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Article

MODIS Hotspot Validation over Thailand

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Abstract: To ensure remote sensing MODIS hotspot (also known as active fire products or hotspots) quality and precision in forest fire control and management in Thailand, an increased level of confidence is needed. Accuracy assessment of MODIS hotspots utilizing field survey data validation is described. A quantitative evaluation of MODIS hotspot products has been carried out since the 2007 forest fire season. The carefully chosen hotspots were scattered throughout the country and within the protected areas of the National Parks and Wildlife Sanctuaries. Three areas were selected as test sites for validation guidelines. Both ground and aerial field surveys were also conducted in this study by the Forest Fire Control Division, National Park, Wildlife and Plant Conversation Department, Ministry of Natural Resources and Environment, Thailand. High accuracy of 91.84 %, 95.60% and 97.53% for the 2007, 2008 and 2009 fire seasons were observed, resulting in increased confidence in the use of MODIS hotspots for forest fire control and management in Thailand.

Keywords: MODIS; hotspots; active fire product; field validation; forest fire; Thailand; protected area; management; false alarm; accuracy

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1. Introduction

Forest fire is a major cause, not only of global deforestation, but also the reduction of carbon storage in carbon sinks. In Thailand the forest fire season coincides with the dry season, from the beginning of November to the end of April, with its peak in March. The majority of the forest fires are ground fires in the dry dipterocarp and mixed deciduous forests, consuming surface litter and small vegetation. These fires may spread to the upper levels of the canopy in mixed deciduous forest with bamboo or pine plantations. Almost all forest fires in Thailand are man-made, primarily started by rural settlers who live in or adjacent to the forests [1]. The main activities that cause forest fires in Thailand include the gathering of forest non-timber products, spreading of agricultural debris burning, hunting, and carelessness. In certain extremely dry sites, double burning in one season is also common [1,2]. In Thailand, the National Park, Wildlife and Plant Conservation Department (NPWPCD; http://www.dnp.go.th) is responsible for forest fire control and management. The Forest Fire Control Division (FFCD; http://www.dnp.go.th/forestfire) consists of 21 regional centers, 64 provincial offices, and 138 forest fire stations. The forest fire patrols are done on ground (on-foot and with patrol vehicles) and via aerial methods (through fire towers, by helicopters, and now with the new satellite monitoring system) [1].

Though the traditional methods are still being used in daily operation, satellite remote sensing is becoming more common in forest fire management [3]. The Moderate Resolution Imaging Spectroradiometer (MODIS) is a multi-temporal remote sensing device. The collected data are available in near real time. It is therefore a promising data source for use in tracking both active fires and burned areas, and can potentially be used in improved management during the forest fire season [4,5]. MODIS is one of the sensors in the Earth Observing System (EOS).

It has been shown that the best way to obtain large scale information on forest fires over the past three decades was via satellite remote sensing [1,3-11]. One of the first systems utilized was the Advanced Very High Resolution Radiometer (AVHRR) of the National Oceanic and Atmospheric Administration (NOAA) in the Polar Orbiting Environmental Satellites (POES) family. It was originally used for weather monitoring then employed as the main sensor in the detection of active fires, or “hotspots” on the global scale and with relatively high temporal frequency. Other sensors include those in the Geostationary Operational Environmental Satellite (GOES) such as the Visible Infrared Spin Scan Radiometer Atmospheric Sounder (VAS) [11] and the GOES Imager [10]. In addition to their main functions, the Defense Meteorological Satellite Program Operational Linescan System (DMSP-OLS) [7,12], the Along Track Scanning Radiometer (ATSR) [6], and the Tropical Rainfall Measuring Mission - Visible and Infrared Scanner (TRMM-VIRS) [13] are also utilized in the forest fires monitoring. However, MODIS is the first sensor specifically designed and developed to include capability for forest fires detection [8,14].

This study obtained information from the readily available fire data from the Fire Information for Resources Management System (FIRMS; http://maps.geog.umd.edu/firms) at the University of Maryland. FIRMS is the information distributor of hotspot information obtained from the MODIS Rapid Response (RR; http://rapidfire.sci.gsfc.nasa.gov) system that is located in the Goddard Space Flight Center (GSFC), National Aeronautics and Space Administration (NASA). According to FIRMS, countries currently using this information for their daily forest fire control are the United States of

America (USA), Botswana, Canada, Australia, Mozambique, Namibia, Russia, Ukraine, and Thailand. Utilization of hotspot information through the web map server (http://maps.geog.umd.edu/firms/imsmaps.htm) for forest fire control and management is a common practice in the USA and several other countries. Work validating MODIS hotspots has been conducted, using the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) onboard the Terra satellite, in Southern Africa [15], South America [16] and Northern Eurasia [17], but not in Southeast Asia. Unlike previous works, this validation study is done using the MODIS information from both the Terra and Aqua satellite and does not employ the ASTER, but uses the field surveys instead.

To establish standards for hotspot data usage in Thailand, the Ministry of Natural Resources and Environment (MNRE) approved the use of information only from MODIS, due to its reliable distribution, and the near real time frequency available since 2007. This policy also eliminates confusion arising from the usage of hotspot information from different sources. The FFCD in Thailand began implementing the MODIS hotspot monitoring system in its daily operation in December 2006 (in the beginning of the forest fire season in Thailand) through the collaboration between the FFCD (Thailand) and FIRMS (USA). The accuracy assessment and validation were then needed. This study was therefore initiated immediately to establish standards in the forest fire remote monitoring system in Thailand. The field surveys in this study lasted until May 2009 as shown in Table 2. Since 2007, the delivery time of data from FIRMS to the FFCD has been reduced from once a day to every five hours.

2. Study Sites

Three validation test sites were carefully selected in which to perform an accuracy assessment of MODIS data. This is to establish guidelines for field validation of all other forest fire stations in Thailand. The locations of these three chosen sites are:

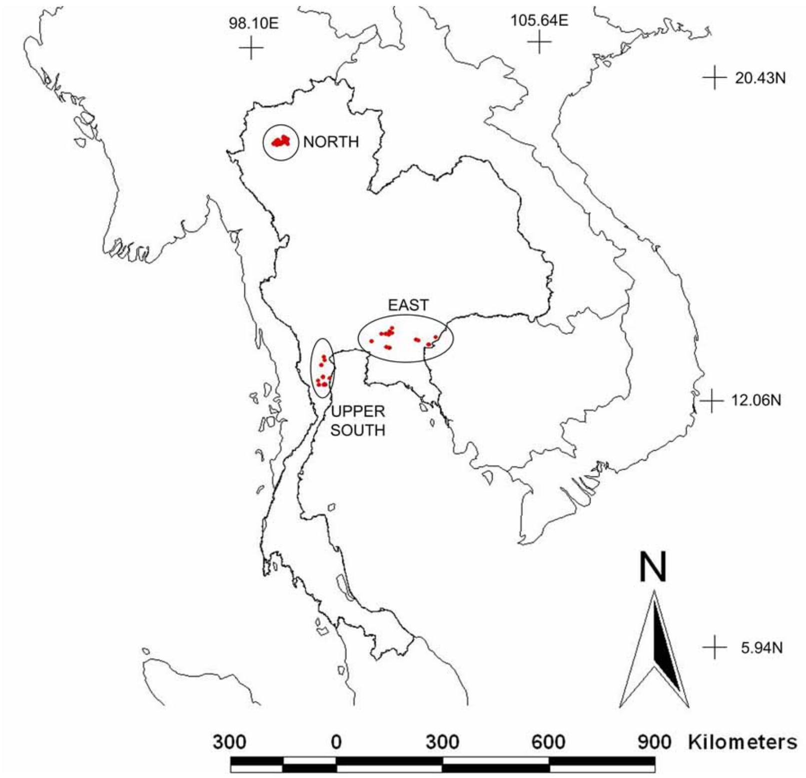
(1) In the North (approximate geographic extension within 18.83N, 98.52E, 18.96N, 98.88E, 18.70N, 98.56E, and 18.76N, 98.95E, in Op Khan and Doi Suthep-Pui National Park, Chieng-mai Province)

(2) In the Upper South (approximate geographic extension within 13.15N, 99.60E, 13.15N, 100.06E, 12.60N, 99.60E, and 12.60N, 100.06E, in Petchaburi Province)

(3) In the East (approximate geographic extension within 14.10N, 100.98E, 14.10N, 102.70E, 13.55N, 100.98E, and 13.53N, 102.70E, in Chacheongsao, Chanthaburi, and Sakkaew Provinces)

These three locations are illustrated in Figure 1. In the North, there are two major forest cover types. The first one is the hill mixed tropical rain forest dominated by Yang-Dang (*Dipterocarpus turbinatus*), Ma-Ka-Momg (*Afzelia xylocarpa*), Pa-Yung (*Dalbergia cochinchinensis*), and Koi-Nam (*Streblus ilicifolius*). The second type is the dry deciduous dipterocarp with Tang (*Shorea obtuse*), Rung (*Shorea siamensis*), Heing (*Dipterocarpus obtusifolius*), and Poorg (*Dipterocarpus tuberculatus*) as dominant species [18]. In the Upper South, the land cover is the mixed deciduous forest consisting of Pra-du (*Pterocarpus macrocarpus*) and Pai (*Bambusoideae*), mainly; and the sugar-cane (*Saccharum officinarum*) orchard. In the East, the majority of the area is the dry deciduous dipterocarp forest rich in Pra-du (*Pterocarpus macrocarpus*; and the arable land to grow Thai jasmine rice (*Oryza sativa Indica*).

Figure 1. Thailand–the three validation test sites of MODIS hotspots in 2007 are circled.



The guidelines obtained from these three test sites will be deployed to the 187 protected areas (with 138 forest fire stations). These protected areas are located within 130 National Parks and 57 Wildlife Sanctuaries in Thailand as shown in Figure 2.

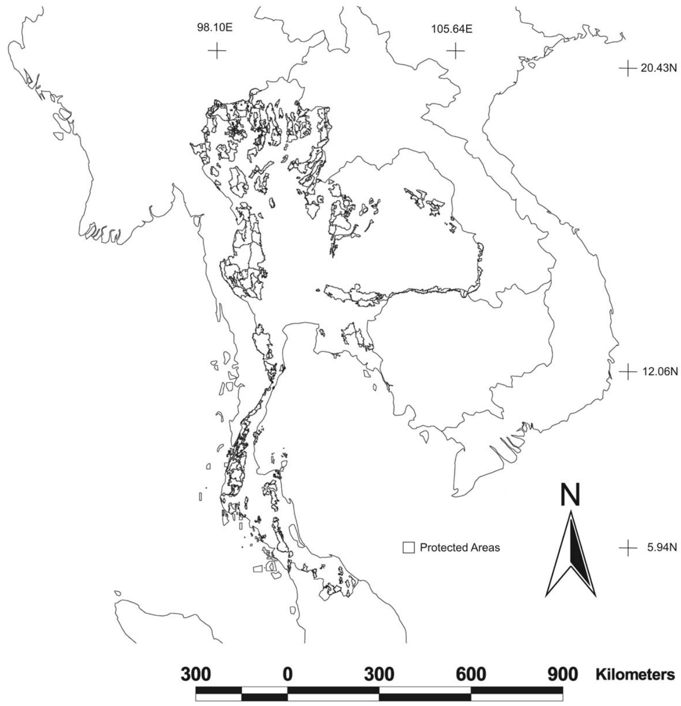
Thailand is under tropical climate influence with two main seasons a year. The dry period is from November to April and the rest of the year is dominated by monsoons, a rainy season. The average precipitation and humidity are summarized in Table 1 [19].

Table 1. Average precipitation and humidity of Thailand and the three validation test sites.

	Average precipitation in dry period* (mm)	**Average precipitation in wet period** (mm)**	**Average humidity in dry period* (%)**	**Average humidity in wet period** (%)**
Thailand	234.3	1,165.1	70.5	80.5
North	116.5	955.2	62	81
Upper South	197.9	661.2	77	78
East	257.8	1,440.2	74	81

* Dry period is between November to April and ** Wet period is between May to October. Source: Royal Thai Meteorological Department, 2009.

Figure 2. 187 protected areas (in 130 national parks and 57 wildlife sanctuaries) in Thailand.



3. Materials and Methods

The first MODIS, onboard the Terra satellite (also known as the EOS AM-1, morning satellite), was launched in December 1999. It has a daytime overpass of Thailand around 10:30 AM and 10:30 PM for nighttime. The second MODIS sensor, launched in May 2002, is onboard the Aqua satellite (also known as the EOS PM-1, afternoon satellite), and has around 1:30 PM daytime overpass of Thailand and 1:30 AM for nighttime.

3.1. Materials

3.1.1. MODIS fire products

There are two types of MODIS fire products: active fires (hotspots; MOD 14) and burned areas (MOD 40) [10,11]. With the active fire data being available from FIRMS and LAADS, the active fire products were then used in this study (Note: LAADS is the NASA Communications (NASCOM)'s Level 1 and Atmosphere Archive and Distribution System; http://ladsweb.nascom.nasa.gov/index.html).

Hotspots are derived from multiple MODIS channels (channels 21, 22, 31 and 32) to detect the thermal anomalies on a per-pixel basis. The fire detection concept is based on an absolute detection of the fire pixels where they have clearly higher temperature than that of the surrounding pixels. In case of the uncertainty, more refined differential comparison with the surrounding pixels is done to confirm the anomaly behavior [10,11]. Hotspots are calculated by the MODIS Rapid Response system and reported by FIRMS with multiple reported fields. These fields include latitude and longitude (center point location), confidence percentage, acquisition date, time of the overpass of the satellite, satellite name (Terra or Aqua), scan and track (actual spatial resolution of the scanned pixel), and brightness temperature (BT) of either channel 21 or 22 (in Kelvin). Note: a confidence percentage is intended to help users gauge the quality of individual hotspots/active fire pixels. This confidence estimate, which ranges between 0% and 100%, is used to assign one of the three fire classes (low-confidence fire, nominal-confidence fire, or high-confidence fire) to all fire pixels within the fire mask; http://maps.geog.umd.edu/firms/faq.htm#confidence.

3.1.2. MODIS Level 1 data

The MODIS information used in this work is a Level 1B (calibrated radiances) product called MOD21KM. It has 1-km resolution. The data source is LAADS. The brightness temperature (BT) values of the 51 MODIS scenes (Terra and Aqua satellites) came from channels 21, 22, 31 and 32. They were calculated using the modified fire C codes with the center wavelength values provided by the MODIS Characteristics Supporting Team (MCST).

3.1.3. Field data from test sites, forest fire validation reports and daily forest fire report

In this study, data were collected in the following order.

(1) Seventy two hotspots out of 35,278 (during March–April, 2007) from the three validation test sites (Figure 1): 43 hotspots in the North, 13 in the Upper South, and 16 in the East. Out of the 72 total hotspots, 43 were within the protected areas (Op Khan and Doi Suthep-Pui National Parks) while 29 were outside, and in the suburban and agricultural zones. Feasible guidelines are to be established from this data collection.

(2) The established guidelines were employed by 138 forest fire stations (for 187 protected areas) around the country. The total of 10,589 hotspots during 2007–2009 was to be validated. However, only 2,223 hotspots were verified and reported back to the FFCD (Table 2).

The other set of data came from the daily forest fire reports (FFR) of 2007, 2008 and 2009 (Table 3). These are daily fire reports where each individual fire was attended by fire fighters.

Table 2. Hotspot validation summary within protected areas by 138 forest fire stations.

Recording period of hotspots	Hotspots	Validated	%Validated	Found	%Found	Not Found	%Not Found
1. Mar 07–Apr 07	2,114	478	22.61	439	91.84	39	8.16
2. Oct 07–Apr 08	4,167	773	18.55	739	95.60	34	4.40
3. Dec 08–May 09	4,308	972	22.56	948	97.53	24	2.47
Total	10,589	2,223	20.99	2,126	95.64	80	4.36

Source: Forest Fire Control Division, National Park, Wildlife, and Plant Conversation Department, 2009.

Table 3. Number of MODIS hotspots (HS) within 187 protected areas (130 National Parks and 57 Wildlife Sanctuaries) from FIRMS and number of fires from daily forest fire reports (FFR), 2007–2009.

Month	HS AM	FFR AM	HS PM	FFR PM
Jan–07	1,672	373	4,055	692
Feb–07	2,628	843	7,949	1,737
Mar–07	3,651	935	14,485	2,166
Apr–07	982	257	1,936	621
Jan–08	1,035	201	2,668	434
Feb–08	1,018	451	2,544	1,146
Mar–08	2,404	808	9,529	1,706
Apr–08	632	166	1,992	553
Jan–09	29	89	105	206
Feb–09	372	648	1,243	1,679
Mar–09	506	592	2,465	1,468
Apr–09	81	91	477	284
Total 07–09	15,010	5,454	49,448	12,692
Total–07	8,933	2,408	28,425	5,216
Total–08	5,089	1,626	16,733	3,839
Total–09	988	1,420	4,290	3,637

Sources: The Fire Information for Resources Management System (FIRMS) at the University of Maryland and Forest Fire Control Division (FFCD).

3.2. Method

The MODIS hotspot data received from FIRMS were plotted on 1:50,000 topographic paper maps to visually check the distribution and accessibility under the Universal Transverse Mercator (UTM) projection of the WGS84 datum. The hotspots were also plotted on the GIS (Geographic Information Systems) and two web map server systems (WMS, Google Earth; http://earth.google.com, and Point Asia; http://www.pointasia.com) to cross check each location. Reachable accessibility is one important criterion in sites selection in this study. Some areas could only be accessed on foot or by helicopter.

Three conditions were employed in our hotspot location selection:

(1) The hotspots selected must be evenly-distributed throughout the study areas.
(2) The locations must contain representative dominated land cover type.
(3) Those selected locations must not be too difficult to access due to time and budget constraints.

The hotspot locations were input into a portable GPS unit (Etrex or Legend, Garmin). The "Goto" navigated function was used to identify each location. At least two investigators per location were teamed up to trace those hotspots using existing routes. After reaching the destination, a circular survey of 500 meters radius was conducted to validate the hotspot. Within the 500 meters radius, if any recently burned areas of at least 50 by 50 square meters were found, the hotspot would be considered an accurate detection, otherwise it would be considered a false alarm. The locations were then recorded in the survey. Photographs (e.g., Figure 3) and notes on characteristics were taken for each location. The locations of false alarms found were further investigated to identify the cause of the false alarm. The study results are presented in the next section.

Figure 3. Field validation pictures.

4. Results and Analyses

4.1. Field Data from Test Sites

From the validation of the test sites, one false alarm (hotspot pixel ID11 in Table 4.) was observed in the North. No burned area for the detected pixel was found on foot. The area cover is a hill mixed tropical forest of pine and dry dipterocarp deciduous. The fire fuel on the ground was about 7 cm in height implies no fire in the area in that forest fire season. However, when expanding the window to 7 by 7 pixels, it is noticed that the pixel ID11 has the highest brightness temperature (BT) and the highest BT differential of that particular scene. It is due to the latent heat of the burned and ashes covered area of pixels ID8 and ID9 nearby being released faster on the day of the fire leading to a relatively higher temperature for ID11. The false alarm found in the North is 1 of 43 hotspots (or 2.33%), with the detection accuracy of 97.67%.

In the Upper South, two false alarms were identified with one common characteristic. Both have the highest BT and the largest BT differential compared to surrounding pixels from the 7 by 7 window expansion. When examined the first of the two false alarm pixels on foot, it was noted that the dominant land cover was a flat rice field with rice having grown for the past 90 days. And the MODIS data for this false alarm pixel were collected 52 days before the ground investigation. This proves there had not been fire around the day of the detection. However, there was a crematorium site in the same pixel which was presumably the source of the heat signal that could lead to the false alarm. For the second one, it was found in the middle of a mangoes field. Again, from the ground assessment (with 7 by 7 window expansion), no burning evidence was observed at this location. In addition, debris burning is not a common practice in a mangoes field. Yet, we have not found an explanation for this false positive. Both false alarms are two out of 13 hotspots validated at this site (15.38 %). This translates to 84.64 % MODIS detection accuracy for these agricultural and suburban areas.

Table 4. Examples of hotspots brightness temperatures in the North.

ID	OBJECTID	LATITUDE	LONGITUDE	BT	ACQDATE	Local Time	SATELLITE	BT 21	BT 31	Diff BT21-31
1	6214434	18.7620	98.8960	326.80	2007-03-01	1320	A	324.46	305.28	19.18
2	6320543	18.7890	98.7620	312.10	2007-03-02	1100	T	309.61	301.47	8.14
3	6540048	18.8000	98.8050	314.50	2007-03-04	1045	T	311.18	303.03	8.15
4	6819666	18.9060	98.8390	311.40	2007-03-06	1340	A	310.99	295.96	15.02
5	7107491	18.8060	98.7870	314.70	2007-03-08	1330	A	313.54	302.76	10.78
6	7107544	18.8800	98.8120	316.90	2007-03-08	1330	A	314.00	304.00	10.00
7	7249268	18.7560	98.5630	314.40	2007-03-11	1050	T	311.97	301.44	10.53
8	7453910	18.7900	98.8870	313.60	2007-03-13	1345	A	308.87	301.52	7.35
9	7453919	18.7610	98.5660	316.80	2007-03-13	1345	A	311.72	300.92	10.80
10	7448920	18.8350	98.6070	311.60	2007-03-13	1040	T	309.35	299.95	9.40
11	7462887	18.7950	98.8940	308.80	2007-03-13	200	A	303.54	295.33	8.21
12	7572197	18.8590	98.8460	316.50	2007-03-14	1125	T	308.80	303.05	5.75
13	7572221	18.7660	98.5740	315.60	2007-03-14	1125	T	309.28	301.25	8.03
14	7753458	18.7820	98.6320	317.20	2007-03-15	1335	A	308.99	304.51	4.47
15	7753487	18.8000	98.6170	320.80	2007-03-15	1335	A	312.33	303.45	8.88
			AVG	315.45				311.24	301.60	9.65
			MAX	326.80				324.46	305.28	19.18
			MIN	308.80				303.54	295.33	4.47

Note: 'BT' is brightness temperature in Kelvin, 'Acqdate' is acquisition date, 'BT 21' is brightness temperature of channel 21 in Kelvin, 'BT 31' is brightness temperature of channel 31 in Kelvin, and 'Diff BT21-31' is difference between channel 21 and channel 31 in Kelvin.

Two false alarms were identified in the East. Both have high BT and similar BT differential values. The field investigation of the first one led us to an iron ore rock covered flat land and a metal recycling yard, surrounding by rice fields. These metals could be responsible for the high temperature in that particular scene, leading to the first of the two false alarms. The second of these two was located in the middle of a dry dipterocarp deciduous plantation with a nearby big water pond. The field assessment team found no evidence of any burning in this area for many years. The reflection from the water pond could be the reason for the false temperature differential between the pond and the surrounding areas leading to this false alarm. These two false alarms validated were out of 16 (12.50%). The detection accuracy in this agricultural and suburban area is 87.50%. All three test site validations were done in the 2007 forest fire season. The site by site and total accuracy summary is reported in Table 5.

Table 5. Test site validation summary.

Test Site	Hotspots	False Alarms	Accuracy (%)
North	43	1	97.67
Upper South	13	2	84.64
East	16	2	87.50
Total	72	5	92.06

4.2. Forest Fire Validation Reports

The three test site validations reported in Section 4.1 have led to the establishment of the hotspot validation guidelines for the national forest fire system in Thailand. These guidelines were utilized by the 138 forest fire stations around the country to further assess the MODIS hotspot accuracy. The employment of these guidelines started in late May 2007. The continued validation was performed in the 187 protected areas of Thailand. Results are presented in Table 2.

In addition, the burned area size has also been recorded with a minimum dimension of 1 rai (1,600 square meters or 0.4 acre) and the maximum of 1,200 rais (1.92×10^6 square meters or 480 acres). These official field validation reports are supportive evidence in the accuracy assessment of MODIS in its utilization for remote sensing of forest fires. High level of confidence is now gained in the utilization of the MODIS hotspot in our daily forest fires control and operation in Thailand.

4.3 Daily Forest Fire Reports

Though Table 3 shows the same trend (both AM and PM) of the forest fires detected by the traditional forest fire patrols and by the satellite remote sensing observation, the numbers recorded are different. The larger difference is seen in the El Niño year, while the smaller in the La Niña one. There are 3.71 and 3.13 times more AM hotspots detected than those recorded in the daily forest fire reports, in 2007 and 2008. However, in 2009, the number of AM hotspots is 0.69 time less. On the contrary, there are 5.47, 4.36 and 1.18 times more PM hotspots in 2007, 2008 and 2009. In the sum of 3 years, it is observed that there are 2.7 times higher AM hotspots and 3.89 times more PM hotspots than those in the daily forest fire reports. This finding is one of the leading reasons why it is imperative to have the satellite remote sensing observation as part of the daily forest fire control management.

5. Discussions and Conclusion

The three MODIS test site validations in 2007 concluded with 93.06% accuracy in the forest fire detection. In addition, 95.64% confidence was reported from the 2007–2008–2009 further operational assessment throughout Thailand.

From the three year evaluation, false alarms (<5%) were found in the geographical characteristics like garbage dump sites, houses with aluminum roof-tops, water bodies, rocky fields, tidal areas, savannas, unpaved roads, flat fields, bare lands, and encroached areas.

MODIS would be an advanced and complimentary tool to the existing forest fires control and management in Thailand for 3 reasons: (1) larger area coverage, (2) high accuracy, and (3) faster response to remote areas. The last one is particularly true especially with the frequency of the data received from FIRMS improved to every one hour. At present, the overhead revisiting time of the Terra and Aqua satellites (where MODIS resides) over Thailand is every one or two days. This presents an under-coverage limitation of the near real time monitoring system for Thailand (and anywhere). Additional satellites in the Earth Observing System with similar or better than MODIS capabilities onboard are needed to provide more complete information for more efficient forest fire control and management. This important validation campaign will continue towards the goal of increasing the even higher level of confidence in the MODIS hotspot utilization.

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