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# Land cover mapping with emphasis to burnt area delineation using co-orbital ALI and Landsat TM imagery

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ABSTRACT

In this study, the potential of EO-1 Advanced Land Imager (ALI) radiometer for land cover and especially burnt area mapping from a single image analysis is investigated. Co-orbital imagery from the Landsat Thematic Mapper (TM) was also utilised for comparison purposes. Both images were acquired shortly after the suppression of a fire occurred during the summer of 2009 North-East of Athens, the capital of Greece. The Maximum Likelihood (ML), Artificial Neural Networks (ANNs) and Support Vector Machines (SVMs) classifiers were parameterised and subsequently applied to the acquired satellite datasets. Evaluation of the land use/cover mapping accuracy was based on the error matrix statistics. Also, the McNemar test was used to evaluate the statistical significance of the differences between the approaches tested. Derived burnt area estimates were validated against the operationally deployed Services and Applications For Emergency Response (SAFER) Burnt Scar Mapping service.

All classifiers applied to either ALI or TM imagery proved flexible enough to map land cover and also to extract the burnt area from other land surface types. The highest total classification accuracy and burnt area detection capability was returned from the application of SVMs to ALI data. This was due to the SVMs ability to identify an optimal separating hyperplane for best classes' separation that was able to better utilise ALI's advanced technological characteristics in comparison to those of TM sensor. This study is to our knowledge the first of its kind, effectively demonstrating the benefits of the combined application of SVMs to ALI data further implying that ALI technology may prove highly valuable in mapping burnt areas and land use/cover if it is incorporated into the development of Landsat 8 mission, planned to be launched in the coming years.



## 1. Introduction

Land cover is a fundamental variable of the Earth's system strongly connected with many parts of the human and physical environment. Changes in land cover dynamics is regarded as the most important variable of global change affecting ecological systems (Otukei and Blaschke, 2010). Wildland fires are a major ecological disturbance factor of natural ecosystems threatening environmental systems and infrastructure worldwide, affecting the distribution of land use and land cover (e.g. FAO, 2001; Petropoulos et al., 2011a). Those have a major impact to the economy of an affected country, influencing also the broader economies through the destruction occurred in marketable assets (Sifakis et al., 2011). Thus, the extraction of information on past fire events including accurate mapping of burnt areas is underlined as a matter of key importance and priority for future attention by both environmental scientists and policy makers (Giglio et al., 2006; Kontoes et al., 2009).

The progress in earth observation technology of the past three decades or so has allowed monitoring from space the landscape destruction caused by wildland fires. Several algorithms applied to satellite imagery acquired at various spatial, spectral and temporal resolutions have shown promise in delineating the burnt areas (e.g. Dixon and Candade, 2008; Petropoulos et al., 2010a,b). Satellite image classification is generally regarded as the most commonly used approach in deriving information on the pattern and the spatial distribution of land cover and of its changes (Mathur and Foody, 2008). It is also one of the most widely used approaches in mapping burnt areas (Kokaly et al., 2007; Petropoulos et al., 2011a). Numerous image classifiers have been developed, a recent comprehensive review of which can be found in Lu and Weng (2007). The selection of the suitable classifier as well as of the appropriate spectral bands- original or derived- are both crucial for the success of the classification. Limitations of previous generation satellite sensors with respect to their suitability for burnt area mapping

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have been extensively discussed and identified (e.g. Quintano et al., 2006).

At present we are in an era characterized by the development of new spaceborne sensing. Those aim to replace existing radiometers such of Landsat series, yet ensuring the continuity of observations so that their archive can be maintained (Thenkabail et al., 2004). The need to evaluate specifically the capability of new generation remote sensing sensors combined with contemporary techniques with respect to land use and land cover and/or burnt area mapping has been pointed out as a direction of critical importance and priority (Silva et al., 2005; Roy and Boschetti, 2009). In this context, the Earth Observing-1 (EO-1) mission launched in November 2000 under United States National Aeronautics and Space Administration (NASA's) New Millennium Program, aims at developing and validating instruments and technologies for space-based Earth observation with unique spatial, spectral and temporal characteristics not previously available (Pu et al., 2005). The Advanced Land Imager (ALI) is one of three operational instruments on board the EO-1 platform (Ungar et al., 2003). ALI is a multispectral sensor included in EO-1 with the intention to be used specifically in evaluating new technologies for the development of the future Landsat 8.

The use of ALI data has so far been explored in various applications related to geology (Hubbard and Crowley, 2005; Deller, 2006), vegetation mapping (Pimstein et al., 2009; Helmer et al., 2010) as well as lake water dissolved organic matter (Chen et al., 2009). Many investigators have also examined ALI's potential comparative to that of Landsat TM/ETM+ (e.g. Thenkabail et al., 2004; Neuenschwander et al., 2005; Deller, 2006; Helmer et al., 2010). However, to our knowledge, not adequate attention seems to have been paid in examining ALI's capability in land cover mapping with emphasis to burnt area delineation, particularly in comparison to other sensors. Given that Landsat TM/ETM+ performance in both land cover and burnt area mapping has been extensively examined using diverse classification approaches (e.g. Dixon and Candade, 2008; Petropoulos et al., 2010a,b), it would be of great interest to examine ALI's potential versus TM/ETM+ for this purpose. Understandably, such a study should be performed in a Mediterranean setting, a fire-prone region (Castillejo-Gonzalez et al., 2009).

In this context, the objective of our study was to identify the capability of ALI to land use/cover and burnt area mapping, based on a single image and a range of pixel-based classification techniques. An additional objective was to evaluate the contribution of the advanced technology incorporated in ALI, namely the role of additional bands as well as the higher signal to noise ratio and increased dynamic range, versus the traditionally used TM imagery in land use/cover and burnt areas mapping. As a case study we used a destructive Mediterranean fire that broke out in August 2009 close to Athens, the capital of Greece, for which near co-orbital ALI and TM images acquired shortly after the fire suppression were available.

## 2. Experimental set up

### 2.1. Study site

The study site comprises the area of eastern Attica, located approximately 30 km north-east from the city of Athens. The surface area covered is approximately 220 km$^2$, extending approximately from 23°2′ to 26°1′ East, and from 36°4′ to 38°4′ North. The region is representative of typical Mediterranean conditions in terms of both landscape structure and land surface cover variation. The terrain varies highly from sea level to approximately 800 m, whereas the vegetation of the area also varies with altitude. The climate of the area is typical Mediterranean, characterised by hot, dry summers and cool, wet winters, with a long dry period starting in April and lasting until September. At lower elevations, land is covered mainly by schlerophyllous vegetation, sparse vegetation areas and some agricultural land. At higher altitudes, areas are covered mainly by forest of different types as well as transitional woodland/scrubland areas. The study site experienced severe damage from a wildfire outbreak on August 21st, 2009, which was suppressed approximately 3 days later.

**Table 1**
Wavebands and spatial resolution of the ALI and Landsat TM/ETM.

| Landsat TM/ETM+ | | EO-1 ALI | |
|---|---|---|---|
| Band | Range (μm) | Band | Range (μm) |
| | | 1p (30 m) | 0.432–0.451 |
| 1 (30 m) | 0.450–0.520 | 1 (30 m) | 0.458–0.511 |
| 2 (30 m) | 0.530–0.610 | 2 (30 m) | 0.532–0.602 |
| 3 (30 m) | 0.630–0.690 | 3 (30 m) | 0.632–0.688 |
| 4 (30 m) | 0.780–0.900 | 4 (30 m) | 0.775–0.805 |
| | | 4p (30 m) | 0.845–0.888 |
| | | 5p (30 m) | 1.200–1.288 |
| 5 (30 m) | 1.550–1.750 | 5 (30 m) | 1.554–1.725 |
| 7 (30 m) | 2.090–2.350 | 7 (30 m) | 2.090–2.362 |
| Pan (15 m)[a] | 0.520–0.900 | Pan (10 m) | 0.480–0.690 |

[a] Pan band is not available on the TM sensor. Also the Landsat TM/ETM+ thermal band has not been included in the table.

### 2.2. Datasets

ALI is a multispectral sensor onboard EO-1 that follows a sun-synchronous, near-polar orbit with a nominal altitude of 705 km at the equator. ALI acquires data covering a ground swath width of 185 km. The primary characteristics of ALI reflective bands contrasted with those from Landsat TM/ETM+ are listed in Table 1. In comparison to Landsat TM/ETM+, ALI sensor has three additional bands at 30 m spatial resolution and also one panchromatic band at a spatial resolution of 10 m. Furthermore, in comparison to Landsat TM/ETM+, ALI has an increased dynamic range (12 bit vs. 8 bit) and an improved signal-to-noise ratio (SNR). The prototype ALI instrument was found to exceed ETM+ SNR by a factor of 4–8 (CEOS, 2012). Because ALI was developed as a technology demonstration instrument and not as an operational land imager, ALI observations are mission-objected and programmed.

In our study, near co-orbital satellite imagery from Landsat TM (path: 182, row: 34) and ALI (path: 183, row: 33) over our study region was obtained. Images were acquired at no cost from the United States Geological Survey (USGS) archive (http://glovis.usgs.gov/). The acquisition dates of the TM and ALI images were September 3rd, 2009 and August 30th, 2009, respectively. The TM image was acquired as a full long scene in GeoTiff format at Level 1G, meaning that it was radiometrically, geometrically and terrain corrected, the latter meaning that a Digital Elevation Model (DEM) has been employed for topographic accuracy (USGS web site). The ALI image was also received as a full long scene in GeoTIFF format and at L1GST processing level, meaning that it was radiometrically corrected, geometrically resampled and registered to a geographic map projection image with elevation correction applied to the 16-bit integer radiance values. The ALI image was acquired georeferenced to a UTM 34N projection with a WGS84 ellipsoid, whereas the TM image was provided in UTM 35N projection and WGS84 ellipsoid.

In addition to the above datasets, a burnt area map generated in the framework of the Burnt Scar Mapping service (BSM-1) of the Services and Applications For Emergency Response (SAFER) European Commission (EC) project (http://www.emergencyresponse.eu) was used for validation