Validation of MODIS fire product over Sumatra and Borneo using High Resolution SPOT Imagery

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Abstract: We performed a validation study of the MODIS active fire detection algorithm using high resolution SPOT image as the reference data set. Fire with visible smoke plumes are detected in the SPOT scenes, while the hotspots in MODIS data are detected using NASA's new version 4 fire detection algorithm. The detection performance is characterized by the commission error rate (false alarms) and the omission error rate (undetected fires). In the Sumatra and Kalimantan study area, the commission rate and the omission rate are 27% and 34% respectively. False alarms are probably due to recently burnt areas with warm surfaces. False negative detection occur where there are long smoke plumes and where fires occur in densely vegetated areas.

Keywords: MODIS, SPOT, fire, hotspot.

1. Introduction

The Moderate Resolution Imaging Spectrometer (MODIS) on-board the TERRA and AQUA satellites have 36 spectral bands spanning from the visible to the thermal infrared regions. The thermal bands in the 3 to 4 μm and 10 to 13 μm wavelength regions are particularly useful for detection of active fires. Unlike AVHRR, the MODIS thermal bands saturate at a much higher temperature, making it a more reliable sensor for active fire detection with a much lower false alarm rate. Several versions of fire hotspots detection algorithms have been developed for MODIS. They are all based on the conventional two-bands thresholding method. The earlier versions of MODIS hot spot algorithms use a combination of fixed thresholds and thresholds adaptively determined from the means and standard deviations of the brightness temperature of the neighboring pixels [1, 2]. The more recent version uses only adaptive thresholds.

MODIS fire products have undergone validation by field surveys, airborne imagery and high-resolution imagery [1, 3]. A validation study using high resolution ASTER imagery over southern Africa has been reported [1]. In this paper, we describe our validation study of MODIS active fire product over Sumatra and Borneo. using high resolution SPOT imagery as reference data. The results would enable better understanding of the performance of MODIS hot spot detection algorithm in the humid tropical regions, and the development of hotspots detection algorithms optimized for this region.

2. Methods

Seventeen SPOT scenes acquired in 10 days during two fire seasons (Aug-Sep 2002 and May-July 2003) in Sumatra and Kalimantan were used as reference data for validating MODIS hot spots (see Table 1). The time separation between MODIS and SPOT acquisitions was less than 40 minutes for all cases.

Table 1: SPOT and MODIS data used in the study

	Date	SPOT acquisition time (UTC)	MODIS acquisition time (UTC)	Number of fires in SPOT	Number of hot-spots in MODIS
1	2002-08-16	03:56	04:20	15	12
2	2002-08-17	04:05	03:26	14	7
3a	2002-08-19	02:58	03:15	23	26
3b	2002-08-19	02:58	03:15	20	17
3c	2002-08-19	02:58	03:15	50	23
3d	2002-08-19	02:58	03:15	5	0
4	2002-08-27	02:33	02:25	21	12
5	2002-09-10	02:34	02:40	3	3
6a	2002-09-15	02:38	02:55	10	13
6b	2002-09-15	02:38	02:55	54	63
6c	2002-09-15	02:38	02:55	8	16
7	2003-05-24	03:54	04:10	1	4
8a	2003-06-08	04:05	03:27	13	9
8b	2003-06-08	04:05	03:27	7	6
8c	2003-06-08	04:05	03:27	21	22
9	2003-06-15	03:30	03:33	7	7
10	2003-07-10	03:50	03:26	3	6

SPOT does not have thermal bands for fire detection. The SWIR band (1.6 μm) on SPOT 4 is able to detect hot objects. However, this band is dominated by the solar reflectance component and is not useful for retrieving temperature. Fire detection in SPOT imagery is done by visual inspection to identify smoke plumes associated with active fires. The locations of the active fires are determined from the points of origin of the individual smoke plumes. This method has its short-coming, as intense fires with efficient combustion may not produce sufficient smoke plumes and would not be detected. Such fires are not very common in the humid tropics, due to the high humidity. Each fire detected in SPOT data is classified into one of four categories according to the length of the associated smoke plumes:

Class 1: fires with very faint and barely visible smoke plumes;

Class 2: fires with visible smoke plumes less than 1km in length;

Class 3: fires with visible smoke plumes between 1km to 10 km in length;

Class 4: fires with smoke plumes over 10 km in length.

The number of fires detected in each SPOT scene is indicated in Table 1. There are a total of 275 fires detected in the SPOT scenes, with 62 fires in class 1, 78 in class 2, 77 in class 3 and 58 in class 4.

The MODIS Thermal anomaly/fire detection algorithm (version 4) in the suit of MODIS Institutional Algorithms is used for hot spot detection. Essentially, the brightness temperature in the 4 µm (Band 21, 22) and 11 µm (Band 31) wavelength bands are used in fire detection, supplemented by the reflectance in the near infrared band (Band 2). Potential fire pixels are first selected by the criteria $T21>310K$ and $R2<0.3$. Pixels not satisfying these criteria are not processed further. Potential fire pixels with $T21 >360K$ are confirmed fires. Otherwise, potential fire pixels with T21 exceeding a threshold temperature and T21 exceeding T31 by a second threshold value are considered fire pixels. The two thresholds are adaptively determined from the mean and maximum absolute deviation of T21 and T21-T31 for pixels in the neighbourhood of the potential fire pixels.

Validation of MODIS-detected hotspots is performed by the proximity criterion. If a SPOT fire point is located within a 1-km radius of a MODIS hot spot location, then the MODIS hotspot is a validated hotspot. Otherwise, the hotspot is considered a false alarm and there is an error of commission. Note that there may be more than one SPOT fire points detected within a 1-km radius of a MODIS hotspot. In this case, the MODIS hotspot is considered validated, regardless of the number of active fires detected in the SPOT image. If a MODIS hotspot is located within a 1-km radius of a SPOT fire point, then the fire is detected by MODIS. Otherwise, the fire is undetected by MODIS and an error of omission is committed (see Fig. 1). The performance of the fire detection algorithm is evaluated by the errors of commission and omission.

3. Results and Discussions

The results of validating MODIS hotspots with SPOT imagery are shown in Table 2. Of the 183 MODIS hotspots detected in the 17 SPOT scenes, 180 are validated and 66 are false alarms, giving a commission error rate of 26.8%. On the other hand, of the 275 active fires detected in the SPOT reference data, 181 are detected by MODIS and 94 remain undetected, giving an omission error rate of 34.2%.

Table 2 shows that the commission error and omission error are substantial. About one quarter of the detected hotspots are false alarms. Visual inspection of the false alarm areas in the SPOT scenes reveals that most of the false alarms have signs of fresh burn scars located within the MODIS false alarm pixels. Thus, the false positive detection is probably triggered by warm surfaces of the new burn scars. The MODIS algorithm is able to detect about two-third of the active fires with visible smoke plumes.

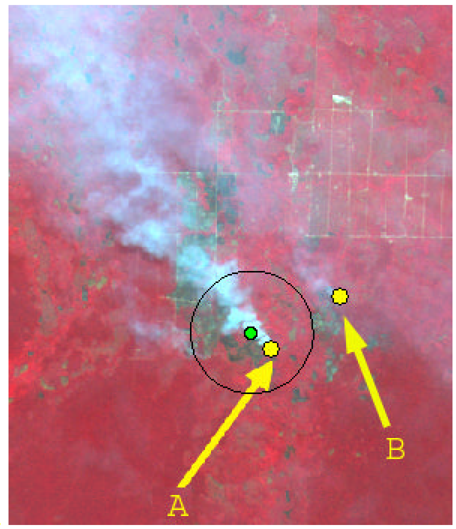

Fig. 1 SPOT image acquired on 2002-08-19 in West Kalimantan. A, B (yellow circles) indicate the locations of active fires detected in the SPOT image. The green circle indicate the location of a fire hot spot detected in MODIS data. In this example, fire A falls within 1 km radius of the MODIS hot spot. Thus, the hot spot is validated. Fire B does not have any MODIS hotspot within its 1-km radius. Thus, B is not detected by MODIS. (Copyright CNES 2002)

Table 2: Commission and Omission Errors of MODIS version 4 Fire Detection Algorithm (this study) for Sumatra and Kalimantan study areas

MODIS Hotspots		SPOT fires	
Validated by SPOT	180	Detected by MODIS	181
False alarms	66	Undetected fires	94
Total	246	**Total**	275
Commission Error Rate	**26.8%**	**Omission Error Rate**	**34.2%**

Table 3: Omission error rate for the four fire classes based on smoke plume length

Fire class	Undetected fires	Total SPOT fires	Omission error rate
1	11	62	17.7%
2	37	78	47.4%
3	29	77	37.7%
4	17	58	28.3%
Total	**94**	**275**	**34.2%**

Table 3 shows the breakdown of the omission error in terms of the length of smoke plumes associated with the fires detected in SPOT scenes. It seems that the omission error rate is low for fires with little smoke plumes. The omission rate is higher for fires with long smoke plumes. Table 4 shows the breakdown of the omission rate according to the land cover where fires occur. The undetected fires occur mainly in dense vegetation areas. The fires in plantations and agricultural areas are mainly used for land clearing where the vegetation density is low.

Examination of the MODIS band 2 (near infrared) reflectance values at locatons of the undetected fires indicates that the MODIS pixels have high reflectance in band 2. Thus they do not pass the potential fire test because they are falsely considered to be bright surfaces. The highly reflective smoke plumes and the high reflectance of vegetation in the NIR band has contributed to the rejection of the MODIS pixel in the potential fire test.

Table 4: Omission error rate according to land cover types where fires occur

Fire class	Undetected fires	Total SPOT fires	Omission error rate
Primary Vegetation	23	59	39.0%
Secondary growth	63	172	36.6%
Plantation	5	26	19.2%
Agriculture	3	18	16.7%
Total	**94**	**275**	**34.2%**

Table 5: Commission and Omission Errors of MODIS version 3 Fire Detection Algorithm derived from reference [1] for southern Africa study area

MODIS Hotspots		ASTER fires	
Validated by ASTER	33	Detected by MODIS	33
False alarms	3	Undetected fires	98
Total	36	**Total**	131
Commission Error Rate	**0.8%**	**Omission Error Rate**	**74.8%**

A similar analysis can be performed using the validation data reported in reference [1] for the southern Africa test area using ASTER imagery as the reference data. In ref. [1], a MODIS hotspot is validated if there is one or more saturated pixels in Band 9 (2.43 μm) of the ASTER reference data located within the field of view of the MODIS hotspot pixel. The validation results for this data set are shown in Table 5.

The southern Africa validation data [1] has close to zero commission error for MODIS hot spot detection. However, the error of omission is much higher than what is observed for the Sumatra and Kalimantan areas. The undetected fires in [1] are mainly small fires.

4. Conclusions

In this paper, we conduct a validation study of MODIS fire detection algorithm (MOD14 version 4.3.2) over Sumatra and Kalimantan using fires detected in high resolution SPOT imagery as reference data. The performance of the algorithm is characterized by two error rates: commission error and omission error. In the Sumatra and Kalimantan study area, the commission error rate is 27% and the omission error rate is 34%. The algorithm fails to detect one third of the fires with visible smoke plumes while one quarter of the detected hotspots are false alarms. Many of the undetected fires have dense smoke plumes, a very clear sign of fires. In comparison, in the southern Africa study [1] the commission rate is practically zero, while the omission rate is much higher at 75%.

The differences in performance of the algorithm may be due to the different types of fires in the two regions. In Africa, the fires are mainly grassland fires which are intense producing little smoke plumes. In the humid tropical areas of Sumatra and Kalimantan, the fires are associated with dense smoke plumes and most occur in dense vegetation area. False alarms in this region are probably due to recently burnt areas with warm surfaces. For fires with dense smoke plumes the fire detection algorithm fails due to the false rejection of the fire pixels as bright surfaces. High reflectance in dense vegetation areas can also trigger this false rejection. This observation points to the possibility of adapting the algorithms to the local conditions. For example, by increasing the threshold of R2 for potential fire test, or replacing R2 with R1 may reduce the omission error rate. A study on the effects of changing the various parameters in the hotspot detection algorithms on the fire detection performance is in progress. A set of parameter values optimized for fire detection in the humid tropics would be obtained by minimizing the errors of commission and omission.

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