Burned Area Mapping and Post-Fire Monitoring Using Time Series of Proba-V Simulated and SPOT VEGETATION Data and by Employing the BFAST Trend Analysis Method

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Abstract. This work aims to investigate the potential of high-temporal and low-spatial resolution sensors such as the PROBA-V simulation (MODIS) and SPOT VEGETATION in burned area mapping and post-fire monitoring. The specific objectives are: i) to implement and evaluate a trend analysis approach, for mapping burned areas and monitoring post-fire vegetation recovery, and ii) to assess the relative effectiveness of PROBA-V data when compared to VEGETATION data in the mapping of burned areas as well as in the monitoring of post-fire vegetation recovery. The Breaks For Additive Seasonal and Trend (BFAST) method can decompose time series into trend, seasonal and noise components, leading to the detection of gradual and abrupt changes in ecosystems. The method is applied to time series of three vegetation indices, namely NDVI, GEMI and SAVI with satisfactory results in each case. PROBA-V based analysis reveals a better overall performance than VEGETATION results in burned area mapping with GEMI having the highest performance than the other indices. Regarding the post-fire vegetation recovery, BFAST reveals a positive trend in all datasets that being analyzed, but more reference data are needed to evaluate the post-fire results and perform a solid sensor comparison.

Keywords. PROBA-V, burned area mapping, post-fire monitoring, time series, remote sensing, trend analysis.

1. Introduction

Fires occurring in natural ecosystems, especially in fire prone environments such as in the Mediterranean region, have a great impact on vegetation composition and succession and contribute to soil erosion and degradation processes [1], [2], [3]. Detection of fire induce changes, therefore is of primary importance in terms of estimating the size of the burned area initially, and on a long term setting the basis for monitoring the post-fire vegetation condition over time. In the recent years, satellite data with varying spatial, spectral and temporal resolution have been widely utilized in fire related studies, followed by a parallel increase in developed methods and techniques [4], [5], [6], [7].

However, for an in-depth understanding of fire behaviour and quantification of changes over long periods, time series of satellite data are needed. Extensive multitemporal datasets have been mainly provided by coarse and medium resolution sensors, such as the Moderate Resolution Imaging Spectroradiometer (MODIS), the Advanced Very High Resolution Radiometer (AVHRR) and SPOT VEGETATION (VGT). These datasets have been widely used in burned area mapping and post-fire assessment studies [8], [9], [10], [11].

The majority of existing change detection methods rely on the analysis of short time series, where usually only a few or pair of images are acquired at the same season over different years [12].

However, there is often the risk of interpreting seasonal variation as change, when the frequency of acquired images is inconsistent with the change step or if the number of images is too small [13]. In addition, selection of specific thresholds in change detection studies can be misleading due to scene-dependency and subjectivity of the selected thresholds. A recently developed method of detecting changes has been successfully applied to long time series data, without having to select specific thresholds or change trajectories not affected by seasonal variation. The Breaks For Additive Seasonal and Trend (BFAST) method allows the iterative decomposition of time series into trend, seasonal and noise components, leading to the detection of gradual and abrupt changes in ecosystems [14].

In this study, the BFAST method is implemented for the mapping and monitoring of a burned area in the Mediterranean with the use of spectral indices derived from multitemporal datasets of the VEGATATION and PROBA-V sensors. The PROBA-V sensor is designed as a continuity mission to the VEGATATION sensor and is expected to provide daily data across the globe at an improved spatial resolution of about 300m. This work aimed to investigate the potential of high-temporal and low-spatial resolution sensors such as the PROBA-V and VEGETATION in burned area mapping and post-fire monitoring.

The specific objectives were:

- to implement and evaluate a trend analysis approach, for mapping burned areas and monitoring post-fire vegetation recovery
- to assess the relative effectiveness of PROBA-V data when compared to VEGETATION data in the mapping of burned areas as well as in the monitoring of post-fire vegetation recovery

2. Study area and data

2.1. Study area

The study area is located at the Peloponnese, in southern Greece (36°30'-38°30' N, 21°-23° E), in the prefecture of Arkadia. Elevations range between 0 and 1300m above sea level and the climate is characterized as typically Mediterranean with hot, dry summers and mild, wet winters. The main vegetation types in the area are coniferous and broadleaved forests, shrublands (maquis and phrygana communities), and olive groves. Black pine (Pinus nigra) and Aleppo pine (Pinus halepensis) are the dominant conifer species while oaks are the dominant broadleaved species [15]. In August 2007, after a severe drought, large fires broke out in Peloponnese, resulting in human losses and the destruction of infrastructures and more than 150000 ha of natural and managed land. The 2007 fires were considered as one of the worst natural disasters recorded during the past decades in Greece.

2.2. Data

Since actual PROBA-V data are not yet available, the creation of accurate simulated data over the area extent and time length required for this study was not feasible. Since the implemented methodology in this study relied on the use of red/near-infrared based data, it was assumed that the use of a different sensor's similar data would be an acceptable substitute, provided that these shared similar spectral and spatial characteristics with the PROBA-V dataset. MODIS was selected as the best candidate to this, initially because of the similar spatial resolution. Moreover, a previous study [16] has shown a high correlation between MODIS and VGT NDVI values over the same targets, which considering the similarity between the VGT's and PROBA-V's red and near-infrared bandwidths. It is suggested that a high correlation between MODIS and PROBA-V NDVI, or any red near-infrared based index, values over the same targets is very possible.

The datasets used for the study were:

- PROBA-V substitute Data (MODIS). The MOD09Q1 products were acquired for the period from 01/01/2004 to 31/12/2010 along with Quality Assurance (QA) information, covering the Greek region. The MOD09Q1 (Surface Reflectance (SR) 8-Day L3 Global 250m) products provide 2 spectral bands, red and near-infrared, at 250-meter resolution in an 8-day gridded level-3 product in the Sinusoidal projection.
- SPOT-VGT D-10 products with Status Map (SM) information were also acquired for the period from 01/01/2004 to 31/12/2010. These are 10-day BDC syntheses or BiDirectional Composite syntheses with 1km spatial resolution, which are based on a bidirectional reflectance distribution function.
- Reference data obtained from classification and photo-interpretation of a Disaster Monitoring constellation (DMC) image, as well as field data collected from the study area.

3. Methods

3.1. Data pre-processing

The PROBA-V substitute (MODIS) data initial pre-processing activities included importing of the raw imagery and reprojection to WGS-84 Lat/Lon projection system, geographical subsetting to the Peloponnese boundaries and masking of the sea. Low quality, as well as cloud affected and not atmospherically corrected pixels in the red and near-infrared bands were excluded from the analysis with the use of the QA information. Importing of raw data and geographical masking was similarly applied to the VEGETATION composites. In addition, the BDC Status Map (BSM) quality information of the VGT composites was utilized so as to exclude cloud affected and low quality pixels in the red, near-infrared bands. The processed bands of the two datasets were then used to derive the time series of the Vegetation Indices (VIs), namely Normalized Difference Vegetation Index (NDVI), Global Environmental Monitoring Index (GEMI) and Soil Adjusted Vegetation Index (SAVI):

$$NDVI = (\rho_{NIP} - \rho_{RED})/(\rho_{NIP} + \rho_{RED}) \quad (1)$$

$$GEMI = (\gamma(1-0.25\gamma) - (\rho_{RED} - 0.125)) / (1- \rho_{RED}) \quad (2)$$

where $\gamma = (2(\rho^2_{NIR} - \rho^2_{RED}) + 1.5\ \rho_{NIR} + 0.5\ \rho_{RED})/(\rho_{NIR} + \rho_{RED} + 0.5)$,

$$SAVI = ((1+L) * (\rho_{NIP} - \rho_{RED})) / (\rho_{NIR} + \rho_{RED} + L) \quad (3)$$

where the term L can vary from 0 to 1 depending on the amount of visible soil. L=1 is generally used when the amount of soil is unknown.

Besides NDVI, which has been widely employed in fire mapping and monitoring, GEMI and SAVI have also been used for burned land discrimination [17] and vegetation discrimination in sparsely vegetated areas [18], respectively. Therefore, it was assumed that their use with the BFAST approach in this work should be worth investigating.

Prior to the VIs series analysis, continuous time series were generated by smoothing any noisy data. For the generation of the continuous time series, a local second-order polynomial function, also known as an adaptive Savitzky–Golay filter, was applied to replace affected and noisy observations, with the use of TIMESAT software [19].

3.2. The breaks for additive seasonal and trend (BFAST)

BFAST is an additive decomposition model that iteratively fits a piecewise linear trend and seasonal model, given by the equation: $Y_t=T_t+S_t+e_t$, t=1,…, n, where Y_t is the observed data at time t, T_t is the trend component, S_t is the seasonal component, and e_t is the remainder or noise component [14]. This decomposition facilitates the discrimination of phenological (gradual) and rapid changes that occur in an ecosystem without having to define a certain threshold in the applied method.

The generated VI datasets from the two sensors were analyzed as single series with BFAST in order to detect the rapid (burned area) and gradual (vegetation recovery) changes. The implementation of the method for the Arkadia site resulted in the identification of break points for all major changes revealing the number and time of these within the trend component. More specifically, BFAST was applied for terms of comparison:

i. to PROBA-V VIs series at the degraded resolution of 1 km , and
ii. to VEGETATION VIs series at the standard spatial resolution of 1km.

Various settings had to be tested and set prior to analysis. The seasonal model used to fit the seasonal component, the maximum number of breaks that would be estimated and the maximum number of iterations for the calculation of the breakpoints in the components. Finally, accuracy estimation of the results allowed for the comparison between the sensors, and also showed the performance of each index in terms of spatial comparison.

4. Results

The implementation of BFAST resulted in the detection of the number and time of the sudden and gradual changes. The break points identified in the trend component revealed the time and range of the sudden changes caused by fire and led to the mapping of all fire affected pixels (Figure 1). Furthermore, the observed gradual changes within the trend component revealed a positive increase of the VIs values over time, and thus a potential post-fire vegetation recovery. That positive trend after the fire is presented by the slope of the gradual change (Figure 2). The inclination varied for every vegetation index and according to different vegetation types. However, according to the general trend, post-fire vegetation recovery was evident in both sensor datasets that were analyzed.

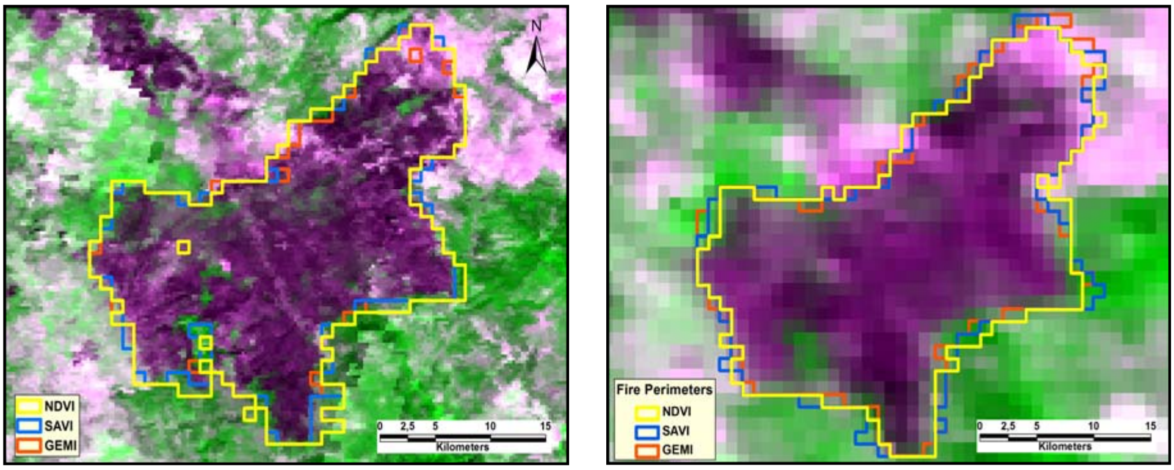

Figure 1: Derived fire perimeters by the BFAST implementation to: (left) degraded PROBA-V VI series and, (right) VEGETATION VI series at the Arkadia study area.

The resulting fire perimeters by the BFAST implementation were spatially compared with a validated perimeter derived by a classified DMC image, providing quite satisfactory results (Table 1). The PROBA-V derived perimeters for every vegetation index show a better spatial agreement than the respective estimations from the VEGETATION analysis. The spatial comparison revealed that GEMI performed better than other indices followed by NDVI in the case of PROBA-V analysis, while for VEGETATION NDVI had the lowest agreement. As it can be viewed in Figure 1, the differences among the indices exist mainly along the perimeter borders and can be attributed to the coarse pixel resolution.

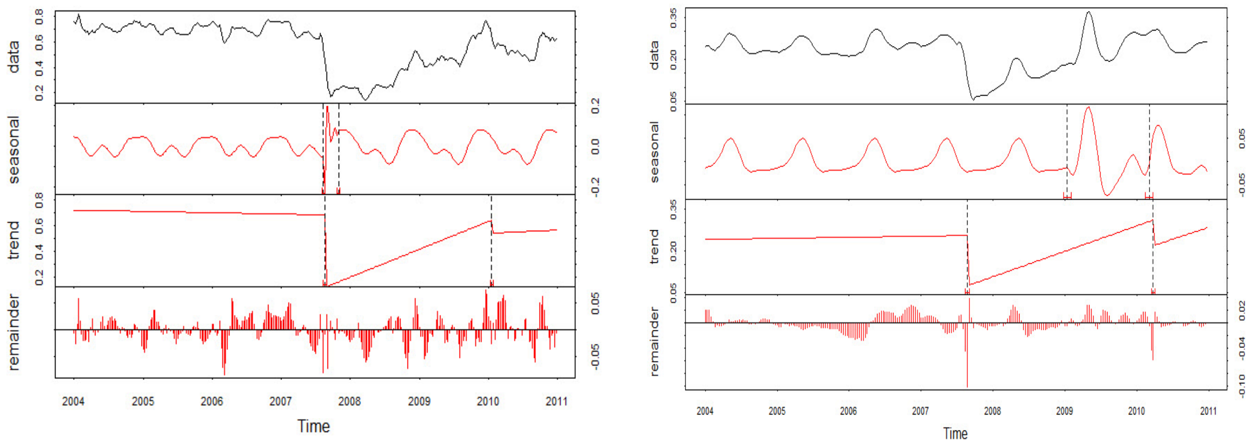

Figure 2: Seasonal, trend and remainder fitted components of the PROBA-V (left) and VEGETATION (right) NDVI series as derived from a single pixel in a conifer forest of the study area.

Table 1. Estimations of the burned area and comparison results.

VIs	Area (ha) PROBA-V deg	Area (ha) VGT	Common area % PROBA-V deg	Common area % VGT
NDVI	48,412	50,709	82.54	79.90
GEMI	45,078	49,766	87.57	80.79
SAVI	46,600	52,042	86.13	77.92

Regarding the post-fire validation, existing field data was not considered sufficient to provide a thorough and objective estimation of the post-fire vegetation condition for the whole area and of course to compare the performance of the two datasets. Nevertheless, even with the existing recovery ground data, the results from BFAST post-fire recovery showed a high agreement and a positive trend after the fire event in all datasets that were analyzed.

5. Conclusions

In this work, an innovative trend analysis technique of satellite time series was implemented for mapping burned areas and monitoring post-fire vegetation recovery. The BFAST (Breaks For Additive Seasonal and Trend) method performs decomposition of time series into seasonal, trend and noise components, thus facilitating the detection of rapid and gradual changes. The BFAST application to the derived vegetation indices resulted in the detection of the time and direction of fire induced changes. Spatial comparison of the generated fire perimeters with reference data was found to be quite high, with PROBA-V based analysis displaying always a better agreement than the VEGETATION results. This can be attributed to the improved spatial resolution of the former sensor. Also, GEMI index was found to perform better than the other indices in all datasets that were analyzed.

Moreover, the slope of the gradual change observed in the trend component revealed post-fire vegetation recovery in every vegetation index series that was processed. However, more work is needed in order to provide more complete and precise estimations of the vegetation recovery. It should be mentioned, that although BFAST provides the time, number and range of changes, one should combine this information in order to characterize the type of change, otherwise misleading results could be yielded. When actual PROBA-V data become available, the sensor's enhanced spatial and technical characteristics can be then fully exploited and potentially provide high quality global products in the field of fire research.

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