VALIDATION OF THE MODIS BURNED-AREA PRODUCTS ACROSS DIFFERENT BIOMES IN SOUTH AFRICA

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ABSTRACT

The Moderate Resolution Imaging Spectroradiometer (MODIS) time-series data afford the remote sensing community a unique opportunity to investigate the frequency and distribution of fires. Previous research that validated the MODIS burned area product (MCD45A1) in South Africa was only limited to two Landsat 7 Enhanced Thematic Mapper plus (ETM+) scenes in savanna vegetation, which is not adequate for robust assessment of fire distribution across diverse environments. In this study, validation of the MCD45A1 and the Backup MODIS burned area product (hereafter BMBAP) was extended over different South African vegetation types by quantifying their burned area detection and estimation accuracy using Landsat 5 Thematic Mapper (TM) imagery. Results from the four validation sites reveal that there are subtle differences in the accuracy of the two products. These differences could be influenced for example by, vegetation type, spectral characteristics, and size distribution of the burned areas. These results have significant implications for fire monitoring in Southern Africa.

Index Terms— MODIS, Landsat, burned area product, omission and commission errors, fire

1. Introduction

Biomass burning has significant global impacts on climate systems, vegetated ecosystems and atmospheric chemistry. The scientific community, policymakers, and resource managers require information on the frequency of occurrence, distribution and severity of biomass burning over large areas [1, 2, 3]. Although localized fire records exist especially for some protected areas with specific fire management policies [3], they may not provide a comprehensive spatial representation of biomass burning activity over extensive regions.

Satellite remote sensing has proven to be a valuable method for extensive monitoring of biomass burning at different spatio-temporal scales. In the last few years, previous attempts to systematically map the location and approximate date of burned areas using low (~1-5km) and moderate (~250-500m) resolution satellite data across the African continent have been successfully demonstrated [4, 5, 6, 7] and their results show potential for extensive regional applications, in particular the estimation of burned biomass, gas and aerosol emissions. However, [8] reported about the uncertainties in the accuracy of automated burned area products. The accuracy is influenced by differences between burned and unburned area reflectances, temporal persistence of the burned area signal, similar spectral changes not caused by fire, and the size and spatial distribution of the burned areas [9, 10].

The MODIS sensor onboard the NASA's Terra (~10:30 a.m. ascending equatorial crossing time) and Aqua (~1:30 p.m. descending equatorial crossing time) satellites have specific lineaments for reliable and long-term earth observations. Recently, regional southern Africa burned-area products have been produced using 500 m MODIS surface reflectance time-series data which includes the official MODIS burned area product (MCD45A1) [9] as well as the Backup MODIS burned area product (hereafter BMBAP) [11]. Previous research on the validation of the MCD45A1 product in South Africa was limited to only two Landsat 7 Enhanced Thematic Mapper plus (ETM+) scenes that covered the Lowveld savanna biome around the southern Kruger National Park [12]. In the present study, the validation work of MCD45A1 and BMBAP is extended across the main fire prone biomes in South Africa, using similar analysis procedures to Roy et al. [12]. Therefore, the objectives of this study were to: i) quantify the commission and omission errors in the MCD45A1 and BMBAP; ii) compare the burned area estimates derived from the MCD45A1 and BMBAP to that of Landsat TM reference data for the 2007 burn season; and iii) to quantify the influence of the extend of sub- MODIS-pixel burned area on the probability of detection by each burned area product.

2. METHODS

The June-September fire season of 2007 (generally dry season) was analysed for the sites in the summer rainfall region in eastern South Africa. In addition, the winter rainfall (January-April of 2007) region of the south-western South Africa was also considered. The accumulative active fire data [13], Tropical Rainfall Measuring

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Table 1: Classification error assessment validation results for the MCD45A (highlighted in grey to aid interpretation) and the BMBAP burned area products compared with Landsat TM burned area at 30m pixel.

Biome	Site, Landsat path/row	TM dates	Product	Landsat Burned (%)	Product Burned (%)	Unmapped Area (%)	Correctly Classified (%)	Omission Error (%)	Commission Error (%)
Lowveld Savanna	Southern Kruger 168/077	11/8/07 27/8/07	MCD45A1	3.22	2.8	0	99.78	40.38	31.35
			BMBAP		2.33		99.83	40.39	17.68
Highveld Grassland	Middelburg 169/078	18/8/07 3/9/07	MCD45A1	2.63	1.42	0.38	97.90	62.87	31.52
			BMBAP		1.21		97.96	65.79	25.64
Fynbos	Western Cape 175/083	17/2/07 6/4/07	MCD45A1	10.28	2.98	2.75	91.42	77.25	21.47
			BMBAP		2.21		91.12	82.85	18.47
Pine forest	Sabie 169/077	15/6/07 18/8/07	MCD45A1	26.72	13.22	1.93	76.21	62.14	23.5
			BMBAP		36.65		71.81	14.63	37.76

Mission (TRMM) data [14] and the Vegetation map of South Africa [15] were used to guide the selection of the seven validations sites encompassing savanna, grassland, forest and fynbos biomes. These sites represent important features that may influence the MODIS burned area product accuracy such as, the degree of spectral change from unburned to burned vegetation, size distribution of the burned areas, and spectrally similar non-fire induced changes [10].

The MCD45A1 product is generated from MODIS daily surface reflectance time-series data using a predictive bi-directional reflectance modeling approach to locate the occurrence of persistent post-fire changes as well as a robust statistical comparison to quantify the discrepancies in change probability [9]. On the other hand, the BMBAP product uses a vegetation index (VI) to summarize persistent post-burn changes in the daily MODIS surface reflectance data. These changes are coupled with 1 km MODIS active-fire observations to guide the generation of statistical functions and selection of classification procedures suitable for the mapping of burned areas [11]. Both MCD45A1 and BMBAP map the location and approximate Julian day (1-366) of burning at 500 m spatial resolution, and are distributed as monthly products gridded to a Sinusoidal equal area projection in fixed geolocated tiles.

Two Landsat 5 Thematic Mapper (TM) scenes were obtained for each site, acquired before and after biomass burning events. A burn-sensitive vegetation index using the TM near-infrared and middle-infrared bands was computed to provide a good burned-unburned discrimination, and to minimize the effects of identical surface changes [10]. Thereafter, a band ratio temporal difference image was computed and the burned areas that appeared to have occurred between the TM acquisitions were enhanced. High resolution burned area maps were derived by visual interpretation and on-screen digitizing. Only Landsat burned areas with a small axis of 4 pixels (240 m) or greater were included in the evaluation process [10]. To allow comparison of the 500 m MODIS burned area products with the 30 m Landsat independent reference data, the spatial properties of the moderate resolution products were transformed to correspond with that of Landsat data to enable direct comparison on a per-pixel basis (30 x 30m).

The detection accuracy (at local scale) of the burned area products was summarized through confusion matrices, and the errors of omission and commission were quantified in the burned area products and compared across the main fire prone biomes in South Africa. Unmapped areas which included cloud and cloud shadow interpreted scenes were also reported, in order to minimize biases in the summarized burned area statistics [10]. Further, a linear regression analysis was used to compare estimated burned area proportions of the MODIS products with that of the independently-derived Landsat reference data across the 2.5 km grid cells. Lastly, an analysis of the relationship between fractional areas of 500 m MODIS pixel burned and their probability of detection was conducted in each study site to assess the influence of sub-pixel burned area on product accuracy.

3. RESULTS

3.1 Classification error assessment for local scale applications

The commission errors of the two burned area products over four study sites indicated subtle differences (~10%), which have a spatial dependence. From the analysis, it can be concluded that both products had lower errors of commission than omission which is also the case for the validation results of the MCD45A1 reported by [12]. Additionally, the validation results of the MCD45A1 reported by [12] and presented in Table 1 indicated slight differences in the commission (~11%) and omission (~9%) errors across the savanna biome. The observed differences may have resulted from different extents of the mapped region and study periods considered. In particular, the BMBAP had the lowest commission error of ~17% (Table 1). As a result, the BMBAP gave the highest overall user accuracy of 75.11% than the MCD45A1 at 73.04%. The differences in the commission errors could be attributed to differences in the size distribution and the heterogeneity of the burned areas which, due to the inherent MODIS resolution resulted in numerous inclusions of unburned Landsat 30 m pixels. Conversely, results in Table 1 show that both products had generally higher errors of omission than commission, and that the omission errors did not reveal marked differences except for one scene in the Sabie region (~48%). The BMBAP product demonstrated higher detection capability in the commercial pine forests with the lowest omission error of 15%, while the omission errors were higher (40 - 80%) for the BMBAP and MCD45A1 products in the savanna, grassland and fynbos biomes, and therefore did not reveal marked differences (~6%). The differences in errors of omission could be as a result of unburned tree canopy, small and/or spatially fragmented burned areas, and the low spectral reflectance (across e.g. the fynbos) caused by low combustion completeness burns.

3.2 Analysis of burned area proportion estimates

For regional scale applications, regression analysis was used to assess the linkage between the estimated burned area by MCD45A1 and BMBAP. The results shown in Fig 1 depict a spread in the spatial variance. The variance quantified by the coefficient of determination (R^2) indicated a significant level of agreement between the Landsat independent reference data and the MODIS burned area products. However, the BMBAP revealed a stronger relationship with R^2 values > 0.8 for all validation sites than the MCD45A1, except in the Western Cape region. The regression results (Fig 1) suggests that the BMBAP underestimated burned area in the savanna, grassland and fynbos biomes (slope values < 1) but slightly overestimated burned area in the pine forests (slope value > 1). Conversely, the MCD45A1 underestimated area burned in all four sites. Therefore, the most accurate burned area estimates for the BMBAP in ascending order were 93%, 90%, and 56% in the savanna, grassland and fynbos biomes. Meanwhile, the MCD45A1 product obtained 92%, 83%, 75% and 49% of the estimated true area burned in the grassland, savanna, fynbos and pine forest biomes.

3.3 Analysis of fractional burned area of a MODIS pixel

Fig 2 illustrates a positive linear trend between the proportion of the MODIS 500 m pixel burned according to the Landsat burned area polygons and probability of detection. This suggests that the probability of burned area identification (by MODIS in either product) increases as the burned area fraction increases. Generally, the MCD45A1 showed high (6 - 44%) burned area detection probability relative to BMBAP (3 - 30%) for small burns e.g. below 50% of a MODIS pixel in all sites. Conversely, the BMBAP show a steady increase in the probability of detection compared to the MCD45A1 for burned area proportions that are more than half a MODIS pixel, particularly in the savanna and pine forest ecosystems. These results quantitatively demonstrates the influence of fractional burned area in the accuracy of the moderate resolution MCD45A1 and BMBAP products, that the probability of burned area identification increases with sub MODIS pixel burned area size. In addition, these observations may be used to explain the inherent error in the products due to limitations arising from the spatial resolution of the MODIS instrument.

4. CONCLUSION

The MODIS burned area products were validated across savanna, grassland, fynbos biomes and commercial pine forests in South Africa. Generally, the differences in the accuracy of the burned area products depend on the type of vegetation, spatial pattern, distribution and spectral reflectance of the burned areas. In this paper, we have demonstrated that the probability of identifying a burned area within a MODIS pixel is directly related to the proportion of the MODIS pixel burned (Fig 2). The accuracy assessment conducted by [12] and given in Table 1 assesses the entire 500m MODIS pixels at 30m resolution as either burned or unburned and does not take cognisance of fractional burned area. For example, even where only 20% of a MODIS pixel has been burned according to the Landsat the assessment expects the MODIS product to detect it as burned, although assigning the burned classification to all 30m pixels inside the 500x500m area naturally leads to large commission errors. This assessment therefore overestimates the error, simply due to the inherent difference in resolution of Landsat and MODIS, i.e. 30m vs. 500m. An appropriate fractional burned area threshold could therefore be useful when assessing product accuracy and may limit biasing product error quantification.

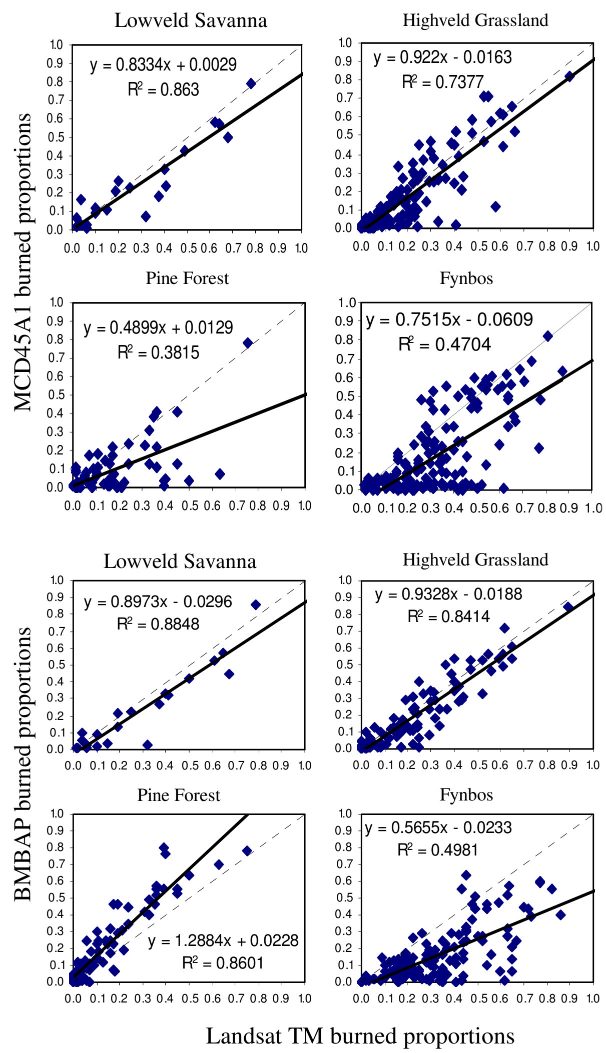

Fig 1: Scatter-plots of burned area proportions derived from the MODIS burned area products (y-axis) and multitemporal Landsat data (x-axis) across the 2.5 km × 2.5 km grid cells for four validation sites. Only grid cells containing burned proportions in the Landsat and the burned area products were considered.

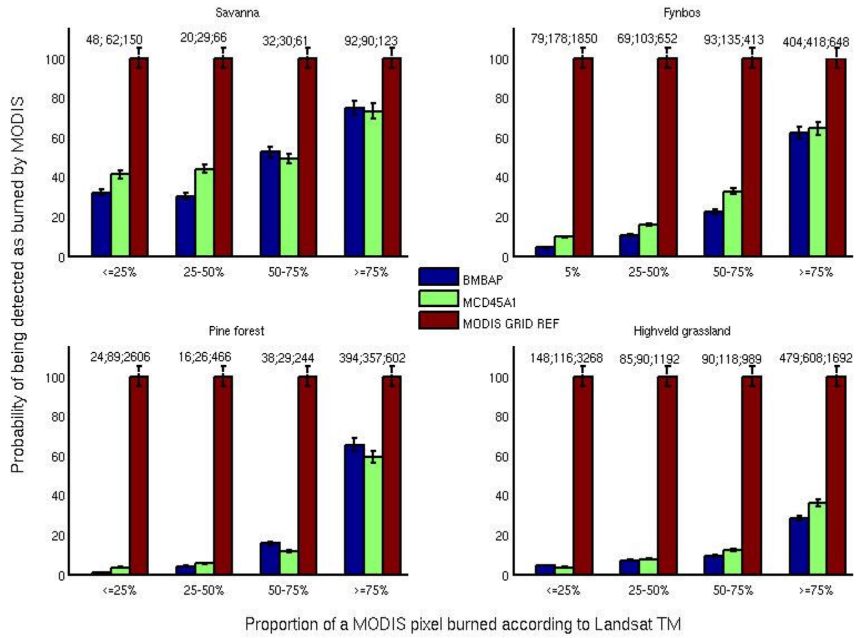

Fig 2: Histograms of the fractional burned areas of <=6.25 Ha, 6.25-12.5 Ha, 12.5-18.8 Ha and >=18.8-25 Ha of a 500 m MODIS pixel used to depict the relationship between burned area proportions according to Landsat and probability of detection by MODIS. The values corresponding with each bar represents the number of 500 m MODIS burned pixels identified at sub-pixel level.

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