The Integrated Use of a Surface Agrometeorological Network and Remote Sensing Data in Catalonia

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ABSTRACT

Presented herein are the first results obtained on the basis of satellite images treatment within the Agroclimatic Characterization of Catalonia. In order to define “homogeneous” zones, emissivity and albedo distribution for 20 different land use types were obtained, together with the surface temperature. Faced with a widespread lack of the soil temperature sensors necessary for checking of results, various methods are proposed for obtaining those temperatures using data of the pilot network. The aim of the present study is installation of a network of automatic agrometeorological stations sufficiently representative of the whole Catalonia, the main characteristics and applications of which are described below.

INTRODUCTION

It is well known that the analysis of the agricultural activity must be carried out from a global point of view showing the interrelations among all the factors that take part in the production, as type of crop, type of soil, weather, climate, etc. The weather is important in order to prepare short-term actions in a rational way (irrigation, pest control, frost prevention, etc.) and climate is important for long-term actions (crop distribution).

This is the reason why the P.A.C. (Agrometeorological Plan of Catalonia) is being developed by the Agriculture Service of the “Generalitat de Catalunya”, the Catalan autonomous Government. Within this project, it was considered the necessity of installing a new network of automatic agrometeorological stations to aid in the development and application of the latest agrometeorological techniques. The management of these stations and their uses are considered in the PAC-COM (Communications) Project.

In order to set up a rational agrometeorological network, a study should be carried out permitting the selection of key points as representative of extensive though “homogeneous” areas in agroclimatic terms. Hence the origin of the need to define the Agroclimatic Characterization of Catalonia (Llasat et al., in press). Within this, radiative properties of the different uses of soil as emissivity, albedo, soil temperature and thermal inertia are obtained. To determine soil temperature from surface measurements, the pilot agrometeorological network has been used.

1. THE AGROMETEOROLOGICAL NETWORK

Catalonia is situated at the northeastern part of Iberian Peninsula, and has an area of 31930 km². At present, more than 12 largely independent meteorological networks with a total of 655 stations exist in this region. The majority of these are manual, making one to three daily observations; fewer than 10% have wind-measuring instruments at 10 m above the ground, and usually there are no net radiation measurements. Furthermore, for the most part, data are sent to the coordinating centre once a month. However, good management of agriculture needs frequent measurements and real-time information on temperature, humidity, radiation, wind (at 2 m above the ground) and rainfall data.

For this reason, in 1988 the Agriculture Service undertook the installation of a pilot agrometeorological network. There are 15 stations working at present. The sites have
been chosen taking into account the different needs of agricultural areas (fig.1). At the moment, this selection is not intended to cover the whole of Catalonia in a homogeneous way, as the agrometeorological characterization is needed beforehand.

The stations are models 21X or a CR10 manufactured by Campbell Ltd. The main difference between them is the memory and the datalogger program. These stations have a wind vane, an anemometer and a pyranometer, set up at 2 m above the ground, temperature and humidity sensors placed at 1.5 m and a net-radiometer and a tipping-bucket raingauge at 1 m. Some stations have two subsoil temperature sensors and a humectograph.

A datalogger is programmed to record wind and radiation measurements every 20 s and temperature, humidity and rainfall every 10 min. It calculates hourly and daily mean values, extreme values, and several wind statistics as well. The Control Center, located in Barcelona, interrogates the stations every morning in order to collect the data once a day. From these data, potential evapotranspiration (for irrigation management), dew point temperature, rainfall rate (for erosion studies) and other parameters are computed. Degree-days are calculated by different methods for pest management, while warnings for vineyard diseases and frost protection are other uses. Scientists and farmers can have access to that information by means of a PC with a modem.

2. REMOTE SENSING ANALYSIS

One of the primary objectives of this study was to obtain terrestrial surface temperature by means of the data provided by NOAA-9 satellite. This study was made with the "Institut Cartografic de Catalunya". The procedure used was as follows.

2.1. Maps of emissivity and albedo

The distribution of emissivity must be known in order to obtain the true surface temperature. For this, we have the "Map of land uses" obtained by multispectral classification through imagery of the Thematic Mapper (Viñas et al, 1991). Twenty land uses were differentiated with pixels of 30 x 30 m². Emissivity and albedo values are assigned to each one depending on the phenological state of the vegetation. Of these, the following have been considered: December to February, March, April, May, June, July to September and October-November. It must be borne in mind that each land use includes various different vegetation types and also that the same crop may be grown in different soils, though the characteristics of any particular crop will dictate, to a large extent, the type of soil to which it is best suited. For this purpose, lithological and crop maps of Catalonia were used (Instituto Geológico y Minero de España, 1972; Ministerio de Agricultura, Pesca y Alimentación, 1984, 1986, 1988). From these, model vegetation cover and soil types were established for each land use and different emissivity and albedo were assigned from the following equations:

\[ \varepsilon_{kl} = z_l \cdot \varepsilon_{kl} + (1 - z_l) \cdot \varepsilon_{tl} \]

\[ a_{kl} = z_l \cdot a_{kl} + (1 - z_l) \cdot a_{tl} \]

\[ \varepsilon_{kl} / a_{kl} : \text{emissivity/albedo of model vegetation cover} \]

\[ \varepsilon_{kl} / a_{kl} : \text{emissivity/albedo of model soil type} \]

\[ z_{kl} / a_{kl} : \% \text{area covered with vegetation} \]

Values of \( \varepsilon_{kl} \), \( \varepsilon_{kl} \), \( a_{kl} \) and \( a_{kl} \) have been obtained both from the bibliography on the subject (Caselles, 1983; Pielke, 1984; Oke, 1987) and from experimental data (Jordi, 1989); values of Epsilon sub kl and akl are presented in tables 1 and 2.
Tab. 1: Values of emissivity for the different land uses and months. Some months have been grouped together as they correspond to the same phenological state. The values indicated with an asterisk do not change over the course of the year.

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Tab. 2: Values of albedo for the different land uses and months. Some months have been grouped together as they correspond to the same phenological state. The values indicated with an asterisk do not change over the course of the year.

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2.2. Determination of soil temperature

This is obtained means of NOAA-9 satellite images working on channel 4 (10.3 μm - 11.3 μm) and channel 5 (11.5 μm - 12.5 μm). First of all, geometrical corrections were made in order to be able to superimpose the digital map of land uses on the images from the NOAA-9.

Secondly, the NOAA-9 captures the radiance from pixels of 1 x 1 km², meaning, of course, that this larger pixel may consist of pixels with different emissivity values, which are termed subzones. Hence the following expression determines the temperature of each channel corrected from the emissivity effects. This equation has been obtained taking into account the definition of emissivity and substituting into Plank’s law (inverted)

\[
T_{\lambda} = \frac{C_2}{\lambda} \cdot \ln \left( \frac{1}{1 + \frac{C_1}{\lambda^5 \cdot L_\lambda \cdot A_T \sum_{i=1} A_i}} \right)
\]

\[
\lambda: \text{ representative wavelength of each channel (10.8 μm for channel 4; 11.9 μm for channel 5)}
\]
\[L_\lambda: \text{radiance values supplied by the satellite} \]
\[A_T: \text{total NOAA 9 pixel area} \]
\[A_i: \text{subzone area occupied by each subzone} \]
\[n: \text{number of subzones} \]
\[C_1, \ C_2 \text{are constants:} \]
\[C_1 = 1.19 \cdot 10^8 \text{ W m}^{-2} \text{ sr}^{-1} \mu\text{m}^4 \]
\[C_2 = 1.439 \cdot 10^4 \mu\text{m} \cdot K \]

During a clear, cloudless day, the spectral interval under consideration is fairly transparent to solar radiation except for the effects of water vapour contained in the atmosphere. So the absorption and emission of radiation due to CO₂, O₃, aerosol, etc., may be disregarded, but not the absorption by water vapour. Solving this problem has meant resorting to various different methods. Since there is no radiosounding station in Catalonia, the split-window method has been used. After working with different equations for the calculation of surface temperature \(T_s\) (Cunillera et al, 1991), we have selected the one proposed by Price (1984), which gave the best results (Llasat et al, in press):

\[
T_s = T_{10.8} + 2.78 \cdot (T_{10.8} - T_{11.9})
\]

where we have previously corrected \(T_{10.8}\) (temperature for channel 4) and \(T_{11.9}\) (temperature for channel 5) from the emissivity effects.

The temperature values thus obtained can be compared to the actual results measured on the ground, assuming the existence of a sufficiently dense network of surface measurements.

3. DETERMINATION OF SOIL TEMPERATURE FROM SURFACE DATA

The split-window algorithm used for the determination of \(T_s\) must be calibrated, using experimentally measured soil temperatures. Unfortunately, these are not commonly measured, so one must resort to some alternative methods.

On the basis of the stations of the pilot agrometeorological network, various methods have been tested to evaluate \(T_s\) where air temperature \((T_a)\) and/or other variables are available. As it is advisable to take satellite pictures on cloudless days, where the aim is characterization of the soil, the studies carried out correspond to that type of days. These methods are described in the following paragraphs.

3.1. On the basis of net radiation, \(R_n\):

This method (Llasat et al, 1992), is based on the energy balance according to which the net radiation reaching the surface (cloudless day) is:

\[
R_n = E_K \downarrow - E_K \uparrow + E_L \downarrow - E_L \uparrow = (1 - \alpha) E_K \downarrow + \varepsilon_a (0) \sigma T_a^4 - \varepsilon \sigma T_s^4
\]

\[
R_n: \text{net radiation} \]
\[E_K \downarrow: \text{downward shortwave radiation} \]
\[E_K \uparrow: \text{upward shortwave radiation} \]
\[E_L \downarrow: \text{downward longwave radiation} \]
\[E_L \uparrow: \text{upward longwave radiation} \]
\[\alpha: \text{surface albedo} \]
\[\varepsilon_a (0): \text{clear sky emissivity} \]
\[\sigma: \text{Stefan-Boltzmann constant, } 5.67 \cdot 10^{-8} \text{ W m}^{-2} \text{ K}^{-4} \]
\[T_a: \text{air temperature} \]
\[\varepsilon: \text{surface emissivity} \]
\[T_s: \text{surface temperature} \]

So the surface temperature will be:

\[
T_s = \left( \frac{(1 - \alpha) \cdot E_K \downarrow + \varepsilon_a (0) \cdot \sigma \cdot T_a^4}{\varepsilon \cdot \sigma} \right)^{\frac{1}{4}}
\]
Considering that the plant canopy under the stations of reference is grass, albedo has been calculated on the basis of the expression (Dong et al., 1988):

\[ a = 0.00158 \cdot \theta + 0.386 \cdot \exp (-0.0188 \cdot \theta) \]

where \( \theta \) is the solar height in degrees.

On the supposition that clear sky emissivity depends only on the influence of the water vapour, the equation proposed by Berdahl and Fromberg (1982) has been taken, as follows:

\[ \varepsilon_a (\theta) = 0.741 + 0.0062 \cdot T_d \]

where \( T_d \) is the dew-point temperature.

By way of example, application of this method to 27 May 1991, at the Mas Badia station (Fig. 1) at the time of passage of the satellite (14:30 GMT), provides a temperature of 28.41°C, compared to an actual temperature of 29.20°C.

Figure 2 presents the evolution of solar radiation, net radiation, air temperature and soil temperature for that same day. As might be suspected, there is a time lag between the respective maxima. The time of passage of the satellite corresponds to a moment shortly before the air and soil temperature curves intersect.

3.2. On the basis of air temperature, \( T_a \):

Knowing their respective hourly values, the relationship between \( T_s \) and \( T_a \) can be represented by the first-order equation

\[ T_s = A + B \cdot T_a \]

whose slope \( B \) will basically depend on the time of the year.

This method has been applied to values measured during April and May 1991. Figure 3 shows the daily evolution of the actual \( T_s \) and \( T_a \) obtained on the basis of \( T_a \), according to the previous algorithm. It can be observed that this method provides very favourable results at the times of passage of the satellites used. On the basis of this it is possible to determine the soil temperature at all those stations having a thermograph, which increases the number of control points available.

Application of this method to 27 May 1991 provides a temperature of 29.92°C.

3.3. On the basis of daily evolution of \( T_s \) or \( T_a \):

Knowing the maximum and minimum \( T_s \) for a solar angle greater than 20°, the following equation can be applied (Llasat et al., 1990):

Fig. 2 - Daily evolution of: a) solar radiation, b) net radiation, c) air temperature and d) surface temperature. The vertical line corresponds to the time of passage of the satellite.

Fig. 3 - Daily soil temperature evolution a) actual; b) calculated. Daily air temperature evolution is also shown in order to explain the anomaly observed. The vertical line corresponds to the time of passage of the satellite.
\[ T_s (t) = T_{s \text{min}}^0 + (T_{s \text{max}} - T_{s \text{min}}^0) \cdot \sin [\omega \cdot (t - t_0)] \]

where \( t_0 \) is the time at which \( \theta = 20^\circ \).

This expression provides quite good accuracy for the daylight hours, while it is not so good for the night hours. It has been applied to the months of April and May 1991, and figure 4 shows the daily evolution of \( T_s \) for the Mas Badia Station according to the measured (actual) and the calculated (theoretical) values.

Where only maximum and minimum air temperatures are available, an analogous equation is applied, and once \( T_s \) is obtained at the time of passage of the satellite it is possible to evaluate the soil temperature using the expression derived in the previous section.

Application of this method to 27 May 1991 provides a temperature of 30.51°C.

![Graph of soil temperature evolution](image)

**Fig. 4 - Daily soil temperature evolution a) actual; b) calculated. The vertical line corresponds to the time of passage of the satellite.**

**CONCLUSIONS AND DISCUSSION**

From the above exposition, it may be concluded that the existence of a surface agrometeorological network and the use of remote sensing data are complementary and will be used in an integrated way. On the one hand, the pilot network of automatic agrometeorological stations already installed provides the information necessary for better management of agricultural resources, especially in respect of irrigation schedules and pest management, while on the other hand it makes available data necessary for calibration of the algorithms used in satellite thermal image processing.

Although the methods presented in this paper constitute a first approximation, they always provide better results than the simple hypothesis that soil temperature can be identified with air temperature at one and a half metres, or that it can be obtained by mere addition of a constant coefficient for the whole year. In the example proposed, the relative error for the three methods is of -2.71%, 2.47% and 4.48%, respectively. As may be observed, the margin of error is very similar.

Of the three procedures suggested, the first is the most correct, since it is based on the physical principal of radiative balance, while the others are purely empirical. It nevertheless presents the disadvantage of being very sensitive to any change or error in radiation measurements. Application thereof calls for the existence of a surface meteorological network such as that developed in the PAC-COM project.

Once the surface temperature has been determined, it is possible to obtain the thermal inertia, defined as (Caselles, 1983)

\[ P = 1.22 \cdot \frac{(1 - a)}{\Delta T_s} \]

\( P \): thermal inertia
\( a \): surface albedo
\( \Delta T_s \): difference between daily maximum and minimum surface temperature

On the basis of satellite images, it is thus possible to determine thermally homogeneous zones with a precision equal to the pixel size used and, therefore, to select the ideal siting of future meteorological stations, as long as the only factor of interest is the thermal representativeness of same. Should greater representativeness be required, recourse must be had to application of multivariate analysis to already existing climatic data, such as pluviometry and wind. Account must be taken in both cases of orographic conditions. An early result applied by application of this last method shows that if the extreme monthly temperatures are replaced by the corresponding thermal inertia, the clusters distribution so obtained hardly differs. There therefore exists the possibility of using a result obtained by remote sensing to replace climatic data in zones where temperature series are not available.
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