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Comparing the accuracies of remote sensing global burned area products using stratified random sampling and estimation

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ABSTRACT

The accuracies of six global burned area (BA) products for year 2008 were compared using the same validation methods and reference data to quantify accuracy of each product. The selected products include MCD64, MCD45 and Geoland2, and three products developed within the Fire Disturbance project (fire_cci), which is part of the European Space Agency's (ESA) Climate Change Initiative (CCI) program. The latter three products were derived from MERIS and VEGETATION sensors (one product from each sensor separately, and a third one from the merging of MERIS and VGT products). The reference fire perimeters were mapped from two multi-temporal Landsat TM/ETM+ images at 103 non-overlapping Thiessen scene areas (TSA) selected with a stratified random sampling design. The validation results were based on cross tabulated error matrices from which six accuracy measures were computed following the requirements of end-users of burned area products. While overall accuracy (OA) exceeded 99% for all products, overall accuracy was lower for the burned class. Burned area commission error ratio was above 40% for all products and omission error ratio was above 65% for all products. The statistical significance of differences in accuracy between pairs of products was evaluated based on theory of the stratified combined ratio estimator. Statistical tests identified the MCD64 as the most accurate product, followed by MCD45 and the MERIS product.

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1. Introduction

Fire affects atmospheric emissions of gases and aerosols (van der Werf et al., 2004) and influences carbon budgets, as it impacts carbon stocks and vegetation succession patterns. Therefore, accurate information on fire occurrence is critical to better understand the role of vegetation dynamics in earth system models (Bowman et al., 2009). For this reason, the Global Climate Observing System (GCOS) program (GCOS, 2004) identified Fire disturbance as one of the Essential Climate Variables (ECV). This variable has been selected by the European Space Agency (ESA) as one of the target variables for the Climate Change Initiative (CCI) program (http://ionia1.esrin.esa.int/, last accessed December, 7th 2014). The ESA CCI Fire Disturbance project (fire_cci) aimed to develop global burned area products from European sensors for the climate modeling community, with proper validation and uncertainty characterization (http://www.esa-fire-cci.org/, last accessed December, 7th 2014).

In the last few years, several global burned area (BA) products have been made available to the international community, and are being used as input to climate models (Mouillot et al., 2014). Independent validation assessments are necessary to compare the performance of these products and guide their use when incorporated into global atmospheric and carbon models. Knowing the uncertainty of each input product is critical to decouple model and input data limitations.

Validation is defined by The Committee on Earth Observing Satellites Working Group on Calibration and Validation (CEOS-WGCV) as "the process of assessing, by independent means, the quality of the data products derived from the system outputs" (CEOS-WGCV, 2012). Validation quantitatively assesses the performance of a dataset providing essential information to the user community. Existing BA products

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have typically been subject to a first stage validation. Globcarbon (Plummer et al., 2007) and L3JRC (Tansey et al., 2008) were validated with independent data derived from 72 globally distributed Landsat scenes mostly acquired from the year 2000. Chuvieco et al. (2008) validated a regional product for Latin America using 19 Landsat scenes and 9 China–Brazil Earth Resources Satellite (CBERS) scenes. Roy and Boschetti (2009) reported validation results for the MCD45 (Roy, Boschetti, Justice, & Ju, 2008) product and Giglio, Loboda, Roy, Quayle, and Justice (2009) for MCD64, the former in southern Africa using 11 Landsat scenes and the latter using 41 Landsat scenes in the western United States, southern Africa and central Siberia.

Extending the objective to comparing the accuracy of different global products is still a challenge as validation methods and datasets are not fully compatible. Roy and Boschetti (2009) presented a first attempt at the validation and comparison of several global products using a common independent reference data set. They compared Globcarbon, MCD45 and L3JRC BA products with fire perimeters derived from 11 Landsat scenes distributed across southern Africa. Results were reported for each Landsat scene, but global accuracy for the whole study area was not reported.

In this paper we compare the accuracy of six burned area products at a global scale for year 2008 using a stratified random sample developed for the fire_cci project, which was the first attempt to implement a statistically designed sample for global validation of burned area products (Padilla, Stehman, & Chuvieco, 2014). The accuracy measures used to compare the burned area products were selected to address the requirements defined by the end-users of the fire_cci products (Mouillot et al., 2014). Specifically, users expressed interest in metrics providing estimates of accuracy, commission and omission errors, error bias (whether the product under or overestimates true BA) and temporal stability (covered in Padilla, Stehman, Litago, & Chuvieco, 2014). We also employed a statistical test to evaluate the differences in accuracy of product pairs.

2. Methods

2.1. BA products

The products evaluated in this study (Table 1) include two products derived from MODIS (Moderate Resolution Imaging Spectroradiometer), MCD64 and MCD45, one developed in the Geoland2 project from SPOT VEGETATION (VGT) data, and three products developed in the fire_cci project.

The fire_cci project has generated three BA products: the first one derived from SPOT VGT (VGT_cci) and based on a time series change detection algorithm to detect significant decreases in the near-infrared reflectance (Pereira, Mota, Calado, Oliva, & González-Alonso, 2013), another one computed from the MEdium Resolution Imaging Spectrometer (MERIS), (MERIS_cci), which used an hybrid algorithm that takes into account both reflectance time series and MODIS active fire observations (Alonso-Canas and Chuvieco, submitted for publication), and a third product (MERGED_cci) based on the merging of VGT and MERIS data (Tansey, Bradley, & Padilla, 2014).

MCD45 is currently the standard MODIS BA product. It is based on a prognostic model that compares estimated versus actual reflectance for different MODIS spectral bands (Roy, Jin, Lewis, & Justice, 2005). MCD64 is the primary data source of the Global Fire Emissions Database (GFED) Versions 3 and 4 (Giglio et al., 2010; Giglio, Randerson, & van der Werf, 2013). This product is based on MODIS spectral indices and active fire observations (Giglio et al., 2009). Geoland2, based on a temporal index of near infrared reflectances of the SPOT VGT sensor, is built on the experiences of the Global Burned Area (GBA2000), Globcarbon and L3JRC projects (Tansey, Brandley, Smets, van Best, & Lacaze, 2012; Tansey et al., 2008). The latter two could not be assessed in this paper, as they do not include 2008 data, which was selected as the golden validation year for the ESA CCI program.

All six BA products compared in this study include monthly files with pixel values referring to the day of the year (DoY) when a burned area was detected (1–365, 0 meaning unburned).

2.2. Sampling design

The sampling design, reference data generation and methodology for estimating accuracy had previously been documented in Padilla, Stehman, and Chuvieco (2014), where further details are included. The probability sampling design employed a spatial stratification to distribute the sample among the major Olson biomes (Olson et al., 2001), with proportionally larger sample sizes allocated to regions with high BA. Two levels of stratification were implemented using, as sampling units, the Thiessen scene areas (TSAs) constructed by Cohen, Yang, and Kennedy (2010) and Kennedy, Yang, and Cohen (2010) specifically for use with Landsat WRS-II frames. The first stratification level was based on the Olson biomes and the second one on the BA extent in 2008 provided by the Global Fire Emissions Database (GFED) version 3 (Giglio et al., 2009, 2010). Fourteen strata were defined; each one of the seven biome-based (geographic) strata was split into two regions of high and low BA. The global distribution of the sample is illustrated in Fig. 1. Globally, 103 TSAs were analyzed out of the 105 selected for the sample. Two TSAs were excluded because at least one of the BA products did not report results for the region within which that TSA was located. Specifically, the MCD64 had all pixels with no-data available in one TSA, and MCD45 in a second TSA.

2.3. Reference data

The standard protocol defined by the CEOS Cal-Val (Boschetti, Roy, & Justice, 2009) was followed to generate and document the fire reference perimeters for 2008, the year selected for validation of all ESA CCI products. For each TSA sampled, fire perimeters were extracted from a pair of Landsat TM/ETM + image acquisitions at the same location (acquired in two different revisit times at the same path and row), using a semi-automatic algorithm developed by Bastarrika, Chuvieco, and Martin (2011). All scenes were afterwards visually checked and some were repeated by another interpreter to ensure consistency of the results (see Padilla, Stehman, & Chuvieco, 2014).

Table 1
List of products included in the analysis.

Acronym	Sensor characteristics	Project	Institution
MCD45	MODIS images (500 m)	MCD45 (Roy et al., 2005)	University of Maryland
MCD64	MODIS images (500 m), MODIS thermal anomalies (1 km)	MCD64 (Giglio et al., 2009)	University of Maryland
Geoland2	SPOT VGT (1 km)	Geoland2 (Tansey et al., 2008, 2012)	University of Leicester and Flemish Institute for Technological Research (VITO)
MERGED_cci	SPOT VGT and MERIS (300 m)	Fire Disturbance CCI project (Chuvieco, 2013)	University of Leicester
MERIS_cci	MERIS (300 m) MODIS thermal anomalies (1 km)		University of Alcalá
VGT_cci	SPOT VGT (1 km)		Instituto Superior de Agronomia

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