



# ADVANCES IN FOREST FIRE RESEARCH

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## PREFER FP7 project for the management of the pre- and post-fire phases: presentation of the products.

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### 1. Introduction

The PREFER FP7 project aims at responding to major fire prevention needs in Southern Europe. The Mediterranean area is systematically affected by uncontrolled forest fires with large impact on ecosystems, soil erosion, slope instability, desertification trends, and local economies as a whole, with a negative mid-to-long term prospect because of Climate Change. In this scenario, the need to improve the information and the intelligence support to forest fire prevention is widely recognized to be relevant. Fire prevention is still the most cost-effective strategy when compared to firefighting and extinguishing that are costly, local, and triggered only in response to already ongoing crises. The PREFER project intends to contribute to responding to such a pragmatic need of Southern Europe's forests by: 1) providing timely multi-scale and multi-payload information products based on exploitation of all available spaceborne sensors; 2) offering a portfolio of EO products focused both on Pre-crisis and Post-crisis forest fire emergency cycle in the EU Mediterranean area; 3) preparing the exploitation of new spaceborne sensors available by 2020 (e.g.: Sentinels) and 4) contributing to the definition of User requirements for the new EO missions.

The paper is devoted to illustrate the results of the R&D activity and the results of the preliminary validation of the project products.

### 2. Methods

The main objective of the PREFER project is to set up a space-based end-to-end information services to support prevention/preparedness and recovery phases of the Forest Fires emergency cycle in the EU Mediterranean Region (Figure 1). The satellite data The PREFER Service portfolio consists of two main services (see Table 1):

1. Information Support to Preparedness/Prevention Phase" (ISP) Service, and
2. Information Support to Recovery/Reconstruction Phase" (ISR) Service

Hereafter the peculiarities of such information services are listed:



- They will be based on an harmonized set of user requirements, defined by the different users from Portugal, Spain, Italy, France and Greece, also taking into account the different legal frameworks existing in such countries.
- They will be as general as to be usable in the different countries of the Mediterranean Region.
- They will be demonstrated by an interoperable service provision infrastructure (based on OGC / INSPIRE), that will allow easy access to the information.
- They will be complementary to the products provided by the GMES Land and Emergency services of the GMES Initial Operations.
- They will be complementary to the products provided by the EC JRC EFFIS (European Forest Fires Information System) System.
- They will be based on the exploitation of the data from the GMES space infrastructure.
- They will optimise integration of different data: EO, Digital Terrain Models, socio-economic data, in-situ data, meteorological data.

The PREFER consortium has the ambitious objective to start up the formation of a cluster of research institutes, industries and SMEs focused on the provision of space-based information services and products in support to Forest fires emergency management in the Mediterranean Area.



Figure 1. In gray the countries where the PREFER project partners are located and in red the project test areas.

Table 1. List of products to be developed in the framework of the PREFER project.

<b>Service: Information Support to Preparedness/Prevention Phase</b>	<b>Service: Information Support to Recovery/Reconstruction Phase</b>
Seasonal Fuel Map	Post-fire Vegetation Recovery Map
Seasonal Fire Hazard Map	Burn Scar map HR Optical and SAR
Seasonal Exposure (Vulnerability & Economical Value) Map	Burn Scar Map VHR
Seasonal Risk Map	Biomass Burning Aerosol Map
Daily Fire Hazard	3D Fire Damage Assessment Map
Prescribed Fires Map	Damage Severity Map

### 3. Results

This paragraph is devoted to describe more in detail the PREFER products providing, for those that are at a most advanced stage of development (namely: burn scar map, damage severity map and daily fire hazard), a description of results of the preliminary validation procedure. Figure 2 provides an example of one of the products which has been developed in the project. In particular, it shows the accuracy in the estimate of the burned areas reachable by using a suitable automatic algorithm applied on a high spatial resolution satellite images compared with the results routinely provided by JRC's EFFIS (European Forest Fire Information System) system.

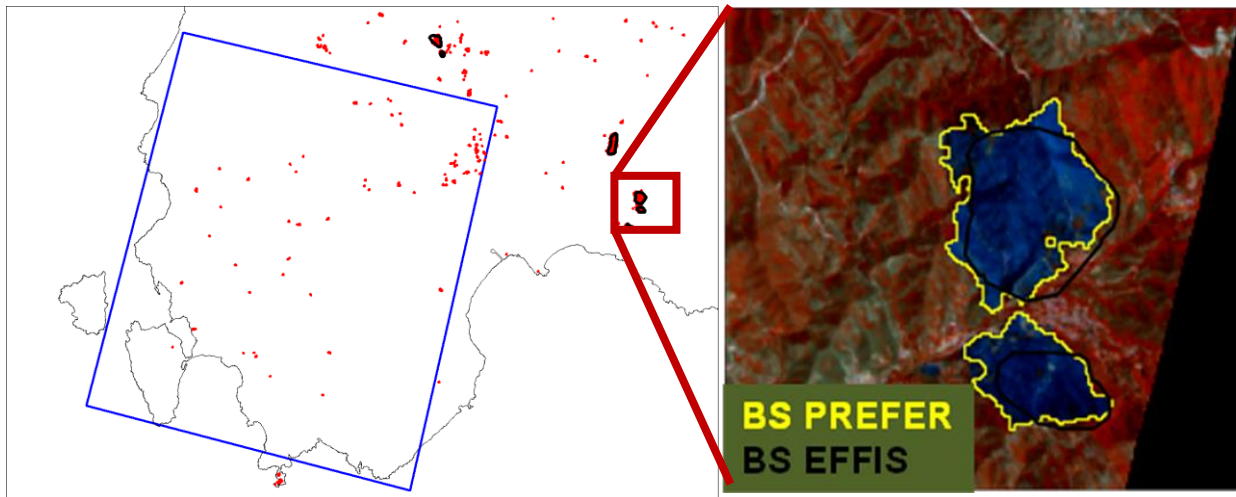


Figure 2. An example of the PREFER product burn scar. The PREFER product based on Landsat is compared with the same product provided by the EFFIS system of JRC.

Figure 3 provides an example of the damage severity map computed for a case study regarding a fire occurred last summer (2013) in Sardinia. The area of interest, Golfo Aranci, has been selected because of its relevance as SCI (Site of Community Interest). A couple of Landsat 8 images (pre and post fire) of the area were used for the computation of the damage severity index. Presently, three indices have been selected for the estimate of the fire severity, namely:

1. the well known dNBR (differential Normalized Burn Ratio) defined as follows (Key and Benson 1999, 2002):

$$dNBR = NBR_{pre} - NBR_{post}$$

where  $NBR_{pre}$  and  $NBR_{post}$  are the NBR indices computed on the pre and post-event images, according to the López García and Caselles relationship:

$$NBR = \frac{NIR - MIR}{NIR + MIR}$$

The dNBR provided a continuous scale of difference that could be related to a magnitude of ecological change, which in turn offered a conceptual model for burn severity: the greater the detected change caused by fire, the higher the severity.

2. a combination of indices called BSI which is composed of the three indices dNDVI, dNBR and dNDII:

$$BSI = (dNDVI + dNDII + dNBR) / 3$$

$$NDII = \frac{NIR - SWIR}{NIR + SWIR} \quad NDVI = \frac{NIR - RED}{NIR + RED} \quad dNDII = NDII_{pre} - NDII_{post} \quad dNDVI = NDVI_{pre} - NDVI_{post}$$

This index, according to some tests made on fires occurred in Sardinia seems to be able to improve the fire damage severity estimation.

3. the DSI (Damage Severity Index) defined as:

$$DSI = MNBR_{pre} - MNBR_{post}$$

based on an optimized version of NBR called Modified Normalized Burn Ratio (MNBR) expressed as:

$$MNBR = \frac{NIR - \frac{1}{1.68}MIR}{(0.7 - NIR)^2 + MIR^2}$$

In the previous equation SWIR and MIR refer to the channels at 1.6 and 2.1  $\mu\text{m}$ , respectively. Each one of the indices has presents some advantages and disadvantages summarized in Table 2.

*Table 2. Comparison of the advantages and disadvantages of the developed indices.*

Index	Advantages	Disadvantages
dNBR	Classical index; Tested in many cases; Thresholds known;	Saturation; Poor optimality; Sensitivity to external effects (Atmosphere, noise, etc... );
BSI	Composed by classical index; Increase of information considered respect other two;	Poor optimality; Sensitivity to external effects (Atmosphere, noise, etc... ); Research of new threshold in calibration phase for damage assessment.
DSI	Optimized for change detection in burned areas; Increased sensitivity in changes due to fire. Using only two bands (less noise) Low sensitivity to external effects	Research of new threshold in calibration phase for damage assessment. Using only two bands (less information)

In figure 3 the damage severity maps computed, in an automatic way, by each one of the previously introduced indices have been compared with the damage level estimate done through the use of field data (MCBI, see below) and very high resolution images (Rapid Eye and Kompsat).

The index that best correlates with ground truth map is the DSI.

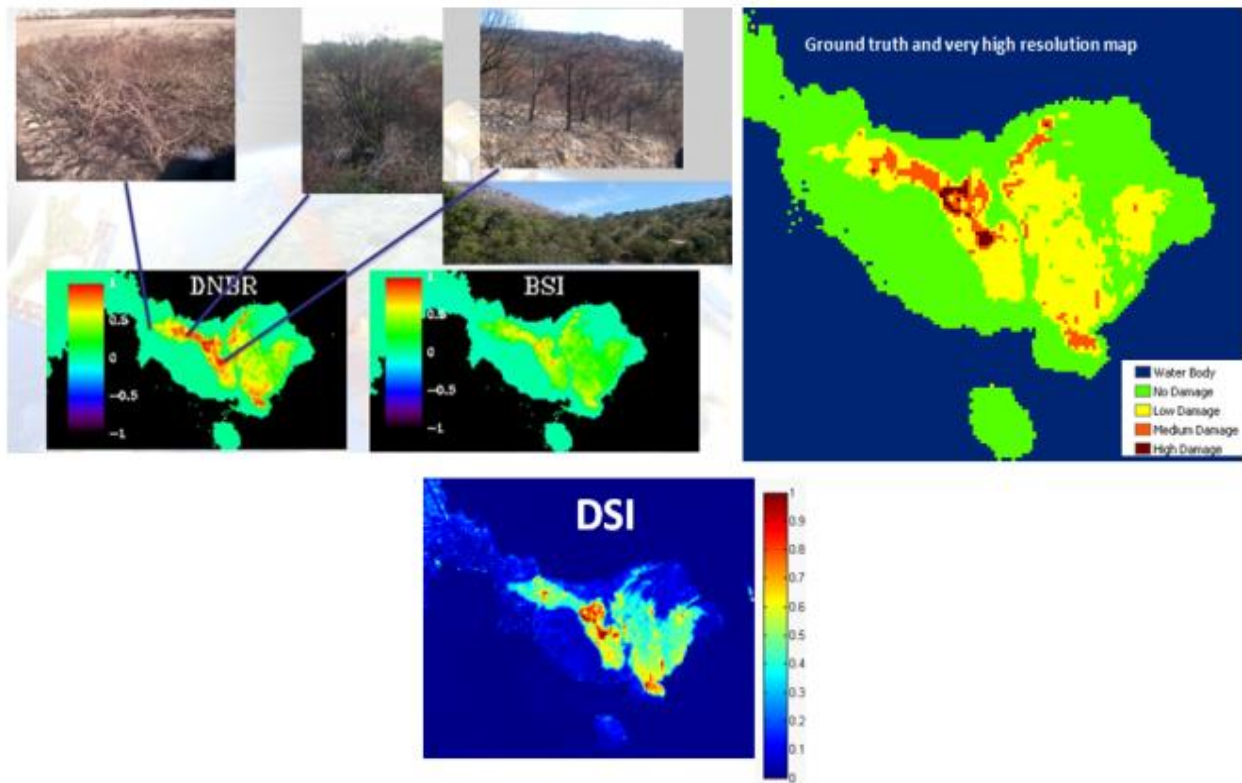


Figure 3. Comparison of the three indices with ground truth data.

The scale of the damage more used in the scientific international field is the CBI (composite burn index), a description of this parameter was given in Key and Benson 2006. In CBI, synthetically, the vegetation is considered made of 5 possible strata: 1) substrates, 2) herbs, low shrubs and trees less than 1 m, 3) tall shrubs and trees from 1 to 5 m high, 4) intermediate trees, 5) big trees.

The CBI was an innovation in the field of damage estimation because it provides an overall view of the damage associated with a number that varies continuously in a established range (0-3), this is a great advantage if we want to connect CBI to satellite observations.

However, we lightly changed the CBI definition for making it more consistent with our definition of damage. In particular, when the plots do not contain all strata, the missing strata have to be considered not damaged if these strata are upper than the existing strata and completely damaged if the missing strata are lower than existing strata.”

Another change that we have made to CBI, is the reduction of the strata from 5 to 3: 1) herbs, low shrubs and trees less than 2 m, 2) tall shrubs and trees from 2 to 4 m high, 3) big trees. This new version of CBI is named Modified Composite Burn Index (MCBI).

Figure 4 shows an example of the third product recalled above, the Daily Fire Hazard Map (DFHI). This index is based on the FPI (Fire Potential Index) derived by Burgan (Burgan, 1998) for U.S. and takes into account the JRC experience (Lopez *et al.*, 2002). The model requires the NDVI to compute the *Relative Greenness*, meteorological data (air temperature, relative humidity, cloudiness and rainfall) for estimating the Ten Hours Time Lag Fuel Moisture (FM10hr) and a fuel map to estimate the percentage of dead vegetation. The relative greenness (RG) or vegetation stress index represents how much green is a pixel, with reference to the range of historical observation of the NDVI used (Burgan, 1993). This quantity allows the estimate of the percentage of green fuel, as function of the fuel model assigned to each pixel.

The *Ten Hours Time Lag Fuel Moisture* has been selected as the quantity representative of the humidity available in the dead vegetation (Nelson, 2000). Such a quantity can be computed by using the meteorological parameters and the relationship described by Lopez (Lopez, San-Miguel, 2002). However, the classic definition of FPI does not allow to take into account the effect of solar illumination conditions in determining the moisture content of the dead vegetation, therefore its proneness to burn. Actually, in Lopez *et al.* 2002 is declared that the *emc* values were corrected to take into account the solar heating but the way how this is obtained was not explained. Therefore, in order to introduce such parameter we decided to apply the formulas used for estimating the vegetation evapotranspiration rate,  $ET_0$ , and to use the computed values as a sort of weight for obtaining the *FM10hr* term for similar vegetation types characterized by a different solar *aspect angle*.  $ET_0$  has been computed by using the Penman-Monteith formula (Allen *et al.*, 1998), modified according with FAO:

$$ET_0 = \frac{0.408 \cdot \Delta \cdot (R_n - G) + \gamma \cdot \frac{900}{T} \cdot u_2 (e_s - e_a)}{\Delta + \gamma \cdot (1 + 0.34 \cdot u_2)} \quad (5)$$

where  $ET_0$  is the reference evapotranspiration [ $\text{mm day}^{-1}$ ],  $R_n$  the net radiation available at the vegetation [ $\text{MJ m}^{-2} \text{day}^{-1}$ ],  $G$  the heat flux [ $\text{MJ m}^{-2} \text{day}^{-1}$ ],  $T$  the daily mean temperature at 2 m [K],  $u_2$  the wind velocity at 2 m [ $\text{m s}^{-1}$ ],  $e_s$  water vapour saturation pressure [kPa],  $e_a$  actual vapour pressure [kPa],  $e_s - e_a$  the deficit of saturation pressure [kPa],  $\Delta$  the slope of the vapour pressure curve [ $\text{kPa } ^\circ\text{C}^{-1}$ ],  $\gamma$  psychometric constant [ $\text{kPa } ^\circ\text{C}^{-1}$ ]. Therefore, the needed meteo data are: the mean temperature and humidity, the wind speed, the net solar radiation computed, in our case by using slope and aspect angle retrieved from a DEM of the area of interest. However, the whole process to obtain the quantities needed can be found in (Allen *et al.* 1998). Anyway others relationship, like these of Hargreaves (Hargreaves, 2003) and Thornthwaite (Thornthwaite, 1948), can be used for computing the same quantity.

Since also the presence of water in the alive vegetation can be considered relevant in determining the fire regime, the problem of estimating the vegetation water content, by using satellite images, has been dealt with. This estimate is made through an index called the *Equivalent Water Thickness* (EWT). We adopted the expression given by Ceccato (Ceccato, 2002) which allows to estimate the value of EWT as a function of GVMI (Global Vegetation Moisture Index), although this index has been defined for the sensor SPOT/VEGETATION. Therefore, it was necessary to compute new coefficients allowing to apply the Ceccato EWT relationship to MODIS images. This was made by carrying out an extended series of simulation by using PROSAIL software. The new parameters have been computed by simulating more than 650000 profiles by using PROSAIL.

The results obtained by means of the simulation have been used for adapting the coefficients of the Ceccato model to the MODIS sensor and, above all, to the Mediterranean vegetation.



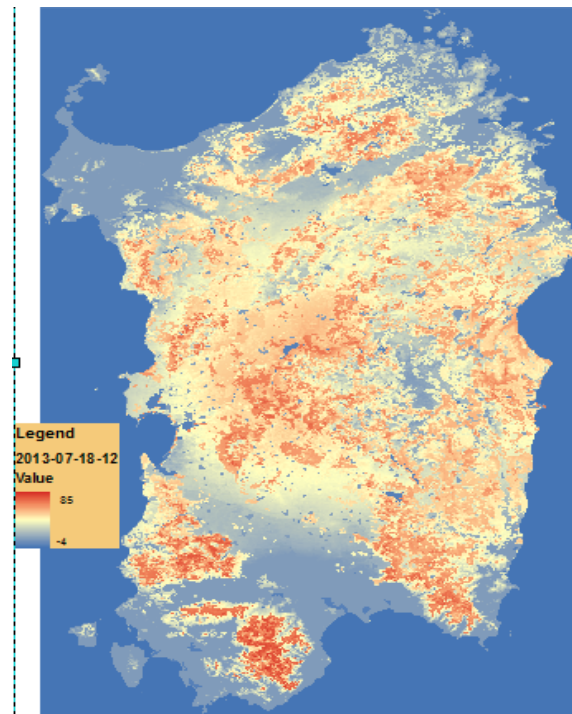


Figure 4. Example of DFHI index computed on the Sardinia region for the day 18 July 2013 at 12:00 UTC.

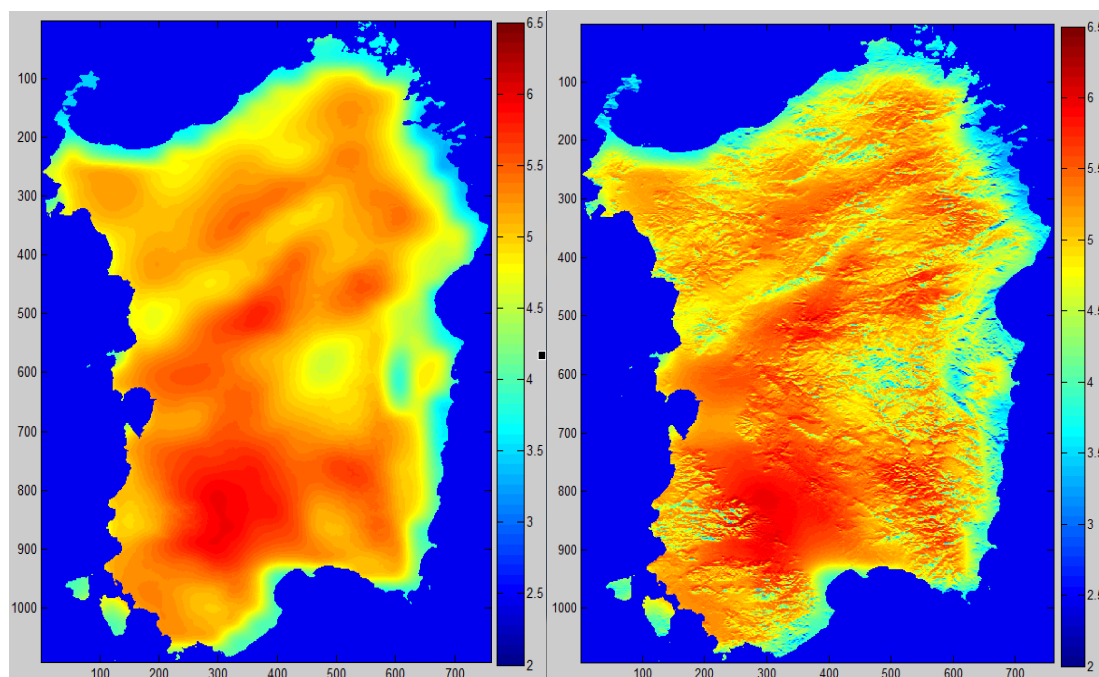


Figure 5. Comparison between the evapotranspiration ( $ET_0$ ) maps computed by assuming a flat surface (right map) or taking into account the topography (left image) for the Sardinia region.

The solar illumination conditions are taken into account for estimating the DFHI by using  $ET_0$  as a way for correcting the air temperature values used for retrieving the emc parameter. This has been done as follows:

- the  $R_n$  term (eq. 5), depending from the local aspect and slope of the surface with respect to the sun, allows us introducing the effect of the illumination conditions. In fact, we can estimate  $ET_0$  assuming a flat surface and using the known meteorological parameters. See Figure 5 (right), as an example for Sardinia. Then, we can estimate the same quantity taking into account



the topographic characteristics of the area of interest (Figure 5, left). From eq. (5), written as function of T, it is possible to estimate the temperature (equivalent temperature) value capable to provide that  $ET_0$  value computed taking into account the topographic effects.

In other words, a LUT has been computed containing 6 parameters: temperature, humidity, latitude, day of the year, available radiation and  $ET_0$ . For each pixel, we enter the LUT looking for the row of the table that minimizes the difference between the actual humidity and the one reported in the LUT, between the actual  $R_n$  and the one reported in the LUT and the actual  $ET_0$  and the one reported in the LUT. The corresponding temperature represents the temperature that takes into account the illumination conditions present in the pixel as consequence of its slope and aspect.

#### 4. Conclusions

The FP7 PREFER project objectives originate from the circumstance that, notwithstanding the improvements in the efficiency of the fire fighting, the phenomenon is not showing any tendency to decrease. Therefore, the European Commission has recently adopted a Communication on the prevention of natural and man-made disasters that focuses on the concept that a common approach is more effective than separate national approaches: for example, developing knowledge, linking actors and policies, and efficient targeting of community funds to prevention. In fact, the prevention is still the most cost-effective strategy, when compared to fire fighting and suppression, able to efficiently mitigate this major environment threat. PREFER intends to contribute at responding to such a pragmatic need of southern Europe's forests by: providing timely information products based on the exploitation of all available spacecraft sensors, offering a portfolio of products focused on pre- and post-crisis forest fire emergency, suitable for the users in the different countries of the European Mediterranean area.

Therefore PREFER will set up a regional service, able to process and distribute the information to end users. The service will be ready for operational deployment at the end of the project, as a new powerful tool at the disposal of the authorities in charge of forest fire management in the Mediterranean area.

#### 5. References

- Key, C.H. and N.C. Benson. 2006. Landscape Assessment: Ground measure of severity, the Composite Burn Index, and remote sensing of severity, the Normalized Burn Ratio. In D.C. Lutes, R.E. Keane, J.F. Caratti, C.H. Key, N.C. Benson, S. Sutherland, and L.J. Gangi. 2005. FIREMON: Fire Effects Monitoring and Inventory System. USDA Forest Service, Rocky Mountain Research Station, Ogden, UT. Gen. Tech. Rep. RMRS-GTR-164-CD:LA1-51.
- Key, C. H. and N. C. and Benson. 1999. Measuring and remote sensing of burn severity. In L.F. Neuenschwander and K. C. Ryan (Eds.), Proceedings Joint Fire Science Conference and Workshop, Vol. II, Boise, ID, 15-17 June 1999. University of Idaho and International Association of Wildland Fire. 284 pp.
- Key, C.H. and N.C. Benson. 2002. Post-fire burn assessment by remote sensing on National Park Service lands, and Measuring and remote sensing of burn severity. U.S. Geological Survey Wildland Fire Workshop, Los Alamos, NM October 31-November 3, 2000. USGS Open-File Report 02-11: 55-56.
- López-García, M.J. and V. Caselles. 1991. Mapping burns and natural reforestation using Thematic Mapper data. *Geocarto International* 1: 31-37.
- Burgan, R. E., R. W. Klaver and J. M. Klaver, "Fuel models and fire potential from satellite and surface observations," *Int. J. Wildland Fire* 8 (3), 159-170, 1998.
- Lopez Garcia, M.J. & Caselles, V., Mapping burns and natural reforestation using Thematic Mapper data. *Geocarto International*, 1, 31-37, 2002.

- Burgan R. E. and Hartford R. A., Monitoring Vegetation Greenness with Satellite data, General Technical Rep. INT-297, USDA Forest Service, 1993.
- Nelson R. M., Prediction of diurnal change in 10-hour fuel moisture content, *Canadian Journal of Forest Research* 30:1071-1087, 2000.
- Lopez A. S., San-Miguel-Ayanz J. and Burgan R. E., Integration of satellite sensor data, fuel type maps and meteorological observations for evaluation of forest fire risk at the pan-European scale, *Int. J. Remote Sensing*, 23 (13), 2713-2719, 2002.
- Allen R. G., Pereira L. S., Raes D. and Smith M., Crop evapotranspiration: guidelines for computing crop requirements. Irrigation and Drainage paper N. 56, FAO, Rome, 1998.
- Hargreaves G. H. and Allen, R. G.: "History and Evaluation of Hargreaves Evapotranspiration Equation", *Journal of Irrigation and Drainage Engineering*, 129 (1), 53–63, 2003.
- Thornthwaite W., An approach toward a rational classification of climate. *Geographical Review* 38 (1), pp. 55-94, 1948.
- Ceccato, P., Gobron, N., Flasse, F., Pinty, B., & Tarantola, S., Designing a spectral index to estimate vegetation water content from remote sensing data: Part 1 Theoretical approach. *Remote Sensing of Environment*, 82, 188, 2002.