Information Extraction for Forest Fires Management

White paper

1 Introduction

Forest fires are a recurrent environmental and economic emergency worldwide. In Southern Europe the year 2003 is considered one of the worst ever with a total burnt area of 740,000 hectares [22]. Even if in some countries according to the national burnt area statistics the problem seems to be under control and of steady or decreasing magnitude, in regions like the western Iberian Peninsula or large parts of North America the trend is worryingly opposite [23, 29]. The causes of such catastrophic events depend on a number of factors, ranging from meteorology to societal changes to vegetation type and emergency response readiness and efficiency.

The main characteristic of the forest fires emergency is its extreme dimension in terms of affected area and number of events. The only technology capable of responding to the requirements of cost effective monitoring and impact estimation is remote sensing. Since the 50s aerial photography has been used to collect information on forest type and health [35]. With the advent of Earth Observation satellites, the forest environment has become a favourite target of scientific observations and image analysis. Thanks to the global coverage, increasing spatial and temporal resolution, and near real time availability satellite imagery is nowadays considered an essential source of information for the fire emergency management activities. Beside increasingly efficient sensors, high performance data processing and computer aided image analysis have been the key technological development for information extraction from satellite images. The large volume of remote sensing data and the intrinsic variability and complexity of the observed phenomena can only be efficiently analysed by intelligent agents. The automatic computational methods give a relevant support to the human expert for solving the specific requirements related to forest fires [36]. Several image processing techniques like neighbourhood filtering and statistical thresholding can be adapted and applied to the automatic interpretation of images of forest regions both for evaluating the vegetation status before the fire as well as for monitoring and mapping the fire severity and burn scars during and after the event [36].

This chapter describes two case studies of operational and autonomous processing chains in place for supporting forest fires management in Europe. The authors focused on the prevention and damage assessment phases of the wildfire emergency cycle, showing how computational intelligence can be effectively used for:

- Fire risk estimation, based on structural and dynamic risk information fusion from in-situ monitoring and remote sensing;

- Burn scars mapping, based on automatic change detection with medium resolution multispectral satellite data.

Conclusions will be drawn on the current state of the art computational tools for fire emergency management and future development derived by remote sensing technological progress.

2 Forest Fire Risk Mapping

2.1 Motivation for service development

Forest fire risk mapping is not a recent practice; it has been used for several decades by diverse institutes and agencies with competences in the prevention and combat of forest fires. Forest fire management actors recognize that the forest fire risk measure is a very powerful tool for supporting the prevention and combat activities.

Although forest fire risk is intimately related to meteorological conditions, the production of an operational forest fire risk map must take into consideration other elements such as land cover, topography, demography, infra-structures or forest-urban interface. The importance of these factors is related to the influence in the occurrence, extension and intensity of forest fires, being the vegetation type and condition the most important elements in the evaluation of the forest fire risk, since it characterizes the forest fuel [15].

During the Year of 2002, in the scope of the PREMFIRE (PREvention and Mitigation of FIRE hazards) project, sponsored by the European Space Agency (ESA Ref. AO/1-3880/01/I-SB), the Remote Sensing Group of the Portuguese Geographic Institute and Critical Software developed and implemented a methodology for the production of a daily forest fire risk mapping for Mainland Portugal, based on satellite imagery and ancillary data [11].

After the 2003 forest fire season, where more then 400 000 hectares burn in Portugal Mainland [22], COTEC Portugal - *Associação Empresarial para a Inovação*, an enterprise association aiming the improvement of the competitiveness of the enterprises located in Portugal, promoted an initiative to encourage the best practices on the management of the Portuguese forest against fires. Within this initiative [2004-2005], the forest fire risk methodology previously developed in the scope of the PREMFIRE project was improved, operated and tested on a semi-operational scenario.

2.2 Data requirements

The fire risk methodology developed under this scope is an adaptation of the methodology suggested by the European Union's (UN) Joint Research Centre [21] for the entire European region, allowing it to be applied to national level scales.

Regarding the temporal scale, the fire risk methodologies can be classified into [21]:

- Structural or long-term indices, derived from factors that do not change in short lapse of time, i.e. topography or land-cover.
- Dynamic or short-term indices, relying on parameters that change fairly continuously over time, i.e. vegetation condition or weather.

- Integrated or Advanced indices, including both structural and dynamic variables. The integrated approach is based on the assumption that the start and progression of a forest fire is affected by different factors, therefore requiring an integrated analysis [14].

The forest fire risk methodology herein presented, the Integrated Forest Fire Risk (IFFR), is an integrated fire risk index based on the combination of a structural fire index and a dynamic index [12, 19, 10].

The Structural Fire Index (SFI), produced on an annual basis, before each forest fire season, is based on five variables considered as the most influent in forest fire occurrence in the Mediterranean basin [14]:

- Land cover map extracted from Landsat TM (Thematic Mapper) imagery and ancillary information.
- This land cover map provides two base maps for the system: vegetation classes and distance to urban areas;
- Digital elevation model (DEM). This DEM provides three different base maps: slope, elevation and aspect.
- Road network, providing the accessibility base map.

The dynamic index applied in the integrated methodology is the Fire Potential Index (FPI) [9, 24], incorporating both satellite imagery and weather forecast in a danger index updated on a daily basis. The FPI initially implemented under the scope of the PREMFIRE project used AVHRR (Advanced Very High Resolution Radiometer) satellite imagery from NOAA (National Oceanic & Atmospheric Administration). However, due to the existence of medium spatial resolution MODIS (Moderate Resolution Imaging Spectroradiometer) sensors, acquiring data in the spectral channels applied in this index, an improvement was made during the COTEC initiative, in order to adapt the system allowing the use of MODIS imagery.

Nowadays, the FPI applies daily imagery acquired by MODIS sensors, on board of the TERRA and AQUA satellites from NASA (National Aeronautics and Space Administration). MODIS products used in this index are the surface reflectance (250 meters of spatial resolution), and the acquisition angles. Acquisition angles product is applied to eliminate parts of images acquired with high solar and sensor zenith angles.

The inputs to the FPI model are:

- Dead fuel moisture of extinction, providing, for each fuel model, the values above which fire will no longer spread due to the amount of moisture content [31].
- A maximum live ratio map and a relative greenness map [8] providing, respectively, the percentage of live fuel load for a given pixel when the vegetation is at maximum greenness, and how green each pixel currently is in relation to the range of historical maximum and

minimum greenness observations for it. The maximum live ratio and the relative greenness maps are assessed using the Normalized Difference Vegetation Index (NDVI) [32].

- A Ten-hour timelag dead fuel moisture [18] map produced with weather forecast data (temperature, relative humidity and nebulosity). Ten-hour timelag fuels are defined as dead woody vegetation in the size range of 0.6 to 2.5 cm in diameter. Fine fuels, namely grass, leaves, bark, and twigs are those materials which ignite and burn easily. Heavy fuels, generally more than 6mm in diameter, will not burn unless fine fuels are present to support fire. While large fuels can take a whole season to dry up, forest fires usually originate in the light fuels. These fine fuels react almost immediately to changes in relative humidity and temperature, making the estimation of the equilibrium moisture feasible [5].

2.3 Methods

Structural Fire Index

The SFI is based on the combination of five variables:

- Vegetation classes;
- Slope;
- Aspect;
- Distance to roads and urban areas;
- Elevation.

To rank each variable's original values into different levels of danger, taking into account the relative importance of each class as a factor for increasing the fire danger, these variables are reclassified, and a coefficient of 0, 1 or 2 is assigned to each level according to their fire danger (respectively from high to low fire danger) [14]. After the reclassification, the following formula is applied, in order to integrate all the variables:

$$\mathrm{SFI} = 100v + 30s + 10a + 5u + 2e \quad (12.1)$$

Where v, s, a, u, and e represent vegetation, slope, aspect, distance to roads and urban areas, and elevation variables, respectively. SFI provides a map with values ranging from 0 to 255, which needs to be further integrated with the dynamic risk (Fire Potential Index) in order to provide the Integrated Forest Fire Risk index.

Dynamic Fire Index

The dynamic fire index (FPI) applied in this integrated approach is based on several intermediate information layers.

- **Dead Fuel Moisture of Extinction** (MX_d) is based on the assignment of dead fuels extinction moisture values to each fuel class on the yearly land cover map. The dead fuels extinction moisture values were identified according to the specific characteristics of each fuel class and indicate moisture values above which fire will no longer spread [31].

- **Maximum Live Ratio** (LR_{max}) is calculated as a function of the live and dead loads assigned to each fuel class in order to determine the live ratio for a given pixel when vegetation is at its maximum greenness [9, 26].

  This process is assessed, for each pixel, recurring to the maximum value of NDVI occurring on a certain fuel class (ND_{absmax}) and to the NDVI value occurring on the pixel. The NDVI values applied are based on 7 day maximum value composite and are reclassified to values between 0 and 200. To calculate the Maximum Live Ratio, the following formula is then applied:

$$\mathrm{LR}_{max} = \left(0.25 + \frac{\mathrm{ND}_{max}}{2\mathrm{ND}_{absmax}}\right) \cdot 100 \qquad (12.2)$$

  Where ND_{max} is the maximum historical NDVI value for a certain pixel.

- **Relative Greenness** (RG) is computed by comparing, for each pixel, the current 7 day NDVI composite value to the available historical range of NDVI data [8]. This process allows comparing the actual value of greenness of a certain pixel to its historical values. To calculate the Relative Greenness, the following formula is applied:

$$\mathrm{RG} = \frac{(\mathrm{ND}_0 - \mathrm{ND}_{min})}{(\mathrm{ND}_{max} - \mathrm{ND}_{min})} \cdot 100 \qquad (12.3)$$

  Where ND_{min} is the minimum historical NDVI value for a certain pixel (based on MODIS images acquired over that area since the launch of AQUA and TERRA satellites) and ND_0 is the NDVI 7 day MVC (Maximum Value Composite) composite value for a certain pixel.

- By scaling the **Maximum Live Ratio map** (LR_{max}) with Relative Greenness map (RG), the Live Fuel Ratio map (LR), which expresses the current live fuel ratio for each pixel, can be computed. In order to calculate LR, RG has to be converted to fractional value (RG_f = RG/100), after which the following formula is applied:

$$\mathrm{LR} = \frac{\mathrm{RG}_f \cdot \mathrm{LR}_{max}}{100} \qquad (12.4)$$

- Ten-hour Timelag Dead Fuel Moisture (FM_{10}) is based on weather forecast (air temperature, relative humidity, precipitation and nebulosity) for the following two days, allowing calculating the fire risk for the current day, as well as a forecast for the following day. Its calculus is based on a system presented by Fosberg and Deeming, [18] that allows crossing all these forecast variables.

- After calculating FM_{10}, the Fractional Ten-hour Fuel Moisture map (TN_f) is calculated for each pixel by normalizing FM_{10} values on Dead Fuel Moisture of Extinction (MX_d), applying the following formula:

$$\mathrm{TN}_f = \frac{\mathrm{FM}_{10} - 2}{\mathrm{MX}_d - 2} \quad (12.5)$$

After calculating the Fractional Ten-hour Fuel Moisture map (TNf) and the Live Fuel Ratio map (LR), the Fire Potential Index (FPI) is calculated with the following formula:

$$\mathrm{FPI} = (1 - \mathrm{TN}_f)\,(1 - \mathrm{LR}) \cdot 100 \quad (12.6)$$

Fire Potential Index provides a map with values ranging from 0 to 100 to be further integrated with the Structural Fire Index in order to provide the Integrated Forest Fire Risk.

Integrated Forest Fire Index

After calculating the Structural Fire Index and the Fire Potential Index, these two indices have to be integrated in order to provide an efficient integrated forest fire risk map. Figure 1 presents the main schema of the entire process allowing providing the Integrated Forest Fire Risk service.

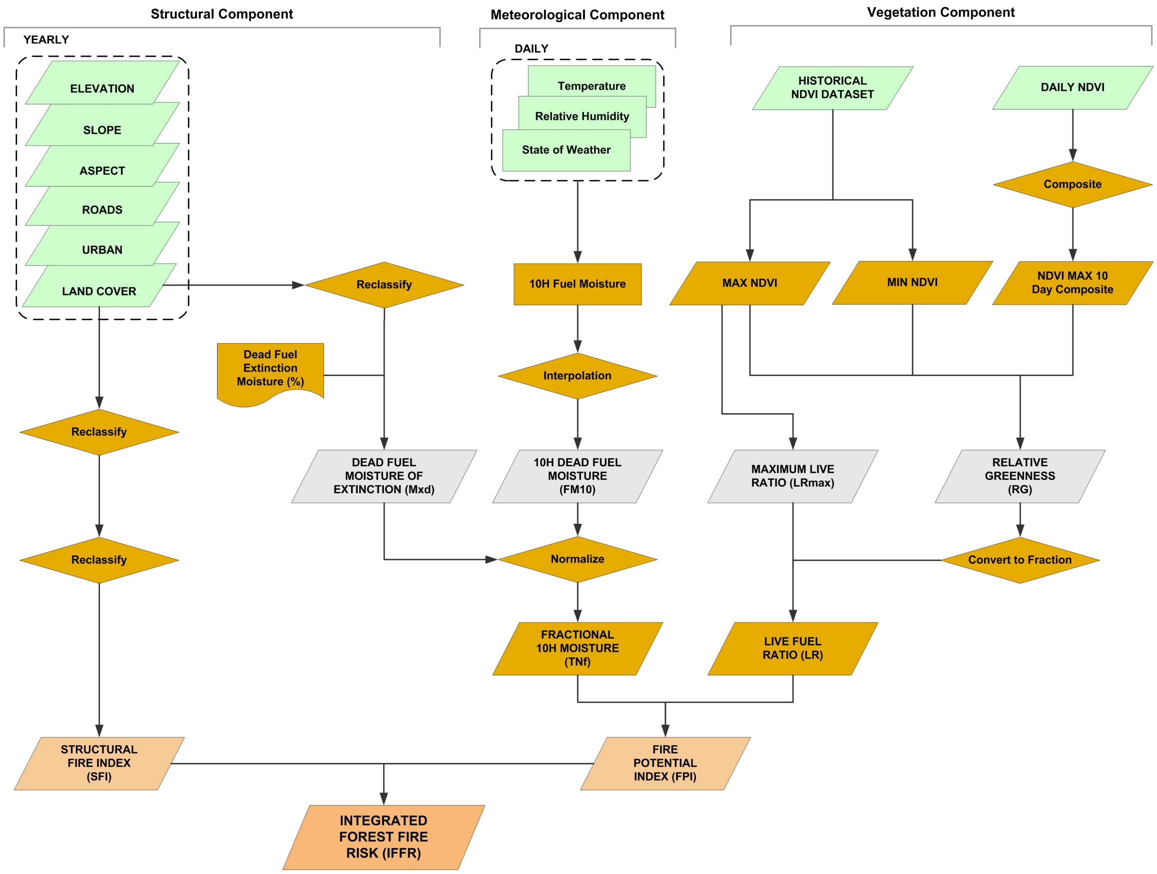

Figure 1 - Integrated Forest Fire Risk Index main schema

During the PREMFIRE project, the integration was made in order to provide four fire risk classes. However, due to the new Portuguese legislation, the system had to be improved in order to provide five risk classes (low, medium, high, very high and extreme). This improvement was made during the COTEC initiative and the fire risk classes' distribution was made by evaluating several possible combinations of FPI and SFI, trying to achieve the best possible compromise between fires and the extent of each fire risk class, with data concerning forest fires occurred during the years of 2004 and 2005 [27]. Table 1 presents the chosen combination after the year 2005, where each colors represent fire risk classes and the arrow direction indicates the increasing of fire risk.

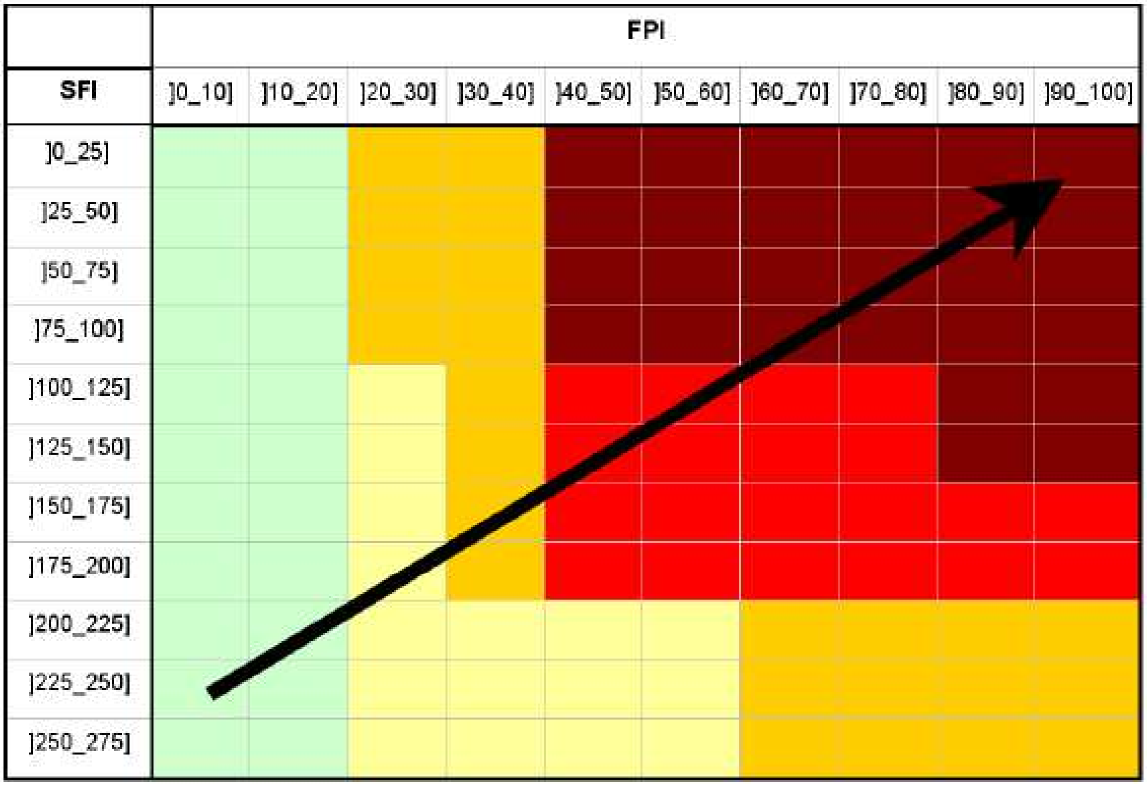

Table 1 - Integration of SFI and FPI providing the Integrated Forest Fire Risk

The result provided to final users is a map in the raster data model (Figure 2) with information regarding the five risk classes of the Integrated Forest Fire Risk.

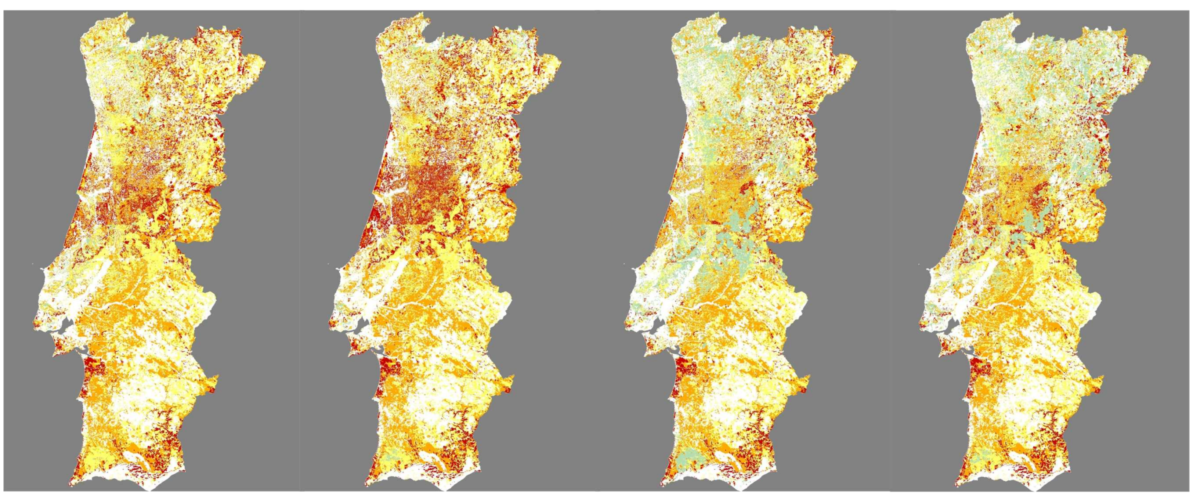

Figure 2 - Examples of Integrated Forest Fire Risk index in Portugal Mainland during the Year of 2005

2.4 Validation

During the Year of 2005, the Integrated Forest Fire Risk methodology has been operated during the Portuguese forest fire season (15th May to 15th of October) and validated against two types of data (ignition points and burnt areas). The validation process used the following data [27]:

- 137 ignition points resulting in fires larger then 6 ha, occurred during the period of 15th of July to 15th of September;
- All burnt areas larger then 48ha, occurred during the period of 21st of July to 13th September.

Since the ignition points provided by the Portuguese Forest Department of the Ministry of Agriculture usually referred to the closest urban area, and since the IFFR does not provide information for urban or agriculture areas, a system to relocate these ignition points to places where they could actually have occurred, was implemented. Thus, a grid of 16 cells (4*4) was centred on each ignition point and each point was then relocated to the pixel with the higher integrated forest fire risk value within that grid. Regarding the burnt areas, the data applied was manually digitized by ISA (*Instituto Superior de Agronomia*) from daily TERRA/AQUA MODIS images, allowing the identification of the amount of burnt area for the days presented on the Table 2.

July	21, 23
August	2, 4, 7, 8, 11, 15, 16, 17, 19, 22, 23, 24, 25, 26, 28, 31
September	2, 4, 8, 13

Table 2 – Days in which burnt areas were collected

In order to evaluate the Integrated Forest Fire Risk Maps against the burnt areas, the following procedure was applied [27]:

1. For each period occurred between two days, identify all new burnt areas;
2. For each pixel, identify the value of Structural Fire Index (SFI);
3. For each pixel, identify, for the period occurred between two burnt areas collection, the average value of Fire Potential Index (FPI);
4. Based on the values identified in the two previous lines, assign to each pixel the class of Integrated Forest Fire Risk (IFFR).

After completing the previous procedures, the percentage of ignition points and burnt areas affected to each IFFR class was identified (Table 3).

Risk Class	Ignition Points (%)	Burnt Areas (%)
Extreme	78	33
Very High	17	27
High	6	25
Medium	0	14
Low	0	1

Table 3 - Results obtained for the Integrated Forest Fire Risk (IFFR) map

As it can be observed on Table 3, the great majority of the ignition points (78%) were found in the Extreme IFFR class and all the ignition points occurred in the three higher risk IFFR classes. Although, the ignitions points' analysis should be done with some reserve, since its inaccuracy was countered with a generalization process. Regarding the evaluation against the burnt areas, it can be observed that during the period under analysis, 60% of the total burnt areas occurred on the two most dangerous IFFR classes.

3 Automatic Burned Area Mapping

3.1 Motivation for service development

Several studies and operational programs based on satellite imagery have been carried out with the aim of producing cartography and statistics of burnt areas [1, 2, 3, 6, 7, 17]. In these projects, several methodologies have been applied to satellite imagery acquired by sensors with different characteristics. These different sensors characteristics, such as the spatial resolution, have obvious consequences in the technical specifications of the cartography and statistics of burned area (e.g., minimum mapping unit). Even though these effects shouldn't be judged as erroneous, once they are a consequence of the characteristics inherent to each image, it is important to define a balance point between final users' needs and the information capable of being provided [1, 2, 3].

After evaluating Portuguese user's requirements and Earth Observation (EO) imagery availability, a system balancing these two factors was developed in order to provide valuable information, on useful time, to final users. The system developed is completely automatic and provides final users with burnt areas cartography, on a daily basis, concerning information acquired four days before. This delay is due to the service chain of the United States Geological Survey (USGS) that provides the surface reflectance product to users worldwide. [4].

3.2 Data requirements

In different situations, there are different needs and possibilities to produce information about burnt areas. During forest fire season, in a first temporal phase, the priority is based on obtaining the information in the shortest period of time as possible, to carry out a fast assessment of damages allowing the provision of public general information and for an eventual redefinition of strategies on fire fighting. This first information is directly influenced by the temporal resolution of the sensors, which often implies the use of lower spatial resolution imagery due to the fact that these two resolutions (spatial and temporal) are indirectly related.

After crisis season, there is the need to identify, with the maximum accuracy as possible, the affected areas, aiming the accurately quantification of the damages and allowing reparation efforts and financial resources allocation. During this phase, there is a greater concern with the spatial resolution, instead of the temporal one. This greater spatial resolution acquired by satellites such as Landsat, SPOT or QUICKBIRD and IKONOS allows the production of cartography with smaller minimum mapping units, i.e. identification of burned areas with smaller extensions [17,25,28,30,34]. Though this kind of data is commonly used in many studies, it is almost impossible to use during the forest fires occurrence because of the low temporal resolution. In fact, there is a need of balance between the spatial resolution, accuracy, acquisition cost, and images availability [13].

After testing several methodologies and evaluating the spatial resolution influence on the information to be extracted from the satellite imagery [1, 2, 3], an automatic system based on medium spatial resolution imagery, acquired by Moderate Resolution Imaging Spectroradiometer (MODIS) hyperspectral sensors, installed in TERRA (1999) and AQUA (2002) satellites from the National Aeronautics and Space Administration (NASA), was developed and implemented in order to provide, on a daily basis, burn scars maps during the forest fire season. Besides land cover data collected by Landsat TM imagery, this automatic system applies the MODIS daily surface reflectance (250 meters of spatial resolution) and acquisition angles products to detect the burn areas.

3.3 Methods

Figure 3 depicts the high level methodology architecture of the burn scar maps service, as well as the different types of data used for their production.

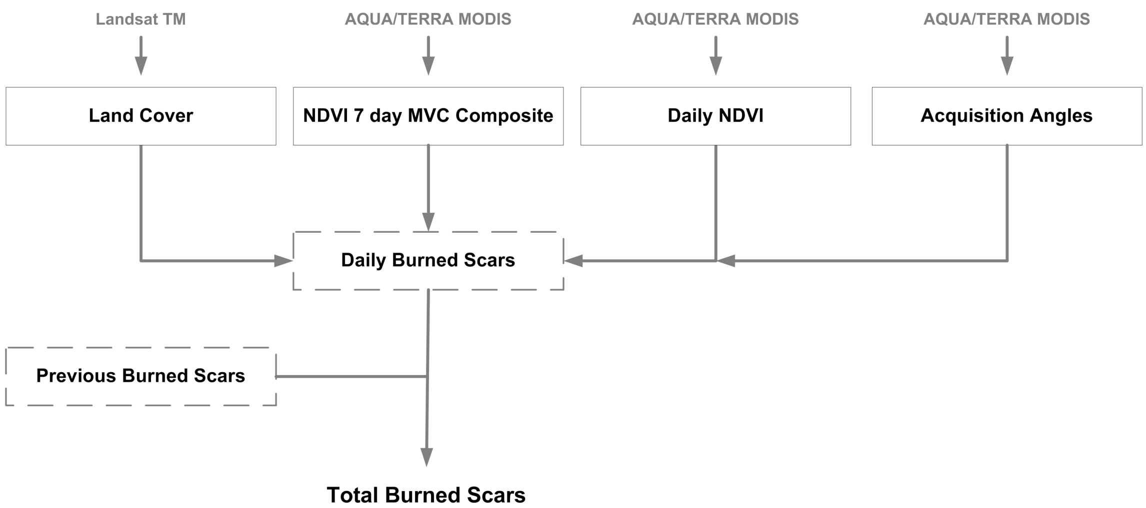

Figure 3 - Main Scheme of the Burn Scar Map Production

The automatic burn scars detection methodology entails two main steps [2]:

- Forest change detection, where changes on forest cover are identified by multi-temporal approach based on vegetation index differences;
- Forest change discrimination, where forest changes detected in the first step are now discriminated by type (i.e., burn areas are separated from other changes such as clear cuts and new plantations).

The selection of this methodology was due to the fact that it allows to implement the system in a systematic way, without human intervention, and also because it has been successfully implemented in several other circumstances (e.g. [16, 20, 33]).

Forest Change Detection

In the change detection methodology, Normalized Difference Vegetation Index (NDVI) from two different dates are subtracted, resulting in a new image with values around zero for places where no changes occurred and positive or negative values for areas with change (depending if there was a decrease or increase in vegetation biomass). To discriminate the less significant differences on NDVI from the relevant ones (which correspond to real changes), a threshold is applied to the NDVI difference image.

In a first step, NDVI is calculated for the current day and subtracted of the maximum value composite (MVC) technique produced with the last 7 days NDVI. Then, it is applied a threshold based on the mean and standard deviation of the vegetation index difference image. Pixels with a value above a certain number of standard deviations to the mean value of the NDVI difference are considered to be changes. Since the decreases in the difference image are the ones intended to be founded, the standard deviation value is subtracted from the mean value of the vegetation index difference image. During this process it is applied an analysis mask based on land cover maps produced with Landsat TM imagery, in order to remove from the analysis changes occurring in urban, agriculture and water land covers. Figure 4 presents the influence of different values of standard deviation on the threshold applied in the change detection methodology.

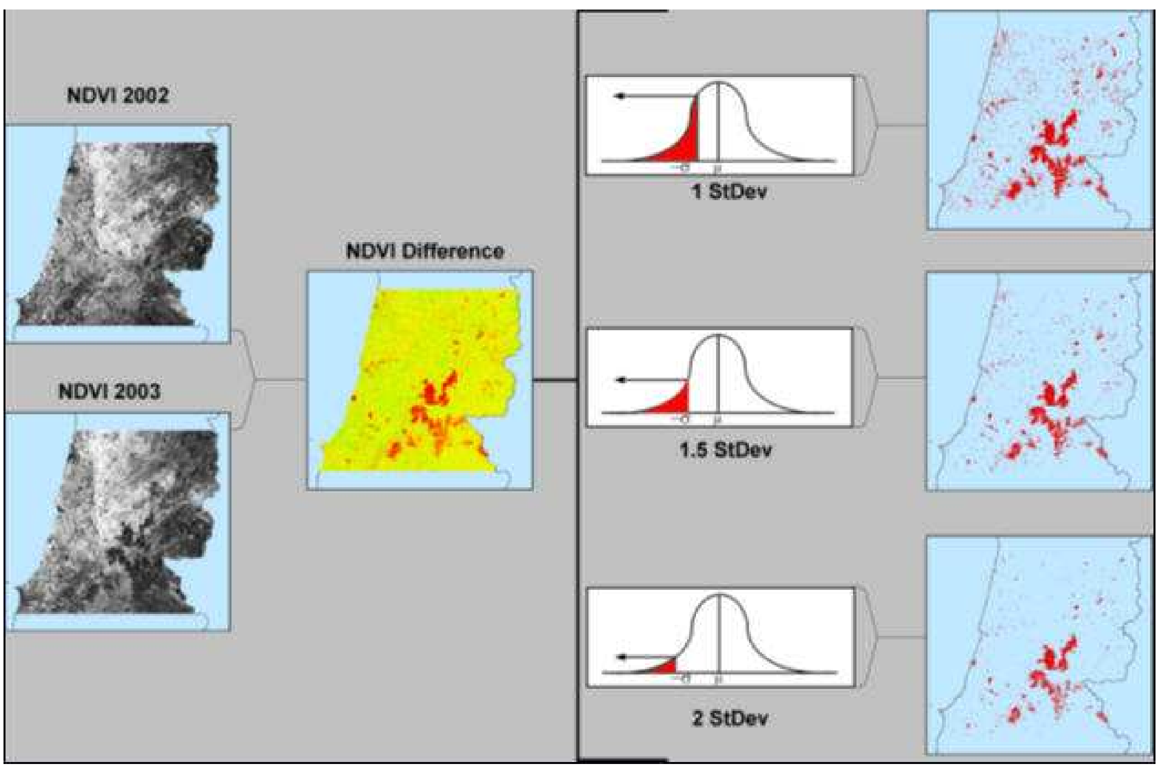

Figure 4 - Forest Change Detection Methodology example with different thresholds applied (adapted from [1])

After detecting the changes, a Minimum Mapping Unit (MMU) of 9 pixels (48 hectares) is applied. All changed areas smaller then the MMU are generalized (i.e., eliminated) before calculating the final product. Before implementing this system, several studies [1, 2, 3] were performed with MODIS imagery in order to evaluate the influence of the standard deviation applied in the change detection threshold, as well as in the MMU definition. Within these studies, the following was confirmed:

- When increasing the size of the MMU, the commission errors decrease, while the omission errors increase.
- When reducing the value of standard deviation in the change detection threshold, the omission errors also decrease, while the commission errors increase.

After evaluating different combinations of MMU and standard deviation values, the combination that minimized the errors in both parameters was selected to implement this system.

Forest Change Discrimination - Burned Areas Detection

After the forest change detection process it is necessary to discriminate the burnt areas and separate them from other kinds of forest changes. For that purpose spectral thresholds are applied to the red and near infrared bands. In Figure 5 the thresholds applied to the red and near infrared reflectance to discriminate the burned areas are plotted against spectral characterization of healthy forest and the main forest changes (burned areas, clear cuts and new forest plantations).

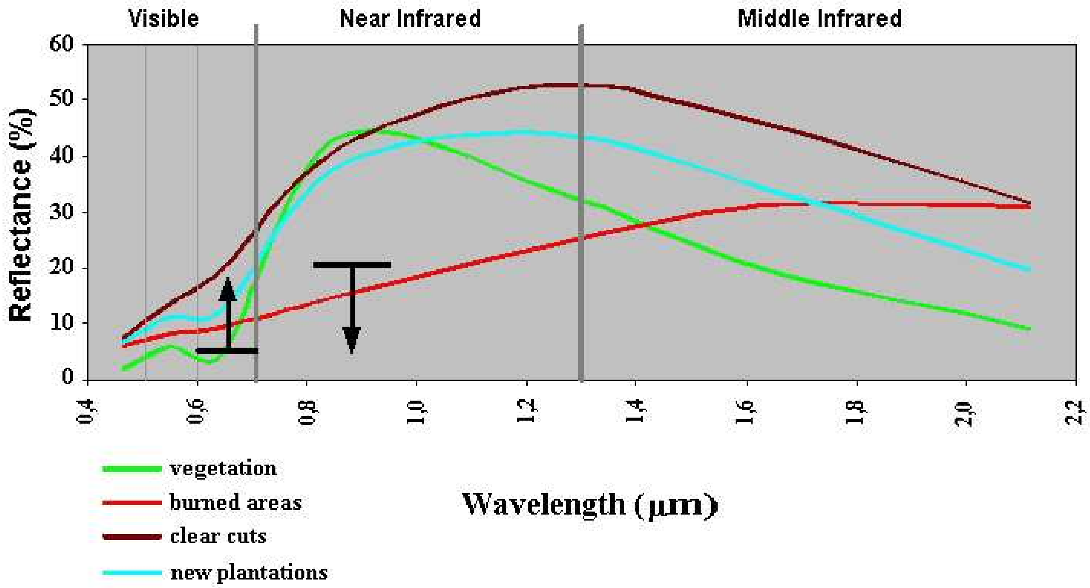

Figure 5 - Thresholds Applied to discriminate burned areas from other forest changes (adapted from [2])

The output data of this system is a map in raster or vector format (.bil, .shp, .kmz). Figure 6 shows three examples of the product referring to the north western part of Portugal during the summer of 2006 (map layer superposed against MODIS images).

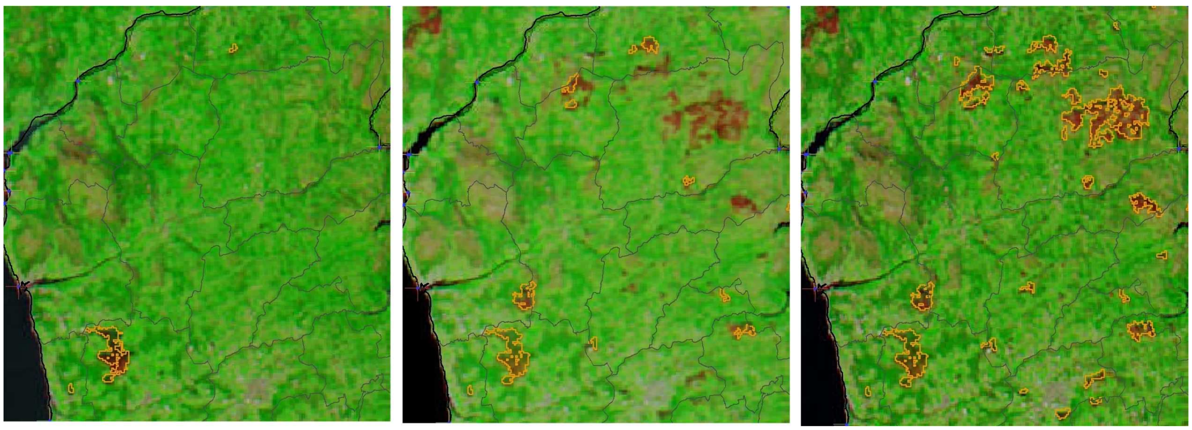

Figure 6 - Automatic Burn Scar Mapping results obtained for the year of 2006

3.4 Validation

This service started to be developed in 2003 and has been under constant improvements since then. During the forest fire season of 2006 it was operated in Portugal, for the first time, as a pre-operational service, achieving excellent results. This methodology has been validated during the years of 2003 and 2006 and, due to the inexistence of ground truth data, the service has been validated against reference data. For the year of 2003, the reference data was manually digitized over high spatial resolution imagery (SPOT-HRG), while for the year of 2006, the reference data was manually digitized over medium spatial resolution imagery (MODIS). The validation processes done until the year of 2007, have taken into account the quantification of omission errors and commission errors obtained for the burnt areas class. The omission error of the "burnt areas" indicates the percentage of changes that were not identified. The commission error of the "burnt areas" indicates the percentage of areas that were misclassified as "burnt areas".

Table 4 presents the accuracy values obtained during the years of 2003 and 2006 [2, 4].

	Portuguese Validation Campaign in 2003	**Portuguese Validation Campaign in 2006**
Commission errors	17,1 %	15,2 %
Omission errors	18,2 %	17,9 %

Table 4 – Automatic Burn Scar Detection thematic accuracy values

As it can be seen, after the validation for the years of 2003 and 2006, similar accuracy results were obtained, indicating the system stability and operationality. Since the Omission and commission results obtained are very similar, it indicates that this system has reached a good compromise between all the parameters within the system. Figure 7 presents the results obtained for the year of 2006 by the system herein presented (in blue) against reference data manually digitized over MODIS imagery (in red).

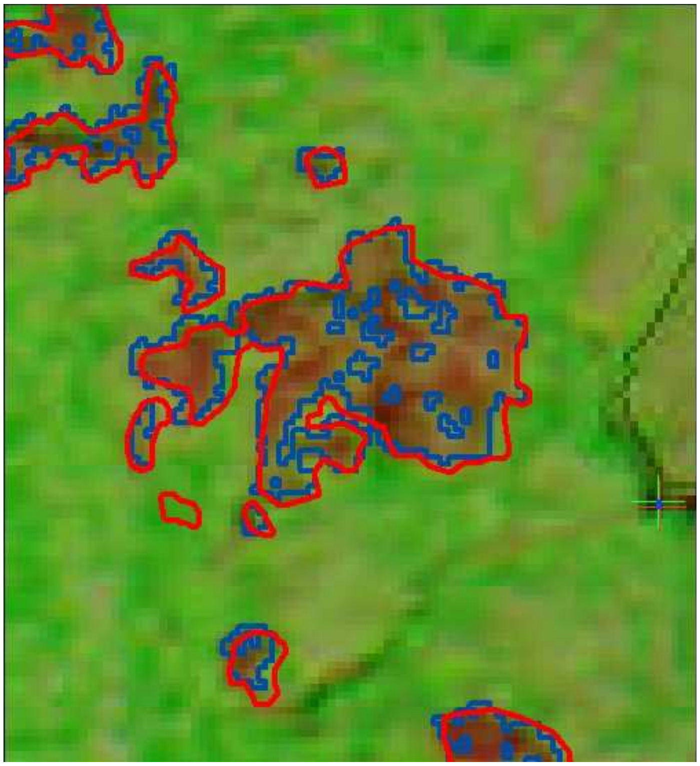

Figure 7 - Automatic detection (blue) plotted against reference data (red) superposed to MODIS imagery [4]

The main advantages of this system are:

- The fully automatic process, eliminating the subjectivity of the human intervention;
- The automatic provision of island polygons not burned inside a large burned area.
- The clear definition between the burned and not burned areas.

The main limitation of this service is its unavailability whenever 50% of the source data (surface reflectance) has clouds or is acquired with large acquisition angles.

12.4 Conclusion

This chapter showed that computational intelligence is a valuable support to solve complex problems where traditional approaches are not sufficient. The case studies presented in this chapter and related to forest fires are based on remote sensing data fusion and automatic change detection in satellite images. The sensors used in these case studies are medium and high resolution space borne multispectrometers (MODIS and Landsat TM). The processing chains are fully automatic and daily maps are delivered throughout the entire fire season without intervention of human experts.

Future developments of earth observation based techniques, especially in the case of forest fires emergency management, will be driven by the following main factors:

- Increased data availability;

- Higher computational performance.

Whereas the pre-fire and post-fire phases are already well supported by currently available remote sensing missions, data availability, i.e. higher revisit frequency, is a key issue for an efficient monitoring of the fire outbreak (early warning) and evolution during the crisis. The ongoing public and commercial efforts to design and build constellations of small satellites bearing the same kind of sensors will be a decisive step forward for a continuous global surveillance of the forest environment.

At the same time the usage of different platforms like unmanned aerial vehicles could complement observations from space and significantly improve the coverage of regions characterised by a high level of risk.

The huge data volume that such a system produces must be processed and analysed in a fully automatic way to guarantee timely maps provision. Computational intelligence plays here a major role and a strong interaction among the computer science community (image processing, high performance computing, computer vision) and the remote sensing data interpretation experts is required.

The results obtained by the usage of computational intelligence to analyse remote sensing data for forest fires emergency management are encouraging. This is true not only from the scientific point of view but also in terms of operational applications that can be already used to better prevent environmental loss as well as to rapidly and objectively monitor and assess the damages.

4 References

1. Armas R. and Caetano M. (2005-a), Scale effect on burned area assessment using earth observation data. In New Strategies for European Remote Sensing (M. Oluic, editor), Millpress, Rotterdam, pp. 61-67.

2. Armas R. and Caetano M. (2005-b) Mapping changes in forest cover using multi-scale MODIS imagery. In Proceedings of the 31st International Symposium on Remote Sensing of Environment - Global Monitoring for Sustainability and Security, 20-24 June 2005, Saint Petersburg, Russian Federation, unpaginated CD-ROM.

3. Armas R. and Caetano M. (2005-c), Cartografia de áreas ardidas com imagens multi-resolução do sensor MODIS. In Cartografia e Geodesia 2005 (J. Casaca e J. Matos, editors), Lidel, Lisboa pp. 293-303.

4. Armas R. and Pelizzari A. (2007) Automatic Burn Scar Mapping - Project Final Report, 37pp., Critical Software.

5. Anderson, H.E. (1985). Moisture and fine forest fuel response. In Proceedings of the 8th Conference of Fire and Forest Meteorology, pp. 192-199, Detroit, Michigan.

6. Barbosa P, San-Miguel-Ayanz J, Schmuck G (2001) Remote Sensing of forest fires in Southern Europe using IRS -Wifs and MODIS data. In: Proceedings SPIE Remote Sensing Symposium. Toulouse, France 18-21, 2001:165-173.

7. Barbosa P, Ayanz J, Martinez B, Schmuck G (2002) Burnt area mapping in southern Europe using IRS-WIFS. In: Proceedings IV International Conference Forest Fire Research. Luso, Portugal, November 18-23.

8. Burgan, R. E., Hartford, R. A. (1993). Monitoring Vegetation Greenness with Satellite Data, Gen. Tech. Rep. INT-297. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station.

9. Burgan, R. E., Klaver, R. W., Klaver, J. M. (1998). Fuel Models and Fire Potential from Satellite and Surface Observations, International Journal of Wildland Fire, 8 (3), pp. 159-170.

10. Caetano M, Carrão H, Freire S (2002) Methodology for Fire Risk Mapping - Premfire, Prevention and Mitigation of Forest Fires in Portugal. PREMFIRE Project WP330 Report. 40pp.

11. Caetano, M., Freire, S, Carrão, C. (2004). Fire risk mapping by integration of dynamic and structural variables. In Remote Sensing in Transition (Rudi Goossens, editor), Millpress, Rotterdam, pp. 319-326.

12. Carrão, H., Freire, S., Caetano, M., (2002). Fire Risk Mapping Using Satellite Imagery and Ancillary
1. Data: Towards Operationally. Proceedings of SPIE Vol 4879 Remote Sensing for Agriculture, Ecosystems and Hidrology IV. (Manfred Owe, Guido dÇUrso, Leonidas Toulios, editors), pp. 154-165.

13. CCRS (2003), Fundamentals of Remote Sensing, Canadian Centre for Remote Sensing. (URL:<http://ccrs.nrcan.gc.ca/resource/tutor/fundam/index_e.php>, consulted on May, 13th 2007)

14. Chuvieco, E. and Congalton, R. G. (1989). Application of Remote Sensing and Geographic Information Systems to Forest Fire Hazard Mapping. Remote Sensing of Environment, 29, pp. 147-159.

15. Chuvieco, E., Salas, F. and Vega, C. (1997). Remote Sensing and GIS for long-term Fire Risk Mapping. In: A review of remote sensing methods for the study of large wildland fires. (E. Chuvieco, editor), pp. 91-108.

16. Daryaei, J. (2003). Digital change detection using multi-scale wavelet transformation & neural network. Master thesis, International Institute for Aerospace survey and Earth Sciences, Enschede, Netherlands.

17. Escuin S, Navarro R, Fernández P (2002) Using Remote Sensing and GIS to assess wildfire damage throughout the Mediterranean, Earth Observation Magazine 11 (5)

18. Fosberg M. A., Deeming J. E. (1971). Derivation of the 1- and 10-hour Timelag Fuel Moisture Calculations of Fire Danger. United States Department of Agriculture, Forest Service, Research Note RM-207, Rocky Mountain Forest And Range Experiment Station, Fort Collins, Colorado.

19. Freire, S., Carrão, H., Caetano, M. (2002). Produção de Cartografia de Risco de Incêndio Florestal com Recurso a Imagens de Satélite e Dados Auxiliares. Proceedings of ESIG'2002- VII Encontro de Utilizadores de Informação Geográfica, November 13 to 15, Oeiras, unpaginated CD-ROM.

20. Gong, P. (2002). Land Cover and Land Use Mapping and change dynamics modeling with remote sensing. Advanced Training Workshop on Landuse and Landcover change Study, Taipei, Taiwan. (URL:<http://www.gcc.ntu.edu.tw/workshop/lecturers_materials.htm>, consulted on March, 20th 2004)

21. Joint Research Centre (2001). Pilot Projects on Forest Fires. (URL:<http://natural-hazards.aris.sai.jrc.it/fires/>, consulted on April, 12th 2002)

22. Joint Research Centre (2004). Forest Fires in Europe - 2003 Fire Campaign. (URL:<http://www.fire.uni-freiburg.de/programmes/eu-comission/JRC-Report-4-Forest-Fires-Europe-2003-Fire-Campaign.pdf>, consulted on May, 15th, 2007).

23. Joint Research Centre (2006), Forest Fires in Europe 2005, EUR 22312 EN (c) European Communities.

24. Klaver, J., Klaver, R., Burgan, R. (1997). Using GIS to assess forest fire hazard in the Mediterranean region of the U.S.. Proceedings of 17th Annual ESRI Users Conference, pp. 10, San Diego.

25. Koutsias, N., Karteris, M., Chuvieco, E. (2000). The use of Intensity-Hue-Saturation Transformation of Lansdat-5 Thematic Mapper Data for Burned Land Mapping. Photogrammetric Engineering & Remote Sensing, 66 (7), 829-839.

26. Lopéz, A., San-Miguel-Ayanz, J. and Burgan, R. (2002). Integration of Satellite Sensor Data, Fuel Type maps and Meteorological Observations for Evaluation of Forest Fire Risk at the Pan-European Scale. International Journal of Remote Sensing, 23(13), 2713-2719.

27. Mangana P, Gonçalves R, Caetano M, Carrão H, Pereira C, Carreira J, Viegas D, Ribeiro L, Galante M (2006), Previsão de Incêndios Florestais. COTEC Portugal - Iniciativa sobre incêndios florestais. PREVINFL Project Final Report. 118pp.

28. Mitri, G. and Gitas, I. (2002). The development of an object-oriented classification model for operational burned area mapping on the Mediterranean Island of Thasos using Landsat TM images. In Forest Fire Research & Wildland Fire Safety (X. Viegas editor) Millpress, Rotterdam.

29. National Interagency Fire Center - NIFC (USA, 2007), Wildland Fire Statistics, http://www.nifc.gov/fire_info/fire_stats.htm

30. Recondo, C., Wozniak, E., Pérez-Morandeira, C. (2003). Map of burnt zones in Astúrias in the period 1991-2001 created from Landsat-TM images. In Proceedings of the 4th International workshop on Remote Sensing and GIS Applications to Forest Fire Management: Innovative concepts and methods in fire danger estimation (Ghent: EARSEL- European Association of Remote Sensing Laboratories), pp. 193-197.

31. Rothermel, R.C. (1972). A mathematical model for predicting fire spread in wildland fuels. General Technical Report INT-115, USDA Forest Service, Intermountain Forest and Range Experiment Station.

32. Rouse, J., Haas, R., Schell, J., Deering, D. (1973). Monitoring Vegetation Systems in the Great Plains with ERTS. Proceedings of 3rd ERTS Symposium, 1, pp. 48-62.

33. Salvador, R., Valeriano, J., Pons, X., Díaz-Delgado, R. (2000). A semi-automatic methodology to detect fire scars in shrubs and evergreen forest with Landsat MSS time series. International Journal of Remote Sensing, 21 (4), 655-671.

34. Sunar, F., Özkan, C. (2001). Forest fire analysis with remote sensing data. International Journal of Remote Sensing, 22 (12), 2265-2277.

35. Wulder, M. A., Franklin, S. E. (2003). Remote Sensing of forest environments, Introduction, Remote Sensing of Forest Environments, Kluwer Acad. Publ., 3-12.

36. Peng Gong, Bing Xu (2003). Remote Sensing of forests over time, Remote Sensing of Forest Environments, Kluwer Acad. Publ., 301-333.