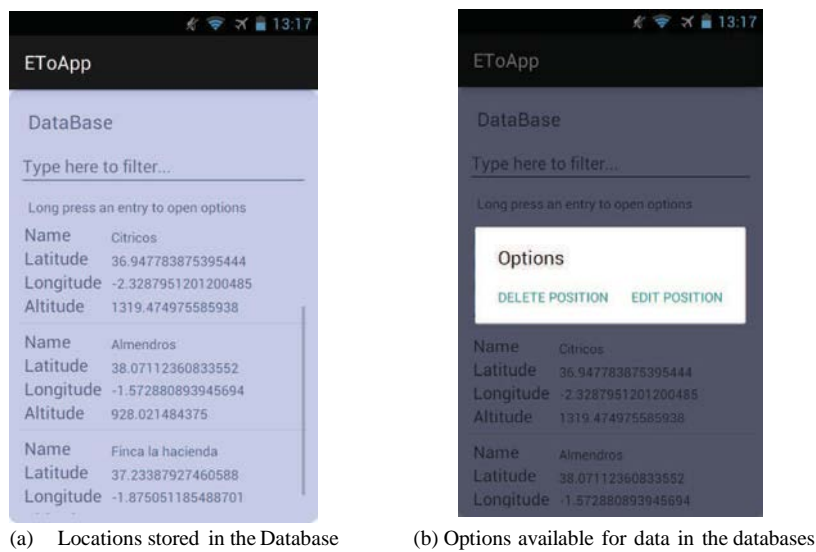


Fig. 4: ETo/ETc app: snapshots of the application (II)

### ETo computation

Once the location data are entered, it is necessary to get the weather data in order to compute the daily and hourly  $ET_o$ . Then, the user must access the  $ET_o$  computation menu (Fig. 5(a)). This section is divided into two parts. At the top of the screen, the user can enter the date and time in which the daily and hourly  $ET_o$  will be calculated. On the other hand, the button “Select Station” allows the user to connect with the SIAM network in order to download the weather values measured close to the location of interest for the day and hour selected. If the date does not correspond to the current day, the hourly  $ET_o$  cannot be calculated.

The data are downloaded as a .csv file, and the app parses it to extract the data of interest, automatically and transparent to the user. Note that the list displays all stations, highlighting those closest to the location entered in the previous step (Fig. 5(b)). The user can select one or more stations. If more than one station is selected, the downloaded weather data are interpolated in order to increase accuracy. Note that selecting stations is an optional step. The user can enter weather data manually, for instance, those obtained by a sensor network installed in the place of interest.

Pressing the “Compute  $ET_o$ ” button, the daily and hourly  $ET_o$  are calculated using the equations described before. The results are shown filling the table under the button. Positively, all results in the table can be edited by the user, for instance, if partial data of temperature, humidity and wind are known in advance.

Finally, the “Access Database” button allows storage of the computed data together with all agro-meteorological data in a second database. The content is accessible by pressing the “View Results” button (Fig. 5(c)).

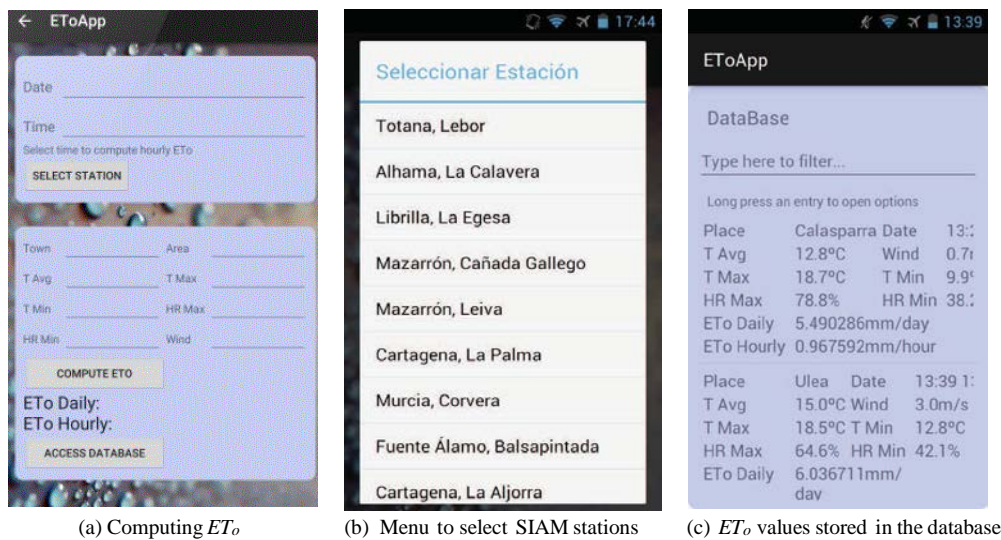


Fig. 5: ETo/ET<sub>c</sub> app: snapshots of the application (III)

### ET<sub>c</sub> computation

This section is designed to calculate the crop evapotranspiration  $ET_c$ . As stated in eq. (13), this value will depend on four parameters:  $ET_o$ , type of irrigation, type of crop and crop stage. The steps to compute it are as follows:

- To load an  $ET_o$  value from the database. The  $ET_o$  must come from the location where the crop has been or will be planted.
- To select the type of crop from a list given by the application, which contains the most common 18 varieties of fruits and vegetables in Murcia Region: lemon, orange, mandarin, grapefruit, apricot, peach, nectarine, almond, apple, pear, olives, grapes, artichokes, broccoli, lettuce, melon, pepper and tomato.
- To indicate the stage of the crop development, given by three options: initial, middle and ending. The application loads automatically the  $K_{ini,(DB)}$ ,  $K_{mid,(DB)}$  or  $K_{end,(DB)}$  values recommended by the FAO (Allen et al. 1998) for the crop and the stage under study. Note that these data are loaded from a non-editable database.
- To select the type of irrigation: rainfall, sprinkling, swimming holes, furrow, drip, etc. Note that each irrigation mode has a specific  $f_w$  value recommended by the FAO (Allen et al. 1998), which are also stored in the application.

Once all data are set, the user has to press the “Compute  $ET_c$ ” button in order to calculate the  $ET_c$  through eq. (13) and with the assumptions described in Crop Evapotranspiration section. The result is automatically displayed and the user can store it in a database, together with the configuration set to compute it. These data, can be edited, deleted and shared.

### Databases

As stated in the previous sections, the app uses the following databases: Geolocation database, Daily/hourly  $ET_o$  database,  $ET_c$  database and Crop-FAO database. All of them are stored in the mobile device, retaining their values between sessions. The first three are designed to easily filter results by name and edit data. To do this, the user has to press on an entry. A new menu is displayed with options: delete, modify any data or share the information of an entry. In addition, the menu provides the option to delete the whole database. The crop-FAO database, in turn, stores the

data about the information required to compute  $ET_c$  for different crops. Such data are those recommended by the FAO about types of crops, stages of development, crop coefficients, irrigation methods and  $f_w$  values. This database cannot be edited or deleted.

### Future work

The app developed in this work is in its first version and new features are being investigated in order to improve its functionality and accuracy, particularly new methods of correction on radiation, since the different degrees of cloudiness may alter the final value; to include charts using the data stored in the databases in order to have a better view about the evolution of evapotranspiration; or to expand the list of fruits and vegetables and include all those studied by the FAO as well as their parameters about the  $ET_c$  computation. Finally, other Spanish weather stations networks are being studied in order to extend its use to other Spanish regions. The final goal is to offer a tool that permits computation of the  $ET_o$  and  $ET_c$  anywhere in the world and for a wide range of crops.

### Conclusions

In this paper, a mobile application has been presented that permits farmers and agricultural technicians to work with their mobile devices for managing those agricultural tasks related to optimizing water resources and irrigation. The app computes daily/hourly  $ET_o$  and  $ET_c$  in an easy and friendly framework and in a couple of clicks, saving time and, therefore, money. This tool computes the required parameters by accessing the SIAM weather stations network, placed in Murcia Region (Spain), to collect real weather data. However, access to the weather station is not mandatory if the farmer knows the weather data. Additionally the app applies the equations recommended by the FAO to compute the parameters. It also uses databases to store, edit and share the data about geographical locations, their  $ET_o$ , weather data,  $ET_c$  and crop information.

The app has been designed to be an attractive product for the end user: it is developed for Android OS, which is a free, stable and the most widely used OS in 2015; it has an adaptive design and the screen elements have been introduced in order to be executed in tablets and all types of smartphones; it includes methods for capturing the input of Cartesian co-ordinates through the display of maps with Google Maps tool, by the selection on the map, including the height given in this co-ordinate by web service. Furthermore, the app provides graphics that facilitate the tool usability, allowing the computed data to be sent by text message, email, whatsapp or social networks. It also permits the use of wireless communication technologies for data transfer, such as Bluetooth or IrDA.

**Acknowledgements** This work was supported by the research projects 3639/13TIC and 3703/13TIC. Thanks to Telenatura S.L. for its technical support.

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