International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:5, No:10, 2011

Estimation of Forest Fire Emission in Thailand by Using Remote Sensing Information

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***Abstract*— The forest fires in Thailand are annual occurrence which is the cause of air pollutions. This study intended to estimate the emission from forest fire during 2005-2009 using MODerate-resolution Imaging Spectro-radiometer (MODIS) sensor aboard the Terra and Aqua satellites, experimental data, and statistical data. The forest fire emission is estimated using equation established by Seiler and Crutzen in 1982. The spatial and temporal variation of forest fire emission is analyzed and displayed in the form of grid density map. From the satellite data analysis suggested between 2005 and 2009, the number of fire hotspots occurred 86,877 fire hotspots with a significant highest (more than 80% of fire hotspots) in the deciduous forest. The peak period of the forest fire is in January to May. The estimation on the emissions from forest fires during 2005 to 2009 indicated that the amount of CO, CO_2, CH_4, and N_2O was about 3,133,845 tons, 47,610.337 tons, 204,905 tons, and 6,027 tons, respectively, or about 6,171,264 tons of CO_2eq. They also emitted 256,132 tons of PM_{10}. The year 2007 was found to be the year when the emissions were the largest. Annually, March is the period that has the maximum amount of forest fire emissions. The areas with high density of forest fire emission were the forests situated in the northern, the western, and the upper northeastern parts of the country.

***Keywords*—**Emissions, Forest fire, Remote sensing information.

I. Introduction

THAILAND is facing problems of air pollution from forest fire continuously especially during the dry season. Most of forest fires are human-related in order to clear lands for cultivation, to haunt, to collect wild products, etc., i.e. all activities enabling local people to get or to increase their income. Based on the air quality monitoring report from the air pollution control station which report the air quality annually; the concentration of the air emission during forest fire season is higher than usual especially in March which is the peak period of forest fire occurrence. The air pollutant measurement is higher than the air quality standard continuously for example the highest of concentration of particulate matter at Chiengmai (Northern part of Thailand) in March of 2007 to 2009 was about 250.9 $\mu g/m^3$, 171.3 $\mu g/m^3$, and 205.2 $\mu g/m^3$ respectively [1]. These cause of local people respiratory health, and transportation visibility.

In addition to its direct effect to local people through air pollution, forest fire emissions may also contribute to global warming. Actually, the burning of biomass emits greenhouse gases including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These gases have strong global warming potential, and would lead to climate change in the long term. The estimation of global annual biomass open burning emission found that the average of CO_2, CO, and CH_4 during 1997 to 2004 was about 7,423 Tg/year, 337 Tg/year, and 15 Tg/year respectively. The average global annual burned area based on MODIS Burnt Area Product was about 3.437×10^6 km^2/year. The average of carbon from the ASIAN was about 159 Tg C/year emitted from 0.134×10^6 km^2/year of area burned [2]. Global Burned Area 2000 used SPOT VEGETATION data to estimate the annual burned area in Thailand. The annual burned area in 2000 was about 197,235 ha included 92,935 ha of woodlands and shrub lands burning and 104,300 ha of grasslands and croplands burning [3].

For Thailand, Pollution control Department has set a national master for open burning control since 2007 in order to reduce the forest fire area 48,000 ha per year [4]. To achieve the goal of master plan, the forest fire control officer must to understand on the spatial and temporal distribution of forest fire and the actual forest fire area occurred annually. This study will use satellite information to assess the spatial and temporal distribution of forest fire and forest fire emissions.

This information will help the forest fire control officer set an efficient plan for reducing the occurrence of forest fire in the future as well. The emissions estimation associated to the actual situation would support the governmental officer realizing the critical issue of forest fires, and so the elaboration of an action plan for forest fire management.

II. Materials and Methods

A. Forest Fire Emission Estimation

Seiler and Crutzen, 1980 has developed an equation to estimate emissions from biomass combustion [5]. The equation mentioned the release of emissions can be calculated by multiplying the mass of biomass combusted with mass of emission emitted per biomass combusted (as known the emission factor). Equation provides as follows:

$$E_j = \sum_i \left(M_i \times EF_{ij}\right) \times 10^{-3} \quad (1)$$

Where: E_j is the emission from biomass combustion of trace gas (j) with CO_2, CO, CH_4, N_2O, and particulate matter (tons).

M_i is the mass of biomass combusted of vegetation (i) (tons dry matter). Forest fire in Thailand was surface fire. Most of biomass burned was surface biomass as dead leaf, twig, grass, and undergrowth.

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EF_{ij} is emission factor of trace gas (*j*) or constant of emission emitted (*j*) per mass of biomass combusted (g/kg dry matter).

i is the vegetation types such as savanna and grassland, tropical forest, and agriculture residual etc.

Due to biomass burning is open burned, the mass of biomass combusted estimation related on 3 factors:

1) The area burned as forest fire area, area burned of agriculture burning, area of savanna burning, etc.
2) The mass of biomass burned in unit area, type of biomass burned is very important for calculation. There should be choose the type of biomass suits for the type of fire for example in case of agricultural burning, the mass of biomass combusted is the residual left after harvesting; in case of forest fire, the mass of biomass combusted is the above ground biomass per area (in crown fire forest) or surface fuel per area (in surface fire).
3) We found that biomass is not completely burned. After burning, some of biomass is not burned. So, it needs to assess the ratio between mass of biomass combusted and mass of total biomass as known combustion efficiency for adjustment mass of actual burned biomass.

So, mass of biomass combusted can estimate using (2).

$$M_i = A_i \times BD_i \times C_i \quad (2)$$

Where: A_i is area of biomass burned or area burned (ha).

BD_i is mass of biomass burned per area or biomass density (tons/ha).

C_i is combustion efficiency (dimensionless).

B. Area Burned Estimation

This study uses MODIS Active Fire Product (MOD14) Production Code, version 4.3.2, developed by NASA. The active fire data covering the forest fire during 2005-2006 came from MODIS Rapid Response Project, NASA/GSFC Produce, University of Maryland, Information for Resource Management System Distributor. The data is available on-line http:/maps.geog.umd.edu. And during 2007-2010 came from Geoinformatics Center an operational satellite base on the global environmental change monitoring and management/prevention of disasters of different types in the Southeast Asian region. The data is available on-line http://www.geoinfo.ait.ac.th/mod14/.

These fire hotspots (FHS) were available at local times of 10.30 h and 22.30 h (±1 h) from MODIS on Terra and 13.30 h and 01.30 h (±1 h) from MODIS on Aqua. Local times of satellite overpasses vary by ±1 h due to orbits changing during the 16 day orbital repeat cycle. Data processed from MODIS came from receiving station located in Bangkok, Asia institute of technology.

The MODIS algorithm (MOD14) was developed by NASA for the global detection of fires and suitable for day time detection [6]-[8]. The algorithm uses brightness temperatures derived from the MODIS 4 μm and 11 μm bands. The fire detection strategy is based on absolute detection of the fire, if the fire is radiating at a brightness temperature greater than 360 K during the day and 320 K at night. Moreover, this algorithm is able to classify the hot or bright surface and the smaller fire by checking with the temperature of surrounding pixel that reducing the error of the fire detection at daytime [7].

The type of FHS was classified by using Geographic Information System (GIS) program. The type of fire included agricultural fire, forest fire, and other fire. The FHS was categorized by overlay between the FHS data and land use map in 2007 which was developed by Land Development Department [9]. The resolution 1 km × 1 km of pixel was used as a representative of one spot of area burned. The combustion efficiency of area burned in pixel, which is a measure of how efficiently a device consumes fuel, was about 0.9 [10]. Finally, the result of spatial and temporal variation of forest fire area and emissions were presented in the grid map (size of grid 10 km ×10 km) which covered the period of 2005 to 2009.

C. Biomass Density Estimation

These data were received by taken part within many Forest Fire Control Division National Park Organizations in Chiengmai. The fuel load estimation only used the surface fuel because the occurrence of forest fire in Thailand is surface fire which specifically combusted fuel on surface area of forest [11]. The surface fuel load in the deciduous forest was collected during January to May in 2009 which has the highest frequency of forest fire in Thailand [12]. There are 2 types of surface fuel, classified by size; fine fuel and coarse fuel. Fine fuel included dead leaf and grass. Course fuel included twig and undergrowth [11]. The experimental size is 1 m × 1 m, 40 sample plots. The data shows the density of surface fuel classified by fuel component. The amount of fuel load available for combustion in Thailand is estimated from the production between fuel density and forest area in Thailand.

D. Combustion Efficiency Estimation

This study has cooperated with the Forest Fire Control Division National Park in Chiengmai. This study simulates real fire in the forest to assess the fraction of fuel that consumed by fire, using (3)

$$C = \frac{M_{BB} - M_{AB}}{M_{BB}} \quad (3)$$

Where: C is combustion factor of surface fuel.

M_{BB} is mass of dried surface fuel before burning (g/m^2).

M_{AB} is mass of dried surface fuel left after burning (g/m^2).

For experiment, this study sets an experiment line in the forest area, as shown in Fig. 1. There are 8 lines. Each line has 30 m length and 45 degree between lines equally. The experiment is plotted in 4 area slopes as 0-14%, 15-24%, 25-35%, and >35% by testing in the deciduous forest. The experiment is done every month between January and May in 2009. So, the overall sample is about 40 sample plots.

After set the sample plot, the 8 random plots, plot size 1 m × 1 m, around the experimental area is collected and weighted. The component of surface fuel is dead leaf, grass, twig, and undergrowth. The result is shown in term of dry matter of fuel load per area classified by size of fuel; fine fuel (dead leaf and grass) and coarse fuel (twig and undergrowth).

Further experiment, start to fire at the center of the circle line and records the distance of fire in each line for every 2 minutes until once of line is burned to 30 m and stops the experiment. In this trail, data collections include: surface fuel weight after burning, combustion time, and burned area.

After burning process, the mass of unburned fuel in 8 plots, 1 m × 1 m is measured, then estimate the combustion factor from the relationship between before and after burned of surface fuel as shown in (3).

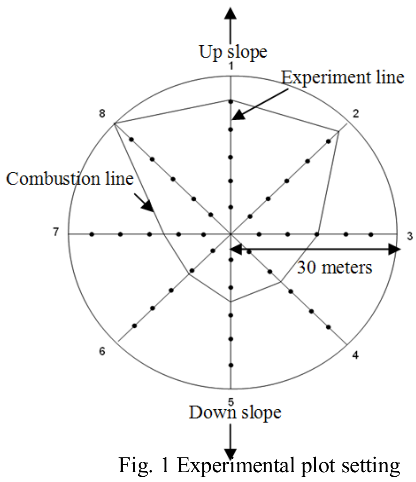

Fig. 1 Experimental plot setting

E. Emission Factor

This study uses emission factor for tropical forest that reported by Andrea and Merlet (2001) in 2006 IPCC Guidelines for National Greenhouse Gas Inventories [13]. The emission factor of tropical forest used in this study is shown in Table. 1.

TABLE I
EMISSION FACTOR OF TROPICAL FOREST

Forest type	Emission factor of tropical forest (g/kg dry matter burned)				
	CO_2	CO	CH_4	N_2O	PM_{10}
Tropical forest	1,580	104	6.8	0.2	11.4
	± 90	± 20	± 2.0	-	± 4.6

III. RESULTS AND DISCUSSIONS

A. Area Burned Assessment

The analytical of the active fire product from MODIS found during 2005 to 2009, the overall number of fire hotspots on the forest land and grass land was about 86,877 fire hotspots. The highest of number of fire hotspots was in 2007 which was about 22,924 fire hotspots. The next was in 2006 which was about 16,909 fire hotspots. The lowest of number of fire hot spots was in 2008 which was only about 14,621 fire hotspots.

The interpretation of fire hotspot on forest land into forest fire area was done by production between active fire and pixel resolution (1 km x 1 km). The interpretation found during 2005 to 2009 the overall of forest fire area was about 8,687,700 ha. The largest forest fire was in 2007 which was about 2,292,400 ha or 13.32% of forest area and 4.46 percent of whole country. The next was in 2006 which was about 1690,900 ha or 9.83% of forest area and 3.29% of whole country. The smallest of forest fire was in 2008 which was about 1,462,100 ha or 8.50% of forest fire and 2.85% of whole country. The information of fire hotspots and area burned is shown in Table. 2.

TABLE II
NUMBER OF FIRE HOTSPOTS AND AREA BURNED DURING 2005 TO 2009

Year	Number of fire hotspots (FHS)	Area burned (ha)	Percent of forest area	Percent of whole country
2005	16,657	1,665,700	9.68	3.24
2006	16,909	1,690,900	9.83	3.29
2007	22,924	2,292,400	13.32	4.46
2008	14,621	1,462,100	8.50	2.85
2009	15,766	1,576,600	9.16	3.07
Total	86,877	8,687,700	50.50	16.91

Fig. 2 shows monthly distribution of fire hotspots in Thailand during 2005 to 2009. Take into consideration on the monthly temporal distribution of the occurrence of active fire found the forest fire has been occurred since December, and then it has been increasing until February. During these 3 months, it is in the winter season. The perennial tree sheds their leaves on the floor, so the accumulation of surface fuel. In the middle of forest fire season which is in March annually found it is the period that has the maximum of MODIS detection. These results associate to the report of forest fire control station that reports the peaks of forest fire occurred and the most violent of forest fire is in March. At that time, fire is burning for a long time that covering the orbit time of satellite (Orbit time is about 3 hr at day time and 6 hr at night time; Terra10.45 ± 1.00 hr and 22.30 ± 1.00 hr, Aqua 13.30 ± 1.00 hr and 1.30 ± 1.00 hr). So, the fire is detected by the one satellite and also detected by the next satellite as well but in the different position.

In 2007, it was the El Nino year so the average temperature in the upper northern, the lower northern, the western, the upper eastern were higher than the average temperature in the normal year about 2-3 degree Celsius [14]. The average rainfall in the northern, the western and the upper northeastern is lower than normal especially during the forest fire season (rainfall is about 18.44 mm) [14]. So, at this year, the forest fire is more violent than usual and more active fire detected by MODIS especially in March. In March, 2007 the number of fire hotspots was about 2 times of the usual year comparing at the same month.

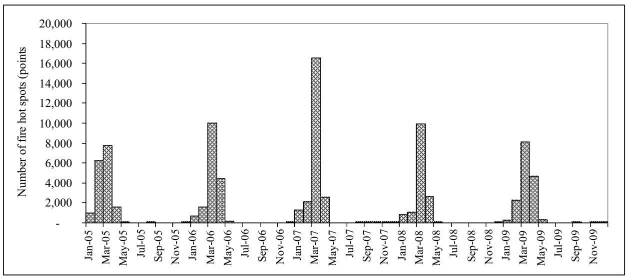

Fig. 2 Monthly distribution of fire hotspots during 2005 to 2009

Take into consideration on the spatial distribution of fire hotspots occurred in 2005 (as shown in Fig. 3) found a lot of the active fires was detected in the national park (fire hotspots density more than 30 fire hotspots per grid) that situated in the upper northern, the western border with Myanmar and Huai Kha Khaeng Wildlife Sanctuaries which situated in the lower northern and the western side of the upper northeastern. There was the deciduous forest, mainly at the inner of the forest, high area slope topography so there was difficult to access for controlling forest fire. Most of forest fire was burning freely and continuously all day all night, there was becoming a large fire so there was detected by satellite at day time and night time as well.

At the outskirt of the forest connects to the agricultural land and settlement land which mainly was deciduous forest. Deciduous forest was distributed around the national park that mainly in the upper northern, the western, the upper north eastern, and the eastern side of the northeastern (connected to Lao). At this area, there was the second of the fire hotspots density (about 11-30 fire hotspots per grid). This area had the lower fire hotspots density because it was accessible area and had the natural fire line as road, river, crop area, settlement area. Most of the forest fire in this area was small fire; it was quite difficult for satellite detection. The low fire density (1-10 fire hotspots per grid) was detected in the evergreen forest in the central and the southern because of this area has high moisture content fuel, and also near the national park as Khao Yai national park. The main cause of the fire in this area was occurred from officer that wants to decrease the cumulated fuel.

In 2006 (as shown in Fig. 4) was similar to the fire in 2005 because of the similarity of the weather (rainfall and temperature) in the forest fire season and the similarity of the fire behavior (violence of fire and forest fire area). The more active fire was detected in 2007 (as shown in Fig. 5). There had the high fire hotspots density (more than 30 fire hotspots per grid). The high density grid distributed in the inner of forest which was the dry evergreen forest through the outskirt of forest which was the deciduous forest. The mainly found in Mae Hong Son, Chiangmai, Tak, and Nan. For the forest fire in Huai Kha Khaeng Wildlife Sanctuaries, there was similar to 2005 and 2006 because of the good monitoring and the raining during forest fire season. The fire hotspots density in 2008 and 2009 were lower than 2007 (as shown in Fig. 6 and Fig. 7). The density of fire hotspots grid was similar to 2005 and 2006. The main of fire hotspots occurred was still in the northern and the western in Tak, Mae Hong Son, Payao, and Chiangrai.

B. Biomass Density Assessment

The assessment on the amount of biomass in deciduous forest during forest fire period in 2009 (as shown in Table. 3) found the average of overall biomass is about 3.76 ± 0.26 tons/ha. The amount of biomass is in the range of 2.72 ± 0.07 - 4.63 ± 0.28 tons/ha. The largest amount of biomass is in March which is about 4.63 ± 0.28 tons/ha. Take into consideration on the trend of biomass found January which is the beginning of forest fire season has the minimum of biomass. The amount of biomass has increased since January and will be decreased in the end of forest fire season (May).

Take into account on the component of biomass found the maximum of the biomass is dead leaf which has the average value about 2.11 ± 0.20 tons/ha. The amount of dead leaf is in the range of 1.35 ± 0.15 – 2.79 ± 0.15 tons/ha or about 45% - 68% of overall biomass. The main of biomass is dead leaf because of the forest fire season has dry weather. Most of tree shed their leaves in the dry season especially during February to April which associates to the middle of the forest fire season.

The second component of biomass is twig which has the average value about 0.97 ± 0.12 tons/ha. The amount of twig is in the range of 0.75 ± 0.08 – 1.32 ± 0.10 tons/ha or about 18% - 29% of overall biomass. Take into consideration on the trend of twig found it has increased since the middle of forest fire season and be constant in the end of forest fire season.

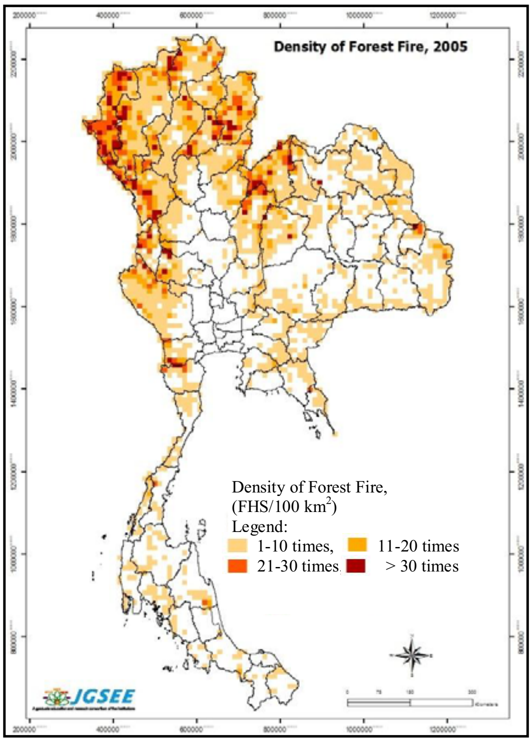

Fig. 3 Annually spatial distribution of forest fire hotspots in 2005

ISSN: 2517-942X
Vol:5, No:10, 2011

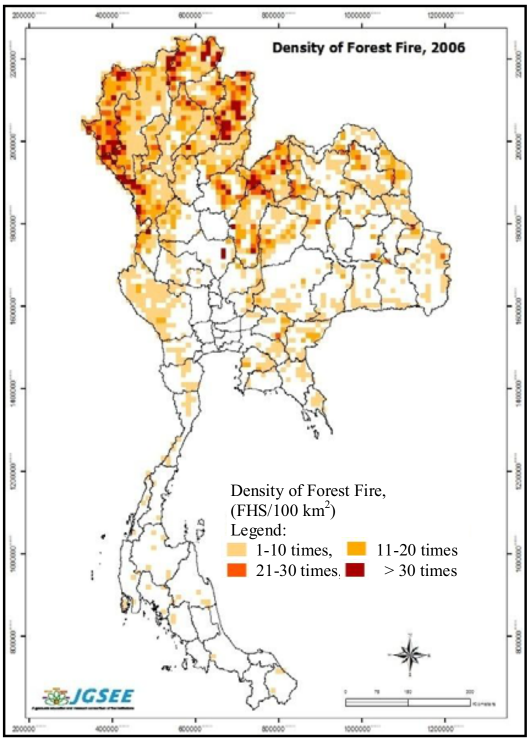

Fig. 4 Annually spatial distribution of forest fire hotspots in 2006

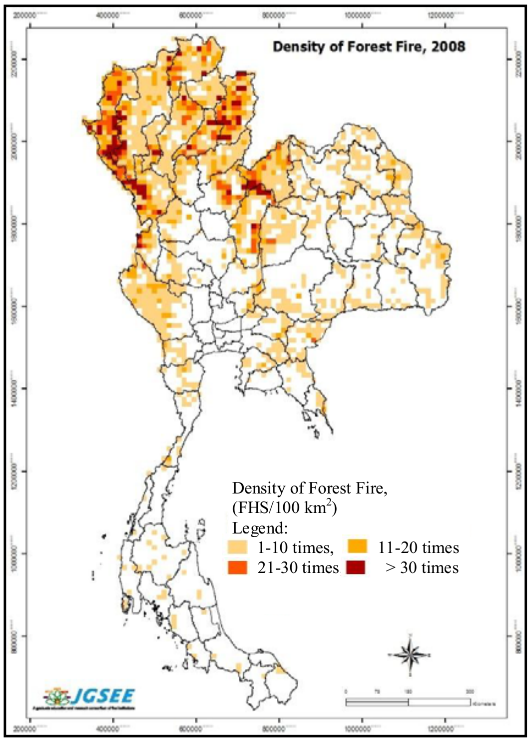

Fig. 6 Annually spatial distribution of forest fire hotspots in 2008

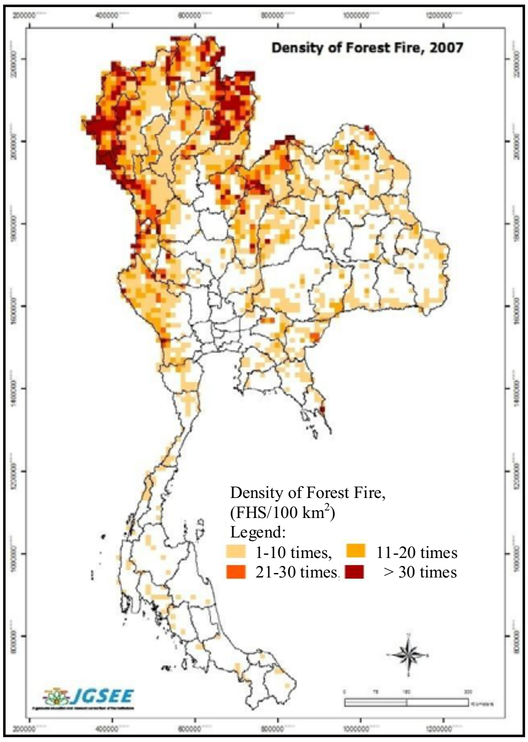

Fig. 5 Annually spatial distribution of forest fire hotspots in 2007

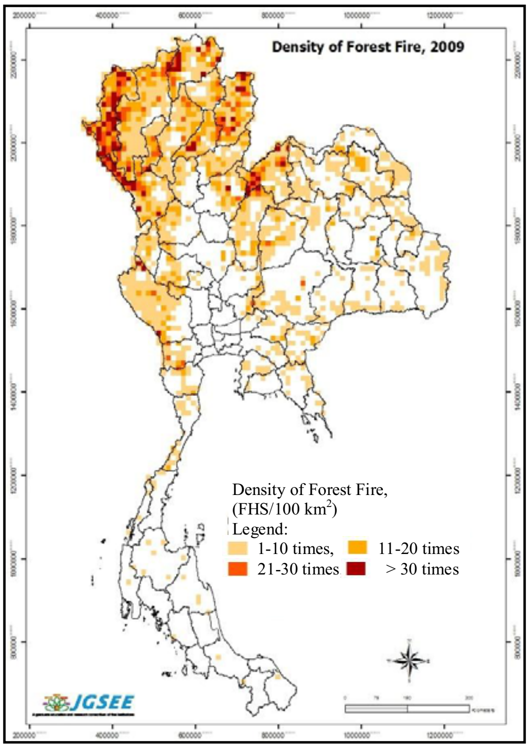

Fig. 7 Annually spatial distribution of forest fire hotspots in 2009

The third component of biomass is undergrowth which has the average value about 0.6 ± 0.13 tons/ha. The amount of undergrowth is in the range of 0.38 ± 0.08 – 1.08 ± 0.13 tons/ha or about 9% – 27% of overall biomass. Take into consideration on the trend of undergrowth found it is constant in the beginning of forest fire season and has been increased in the end of the forest fire season. In the end of forest fire season relates to the beginning of rainy season, the undergrowth can grow easily.

The last component is grass which has the average value about 0.09 ± 0.06 tons/ha. The amount of grass is in the range of 0.05 ± 0.06 - 0.18 ± 0.10 tons/ha or about 1% – 4% of overall biomass. The amount of the grass has the lowest because the grass cannot grow in the dry weather. Take into consideration on the trend of grass found the amount of grass is similarity for every month.

TABLE III
BIOMASS DENSITY OF DECIDUOUS FOREST CLASSIFIED BY BIOMASS COMPONENT AND MONTH

Biomass component		Biomass density (tons/ha)					
		Jan	Feb	Mar	Apr	May	Mean
Dead leaf	Mean	1.35	2.77	2.79	1.84	1.78	2.11
	S.E.	0.15	0.14	0.15	0.12	0.18	0.20
Grass	Mean	0.08	0.18	0.05	0.06	0.07	0.09
	S.E.	0.06	0.10	0.06	0.05	0.10	0.06
Twig	Mean	0.79	0.75	1.32	0.95	1.03	0.97
	S.E.	0.08	0.08	0.10	0.12	0.08	0.12
Under-growth	Mean	0.50	0.38	0.46	0.58	1.08	0.60
	S.E.	0.07	0.08	0.08	0.10	0.13	0.13
Fine Biomass	Mean	1.43	2.95	2.85	1.91	1.86	2.20
	S.E.	0.11	0.19	0.22	0.18	0.10	0.20
Coarse biomass	Mean	1.29	1.13	1.78	1.53	2.11	1.57
	S.E.	0.09	0.16	0.19	0.16	0.18	0.16
Total of biomass	Mean	2.72	4.08	4.63	3.43	3.97	3.76
	S.E.	0.07	0.16	0.28	0.15	0.20	0.21

C. Combustion Efficiency Assessment

The assessment on combustion efficiency of deciduous forest during forest fire season in 2009 (as shown in Table. 4) found the average of combustion efficiency is about 0.79 ± 0.08. The value during the forest fire season is in the range of 0.63 ± 0.03 – 0.90 ± 0.04. In January has the lowest rate of combustion efficiency. The combustion efficiency has increased since February.

Take into consideration on combustion efficiency by size of biomass found the almost of fine biomass as dead leaf and grass are burned which the combustion rate about 0.98 ± 0.05 for dead leaf and 0.94 ± 0.09 for grass. For coarse biomass as twig and undergrowth, only some part is burned that the combustion rate about 0.56 ± 0.09 for twig and 0.49 ± 0.09 for undergrowth. In undergrowth, only the top and leaves are burned so the undergrowth is still growing in the rainy season. This result associates to the fact that the forest area in Thailand has not be changed from forest fire.

TABLE IV
COMBUSTION EFFICIENCY OF MIXED DECIDUOUS FOREST

Month	Biomass Component	Combustion efficiency	
		Mean	Standard error
January	Dead leaf	0.92	0.08
	Twig	0.43	0.09
	Grass	0.70	0.18
	Undergrowth	0.27	0.12
	Total biomass	0.63	0.03
February	Dead leaf	1.00	0.02
	Twig	0.72	0.09
	Grass	1.00	0.00
	Undergrowth	0.49	0.08
	Total biomass	0.90	0.04
March	Dead leaf	1.00	0.00
	Twig	0.61	0.06
	Grass	1.00	0.00
	Undergrowth	0.46	0.09
	Total biomass	0.84	0.04
April	Dead leaf	1.00	0.00
	Twig	0.40	0.11
	Grass	1.00	0.00
	Undergrowth	0.56	0.09
	Total biomass	0.77	0.05
May	Dead leaf	1.00	0.00
	Twig	0.62	0.05
	Grass	1.00	0.00
	Undergrowth	0.66	0.12
	Total biomass	0.81	0.06
Mean of total biomass	Dead leaf	0.98	0.05
	Twig	0.56	0.09
	Grass	0.94	0.09
	Undergrowth	0.49	0.09
	Total biomass	0.79	0.08

D. Forest Fire Emission Assessment

Regarding to the estimation of emission from surface fire in forest Thailand during 2005 to 2009 found the amount of CO, CO_2, CH_4, and N_2O was about 3,133,845 tons, 47,610,337 tons, 204,905 tons, and 6,027 tons respectively or about 6,171,264 tons of CO_2eq. There also emitted 17,029 tons of PM_{10}. Considering a trend of change in air pollutions, it was similar to a trend of change in fire hotspots in each year. From the assessment was found between 2005 and 2009, the occurrence of forest fire had fluctuated every year. The high occurrence of forest fire was in 2005, 2007, and 2009. The low occurrence of forest fire was in 2006 and 2008. The cause of this pattern was the changing of climate especially temperature and rainfall. The changing of climate affects on moisture content of fuel and forest fire intensity can be explained as follow in the normal climate year (2006) [15], fuel dried in the summer. In El Nino year (January, February, April 2005 and December, January, February 2006/2007) [15], the temperature is rising in the summer; rainfall is decreased, so the moisture content of fuel is lower than usual. The forest fire intensity in the El Nino year is higher than the normal climate year (2006). In La Nina year (April, May, June 2008) [15], the temperature is decreased and raining in the summer for a longer time, so the moisture content of fuel is higher than usual. The forest fire intensity in the La Nina year is lower than the normal year. The description of air pollutions from forest fire was shown in Table. 5. The uncertainty of the result was approximately 20% which was the uncertainty of the emission factor. The range of emission estimation of CO_2eq and PM $_{10}$ was shown in Fig. 8 and Fig. 9.

Considering monthly temporal distribution of forest fire emissions, it found that during 5 years, greenhouse gases and particulate matter were most emitted in March. Especially in 2007, CO_2eq and PM_{10} emissions were 1,261,164 tons, and 52,343 tons. It is consistent with a report of pollution control department which proposed that the measurement of particulate matter during forest fire season in North region. It showed that PM_{10} concentration in March is the most exceed safety standard. The description of monthly temporal distribution of CO_2eq and PM_{10} emitted during 2005 to 2009 was shown in Fig. 10 and Fig. 11.

The spatial distribution of forest fire emissions has the same reason of the spatial distribution of fire hotspots. The amount of forest fire emissions related on the forest fire area and the amount of biomass burned. If the grid area has the high density of fire hotspots (more than 20 FHS per grid), there has the amount of biomass burned higher than 5,000 tons of dry matter per grid, there emit more than 500 tons of CO_2eq per grid and more than 500 tons of PM_{10} per grid (as represented in the dark color).

In the area where has the low density of fire hotspots (1-20 FHS per grid), the amount of biomass burned was about 100-5,000 tons of dry matter per grid, there emit 1-500 tons of CO_2eq per grid and 1-50 tons of PM_{10} per grid (as represented in the light color). The spatial distribution of the density of PM_{10} from forest fire was shown in Fig.12 to Fig. 16.

TABLE V
ANNUALLY FOREST FIRE EMISSIONS ESTIMATION DURING 2005 TO 2009

Year	Annually forest fire emissions estimation (tons)				
	CO_2	CO	CH_4	N_2O	PM_{10}
2005	9,043,715	595,283	38,922	1,145	48,653
2006	9,166,415	603,359	39,450	1,160	49,313
2007	12,770,807	840,610	54,963	1,617	68,704
2008	8,033,868	528,812	34,576	1,017	43,220
2009	8,595,531	565,782	36,993	1,088	46,242
Total	47,610,337	3,133,845	204,905	6,027	256,132

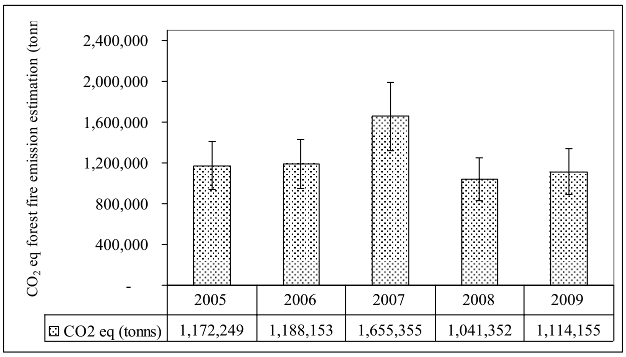

Fig. 8 Annually CO_2eq emission estimation during 2005-2009

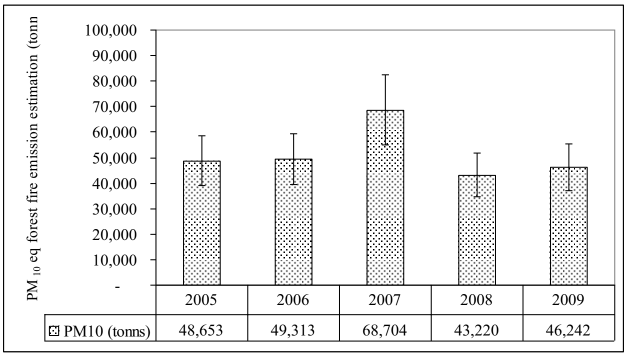

Fig. 9 Annually PM_{10} estimation during 2005-2009

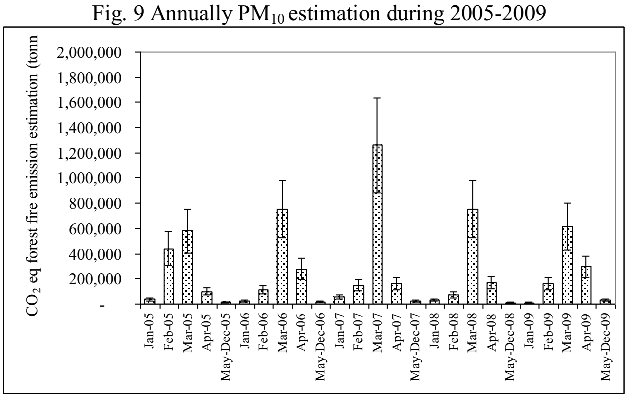

Fig.10 Monthly temporal distributions of CO_2eq estimation during 2005-2009

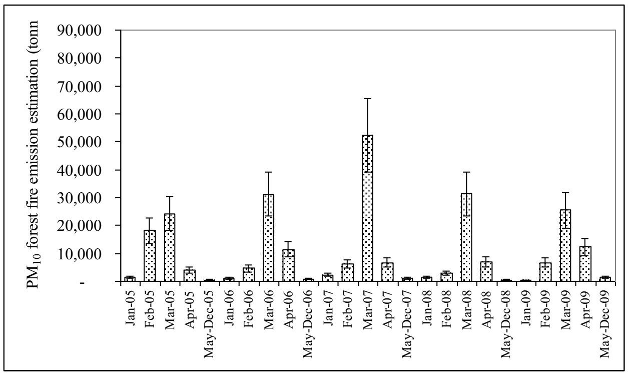

Fig.11 Monthly temporal distributions of PM_{10} estimation during 2005-2009

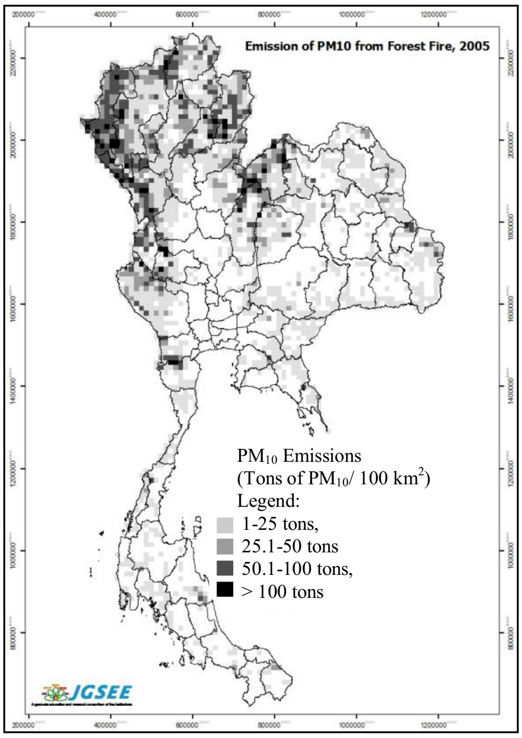

Fig.12 Spatial distribution of PM_{10} from forest fire in 2005

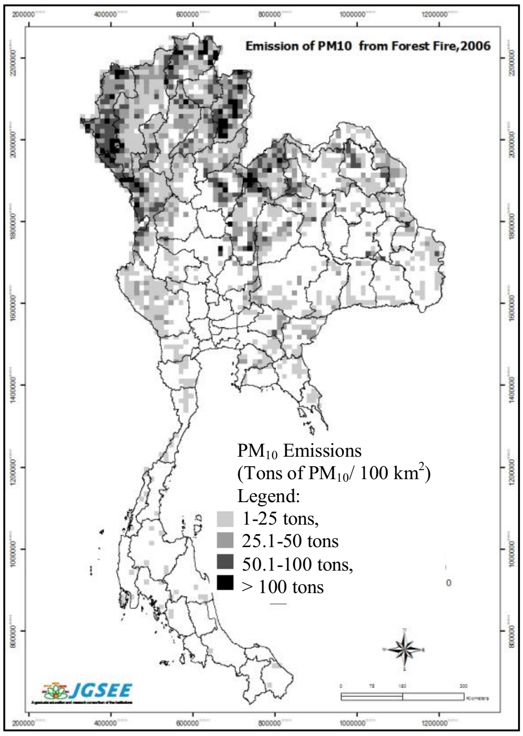

Fig.13 Spatial distribution of PM_{10} from forest fire in 2006

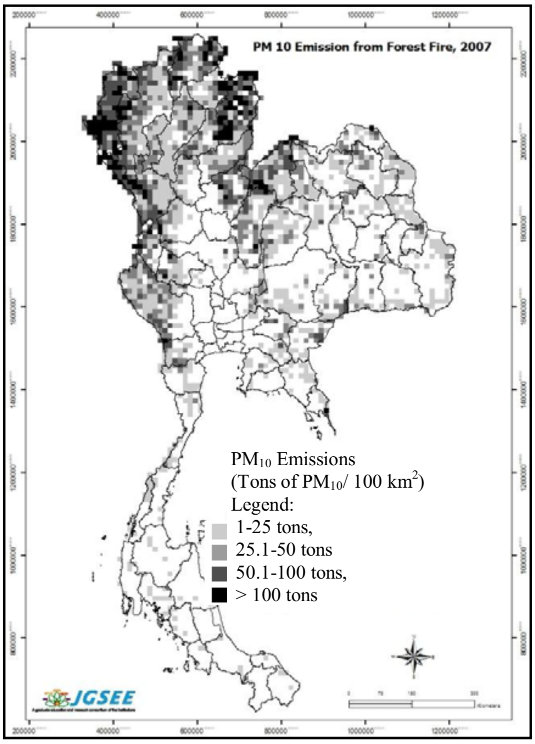

Fig.14 Spatial distribution of PM_{10} from forest fire in 2007

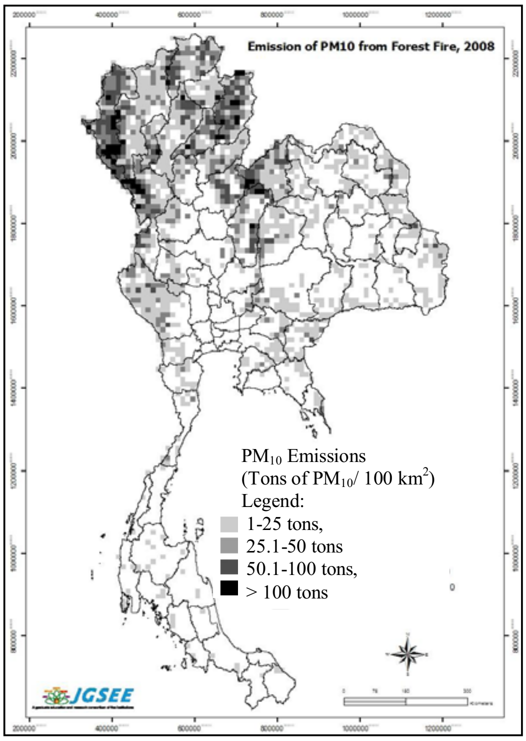

Fig.15 Spatial distribution of PM_{10} from forest fire in 2008

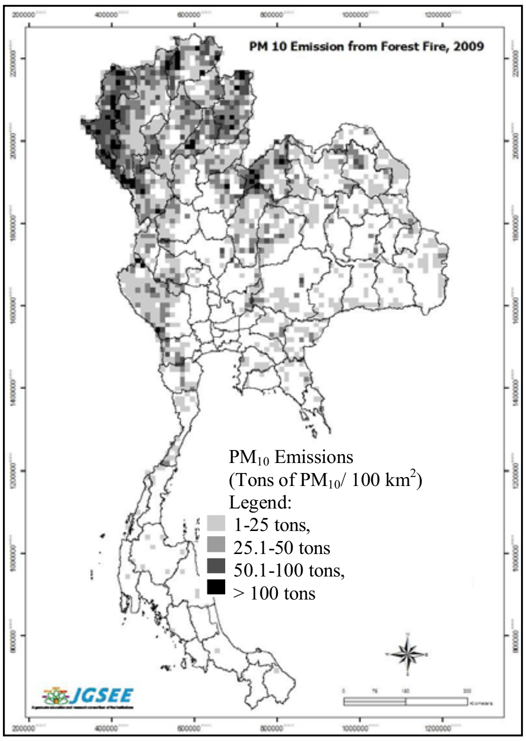

Fig.16 Spatial distribution of PM_{10} from forest fire in 2009

IV. Conclusions

This study demonstrates the satellite data is very useful for emission estimation from forest fire. MODIS data is suitable for monitoring on emission in national scale because of continuous data and easy to implement. Moreover, it can be used to assess the spatial and temporal variation of forest fire.

In future study, for getting high accuracy of estimation, there should adjust the amount of burned area obtained from MODIS with the satellite data that has high resolution as LANDSAT-TM.

Acknowledgment

This work was supported by the Higher Education Research Promotion and National Research University Project of Thailand, Office of the Higher Education Commission. The author would like to grateful to The Joint Graduate School of Energy and Environment for research fund. Thanks for the cooperation of the Forest Fire Control Division National Park and fire fighters for supporting the experiment in this study.

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