International Journal of Applied Earth Observation and Geoinformation 36 (2015) 94–102

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage: www.elsevier.com/locate/jag

Satellite-based automated burned area detection: A performance assessment of the MODIS MCD45A1 in the Brazilian savanna

Fernando Moreira De Araújo*, Laerte G. Ferreira

Federal University of Goiás, Image Processing and GIS Lab (UFG/LAPIG), Brazil

ARTICLE INFO

Article history:
Received 25 May 2014
Accepted 22 October 2014
Available online 18 December 2014

Keywords:
MODIS MCD45A1
Burned area detection
Savannas

ABSTRACT

Burnings, which cause major changes to the environment, can be effectively monitored via satellite data, regarding both the identification of active fires and the estimation of burned areas. Among the many orbital sensors suitable for mapping burned areas on global and regional scales, the moderate resolution imaging spectroradiometer (MODIS), on board the Terra and Aqua platforms, has been the most widely utilized. In this study, the performance of the MODIS MCD45A1 burned area product was thoroughly evaluated in the Brazilian savanna, the second largest biome in South America and a global biodiversity hotspot, characterized by a conspicuous climatic seasonality and the systematic occurrence of natural and anthropogenic fires. Overall, September MCD45A1 polygons (2000–2012) compared well to the Landsat-based reference mapping ($r^2 = 0.92$) and were closely accompanied, on a monthly basis, by MOD14 and MYD14 hotspots ($r^2 = 0.89$), although large omissions errors, linked to landscape patterns, structures, and overall conditions depicted in each reference image, were observed. In spite of its spatial and temporal limitations, the MCD45A1 product proved instrumental for mapping and understanding fire behavior and impacts on the Cerrado landscapes.

Introduction

Burnings cause major changes to the environment, by promoting seed germination (Menezes and Rossi, 2011) and the renewal/re-sprouting of grasses (Keeley, 2006), altering the structure and composition of soil and vegetation, accelerating erosive and sedimentation processes (Ice et al., 2004), as well as by releasing large amounts of trace gases and aerosols to the atmosphere (Longo et al., 2009). The estimated consumption of biomass and the chemical composition of the atmosphere after fires occur are two of the most complex factors for modeling gas emissions, for which it is necessary to conduct accurate mapping of burned areas and assessment of fire severity, as well as pre-fire evaluation of biomass (Randerson et al., 2005).

The occurrence of fires within landscapes, and most important, the understanding of their spatial and temporal distribution, according to the natural land-cover (Roy et al., 2008; McCarty et al., 2009; Araújo et al., 2012) and land-use classes (crops and pastures), have been monitored by different remote sensing imagery and products (Hantson et al., 2013). Specifically, the mapping of fire occurrence through satellite data focuses on both the identification of active fires, through temperature anomalies registered in the middle and thermal infrared (Giglio et al., 2003; Justice et al., 2002a,b; Schroeder et al., 2008), and the estimation of burned areas, detected based on the spectral and temporal contrast between unburned and burned areas (Hantson et al., 2013; Bastarrika et al., 2011a,b).

Although burned areas can be easily identified in medium/high spatial resolution orbital images, their automated discrimination is a complex process, due to both their spatial extension and the variety of spectral responses related to the fire severity, which depends on the vegetation structure and soil/surface properties (Roy et al., 2002; Pivello et al., 2010; Bastarrika et al., 2011a,b), organic matter availability, climatic conditions (air humidity, wind speed, and temperature), and moisture content of the flammable material (Tansey et al., 2004a).

Among the many orbital sensors suitable for mapping burned areas on global and regional scales, the low spatial resolution advanced very high resolution (AHVRR) (França and Setzer, 2001; Soja et al., 2004), the SPOT vegetation (VGT) (Tansey et al., 2004a,b; Silva et al., 2005), and the moderate resolution imaging spectroradiometer (MODIS) (Roy et al., 2005, 2008; Libonati et al., 2010), have

* Corresponding author. Tel.: +55 6281875510; fax: +55 6235211360.
E-mail addresses: fernandomsbl@gmail.com (F.M.D. Araújo), laerte@ufg.br (L.G. Ferreira).
URL: http://www.lapig.iesa.ufg.br (L.G. Ferreira).

http://dx.doi.org/10.1016/j.jag.2014.10.009
0303-2434/

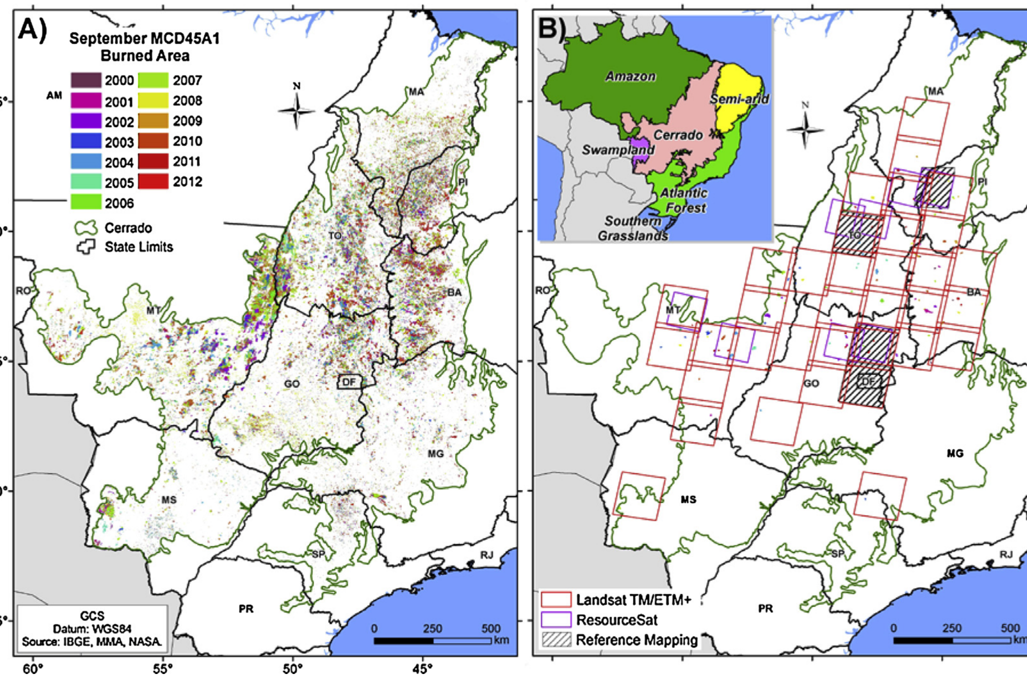

Fig. 1. Location of the September burned area (2000–2012) (A) and of the 130 randomly selected MCD45A1 burned polygons overlaid by the respective Landsat TM, ETM+ and ResourceSat 1 LISS3 scenes utilized for the validation of MODIS MCD45A1 product (B).

been the most widely utilized. At finer scales, the middle spatial resolution sensors, such as the ones onboard the Landsat satellite series, yield highly accurate burned area mappings, that are substantially less affected by both omission and commission errors and are often utilized in support of validating burned area products at a global scale (Krug et al., 2004; Román-Cuesta et al., 2005; Laris, 2005; Bastarrika et al., 2011a,b; Stroppiana et al., 2012).

The MODIS sensor, onboard the Terra and Aqua platforms, has 36 spectral bands (wavelengths ranging from visible to infrared), spatial resolutions of 250 m, 500 m, and 1 km, and temporal coverage of 1–2 days (Justice et al., 1998, 2002a,b). Among the various MODIS data products, the MCD45A1 was specifically developed for the global mapping of burned areas, at 500 m spatial resolution and 30 days repeating cycle (Roy et al., 2005). This product is based on a bi-directional reflectance distribution function (BRDF) model applied to MOD09 (bands 5 and 7) time-series, detecting, on a pixel basis, and according to a look-up-table, daily changes in surface reflectances. Based on a priori criteria, a statistical measure is attributed to each detected difference (i.e., between the previous and subsequent sampled reflectances), which is classified into four categories, according to the respective confidence levels (Roy et al., 2005, 2008; Roy and Boschetti, 2009).

Although different validation exercises of the MODIS burned area product, compared to other global scale products, corroborate its potential applications at an acceptable accuracy (Boschetti et al., 2008; Chuvieco et al., 2008; Roy and Boschetti, 2009; Merino-DE-Miguel et al., 2011), there is still a need for additional and more detailed error assessments for distinct environments. Within this context, the main purpose and contribution of the present study was to quantitatively evaluate, according to distinct land-cover classes and landscapes, the performance of the MODIS MCD45A1 product in the Brazilian savanna (known as Cerrado), the second largest biome in South America and a global biodiversity hotspot (Myers et al., 2000), characterized by a conspicuous climatic seasonality, with very little rain during the dry season months from May to September (Castro et al., 1994), and the systematic occurrence of severe natural and anthropogenic fires.

Data and approaches

The evaluation of the MODIS MCD45A1 product in the Cerrado biome comprised two complementary steps. First, 130 burned scar polygons (from 2000 to 2012) with the highest confidence (i.e. MCD45A1 quality assurance = 1) and larger than 10 km^2, detected during the month of September, a period of great fire intensification in the Cerrado (Araújo et al., 2012), were randomly selected (Fig. 1).

The Landsat TM and ETM+ utilized in the validation process were selected according to the location of the 130 MCD45A1 burned polygons. On average, for the inspection of each polygon, two TM or ETM+ overpasses were selected (beginning and end of September, or, in some cases, in the first days of October). Regarding the visual identification and manual delineation of burned scars, these were based on a GIS platform and the TM/ETM+ spectral bands 4 (0.76–0.90 μm), 5 (1.55–1.75 μm), and 7 (2.08–2.35 μm), which results in an optimum color composite contrast, capable of discriminating burned areas of low, medium, or high severity. For 2011 and 2012, when TM images were mostly unavailable, ResourceSat 1 – LISS3 scenes, comprising bands 4 (0.77–0.86 μm), 5 (1.55–1.70 μm), and 3 (0.62–0.68 μm) were acquired. Table 1 shows the TM, ETM+, and LISS3 images used for the evaluation of the MODIS MCD45A1 product in the Brazilian savanna, totaling 91 images.

Ideally, for this analysis it would be desirable to have images prior to, during, and after the burning event, so that the fire behavior and severity, as well as the distribution and characteristics of the burned areas in the landscape could be properly investigated. However, for some of the polygons considered in this work, only one image was available, in part due to quality issues, as extensive fire fronts, particularly over natural areas, release a great amount of smoke and particulates into the atmosphere. This was the case of the 2000, 2002, 2006, and 2011 (the last year of Landsat 5 – TM data) polygons, evaluated on a single overpass basis.

As the burned areas in the Brazilian savanna occur mainly at irregular paths and over large areas (as is particularly the case