The global MODIS burned area product

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Abstract

Earth-observing satellite systems provide the potential for an accurate and timely mapping of burned areas, also known as fire-affected areas. Remote sensing algorithms developed to map burned areas are difficult to implement reliably over large areas however because of variations in both the surface state and those imposed by the sensing system. The availability of robustly calibrated, atmospherically corrected, cloud-screened, geolocated global data provided by the Moderate Resolution Imaging Spectroradiometer (MODIS) allows for major advances in satellite mapping of burned area.

This paper presents the first global MODIS burned area product (MCD45A1) which is part of the NASA Collection 5 MODIS land product suite. The algorithm is developed from the recently published Bi-Directional Reflectance Model-Based Expectation change detection approach and maps at 500m the location and approximate day of burning. It has been implemented in the MODIS land production system to systematically map burned areas globally for the 6+ year MODIS observation record. The product format and preliminary product examples are presented. A comprehensive program of validation is under development and international collaborations have been made and are sought with regional networks of fire scientists and product users, in the framework of the GOFC/GOLD program and the CEOS Land Product Validation Working group.

Introduction

Fire is a prominent disturbance factor and is an agent of environmental change with local to regional impacts on land use, productivity, carrying capacity, and biodiversity, and regional to global impacts on hydrologic, biogeochemical, and atmospheric processes (Csiszar et al. 2004). Satellite remote sensing provides the only means of monitoring vegetation burning at regional to global scale. Satellite data have been used extensively in the last twenty years for the detection of active fires and, in the last decade, for mapping burned areas (Eva and Lambin 1998, Barbosa et al, 1999, Tansey et al., 2004).

As part of NASA's Earth Observing System, the Moderate Resolution Imaging Spectroradiometer (MODIS) is onboard the Terra (launched 1999) and Aqua (launched 2001) polar orbiting satellites and their data are being used to generate global coverage data products on a systematic basis (Justice et al. 2002a). The algorithm used to define the global 1km MODIS active fire product has been refined several times (Kaufman et al. 1998, Justice et al. 2002b, Giglio et al. 2003). A complementary MODIS algorithm defined to map burned area has been developed and demonstrated in southern Africa (Roy et al. 2002, Roy 2003) and modified for global application (Roy et al. 2005a); this algorithm has been implemented in the

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MODIS processing chain to map burned areas globally. The present paper overviews the main characteristics of the resulting global burned area product (MCD45A1).

Algorithm Overview

Burned areas are characterized by deposits of charcoal and ash, removal of vegetation, and alteration of the vegetation structure (Roy et al. 1999). The MODIS algorithm to map burned areas takes advantage of these spectral, temporal, and structural changes. The algorithm detects the approximate date of burning at 500 m by locating the occurrence of rapid changes in daily surface reflectance time series data. It is an improvement on previous methods through the use of a bidirectional reflectance model to deal with angular variations found in satellite data and the use of a statistical measure to detect change probability from a previously observed state. The algorithm maps the spatial extent of recent fires and not of fires that occurred in previous seasons or years.

MODIS reflectance sensed within a temporal window of a fixed number of days are used to predict the reflectance on a subsequent day. A statistical measure is used to determine if the difference between the predicted and observed reflectance is a significant change of interest. Rather than attempting to minimize the directional information present in wide field-of-view satellite data by compositing, or by the use of spectral indices, this information is used to model the directional dependence of reflectance. This provides a semi-physically based method to predict change in reflectance from the previous state. A temporal constraint is used to differentiate between temporary changes, such as shadows, soil moisture changes and sensor data artifacts, that are spectrally similar to more persistent fire induced changes. Further details are provided in Roy et al. 2005a.

Product Format

The MODIS burned area product (MCD45A1) is a monthly gridded 500m product that describes the approximate day of burning. The product is produced in the standard MODIS Land tile format in the sinusoidal projection (Wolfe et al. 1998). Each tile has fixed earth-location, covering approximately 1200 x 1200 km (10° x 10° at the equator). The product is distributed in the standard Hierarchical Data Format, and includes the following data layers, defining for each 500m pixel:

- Burndate: Approximate Julian day of burning from eight days before the beginning of the month to eight days after the end of the month, or a code indicating unburned, snow, water, or insufficient data to make a decision.
- Burn quality assessment: Confidence of the detection; 1 (most confident) to 4 (least confident).
- Number of Passes: Number of MODIS observations where the temporal consistency test is passed.
- Number Used: Number of MODIS observations used in the temporal consistency test.
- Direction: Direction in time in which burning was detected (forward, backward or both).

- Surface Type: Information describing the land and atmospheric properties (e.g. water, snow, high aerosol, high view and solar zenith angles).
- Gap Range 1 and 2: Information describing the two largest numbers of consecutive missing/cloudy days (if any) in the time series and their start day.

Mandatory metadata required by the EOS Data Information System (EOSDIS) Core System (ECS) are included in each product tile to enable the product to be archived and ordered. In addition, metadata describing for each tile the:

- percentage of land pixels detected as burned.
- percentage of pixels not processed due to insufficient cloud-free data.
- percentage of pixels in each of the “Burn quality assessment” categories.
- number of pixels detected in each direction in time (forward, backward or both).

A synthetic overview of the burned area mapping algorithm is contained in the Algorithm Theoretical Basis Document (ATBD), while more information on the product format and on how to use it for scientific investigations is contained in the Product User Guide. Both are available on the MODIS Fire website http://modis-fire.umd.edu/MCD45A1.asp

Example Results

Figures 1-4 illustrate results of the first global run of the Collection 5 burned area product, and show the 1km MODIS active fire product for the same period/location for comparative purposes.

Figure 1 shows results for burning in August 2001 over southern Africa (parts of South Africa, Mozambique, Botswana and Zimbabwe). The independently derived fire products exhibit a similar, locally coherent, spatio-temporal progression of burning. Generally, a high correspondence is observed between the locations and dates of the 500 m burned area results and the cumulative 1km day and night active fire detections. Substantially more burned areas (~40%) are detected by the global burned area algorithm than by the cumulative day and night 1 km active fire detections.

Figure 2 illustrates 12 months of MCD45A1 burned area product for all of Africa. These data are shown visualized in the World Wind 3D Virtual globe which we are using to visualize the product for quality assessment purposes (Boschetti et al. 2007). The non–burned, non-fill pixels are set as transparent to allow visualization of the MODIS surface reflectance background. The progression of burning across the African continent is seen, with the burning season of the Northern hemisphere from October to March and the burning season of the Southern hemisphere from May to October clearly evident. In each month the progression of burning within the month is also apparent. No burned area product was produced in June 2001 because the MODIS instrument was off for several weeks due to an engineering problem.

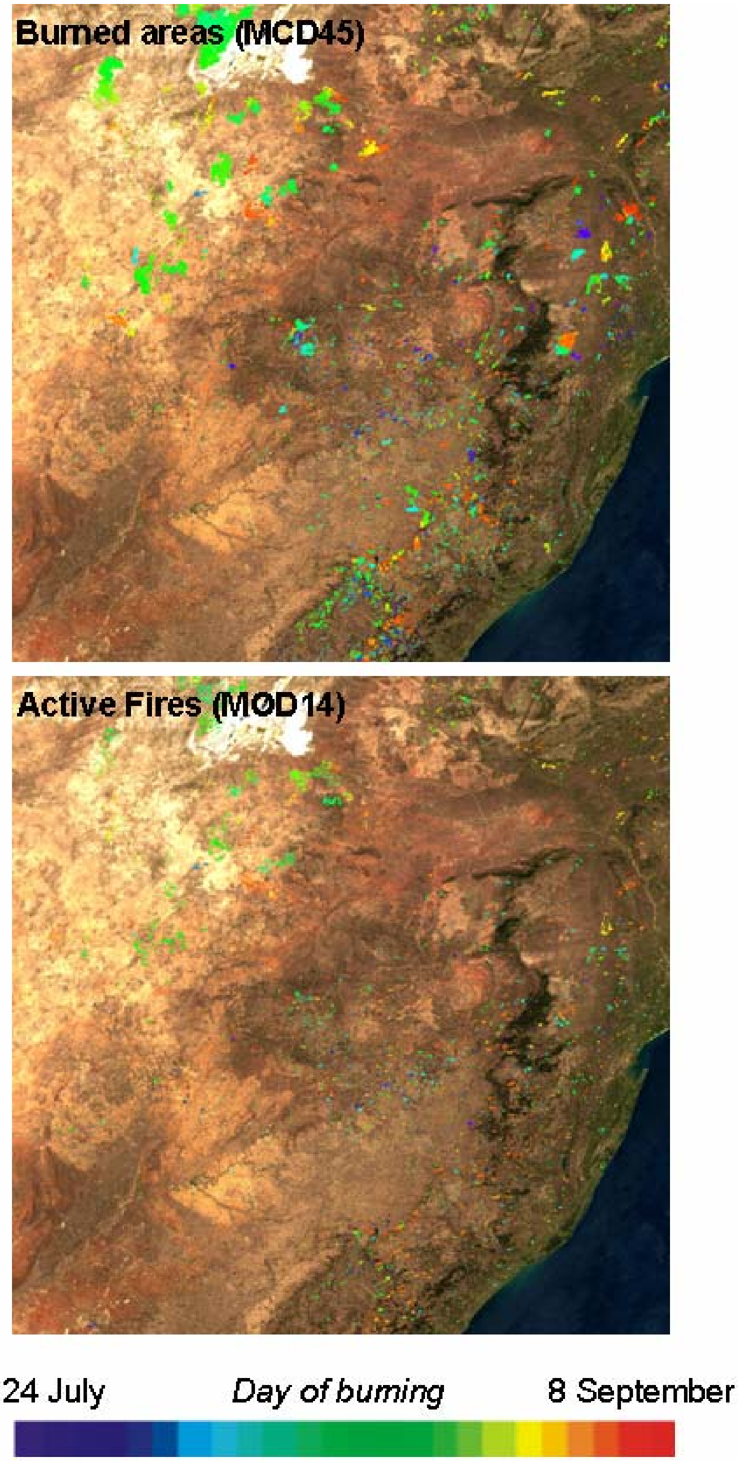

Figure 1: Comparison between MODIS 500m Burned Areas (top) and cumulative 1km day and night MODIS active fires (bottom) for August 2001 over the 1200x1220km MODIS land tile h20v11 (Southern Africa). The approximate day of burning is overlain on MODIS surface reflectance to provide geographic context.

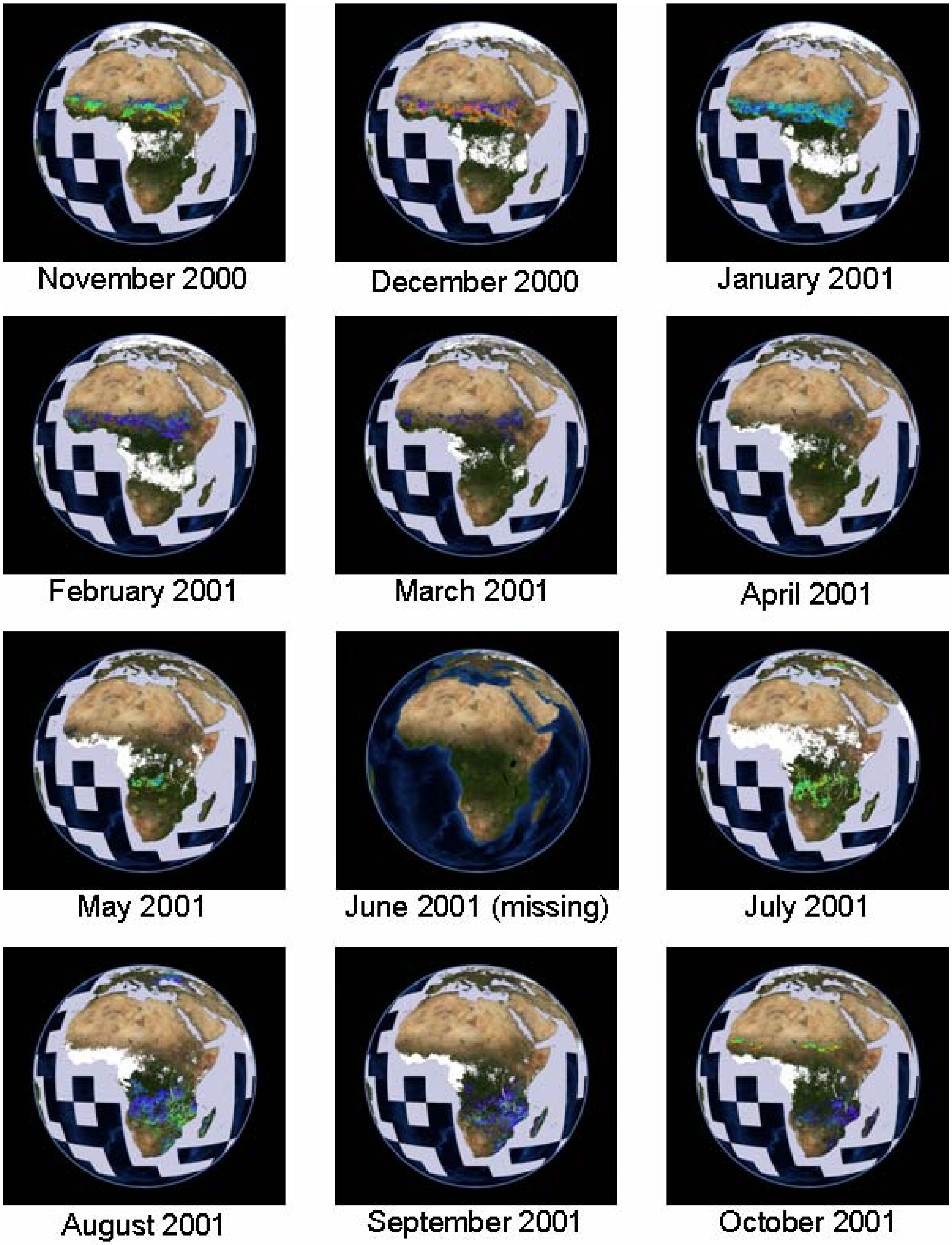

Figure 2: MODIS 500m Burned Areas for Africa overlain on MODIS surface reflectance. The rainbow colours (blue to red) indicate the approximate day of burning in each month, white indicates no decision because of persistent cloud cover or missing data, grey indicates no burning but snow detected, lilac indicates water.

Figure 3 shows scatter plots comparing the global proportion burned as labeled by the 500m MODIS burned area product (y axis) and by the corresponding day and night 1km active fire detections (x axis) for August 2001. Each point on these plots corresponds to the proportions found in a 10x10km window. Evidently the MODIS burned area product detects more area burned at this scale than the active fire product, which is expected as the active fire product only detects fires that are burning at the time of cloud-free overpass (Roy et al. 2005a).

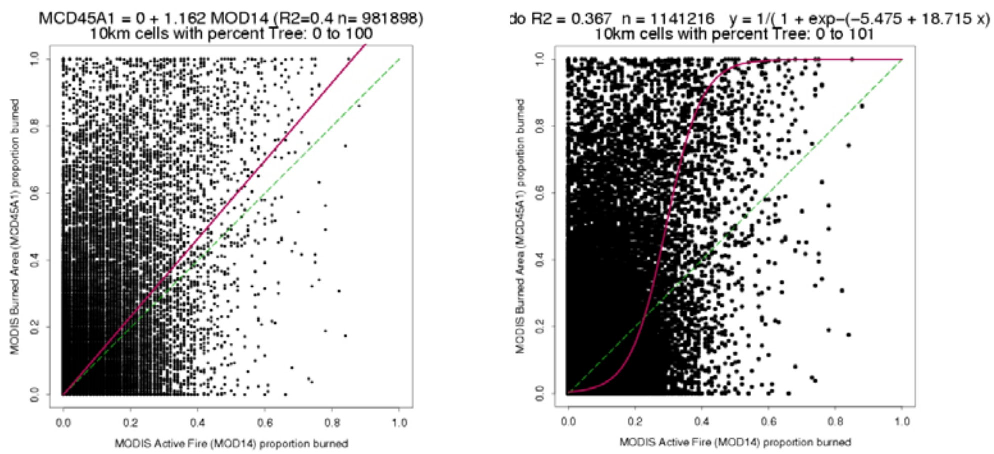

Figure 3: scatterplots of the global proportion of area burned (on the y axes) and active fire pixels (on the x axis). The scatter plot on the left shows a linear regression (red line) of these data with the regression line forced to pass through the origin. The scatter plot on the right shows a logistic regression (red line). Data for all global non-snow covered land, August 2001.

Figure 4 shows the same data as Figure 3 but considering only those pixels falling within low (0-10%) medium (10-30%) and high (30-60%) percentage tree cover ranges. At low to medium tree cover, the 500m MODIS burned area product detects globally more area burned than the 1km active fire product by approximately 44% and 21% respectively. At high tree cover (30-60%) the opposite is true with the burned area produced underestimating the area burned relative to the active product, although the strength of the relationship between these products is low (R^2= 0.18). This may be because under high tree cover conditions reflectance changes detected by MDC45A1 are not as easily discernable as hot spots detected by MOD14, and/or that the 1km MODIS active fire detections are exaggerating the area burned. Further research is required in this respect.

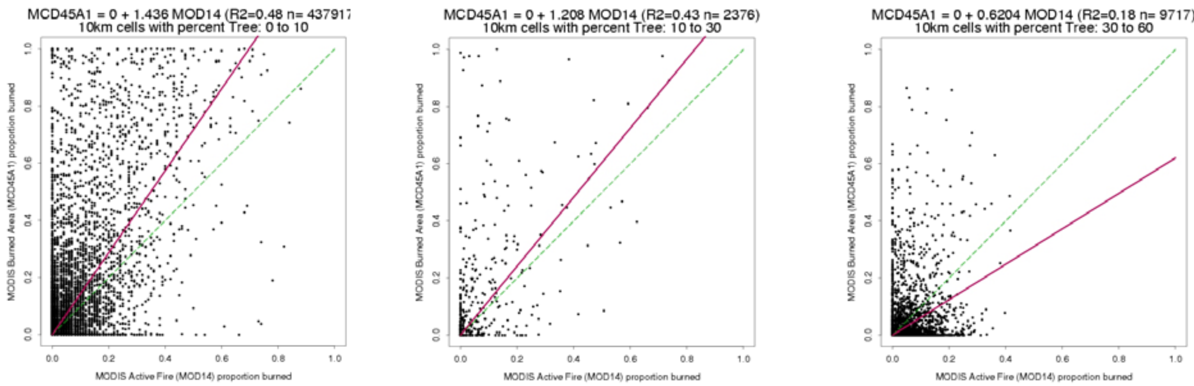

Figure 4: scatterplots of the proportion of area burned (on the y axes) and active fire pixels (on the x axis) for low (0-10%) medium (10-30%) and high (30-60%) percentage tree cover ranges defined by the MODIS 500m percent tree cover product (Hansen et al. 2003).

Validation Plan

A comprehensive program of product validation is under development and international collaborations have been made and are sought with regional networks of fire scientists and product users through the GOFC/GOLD program and the CEOS Land Product Validation Working group. A prototype validation protocol has been developed using multi-date Landsat ETM+ data (Roy et al. 2002, Roy et al 2005b) and validation results for southern Africa and Australia are described in separate papers in preparation. The global algorithm may be enhanced further based on the results of these validation initiatives or if the performance of the MODIS instrument changes. Further information and product samples are available at http://modis-fire.umd.edu/MCD45A1.asp.

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