An improved inventory of emissions from biomass open burning in Thailand

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Abstract: *Thailand experiences critical haze pollution from biomass open burning, including forest fires and agricultural burning, especially in the northern part of the country during the dry season running from December to March annually. The application of satellite data for fire-related studies during the past decade in ASEAN helped to improve our understanding of the importance of wildland fires in the region, in terms of location, type of vegetation fires, and associated emission releases. However, high uncertainties persist mainly due to lack of spatially-explicit fuel loads and unreliable burned area estimates both in forestland and cropland subject to burning. In this study, we developed a methodology to improve the determination of burned areas using MODIS-MCD45A1 burned area product by random ground truthing. Investigated vegetation covers tropical deciduous forest, rice paddy, and sugarcane and maize plantations. Fuel loads and combustion completeness factors were collected and reviewed from country-specific literature. The pollutants of interest include carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), nitrous oxide (N_2O), fine particulate matter ($PM_{2.5}$), and black carbon (BC). The obtained results showed that all the ground-truthed burned areas were smaller than those defined using MCD45A1, indicating that adjustment factors specific to each type of land cover should be determined in order to improve the estimation of emissions from biomass burning in Thailand using this satellite information. In addition, it was found that significant adjustments are required for forest burned areas and croplands located in the mountains or terrain with significant slope (>15%). Contributions and trends of forest fires and agricultural burnings in Thailand during 2009-2011were reviewed and assessed using the obtained burned area adjustment factors. A comparison with the global data set, GFEDv3.1, showed that the use of satellite data based only on hotspots detection may lead to a large over-estimation of emissions from biomass open burning.*

Keywords: *Forest fire; agricultural burning; Thailand; MODIS-MCD45A1.*

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1. Introduction

In Thailand, biomass open burning mainly includes forest fires and agricultural burning of paddy fields, and sugarcane and corn plantations. Biomass open burnings generally occur during the dry season running from late December to April, leading to trans-boundary haze pollution, especially in the north of the country. The high variability of open burning process due to effects of terrain, vegetation types, environmental conditions, etc., contributes to a high uncertainty of the emission estimation. Regarding the area burned, the data collection generally rely on satellite information in order to get the overview of the whole country. As for the global scale, the most used satellite information for quantification of biomass open burning activity in Thailand resulted from the MODerate resolution Imaging Spectroradiometer (MODIS) sensor. Active Fire Hot Spots (FHS) with 1km x 1km resolution data have been used until present to estimate the extension of the biomass open burning activity. The comparison of these data with ground measurements showed a highly overestimation of the burned area.

In this study, we investigated the use of MODIS-MCD45A1 Product with 0.5km x 0.5km resolution to estimate burned areas in forestland and cropland, as classified in the land-use map of Thailand by the Land Development Department, Ministry of Agriculture and Cooperatives, Thailand. The results were then compared with ground observations (i.e. ground-truthing method), to document how the MODIS-MCD45A1 may contribute to improve the inventory of air pollutant emissions from biomass open burning in Thailand.

2. Material and methods

The estimation of emissions from biomass open burning can be effectuated following the Equation developed by Seiler and Crutzen (1980).

$$E_i = A \times B \times F \times CE \times EF_i$$

where, E_i =emissions of pollutant *i*, A = area burned, B = biomass load of the area burned, F = fraction of the biomass load being burned, CE = combustion efficiency, and EF_i = emission factor of pollutant *i* . In this study, A was first estimated from MODIS MCD45A1 product then readjusted by correction factors determined from ground-truthing.

3. Results and Discussion

Table 1 shows the estimation of burned area using MODIS-MCD45A1 product data classified by land-use type for the years 2009, 2010 and 2011. It was found that the total burned area amounted 332,700 ha, 410,600 ha, and 144,400 ha, respectively. In addition, more than 80% of the fires occurred in deciduous forest and cropland including rice paddy, and sugarcane and corn plantations. The analysis of monthly distribution of MODIS-MCD45A1 product indicated that the peak period of biomass open burning activity for these 3 years ran from January to March.

Table 1. The annual burned area derived from MODIS burned area product (MODIS-MCD45A1) in Thailand during 2009-2011[1].

Vegetation type		**Burned area (ha)**		
		2009	**2010**	**2011**
Forest	Evergreen forest	18,300	49,000	5,800
	Deciduous forest	129,800	190,200	49,000
	Other forest	39,100	24,900	14,200
	Total	187,200	264,200	69,000
Agriculture	Rice paddy	92,600	83,200	57,300
	Corn	13,300	21,700	4,200
	Sugarcane	7,800	4,800	3,000
	Other agriculture	31,800	36,600	10,800
	Total	145,500	146,400	75,400
All Total		**332,700**	**410,600**	**144,400**

[1]The analysis of MODIS-MCD45A1 data indicated that there was no fire during Jun-Sep 2009, May-Sep 2010 and May-Nov 2011.

The comparison between MCD45A1 data and their associated ground observations are reported in Fig. 1. The results showed that all the ground-truthed burned areas were smaller than those defined using MCD45A1, indicating that an adjustment factor is required for each type of land cover to improve the accuracy of burned area detected by remote sensing. In this study, the adjustment factors found for burned areas detected in paddy fields and sugarcane plantations were 0.87 and 0.77, respectively. In case of burned areas in corn plantations and forestland, large difference between MCD45A1 and associated ground-thruthed data was observed for burned areas in terrains with high slope. Indeed, the adjustment factor for burned areas detected in corn fields with a slope lower than 5% and in the range of 5-10% was 0.53 and 0.66, respectively. In case of forestland, the adjustment factor for burned areas in the terrains with slope lower than 15%, and those with slope higher than 15% was 0.53 and 0.64, respectively. This finding indicates that the higher is the slope the more significant adjustment factor is required.

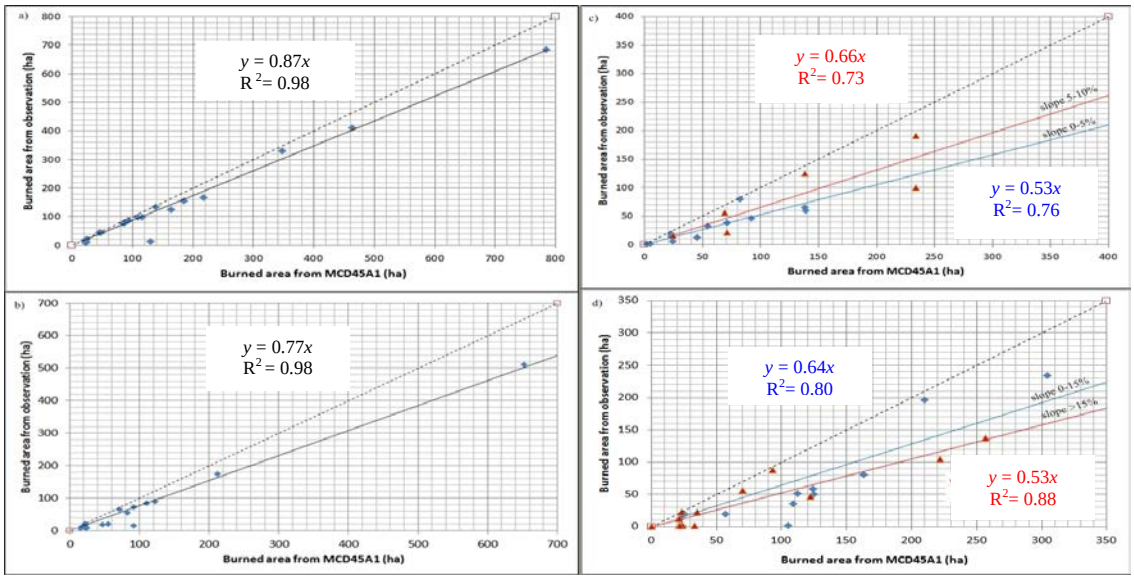

Fig. 1 Plotting of ground measurements vs. associated MODIS-MCD45A1 burned area : (a) paddy fields, (b) sugarcane plantations, (c) corn plantations - (◆) for terrain with slopes ≤ 5%; (▲) for terrain with slopes the slope ranging from 5 to 10%, and (d) forest land - (◆) for terrain with slopes ≤ 15% and (▲) > 15%.

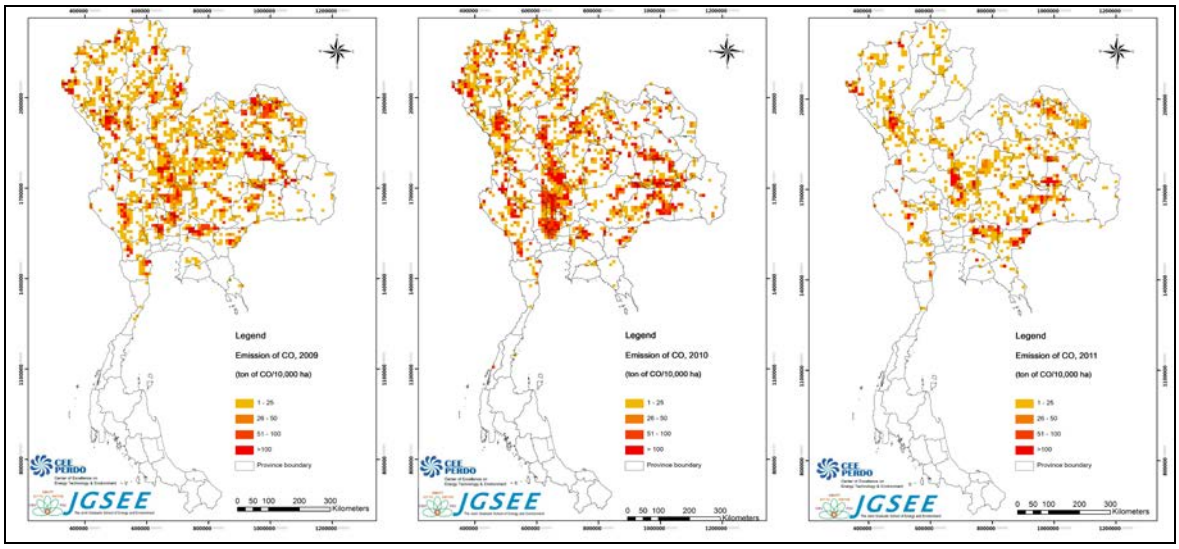

Fig. 2 Spatial distribution of CO gridded emissions estimated from open biomass burning for (a) 2009, (b) 2010, and (c) 2011, in Thailand (Grided /tons per 10,000 ha) using MODIS-MCD45A1 product.

Maps of gridded emissions of CO from biomass open burning in Thailand for three consecutive years, i.e. 2009 to 2011, compiled from MODIS-MCD45A1 burned areas and corrected with the adjustment factors determined in Fig. 1, are displayed in Fig. 2. Their comparison shows that the year 2010 possessed the highest emissions followed by 2009 and 2011. For these three years, the major zones of emissions were located in the northern, lower-northern, and northeastern regions of the country.

Table 2. Comparison of the total emission from open biomass burning in Thailand in 2010 estimated from GFEDv3.1 vs. This study.

Pollutant	Total emissions from biomass open burning in 2010 (tons)					
	GFEDv3.1		This study		Ratio[a]	Ratio[b]
	Forest	Agricultural	Forest	Agricultural	(times)	(times)
CO_2	38,301,000	6,732,000	730,671	330,968	52	20
CO	2,331,000	438,000	48,095	33,086	48	13
CH_4	140,790	40,470	3,145	715	45	57
N_2O	1,500	144	92	19	16	18
$PM_{2.5}$	213,030	38,340	4,208	1,032	51	37
BC	10,023	1,690	319	325	31	5

[a]Ratio is the ratio between forest burning emissions estimated from GFEDv3.1 and This study, [b]Ratio is the ratio between agricultural burning emissions estimated from GFEDv3.1 and This study.

From Table 2, it was found that that our estimation of emissions from forest fires in Thailand are lower than the estimates from GFEDv3.1 by a factor ranging from 16 to 52 with an average of about 40 depending on the pollutant. For agricultural burnings emissions, our results are still lower but the difference with GFEDv3.1 is more reduced, i.e. by a factor from 18 to 57 with an average of 25, although the variability depending on the pollutant is higher.

4. Conclusion

MODIS-MCD45A1 product can be used to support the inventory of emissions from biomass open burning in Thailand. The comparison with ground observations showed that the accuracy of burned area detection using MODIS-MCD45A1 can be improved through the determination of adjustment factor specific to each type of land-use/land-cover. In this study, it was found that for burned areas in paddy fields and sugarcane plantations, the adjustment factor was 0.87 and 0.77, respectively. For burned areas located in corn plantation and forestland, it ranged between 0.53 and 0.66, and 0.53 and 0.64, respectively, depending on the terrain slopes. The obtained results showed that the higher is the slope the smaller is the adjustment factor. The result found in this study confirms that the use of global inventory of emissions from biomass open burning may lead to a significant overestimation for the case of Thailand.

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