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Use of remote sensing for the calculation of biophysical indicators

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Abstract. In recent years, remote sensing has emerged as one of the most useful tools in agronomy. A series of biophysical indicators can be derived from satellite images and become inputs for decision support systems in irrigation management, crop planning or determination of crop yields, thus achieving a better management of resources. An automated system implemented under the Telerieg project provides these indicators on a daily rate to aid in decision-making.

Keywords. NDVI – LST – Remote sensing – NOAA-AVHRR – Telerieg – SUDOE – Evapotranspiration – Temperature – Albedo.

Utilisation de la télédétection pour le calcul d'indices biophysiques

Résumé. Ces dernières années, la télédétection a émergé comme l'un des outils les plus puissants dans le domaine agronomique. La réception d'images satellite permet de calculer une série d'indices biophysiques qui, à leur tour, peuvent alimenter des systèmes d'aide à la décision dans la gestion de l'irrigation, la planification des récoltes ou la détermination des rendements des cultures, conduisant ainsi à une meilleure gestion des ressources. Un système automatisé mis en œuvre par le projet Telerieg fournit quotidiennement ces indices pour aider à la prise de décisions.

Mots-clés. NDVI – LST – Télédétection – NOAA-AVHRR – Telerieg – SUDOE – Évapotranspiration – Température – Albédo.

I – Introduction

Remote sensing science and technology, and its applications in various fields, have experienced a successful development in recent decades. The Earth observation from space has become an irreplaceable tool for monitoring various environmental processes of great importance. Desertification processes, formation and development of hurricanes, reduction of ice areas at the poles, deforestation and forest loss or damage assessment after flooding or after a tsunami are some aspects that can be studied by remote sensing.

Until recently, applications and surveys using remote sensing were restricted to very large areas, but technological development has increased its spatial, temporal and spectral resolution, allowing for the development of applications and tools with accuracies of less than one meter.

This is why remote sensing starts to spread like a very useful tool in various disciplines, including agriculture, where it helps to define irrigation schemes, monitor crop development or perform remote identification, among others.

One of the most important features of remote sensing is its ability to extract thematic information from certain measurements of the sensor. That is, other factors that help us better understand our environment can be derived from sensor data. For example, the chlorophyll content is a variable not directly measured by the sensor, but which changes the reflectance this latter receives, so it can be estimated indirectly by observing on which spectral bands its effect is more evident and isolating this component from other factors that may also influence such bands (Chuvieco Salinero, 2002).

The Telerieg project (www.telerieg.net), which full name is "Remote sensing use for irrigation practice recommendation and monitoring in the SUDOE space", aims to better protect the environment through a more efficient and rational management of water resources in agriculture and a more effective prevention and better response capacity to natural hazards. One of its objectives is to improve the recommendations and monitoring of irrigation practices in major crops of the area of the Tajo-Segura Aqueduct in Southeastern Spain.

To achieve it, we have designed an automatic processing system to generate remote sensing products combining data from NOAA-AVHRR satellite with data from a network of agro-meteorological stations. This system sets in motion a chain of data-driven processes (i.e., triggered by the availability of data) that produce a first set of six basic remote sensing products that will be analysed later.

II – Automatic processing system

So far, one of the problems for automatic generation of remote sensing products was the need of *in situ* sensor data for some of the development stages: generation, calibration, validation, complementation, etc. In many cases these data were not available for several reasons: compulsory application forms, limited accessibility to data that could also be not compatible with computer applications, lack of security of supply or geographical distribution, etc. This entailed waiting times and lack of regular availability of data, which resulted in increased production costs.

To overcome these drawbacks, there is a current trend that tends to make data more easily accessible and open. The idea is to convert what is initially an *in situ* resource providing details of the near physical environment into a web resource compatible with commonly used software tools. The OGC (Open Geospatial Consortium) has created a series of standards for search, access and distribution, applicable to station data, among others. This standard has been called SOS-SWE (Sensor Observation System – Sensor Web Enablement). This method would solve almost all the above-mentioned issues associated with *in situ* data.

In this scenario, a methodological proposal arises for automatically obtaining products derived from NOAA-AVHRR images through "web sensors", according to OGC-SWE standards. Automation has several advantages: decreased generation time, dedicated technical staff not required, regular supply of data and, ultimately, lower costs per product.

The following Fig. 1 shows a context diagram of the proposed and finally developed system.

The NOAA Station (Dartcom), installed in IMIDA facilities, receives the AVHRR images daily and process them up to level 1b (L1B). These images are automatically detected and become part of the database of products. At the same time, the sensors of the network of agro-meteorological stations record hourly weather observations that are stored in a central database.

When a new NOAA-AVHRR L1B image reaches the data archive, the process chain starts: meteorological observations needed to generate the products are queried from the central database. Then, the available data and images are processed to output the following products:

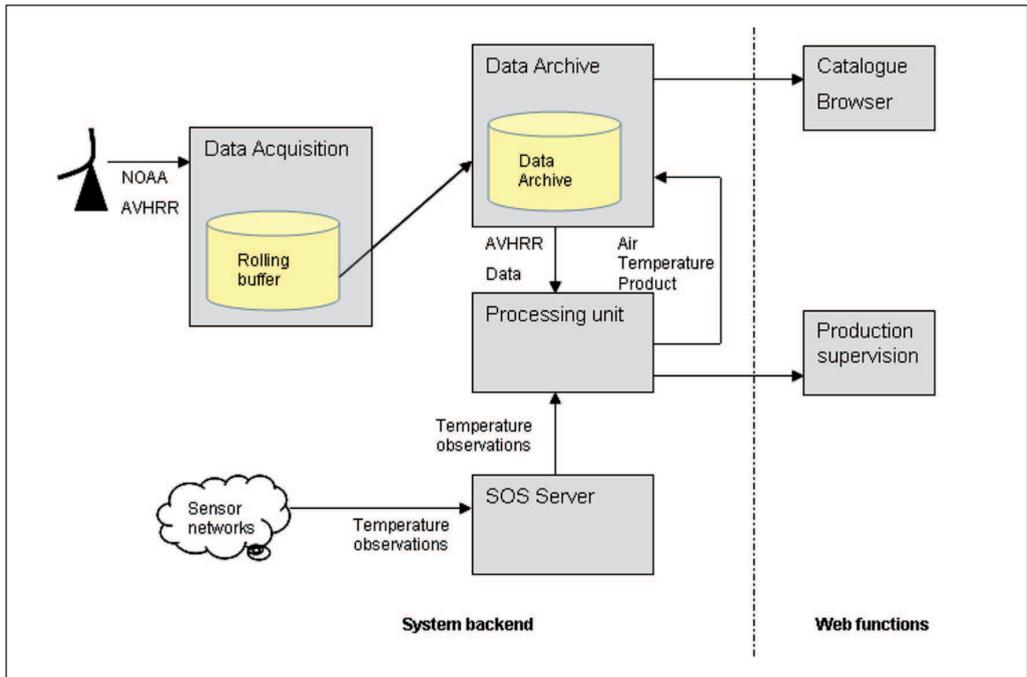


Fig. 1. System description.

1. Level 1C NOAA-AVHRR image (L1C, georeferenced product).
2. NDVI.
3. Land surface temperature (LST).
4. Potential evapotranspiration (ET_0).
5. Air temperature (AT).
6. Albedo (ALB).

Finally, we have developed a web viewer for querying, browsing and downloading products. This catalogue can be searched by acquisition date and product type, and displays the results alongside their legends in an embedded Google Earth viewer. The viewer also offers a smaller version of the metadata for each product and their respective download links.

It should be noted that the design of this system has been driven by expandability and interoperability criteria:

- Receiving data from additional sensors: The system is not limited to the reception of NOAA-AVHRR data, as it can be potentially configured to download Earth Observation (EO) data from any other repository in the world. For example, it could be configured to download and process MODIS data located on an FTP, Landsat or SPOT site.
- It can include additional processors for new products, beyond those initially planned and developed.
- It can process data from other geographical areas where *in situ* images and data are already available.
- It makes use of OGC standards for web services, following the SOS-SWE standard to store and make available data from the sensor observations to any user, ensuring interoperability.

III – Products generated

1. Normalized Difference Vegetation Index (NDVI)

NDVI, proposed by Rouse *et al.* in 1974, is one of the most widely used vegetation indices. This index reveals the presence of vegetation and monitors its development, so we may determine the metabolic efficiency of vegetation in a given area or locate areas where the vegetation growth is less than in the surrounding areas.

This index is based on the distinctive radiometric behaviour of vegetation throughout certain spectral windows. Healthy vegetation shows a characteristic spectral signature with a clear contrast between the visible bands, especially the red band (0.6 to 0.7 μm) and near-infrared (0.7 to 1.1 μm) (Chuvieco Salinero, 2002). The chlorophyll pigments of a leaf absorb most of the energy of the visible light area in contrast to the low absorption of the near-infrared. This marked difference between the absorption spectrum in the visible and near-infrared (NIR) of healthy vegetation allows for distinguishing it from those suffering some kind of stress (water stress, for example, caused by drought), in which there is less reflectance in the NIR and greater absorption in the visible. Thus we can conclude that the greater the contrast between the reflectances of both bands, the greater the vigour of the vegetation cover, a lower difference indicating unhealthy or sparse vegetation. On the other hand, the radiometric spectrum of soil usually does not show this clear difference between the above mentioned spectral bands and, therefore, NDVI makes difficult to distinguish between vegetation and bare soil (Karnieli *et al.*, 2010). To overcome this drawback, indices such as SAVI and MSAVI were created, in order to highlight the vegetation response and reduce that of the soil. The NDVI is calculated using the expression proposed by Rouse *et al.* in 1974:

$$NDVI = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}}$$

Where ρ = reflectance in the corresponding band.

NDVI applications are very diverse (Fig. 2). In agriculture, it is used to evaluate the status and evolution of crops, to estimate crop yields (Moges *et al.*, 2004), to identify crops and develop agricultural inventories and to study crop forecasting, as done by Martínez-Casanova, J. *et al.* (2005) for vines.

2. Land Surface Temperature (LST)

Land surface temperature as derived from satellite data can be defined as the temperature radiated by the Earth's surface and observed by the satellite sensor.

The calculation of LST from satellite images is being regularly and widely used in climate and global change studies, in different disciplines such as geology, hydrology, agronomy, ecology or meteorology.

To obtain LST, data from the thermal infrared band is used, since most of the energy detected by the sensor in this spectral region is emitted by the Earth's surface (Jiménez-Muñoz and Sobrino, 2008). In order to know the temperature of the Earth's surface by using pixel radiance of a satellite image as main input data, basically two quantities of radiation must be related: that which reaches the satellite and that coming from the ground, as the latter depends on the temperature we want to estimate (Pérez *et al.*, 2003).

The most common methodology for obtaining LST is known as split-window algorithm. Over the past 25 years there have been numerous publications on split-window algorithms. Qin *et al.* (2004), for example, considers up to 17 of them in his comparative study of LST products derived from NOAA-AVHRR images.

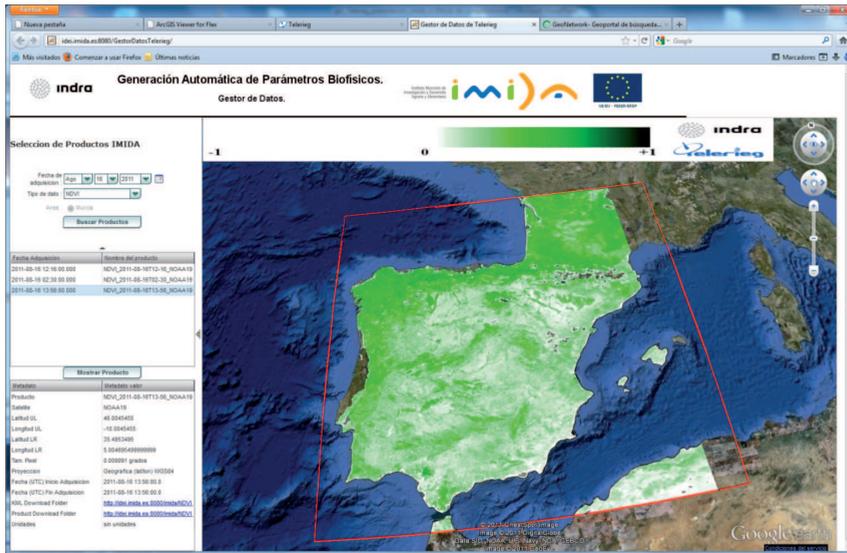


Fig. 2. NDVI products in the catalogue browser.

Retrieval of surface kinetic temperature from AVHRR data by this technique was firstly proposed for sea temperature estimation (Quin *et al.*, 2004). Application of the split-window methodology to estimate LST did not begin until the mid-eighties with Price (1984) (Quin *et al.*, 2004).

The study of Quin (2004) compared each of the algorithms in terms of calculation and accuracy, using measures on the ground and simulations obtained from programs such as LOWTRAN, MODTRAN or 6S. Based on these facts, Quin concluded that one of the best algorithms for LST retrieval from AVHRR was proposed by Sobrino *et al.* (1991), published in the journal *Remote Sensing of Environment*. For this reason, Telerieg has used the algorithm proposed by Sobrino *et al.* (1991), later modified by Sobrino and Raissouni (2000) to produce maps of LST. The coefficients used were obtained from Jiménez-Muñoz and Sobrino (2008), which provide those that can be used with different low-resolution sensors.

The algorithm is given by:

$$T_s = T_i + c_i (T_i + T_j) + c_2 (T_i + T_j)^2 + c_0 + (c_3 + c_4 W) (1 - \varepsilon) + (c_5 + c_6 W) \Delta \varepsilon$$

where T_i and T_j are the at-sensor brightness temperatures (in °kelvin) at the split-window bands i and j , ε is the mean emissivity, $\varepsilon = 0.5(\varepsilon_i + \varepsilon_j)$, $\Delta \varepsilon$ is the emissivity difference of the bands i and j , $\Delta \varepsilon = (\varepsilon_i - \varepsilon_j)$, W is the total atmospheric water vapour content (in grams per square centimetre), and $c_0 - c_6$ are the split-window coefficients determined from simulated data.

3. Evapotranspiration (ET₀)

In agriculture, the estimation of evapotranspiration is especially useful to help determine water demand and thus, irrigation management (definition of irrigation schedules). This in turn improves the management of water resources in the area and thus helps to protect the environment.

Until relatively recently most evapotranspiration estimation models were applied only locally, since they required *in situ* measures from nearby weather stations (e.g. soil water balance, Bowen ratio or Penman-Monteith equation). But with the development of remote sensing, calculation models of evapotranspiration have been applied and extended to larger areas, even where mete-

orological data are unavailable. Remote sensing has thus become a major tool for monitoring the evolution of evapotranspiration at different scales, from whole regions to individual plots, through high-resolution images.

The Telerieg project team has calculated the reference evapotranspiration through the adaptation of the Penman-Monteith equation to remote sensing proposed by Rivas (2004) in his thesis work. This adaptation produces a linear relationship that simply requires calculating two parameters, which represent the radiative and meteorological effects on a hypothetical reference surface, for a given set of local conditions described in Rivas *et al.* (2003). This combination of the Penman-Monteith equation with satellite data is a simple way to estimate evapotranspiration at a regional scale and is expressed as follows:

$$ET_0 = a \cdot T_s + b$$

La temperatura de superficie (T_s) se extrae de las imágenes de satélite NOAA-AVHRR y es uno de los productos ya derivados en el contexto del proyecto Telerieg (ver *apartado 2* de este capítulo). The coefficients a and b are defined on the basis of meteorological data and the features of each region. Meteorological stations must provide data on air temperature, relative humidity, wind speed and solar radiation to estimate analytically the parameters a and b (Rivas *et al.*, 2003). In the present case, we have chosen to use coefficients obtained for a zone similar to that described in the above-mentioned thesis work (Fig. 3). This is the region of Larissa (Greece), whose coefficients are $a = 0.14 \text{ mm}/(\text{day}\cdot^\circ\text{C})$ and $b = -0.40 \text{ mm}/\text{day}$.

| | ET0 NOAA / ET0 in situ | |
|--------------|------------------------|------------|
| | R | Nº Valores |
| 14/10/2010 | ± 0.42 | 33 |
| 15/10/2010 | ± 0.65 | 25 |
| 17/10/2010 | ± 0.55 | 38 |
| 18/10/2010 | ± 0.63 | 43 |
| 19/10/2010 | ± 0.51 | 42 |
| 20/10/2010 | ± 0.63 | 42 |
| TOTAL | ± 0.57 | 223 |

Fig. 3. Results of the partial validation of the ET0 algorithm on the region of Murcia.

4. Air Temperature (AT)

The air temperature near the surface is a key variable to describe the energy and water cycles in the Earth-Atmosphere system (Colombi *et al.*, 2007). It is also a required parameter in environmental and hydrological calculation models.

The air temperature is usually measured by weather stations, which provide only very specific values. This means that it is very difficult to get data from remote or isolated areas where these stations are less frequent. In the last few years, the improvement of remote sensing techniques has allowed for the implementation of an algorithm to calculate the spatial distribution of air temperature by using data derived from remote sensors.

Telerieg proposes to determine AT from land surface temperature as the two variables are related, although this relationship varies depending on the terrain features and on the daily and seasonal atmospheric conditions. The proposed procedure solves, by empirical methods, the problem of establishing this relationship. Through a linear correlation analysis of LST derived from NOAA-AVHRR and air temperature measured *in situ* by the network of agro-meteorological stations of the

SIAM (Agro-meteorological Information System of the Murcia Region), we obtain coefficients which determine the equation that will generate the values of air temperature for the entire study area.

Since the relationship between the two variables depends on soil types and topography, we defined several linear equations for the different types of terrain found in the studied basin (Fig. 4). After determining the coefficients that define the linear equations, these equations were applied to each pixel of the LST maps derived from NOAA-AVHRR, producing an estimate of air temperature at 1 km resolution.

This method is well documented in the literature. For example, Jones *et al.* (2004) estimate the minimum air temperature at night through MODIS LST products in Alabama. Gang Fu *et al.* (2011) estimate the air temperature in an alpine meadow in northern Tibetan Plateau from MODIS LST products. We can find many more examples in various scientific publications.

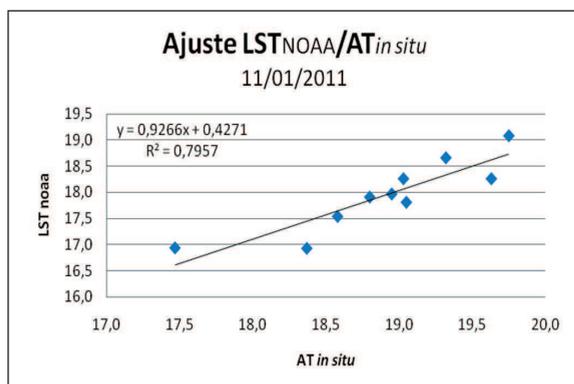


Fig. 4. Least squares fitting for LST-AT values.

5. Albedo (ALB)

Albedo is a quantity that expresses the relationship between incident and reflected energy on the Earth's surface. That is, albedo defines how much solar radiation is reflected (short-wave energy) or absorbed and reemitted (in the thermal infrared) (Dickinson *et al.*, 1990, in Sellers, *et al.*, 1995). Albedo ranges from 0 (totally absorbing surfaces) to 1 (perfectly reflective surfaces).

The albedo calculated in Telerieg has been the TOA (Top-of-Atmosphere). This is a broadband albedo, which measures reflected radiation in the visible range and part of the near-infrared. It is obtained through a linear combination of bands 1 and 2 of NOAA.

The wavelengths of the AVHRR/3 sensor, carried on NOAA-15 and later satellites in the same series, are indicated in Table 1.

Table 1. AVHRR-3 channels. Based on: <http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html>

| Channel | Wavelength (μm) | Spectral region |
|---------|------------------------------|------------------|
| 1 | 0.58 – 0.68 | Visible |
| 2 | 0.725 – 1.10 | Near-infrared |
| 3 | 3.55 – 3.93 | Mid-infrared |
| 4 | 10.30 – 11.30 | Thermal infrared |
| 5 | 11.50 – 12.50 | Thermal infrared |

We used the algorithm proposed by Gimeno-Ferrer *et al.* (2001). It is a linear combination of the radiances of bands 1 and 2 (short-wave):

$$L_{0L} = a_0 + a_1 L_1 + a_2 L_2$$

Where L_{0L} = long-wave radiance, L_1 and L_2 = short-wave radiances of band 1 and 2, respectively, and a_0 , a_1 and a_2 = previously calculated coefficients depending on the type of surface. In Telerieg, we have used the coefficients defined for the AVHRR sensor in the same publication.

After this calculation and in order to transform the albedo in a percentage, the latter is divided by the incident solar radiation (TOA) estimated for the corresponding day and latitude.

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