ESTIMATION OF EMISSIONS FROM BIOMASS OPEN BURNING IN THAILAND USING MODIS-MCD45A1 PRODUCT

MR. THANONPHAT BOONMAN
ID: 54910302

A THESIS SUBMITTED AS A PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENVIRONMENTAL TECHNOLOGY

THE JOINT GRADUATE SCHOOL OF ENERGY AND ENVIRONMENT AT KING MONGKUT'S UNIVERSITY OF TECHNOLOGY THONBURI

2ND SEMESTER 2013

Estimation of Emissions from Biomass Open Burning in Thailand
Using MODIS-MCD45A1 Product

Mr. Thanonphat Boonman
ID: 54910302

A Thesis Submitted as a Part of the Requirements
for the Degree of Master of Science
in Environmental Technology

The Joint Graduate School of Energy and Environment
at King Mongkut's University of Technology Thonburi

2nd Semester 2013

Thesis Committee

(Assoc. Prof. Dr. Savitri Garivait)		Advisor
(Asst. Prof. Dr. Sebastien Bonnet)		Co-Advisor
(Dr. Surachai Ratanasermpong)		Member
(Dr. Vivarad Phonekeo)		Member
(Prof. Dr. Nitin Kumar Tripathi)		External Examiner

Thesis Title: Estimation of Emissions from Biomass Open Burning in Thailand Using MODIS-MCD45A1 Product

Student's name, organization and telephone/fax numbers/email

Mr. Thanonphat Boonman

The Joint Graduate School of Energy and Environment (JGSEE)

King Mongkut's University of Technology Thonburi (KMUTT)

126 Pracha Uthit Rd., Bangmod, Tungkru, Bangkok 10140 Thailand

Telephone: 0-9451-54592

Email: thanonphatjgsee@gmail.com

Supervisor's name, organization and telephone/fax numbers/email

Assoc. Prof. Dr. Savitri Garivait

The Joint Graduate School of Energy and Environment (JGSEE)

King Mongkut's University of Technology Thonburi (KMUTT)

126 Pracha Uthit Rd., Bangmod, Tungkru, Bangkok 10140 Thailand

Telephone: +(66 2) 470 8309-10 ext 4134

Email: savitri_g@jgsee.kmutt.ac.th

Co-Supervisor's name, organization and telephone/fax numbers/email

Asst. Prof. Dr. Sebastien Bonnet

The Joint Graduate School of Energy and Environment (JGSEE)

King Mongkut's University of Technology Thonburi (KMUTT)

126 Pracha Uthit Rd., Bangmod, Tungkru, Bangkok 10140 Thailand

Telephone: +(66 2) 470 8309-10 ext 4123

Email: sebastien@jgsee.kmutt.ac.th

Topic: Estimation of Emissions from Biomass Open Burning in Thailand using MODIS-MCD45A1 Product

Name of student: Mr. Thanonphat Bonnman **Student ID:** 54910302

Name of supervisor: Assoc. Prof. Dr. Savitri Garivait

ABSTRACT

This study estimates the emissions from open biomass burning in Thailand from 2009-2011 using country specific data and the 500-meter MODIS burned area product (MCD45A1) derived exclusively from MODerate-resolution Imaging Spectro-radiometer (MODIS). The spatial and temporal distributions of open biomass burning emissions are analyzed and displayed that base on MODIS satellite product and GIS database in the form of a grid density map. The MCD45A1 burned area data analysis distributed over validation with ground observation suggests that between 2009 and 2011, the actual fire was smaller than the burned area derived from MCD451. The adjusted factor for paddy field and sugarcane was about 0.87 and 0.77 respectively. In case of burned area of corn and forest which mainly occurred in the mountain, the terrain with slopes of area affect to the size of the burned area. The adjusted factor of the burned corn field with the lower than 5 percent of slope and in the range of 5-10 percent of slope was about 0.53 and 0.66 respectively. The adjusted factor of the burned forest with the lower than 15 percent of slope and the higher than 15 percent of slope was about 0.64 and 0.53 respectively. From the validation found that, the total burned area during 2009 to 2011 was about 887,778 ha, including 332,723 ha in 2009, 410,636 ha in 2010, and 144,419 ha in 2011. Considering the total burned area during 2009 to 2011 by the type of vegetation found, the largest of the burned areas was in the forest, which was about 520,488 ha (64.4 percent of total burned area), followed by the paddy field at about 233,167 ha (28.8 percent), corn at 39,241 ha (4.9 percent), and sugarcane at 15,665 ha (1.9 percent). The estimation of emissions of open biomass burning from 2009 to 2011 indicated that the amounts of CO_2, CO, CH_4, N_2O, NO_X, $PM_{2.5}$, PM_{10}, and black carbon (BC) emitted were approximately 2,150,077 tons, 163,175 tons, 7,704 tons, 221 tons, 2,841 tons, 10,469 tons, 16,571 tons and 1,014 tons respectively. In term of spatial distribution of gridded emission found the highest were located in the northern and the central part of Thailand.

Keywords: Emission inventory, Agricultural burning, MODIS product

ACKNOWLEDGEMENTS

It is a pleasure to thank those who made this study possible. In this regard, I would like to express my sincere thanks to Associate Professor Dr. Savitri Garivait (JGSEE), who gave wonderful advice, great encouragement, kindness and guidance, As well as my co-advisor and member, Dr. Sebestien Bonnet (JGSEE), Dr.Vivarad Phonekeo (AIT), and Dr.Surachai Ratanasermpong (GISTDA) for their advice and comments. I would like to sincerely thank the Geo-Informatics and Space Technology Development Agency (Public Organization) for the fire hot spot information, MODIS FIRE User Support at University of Maryland for the MODIS information, NASA, Land Development Department (LDD) of the Ministry of Agricultural Cooperatives for the land use information, and to the Forest Fire Control Coordination Center Mea On Station of Forest Fire Control Division National Park. Also, I would like to express my thanks for all organizations, for their helpful in providing data collection for my thesis.

I would like to especially thank the Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi (KMUTT), and the Center of Excellence on Energy Technology and Environment, Ministry of Education Thailand for financial support. This work was supported by the University of North Carolina at Chapel Hill (UNC) study abroad group, the Higher Education Research Promotion and National Research University Project of Thailand, the Office of the Higher Education Commission (NRU), and ABBA research team.

Finally, my thesis would not have been achieved without the best wish as of my family who gave me their love and support throughout my studies. And the last I would like thanks my friends and coworker for their help and kind encouragement.

CONTENTS

CHAPTER	TITLE	PAGE
	ABSTRACT	i
	ACKNOWLEDGEMENT	ii
	CONTENTS	iii
	LIST OF TABLES	iv
	LIST OF FIGURES	vii
	LIST OF ABBREVIATIONS	xi
1	INTRODUCTION	
	1.1 Rationale and Problem Statement	1
	1.2 Objectives of the Study	3
	1.3 Scope of the Study	3
2	ESTIMATION OF EMISSIONES FROM BIOMASS OPEN BURNING	
	2.1 Principles Estimation of Burned Area Using Satellite Information	4
	2.1.1 Fire Hot Spot (FHS)	8
	2.1.2 Burned Scars/Burned area	9
3	MATERIALS AND METHODS	
	3.1 Vegetation cover subject of Open Burning in Thailand Assessment	17
	3.2 Estimation of Burned Area in Thailand using MODIS burned area product (MCD45A1)	19
	3.3 Validation of burned area with ground observation	24
	3.4 Estimation of Biomass Open Burning Emission s	25
4	RESULTS AND DISCUSSION	
	4.1 Vegetation cover subject of open burning	29
	4.2 Estimation of Burned Estimation Using Burned Area Product (MCD45A1)	30
	4.3 Estimation of Adjustment Factor for Burned areas Estimated Using MCD45A1 Product	40
	4.4 Biomass Open Burning Emissions	55

CONTENTS (Cont')

CHAPTER	TITLE	PAGE
5	CONCLUSIONS AND RECOMMENDATIONS	
	5.1 Conclusions	70
	5.2 Recommendations for further research studies	73
	REFERENCES	75
	APPENDIXES	79
	Appendix A: Forest and agricultural fires with ground observation	80
	Appendix B: The Spatial distributions of emission estimation from biomass open burning emission estimation for 2009 and 2011	84

LIST OF TABLES

TABLES	TITLE	PAGE
2.1	Details of satellites that detect forest fires based on temperature measurement	5
2.2	Fire count product based on active fire product from satellite information	7
2.3	Forest fire data based on burned area product applied to satellite information	7
2.4	Comparison of annually burned area estimation by forest fire control station statistics, MODIS, MODIS and LANDSAT-5 TM, and MODIS and environmental factors	14
3.1	The summary of methodology for assessment of spatial and varied burned areas	21
3.2	Emissions factor of tropical forests and agricultural residues	26
3.3	Biomass fuel of tropical forest and agricultural residues	27
3.4	Combustion Factor of tropical forest and agricultural residues	27
4.1	Number of active fires detected by MODIS, and forest fires and agricultural burning areas in 2013	29
4.2	Area of burning from burned area product (MCD45A1) classified by land use type and month, 2009 -2011, Thailand	31
4.3	The burned areas from burned area product (MCD45A1) data collection and observations of this study for the case of rice fields	41
4.4	The burned areas from burned area product (MCD45A1) data collection and observation of this study for the case of corn	42
4.5	The burned areas from burned area product (MCD45A1) data collection and observation of this study for the case of sugarcane	43
4.6	The burned area from burned area product (MCD45A1) data collection and observation of this study for the case of forest fire areas	44

LIST OF TABLES (Cont')

TABLES	TITLE	PAGE
4.7	The results of the Correlation Coefficient between the burned area product (MCD45A1) and ground measurements of biomass open burning in Thailand	45
4.8	The results of MCD45A1 burned area product was multiplied with the adjusted factor to assess the actual burned area	46
4.9	Annual biomass open burning emissions estimation using burned area estimation from burned area product (MCD45A1) in 2009	56
4.10	Comparison of the total biomass open burning emissions derived from GFED v3.1results Thailand in 2010 with results from this study	67

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	FHS in the north of Thailand, images by MODIS on Terra and Aqua (the left shows FHS 's Terra on March 20, 2011, 4.14 (GMT +7.00), and the right shows FHS's Aqua on March 20, 2012 ,7.18 (GMT +7.00)	8
2.2	The forest burned area estimation by using interpretation of satellite imagery, recorded by LANDSAT-5 on Mach 26,2007 in Ratchaburi province, Thailand (GISTDA, 2007)	9
2.3	Spatial distribution derived from L3JRC and MCD45A1 products with results from calendar year 2006	12
2.4	1997–2008 estimated annual regional and worldwide area burned (Giglio et al., 2010)	14
2.5	Regions and bounding coordinates of the Geotiff format subsets	16
2.6	Bounding coordinates of the Geotiff format subsets in Thailand	16
3.1	Flow chart of methodology for assessment of spatial and varied Derived from MODIS Burned Area Product (MCD45A1)	19
3.2	Burned area classification using GIS system (LDD, 2007)	22
4.1	Total burned area from burned area product (MCD45A1) by month for 2009-2011, Thailand	29
4.2	Burned areas from burned area product (MCD45A1) by land use type for 2009, Thailand	32
4.3	Burned areas from burned area product (MCD45A1) by land use type for 2010, Thailand	32
4.4	Burned areas from Burned area product (MCD45A1) by land use type for 2011, Thailand	33
4.5	The map of fraction of burned area from Burned area product (MCD45A1) in 2009	37
4.6	The map of fractions of burned areas from burned area product (MCD45A1) in 2010	38

LIST OF FIGURES (Cont')

FIGURE	TITLE	PAGE
4.7	The map of fractions of burned areas from burned area product (MCD45A1) in 2011	39
4.8	The map of fractions of burned areas from burned area product (MCD45A1) of agricultural and forest fires during 2009 - 2011	41
4.9	Validated location of burning of paddy fields	49
4.10	Ground observation measurement method and relationship between the burned area product (MCD45A1) with ground-truthed of paddy fields.	49
4.11	Validated location of burning of sugarcane.	51
4.12	Ground observation measurement method and relationship between the burned area product (MCD45A1) with ground-truthed of sugarcane	51
4.13	Validated location of burning of corn area	53
4.14	Ground observation measurement method and relationship between the burned area product (MCD45A1) with ground-truthed of corn area. for terrain with slopes at $\leq$ 5 percent shown by the blue line (◆) and for terrain with slopes ranges between 5-10 percent shown by the red line (⏶)	53
4.15	Validated location of burning of forest area	55
4.16	Ground observation measurement methods and relationship between the burned area product (MCD45A1) with ground-truthed of forest area for terrain with slopes at $\leq$ 15 percent shown by the blue line (◆) and for terrain with slopes at >15 percentage shown by the red line (⏶)	55
4.17	Share of $PM_{2.5}$ emissions from forest fires and agricultural open burning in 2009, Thailand	56
4.18	Share of $PM_{2.5}$ emissions from forest fires and agricultural open burning in 2010, Thailand	57

LIST OF FIGURES (Cont')

FIGURE	TITLE	PAGE
4.19	Share of $PM_{2.5}$ emissions from forest fires and agricultural open burning in in 2011, Thailand	57
4.20	Spatial distributions of CO_2 from biomass open burning in 2010	59
4.21	Spatial distributions of CO from biomass open burning in 2010	60
4.22	Spatial distributions of CH_4 from biomass open burning in 2010	61
4.23	Spatial distributions of N_2O from biomass open burning in 2010	62
4.24	Spatial distributions of $PM_{2.5}$ from biomass open burning in 2010	63
4.25	Spatial distributions of PM_{10} from biomass open burning in 2010	64
4.26	Spatial distributions of NO_x from biomass open burning in 2010	65
4.27	Spatial distributions of BC from biomass open burning in 2010	66
4.28	Comparison of total biomass open burning gridded emissions estimated distribution derived from GFEDv3.1, and this study in year 2010 for (a) GFEDv3.1 and (b) MCD45A1 from this study, Thailand	68
A1	Burned areas collection from observational data for the case of rice fields	80
A2	Burned areas collection from observational data for the case of corn	81
A3	Burned areas collection from observational data for the case of sugarcane	82
A4	Burned areas collection from observational data for the case of forest fires	83
B1	Spatial distributions of CO_2 from biomass open burning in 2009	85
B2	Spatial distributions of CO from biomass open burning in 2009	86
B3	Spatial distributions of CH_4 from biomass open burning in 2009	87
B4	Spatial distributions of N_2O from biomass open burning in 2009	88
B5	Spatial distributions of $PM_{2.5}$ from biomass open burning in 2009	89
B6	Spatial distributions of PM_{10} from biomass open burning in 2009	90
B7	Spatial distributions of NO_x from biomass open burning in 2009	91

LIST OF FIGURES (Cont’)

FIGURE	TITLE	PAGE
B8	Spatial distributions of BC from biomass open burning in 2009	92
B9	Spatial distributions of CO_2 from biomass open burning in 2011	93
B10	Spatial distributions of CO from biomass open burning in 2011	94
B11	Spatial distributions of CH_4 from biomass open burning in 2011	95
B12	Spatial distributions of N_2O from biomass open burning in 2011	96
B13	Spatial distributions of $PM_{2.5}$ from biomass open burning in 2011	97
B14	Spatial distributions of PM_{10} from biomass open burning in 2011	98
B15	Spatial distributions of NO_x from biomass open burning in 2011	99
B16	Spatial distributions of BC from biomass open burning in 2011	100

LIST OF ABBREVIATIONS

BA	Burned area
MCD45A1	MODIS burned area product
MOD14	Thermal Anomalies, Fires & Biomass Burning (MODIS Active Fire Product)
L3JRC	Global VGT burnt area product 2000-2007
GBA2000	The Global Burnt Area 2000
GLOBCARBON	Global Land Products for Carbon Model Assimilation
GLOBSCAR	ATSR Global Burned Forest Mapping
GDBAv1	Global Daily Burnt Area
GFED3.1	Global Fire Emissions Database, Version 3
SPOT	Satellite Pour l'Observation de la Terre
SPOT VEGETATION	Vegetation Sensor
EOS	(NASA) Earth Observing System
LANDSAT	NASA's Earth-observing Satellite
TERRA	NASA's Earth-observing Satellite
AQUA	NASA's Earth-observing Satellite
ENVISAT	Environmental Satellite
AATSR	Advanced Along-Track Scanning Radiometer instruments
BIRD	Bispectral and Infrared Remote Detection
MODIS	Moderate Resolution Imaging Spectrometer
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	NOAA's Advanced Very High Resolution Radiometers
GOES	Geostationary Operational Environmental Satellites
DMSP	The Defense Meteorological Satellite Program
TRMM/VIRS	The Tropical Rainfall Measuring Mission/ Visible and Infrared Scanner
SRTM	The NASA Shuttle Radar Topographic Mission
DEM	Digital Elevation Model
GIS	Geographic Information System
Geotiff	Georeferenced Tagged Image File Format

LIST OF ABBREVIATIONS (Cont')

HDF	Hierarchical Data Format
QA	Quality Assessment
GBA2000	The Global Burnt Area 2000
NASA	The National Aeronautics and Space Administration
NESDIS	National Environmental Satellite, Data, and Information Service
ESA	The European Space Agency
JRC	The European Commission Joint Research Centre
FIRMS	NASA LANCE Fire Information for Resource Management System
NASA/GSFC	NASA 's The Goddard Space Flight Center
LP-DAAC	Land Processes Distributed Active Archive Center
GISTDA	Geo-informatics and Space Technology Development Agency (Public Organization)
FFCD	The Forest Fire Control Division
RFD	The Royal Forestry Department
LDD	Land Development Department
PCD	The Pollution Control Department
IPCC	The Intergovernmental Panel on Climate Change
BF	Biomass fuel
CF	Combustion factor
EF	Emissions factor
CO_2	Carbon dioxide
CO	Carbon monoxide
CH_4	Methane
BC	Black carbon
N_2O	Nitrous oxide
NO_x	Nitrogen oxide
$PM_{2.5}$	Particulate matter ($PM_{2.5}$)
PM_{10}	Particulate matter (PM_{10})

CHAPTER 1
INTRODUCTION

1.1 Rationale and Problem Statement

Biomass open burning, especially forest fires and burning of agricultural residue, is an on-going manmade activity. Most open biomass burning is due to anthropogenic land clearing for cultivation, hunting, and collection of wild products, therefore it can be accounted as either reemission anthropogenic source (Andreae and Merlet, 2001; IPCC, 2006; PCD, 2005). In addition to its direct effect on local people through air pollution, biomass open burning emissions may also contribute to global warming. The burning of biomass emits greenhouse gases including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). According to a national fire emissions inventory, the actual situation of fires requires that the estimation of emissions be as accurate as possible and reflect the conditions leading to fire emissions (PCD, 2005; Garivait et al., 2007)

Thailand faces continuous air pollution problems from open biomass burning, especially during the dry season (FFCD, 2011a). The monthly values available basis indicated that January to April is the most intensive burning period, not only in Thailand, but also other countries in the Greater Mekong Sub region (Bonet and Garivait, 2011). The location of hotspots was overlaid with a land use map from the Land Development Department (LDD) to identify land cover over the fire hotspot. This information is useful to allocate precise land cover-depended factors such as biomass loading and combustion efficiency. In year 2010, the area of burnt agriculture was 2,208 km^2 (paddy field 1,215 km^2, corn 670 km^2, sugar cane 323 km^2) and that of bunt forest was 7,228 km^2 (mixed deciduous 2,971 km^2, deciduous dipterocarp 1,552 km^2 and other types of forest 2,705 km^2). Fuel density of each land use type was obtained from local survey and measurement. For forest fire estimation in Thailand, Junpen and coauthors estimated that biomass density is 371.4 ton dry mass/km^2 for deciduous dipterocarp forest, 364.5 ton of dry mass/km^2 for mixed decidous forest, and combustion completeness is 0.78 for both deciduous dipterocarp forest and mixed deciduous forest (Junpen, 2011). For agriculture burning, biomass density is 237 ton/km^2, 620 ton/km^2, and 247 ton/km^2 and combustion completeness is 0.87, 0.2, and 0.39 for rice, corn, and sugar cane, respectively (PCD, 2005; Cheewaphonphan and Garivait, 2012) .

At present, assessing forest and crop residue burned area open biomass burning is important due to climate change and impacts on human health. There are many factors which affect the degree to which an assessed burned area approximates the actual burned area. One of the biggest difficult accessing area of burned biomass. It is necessary to provide an overview of all data that can affect changes in both the temporal and spatial variations. In the past decade, the study of forest fire measurement and monitoring changes commonly used the Fire Hot Spot (FHS)(Garivait et al., 2007). Even though, the FHS product has been used to analyze past research work and despite high temporal accuracy, It is characterized by high uncertainty in its spatial accuracy. Researchers have pointed out that the use of estimation emissions of burn scar may provide better accuracy (Junpen, 2011; Garivait et al., 2007; Giglio et al., 2010). The accuracy of estimating in burned area by FHS data coupled with ground measurements has been shown to give a high overestimation of the burned area by using active fire product from MODIS (Junpen, 2011). The FHS, known as MOD14, is onboard the Terra and Aqua satellites with 1km x 1km spatial resolution and is used to estimate the extent of the open biomass burning activity (Junpen, 2011; GISTDA, 2012). The burned area reported from FHS data was estimated at 1.4 to 2.3 Mha, from 2005 to 2009, and was compared to MODIS data with satellite images from LANDSAT-5 TM. The comparison revealed that MODIS incorporated a high uncertainty within its data. The potential to assess burned areas has evolved from FHS. Although the ability of such data to provide information on change over time is accepted, there is still a limitation for the spatial variation.

The Forest Fire Control Division (FFCD) of the Royal Forestry Department (RFD) reported that forest fires occur annually during the dry season from December to May. From 2009 to 2011, the forest fire statistics reported by the FFCD show annual forest fire burning to range from 4,078 to 13,308 ha (FFCD, 2011a). The FFCD measured the size of the burned area using the tracking function on a Global Positioning System (GPS) and walking around the perimeter of the burned area. However, statistics reported by the FFCD show an underestimation of the actual biomass area burned (Garivait et al., 2007). The MCD45A1 burned areas were found to range between 22100 and 137700 ha year^{-1} which was between 0.5 and 4.7 times higher than the values reported by the FFCD. This was used to estimate the forested areas burned in Thailand during 2001- 2006 (Chang and Song, 2010).

This study develops and evaluates an emission estimation of the open biomass burned area in Thailand for both forestland and cropland by using a MODIS burned area product (MCD45A1) with a 0.5 km × 0.5 km spatial resolution. The higher spatial resolution is employed to reduce the uncertainty in estimation of burned area from satellite imagery (Roy et al., 2009; Justice et al., 2002). The methodology of MCD45A1 burned area processing and analysis is presented, and the results are discussed. The air pollution from open biomass burning is calculated using a combination of assessed burned area and country specific data on forest fire and agricultural burning. To increase the accuracy of estimated emissions, we can calculate correction factor variables for burned area (BA), biomass burned fuel (BF), combustion factor (CF), and emissions factor (EF) (Garivait et al., 2007; FFCD, 2011b; Bond, T.C. and Sun, H., 2005). Finally, for the emissions obtained in this study are compared with emissions presented by the FFCD and previous studies (Junpen, 2011; FFCD, 2011b). The target emissions are CO_2, CO, CH_4, N_2O, $PM_{2.5}$, PM_{10}, $NO_{X,}$ and BC. The results are shown in spatial distribution of MODIS burned area.

1.2 Objectives of the study

1.2.1 To assess the area burned by biomass open burning in Thailand using a MODIS burned area product (MCD45A1).

1.2.2 To assess the uncertainty associated with using MODIS burned area products (MCD45A1).

1.2.3 To estimate emissions from biomass open burning in Thailand from 2009 to 2011.

1.3 Scope of the study

1.3.1 Burned Area Estimation: Area burned by biomass open burning is estimated by MODIS burned area product (MCD45A1) for the whole of Thailand from 2009 to 2011.

1.3.2 Type of fires: Forest fire and the burning of paddy fields, sugarcane-fields, and corn-fields.

1.3.3 Pollutants of interest: Greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), nitrogen oxide (NO_x) and air pollutants, such as carbon monoxide (CO), fine and coarse particulate matter ($PM_{2.5}$ and PM_{10}), and black carbon (BC).

CHAPTER 2
ESTIMATION OF EMISSIONS FROM BIOMASS OPEN BURING

2.1 Principles Estimation of Burned Area Using Satellite Information

In this chapter, we review previous research and theories that use satellite information for finding burned areas by using the burned area product (MCD45A1). This chapter is divided into three parts: application of remote sensing information to estimation emissions from biomass open burning, description of MCD45A1, and methodology of emission estimation from biomass burning. The methodology is divided by the source of burning, such as forest fire and agricultural burning. We estimated burned area using MCD45A1, verified the results with previous studies, and compared and validated the data with ground observation. The details of the literature review are given below.

- **Detection of Fire Hot Spots (FHS)**

The principal active fire detection is based on temperature measurements in each sensed pixel. The MODIS instruments consists of magnitude MIR and TIR sensors, and are able to detect pixels that have a temperature higher than 360 K during the day and higher than 320 K at night. These pixels represent fires. Nowadays, there are many satellites or instruments that are able to detect active fires such as, AVHRR, GOES, DMSP, TRMM/VIRS, MODIS, ATSR, and ASTER. The details of the satellites and instruments of active fire product based on temperature measurement from the MODIS sensors onboard in TERRA and AQUA satellites, which is widely used for fire emission detection, is shown in Table 2.1**(**Kaiser et al., 2006)

Table 2.1 Details of satellites that detect forest fires based on temperature measurement

Project Name	**Information**
ERS-2/ATSR-2 World Fire Atlas (ESA)	• Based on ATSR - night time data in order to reduce false alarms. • 1995 to 2002: ATSR-2 night-time data (level 1B product). • 2003 to Present: AATSR night-time data (level 1B product). http://shark1.esrin.esa.it/ionia/FIRE/AF/ATSR/
GOES Automated Biomass Burning Algorithm -ABBA/WF-ABBA (University of Wisconsin, NOAA)	• The GOES-8 ABBA fire product includes: fire location (latitude-longitude), estimates of fire size and temperature, 3.9 and 10.7 micron observed brightness temperatures, background brightness temperatures, albedo statistics, ecosystem type, and a flag for non-processed fire pixels to indicate the reason for not processing. • The wild fire -ABBA (WFABBA) imagery is generated blending data from the GOES 10 and 12 satellites and a land cover map derived from 1-km AVHRR. • Plans exist to provide a global product based on the geostationary satellite network. http://cimss.ssec.wisc.edu/goes/burn/detection.html
AVHRR World Fire Web (EU/JRC)	• The fire map is a latitude-longitude raster, where each raster cell contains the number of fires detected within that cell over a period of time. The cell size is typically 0.5° × 0.5° and the time period is typically 1 day or 10 days. http://natural-hazards.jrc.it/fires/detection/wfw/help/overview.html
TRMM-VIRS fire counts	• Tropical and sub-tropical zones (+/- 40° from the equator) for 1998-2002 • Possible extension to mid 2004 • Derived from Tropical Rainfall Measuring Mission (TRMM) Visible and Infrared • Scanner (VIRS) measurements • Number of 4.4 km2 pixels in each half-degree grid cell http://earthobservatory.nasa.gov/Observatory/Datasets/fires.trmm.html
MODIS Global Fire Rapid Response System (NASA)	• 250 m product, daily update, North America emphasis • 1 km global product composite 8 day fire product (MOD14A2) • Several near real-time product on temperature anomalies http://modis-fire.umd.edu/products.asp

Source: Kaiser et al. (2006)

Meyer et al. (2008) estimated the biomass burning area by using hotspot data at 1 km x 1 km resolution from Sentinel, a national bushfire monitoring system managed by Geoscience Australia (based on MODIS). The information is available on-line at https://acres.ga.gov.au/modis data. This study found that the relationship between the number of fire hotspots and burned scar areas depended partly on topography. The burn scar area per hotspot varies from approximately 180 ha per fire hotspot on the central plateau of Arnhem Land (the middle portion of the top half) to > 600 ha per hotspot in the southern regions of the domain. The average hotspot size was determined from a least squares linear regression of burn scar area against fire hotspot number across the complete domain.

Active fires are detected by satellite sensors, which measure individual pixels that are hotter than their surroundings. These thermal anomalies, termed “fire hot spots”, are based on individual pixel temperatures measured from emissions in the Mid Thermal Infrared (MIR) (3.5–4.0 μm) waveband. This is where maximum thermal emissions at flame temperatures occur. Surrounding temperatures are measured in the Thermal Infrared (TIR) (10–12 μm) waveband, where maximum thermal emissions occur at the cooler land temperatures. The Moderate Resolution Imaging Spectroradiometer (MODIS) on the Terra and Aqua satellites has detectors in the MIR and TIR bands suited to FHS detection. Due to the sensitivity of the MODIS MIR and TIR detector, active fires much smaller than the 1 km^2 spatial resolution of the sensors can be detected. The sensor about 4 μm low gain band on MODIS with a saturation level of 500 K is less prone to daytime saturation and is therefore better suited for daytime detection of fires (Richard Smith et al., 2006).

Kaiser et al. (2006), showed that there were many organizations collecting fire data of biomass open burning through interpreting satellite information. The fire data is set up on global, continental, and regional scales. It has a different sensor to detect land surfaces that are provided depending on the purposes of the study. The differences are summarized in Table 2.2 This information demonstrates that active fire data counts at a spatial resolution of 1 km × 1 km and temporal resolutions are obtained daily to monthly. However, the active fire data has a limited condition for assessment of biomass open burned area based on active fire product. The result from active fire has high uncertainty because of the unsuitable spatial resolution that is bigger than the fire burned area.

Table 2.2 Fire count product based on active fire product from satellite information

World fire web-AVHRR (JRC)	Global, 1996-2001	Fire count	0.5 ° × 0.5 ° Daily	Reanalysis
World fire atlas-ATSR (ESA)	Global, 1995-2004	Fire count	1 km × 1 km Monthly	Reanalysis
Thermal anomaly MODIS (NESDIS)	Global, Near real time	Fire count	1 km × 1 km Daily	Operations and reanalysis
ABBA-GOES (NESDIS)	America Near real time	Fire count	1 km × 1 km Daily	Operations and reanalysis
WF-ABBA Geost. Sat.	Global Real time	Fire count	1 km × 1 km Daily	Operations and reanalysis
FIMMA-AVHRR (NESDIS)	N-America Near real time	Fire count	1 km × 1 km Daily	Operations and reanalysis

Source: Kaiser et al. (2006)

- **Detection of Burn Scar/Burned area**

In the literature review (Kaiser et al., 2006; Roy et al., 2009; Chang et al., 2010; Giglio et al., 2010)), there are many organizations that use satellite information to obtain fire data on biomass open burning. They are based on burned area product are appropriated to using the data at a global scale, continental scale, or regional scale, as summarized in Table 2.3. This information demonstrates fire data including the burned area product at spatial resolutions of 1 km × 1 km. A new spatial resolution is 0.5km with a daily to monthly temporal resolution (Kaiser et al., 2006).

Table 2.3 Forest fire data based on burned area product applied to satellite information

Name	Sensor (s)	Period and Area covered	Resolution /Temporal	Possible Usage
MCD45A1	Aqua/Terra-MODIS	Global, 2000-present	0.5km × 0.5km /Monthly	Reanalysis
GBA2000	SPOT-VGT	Global, 1999-2000	1 km × 1 km /Monthly	Reanalysis
GLOBCARBON	ERS2-ATSR2, Envist-AATSR, Envisat-MERIS, SPOT-VGT	Global, 1998-2007	8 km × 8 km /Monthly	Reanalysis
GLOBSCAR	ERS2-ATSR2	Global, 2000	1 km × 1 km /Monthly	Reanalysis

Name	Sensor (s)	Period and Area covered	Resolution /Temporal	Possible Usage
Burnt Area for Geoland (BAG)	SPOT-VGT	Africa and Eurasia, 1998-2003	1 km × 1 km /10 Days	Reanalysis
Global Daily Burnt Area (GDBAv1)	SPOT-VGT	Global ,2000-2005	1 km × 1 km /1 Day	Reanalysis
Name	Sensor (s)	Period and Area covered	Resolution /Temporal	Possible Usage
GBA 1982-1999	NOAA-AVHRR	Global, 1992-1999	8 km × 8 km /Monthly	Reanalysis
VGT4Africa	SPOT-VGT	Global ,2005-present	1 km × 1 km /1 Day	Reanalysis

Source: Kaiser et al. (2006)

2.1.1 Fire Hot Spots (FHS)

Fire Hot Spots (FHS) occurring in northern Thailand on March 20, 2012. is shown in images by the Geo-Informatics and Space Technology Development Agency **(**GISTDA**).** The burned area is estimated by interpreting forest fire area and calculating the actual burned area. This method is suitable for small to medium monitoring forest fire areas, i.e. Thailand's national parks or provinces area have been assessed on a daily or weekly time frame. The burned area is estimated by satellite imagery. Then, the burned area in the satellite image will be distributed to the real area by using a proportional method. The satellite interpretation method and analyst use a remote sensing program. Normally, active fire data is used to display the position of the forest fire and monitoring forest fire real incidence situations. The information of FHS position detected from MODIS sensor onboard the Terra and Aqua satellite is shown in Figure 2.1. Burn scar/burned area is calculated by size of pixel, and depends on spatial resolution of each satellite sensor. The spatial resolution represents the size of burned forest fire area.

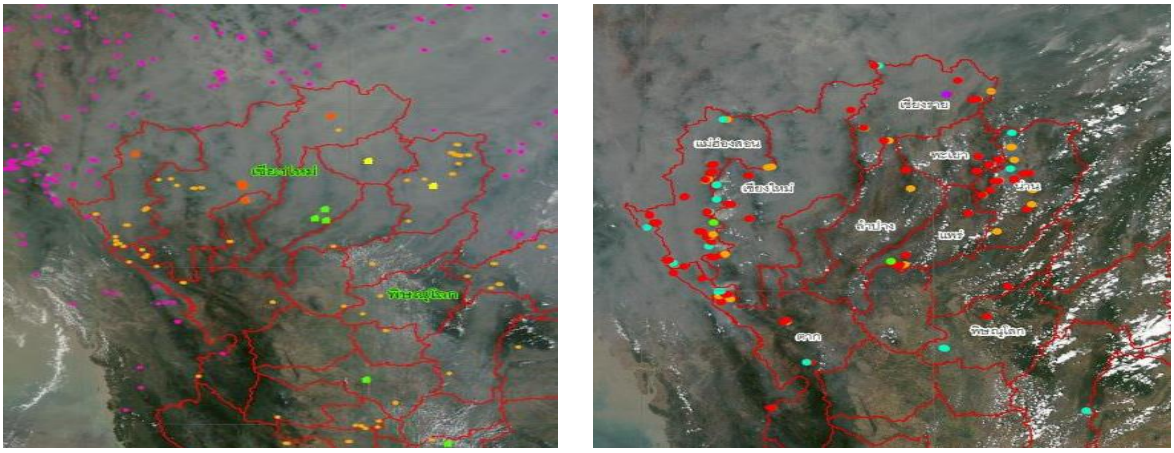


Figure 2.1 FHS in the north of Thailand, images by MODIS on Terra and Aqua (the left shows FHS 's Terra on March 20, 2011, 4.14 (GMT +7.00). and the right shows FHS's Aqua on March 20, 2012 ,7.18 (GMT +7.00).

2.1.2 Burned Scar/Burned area

2.1.2.1 Landsat product

In contrast to burn scars or burned areas, we are able to use satellite imagery to assess the burning area that is obtained on a weekly to monthly timeframe. Therefore, many satellite images have to be used, which are suitable and have high resolution for assessment of burned scars or burned area, i.e. LANDSAT-5, SPOT-5, and BIRTH. Figure 2.2 shows the forest fire satellite image in Ratchaburi province. From the figure, at the upper corner in left hand site and in the lower right hand site, a darker color than the general area can be seen. It represents the incidence of a forest fire situation. The rim of the forest fire area is the line of fire. The assessment will be done to estimate the burned area in satellite imagery. After that, the distribution of burned area in satellite imagery is used to display the real area by a proportional method. The satellite interpretation can be done by using remote sensing software or field data collection by people.

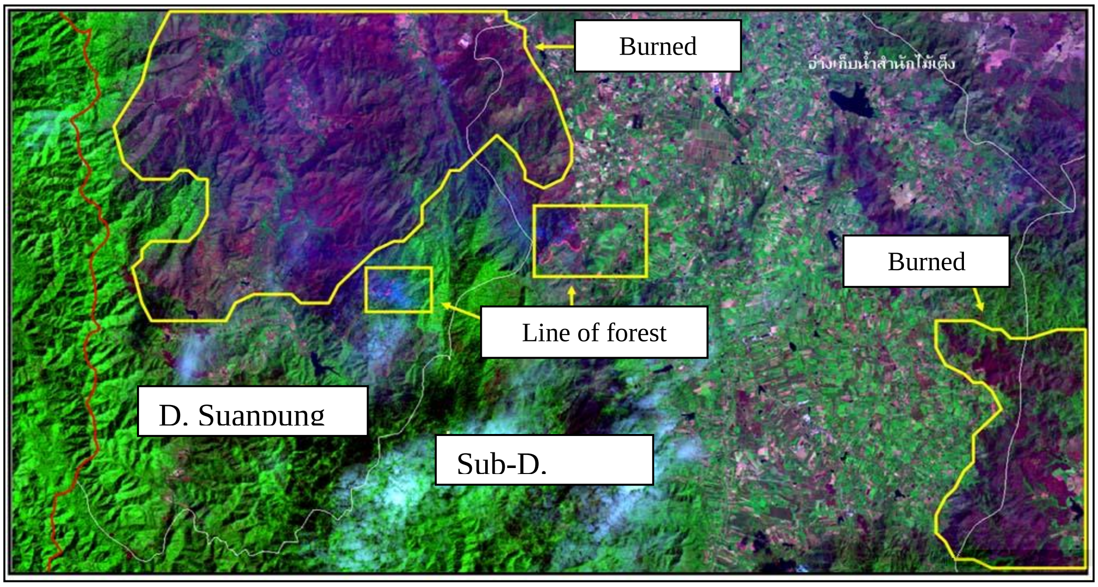


Figure 2.2 The forest burned area estimation by using interpretation of satellite image, recorded by LANDSAT-5 on Mach 26,2007 in Ratchaburi province, Thailand (GISTDA, 2007)

2.1.3 Other product

- **L3JRC burned area**

Roy et al. (2009), stated that the L3JRC burned-area product was developed through collaboration between the University of Leicester, U.K., the Université Catholique de Louvain, Belgium, the Instituto de Investigação Científica Tropical, Portugal, and the Joint Research Centre of the European Commission, Italy, such as GBA2000. The L3JRC product is generated from 1km SPOT VEGETATION data. The L3JRC algorithm used a change detection approach. After preprocessing, it removes clouds and shadows and a reference composite image is created, moving forward in time on a daily temporal scale. It is available as an annual spatial resolution with 1km product which is based on the near-infrared reflectance (NIR). It uses spectral tests based on the 0.83 to 1.66 μm reflective bands.

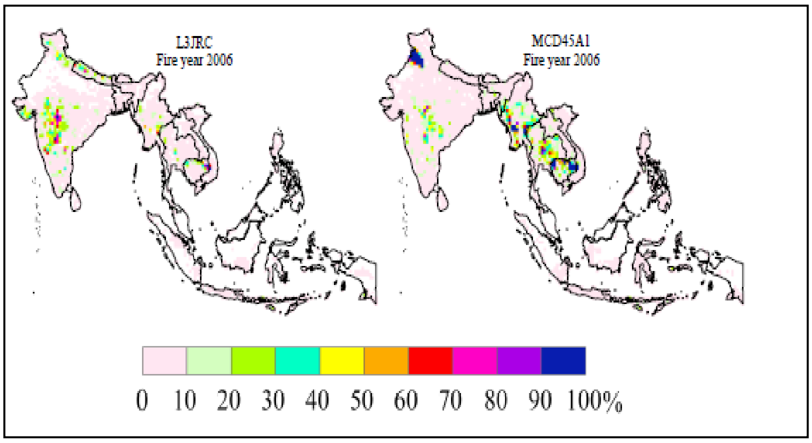
- **GlobCarbon burned area**

Roy et al. (2009), stated that the GlobCarbon burned-area product is generated using two regional algorithms, the GBA2000 algorithm and the GLOBSCAR algorithm, applied to 1km SPOTVEGETATION and ERS2 ATSR2/ENVISAT-AATSR data, respectively. The GLOBSCAR algorithm, applied to ERS2-ATSR2 for 1998 to 2002 and ENVISAT-AATSR data for 2003 to 2007, is based on two separate algorithms. The K1 GLOBSCAR algorithm used the NIR and thermal infrared (TIR) bands with an adaptive contextual window-based approach that assumes burned vegetation has a lower NIR reflectance and higher daytime TIR brightness temperature than surrounding unburned vegetation. The E1 GLOBSCAR algorithm is based on five fixed thresholds applied to red, shortwave infrared, NIR, and TIR brightness temperature values. The GlobCarbon product is available as a monthly resolution with 1km burned area product, as a global binary raster in the Plate Carrée projection.

Chang et al. (2010), described the results using burned area products, such as L3JRC, MCD45A1 and GFEDv2. 1. The annual L3JRC burned areas ranged from 32,713 km^2 in 2006 to 62,277 km^2 in 2001, whereas the annual MCD45A1 burned areas ranged from 64,708 km^2 in 2003 to 126,245 km^2 in 2004 and the annual GFEDv2.1 burned areas ranged from 86,282 km^2 in 2003 to 168,904 km^2 in 2004. Accordingly, the MCD45A1 and GFED2.1 product's figures were not only comparable, but also showed a similar inter-annual variability with the minimum burned area in 2003 and maximum in 2004. They assume that they were both based on the MODIS sensor. In contrast, the L3JRC results were substantially smaller than GFED2.1 estimates and exhibited an entirely different inter-annual change.

Roy et al. (2009), conducted a study in Southern Africa to review the previous studies in terms of burned area products with three available global multi-annual burned area products that are validated using the same independent reference data. However, they focused on three burned area products (L3JRC, GrobCarbon and MCD45A1) which were derived by interpreting multi-temporal LANDSAT ETM^+ (Enhanced Thematic Mapper Plus) data to map the location and approximate date of burning at 11 LANDSAT scenes. The LANDSAT interpretation data reported a greater percentage area burned than the corresponding burned area product (MCD45A1). Moreover, a confusion matrix validated the results of the L3JRC and MCD45A1 and showed that the percentage of correctly classified values was broadly similar among the two products with the lowest percent of correct values of the 11 scenes at confidence 88.9% (L3JRC) and 91.0% (MODIS). The burned area product (MCD45A1) which has the bi-directional reflectance modeling approach produces burned area maps at 500m. Moreover, MODIS surface reflectance imagery provided higher burned area mapping accuracies than the other two products. The results of the data suggest that the MODIS-MCD45A1 product achieved the highest degree of accuracies over other products and was capable of capturing 75% of the burned area estimated by LANDSAT-ETM^+ information.

From Figure 2.3 shows an example of the spatial distribution resulting from the application of a burned area product estimation taken from the inter-annual variability in South East Asia (SEA) biomass burning emissions in 2006 (Chang et al., 2010). This study estimated the SEA burned area from biomass burning between 2001 and 2006 by using MCD45A1 and L3JRC burned area product, with spatial resolutions of 0.5km × 0.5 km and 1 km × 1 km, respectively.



Finger 2.3 Spatial distribution derived from L3JRC and MCD45A1 products with results during calendar years 2006 (Chang et al., 2010).

The emissions of L3JRC and MCD45A1 from the results show that the majority of fire emissions were attributed to forest fires, cropland, shrubland, and grassland fires. The main contributors to fire emissions were Indonesia, India, Myanmar, and Cambodia. Nevertheless, the influence of agricultural burning may have been significantly underestimated due to the difficulty of detecting small sized fires by satellite sensors.

Giglio et al. (2010), compared the global burned area dataset of the L3JRC, MCD45A1, and GLOBCARBON burned area products, as well as the GFED2 burned area data set. The burned area reported in the L3JRC product was consistently much larger than all other data sets in about half of the regions. Our results were consistently much lower than the GFED3 and MCD45A1 products in NH and SH Africa. They showed that the L3JRC product appears to consistently overestimate the area burned in the continental United States and Canada each year by a factor of three to ten. The GLOBCARBON product most closely resembled the L3JRC product, with a similar spatial distribution of burned area, but generally with a lower magnitude. Similarly, GFED3 dataset most closely resembled the MCD45A1 dataset, both in terms of the spatial distribution of burned area, as well as the annual area burned in most regions. The burned areas are shown in Figure 2.4.

	Area Burned (x10^4 km^2 =Mha)												
Region	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Mean
BONA	0.9	4.5	1.5	0.7	0.3	3.2	2.0	5.0	2.9	1.9	1.5	1.4	2.2
TENA	0.5	1.1	1.8	2.2	1.2	1.4	1.3	0.7	1.7	2.4	2.7	1.5	1.5
CEAM	0.9	3.2	1.3	1.7	1.0	1.0	1.7	0.8	1.9	1.3	1.1	1.2	1.4
NHSA	1.7	2.8	2.0	2.4	2.0	1.1	3.3	3.2	1.8	1.5	2.5	1.8	2.2
SHSA	16.0	38.9	30.9	15.8	19.4	21.3	16.1	18.7	22.1	12.5	33.8	13.4	21.6
EURO	0.4	0.8	0.6	1.2	1.1	0.4	0.9	0.5	0.6	0.5	1.0	0.5	0.7
MIDE	0.6	0.9	0.8	0.6	1.2	1.0	0.9	0.8	0.7	0.9	1.2	0.6	0.9
NHAF	152.4	148.7	143.5	145.9	114.4	126.1	128.0	116.4	139.9	115.2	123.4	117.7	131.0
SHAF	111.6	153.1	123.1	118.3	117.3	113.9	126.6	127.1	134.1	122.2	124.2	131.5	125.2
BOAS	3.1	12.9	4.7	7.2	5.8	8.1	15.9	1.6	2.8	4.3	3.2	12.0	6.8
CEAS	17.4	14.6	8.1	11.0	15.0	25.0	12.8	15.6	15.1	17.5	12.5	14.0	14.9
SEAS	3.9	7.9	9.5	4.5	4.5	7.7	6.3	10.7	7.1	5.9	9.9	7.0	7.1
EQAS	9.4	2.6	0.6	0.4	0.7	2.4	0.8	1.2	1.1	2.7	0.5	0.4	1.9
AUST	40.5	39.0	80.2	81.7	88.3	73.1	29.0	60.4	24.9	53.1	48.7	26.6	53.8
Global	359.6	431.2	408.7	393.8	372.1	385.6	345.6	363.0	356.7	342.0	366.3	329.7	371.2

Figure 2.4 1997–2008 estimated annual regional and worldwide area burned (Giglio et al., 2010)

In Thailand, the GISTDA, (2012) and forest fire control division have been used to detect near real-time active fire hotspots (FHS) at 1 km × 1 km spatial resolutions. MODIS has been used for monitoring forest fire situations since 2009 to present and spatial representations of fire hotspot mapping. Even though this result provides the information of active fire count and the spatial and temporal distributions of forest fire occurrences over forest area and agricultural burning, it lacks information on the size of the forest fire or burned area. That is a limitation of the spatial distribution even though the information can access real time temporal resolution that is displayed and can be downloaded at http://www/gistda.or.th/fire.

A study by Junpen, (2011) provides estimations of burned areas using an active fire product (FHS) on the MODIS sensor from Terra and Aqua. The burned area had been about 1.4 to 2.3 Mha. from 2005 to 2009. They have been compared to the MODIS data with satellite images from LANDSAT-5 TM showing that MODIS provided high uncertainty data. This is due to several reasons: (1) using the pixel size 1 km × 1 km as a representative of burned area is not suitable because the actual size represents only 60% of the pixel; (2) MODIS is not designed for detecting small forest fires, and so it is not suitable for the case of surface fires that occurred in Thailand; in this study, it was observed that 98% of forest fire occurrence in Thailand are of a size smaller than 10 ha, representing about 35% of total burned area. Only 2% of forests had a large fire (larger than 10 ha) which was about 65% of the forest fire area, and (3) the satellite did not pass over the area when the fire occurred. Most of forest fires in Thailand are small fires that have a short burning time and mostly occur in the afternoon (local time). Currently, they have estimated burned area from burned area product with the MODIS sensor that provides a spatial resolution of 500m. Knowledge has been developed on the forest fire area correction from MODIS and LANDSAT-5 TM, which allows assessment of the accuracy of these satellites on forest fire application. It is suggested that using the high spatial resolution satellite analysis together with the low spatial resolution (e.g. MODIS-burned area, LANDSAT-TM) is very important for biomass open burning area emission estimation.

The results of the comparison of the forest fire area estimation between Model A1 and Model A2, found that the forest fire area estimated by a combination of MODIS and LANDSAT-5 TM (Model A1) sensors provided the largest area of forest fire at about 1.1-2.0 times Model A2. The results from Model A1 were similar to the result from LANDSAT-5 TM due to the fact that the method was already adjusted for: (1) the uncertainty from MODIS detection, (2) the uncertainty from using pixel resolution to represent forest fire area, (3) the uncertainty from small forest fires, and (4) the comparison of forest fire area estimation is also dependent on environmental factors, such as slope, moisture content of biomass and biomass density. These are shown in Table 2.4

Table 2.4 Comparison of annually burned area estimation by forest fire control station statistic, MODIS, MODIS and LANDSAT-5 TM, and MODIS and environmental factors

Year	Comparison of burned area estimations (ha)			
	Statistic from forest fire control station	MODIS	MODIS and LANDSAT-5 TM (Model A1)	MODIS and environmental factors (Model A2)
2005	201,758	1,665,700	1,870,531	805,561
2006	189,276	1,690,900	1,898,830	764,285
2007	53,885	2,292,400	2,574,296	1,125,110
2008	117,395	1,462,100	1,641,894	727,956

Year	Comparison of burned area estimations (ha)			
	Statistic from forest fire control station	MODIS	MODIS and LANDSAT-5 TM (Model A1)	MODIS and environmental factors (Model A2)
2009	70,810	1,576,600	1,770,475	1,441,229
Total	633,124	8,687,700	9,756,026	4,864,140

Source: (Junpen, 2011)

- **MCD45A1 burned area product**

This section explains some of the standard technical terms used in the documentation of the standard MODIS products. The global MODIS Collection of 5 burned area products (MCD45A1), on the Terra and Aqua satellites, has specific features for monitoring a bidirectional reflectance model based on a change detection approach. It is applied independently to each gridded MODIS pixel to take advantage of spectral, temporal and structural changes that characterize vegetation fire. The MODIS burned area product is available as a monthly Level 3 gridded 500m product containing per pixel burning and quality information, and tile level metadata. The product is provided with a variety of quality assessment information and single summery quality assessment scores for each pixel and each covering approximately 1200 ×1200 km ($10^{\circ} \times 10^{\circ}$ at the equator). Burning detected in the middle month, plus or minus eight days (the detection precision), is reported (Roy and Boschetti, 2009)

The MODIS burned area products are available free of charge and can be ordered from the Land Processes Distributed Active Archive Center (LP-DAAC) using the EOS Data Gateway web interface on the internet at: http://wist.echo.nasa.gov. The product is distributed into eight sections of data, defining for each pixel the approximate Julian day of burning from eight days before the beginning of the month to eight days after the end of the month. This is the Geotiff format.

Additionally, we can use a download from an ftp server, which is maintained by the University of Maryland, mostly to provide support to the science users who need to download systematically large volumes of data. The website for this one download is: http://modis-fire.umd.edu/ (MODIS burned area product).

In order to obtain a username and password to the server host, we can request permission to use the server and fill in a user online form for statistical purposes. In this study, the format type we use is Geotiffs, following a naming convention similar to the official MCD45A1 that was obtained by mosaicing, resampling and reprojecting several tiles of original product, the processing such as of filename of the product. In addition, a the MCD45A1 has metadata by the EOS Data Information System (EOSDIS) Core System (ECS), there is a set of specific products which have the advantage of identifying burned area and analyzing data as well. We can use ArcGIS software to display, subset, and classify the data of the burned area to show a given month in Julian days in either individual colors or in the same color, depending on our settings and regions and bounding coordinates of the Geotiff format subsets. an example is shown in Figures 2.5 and 2.6

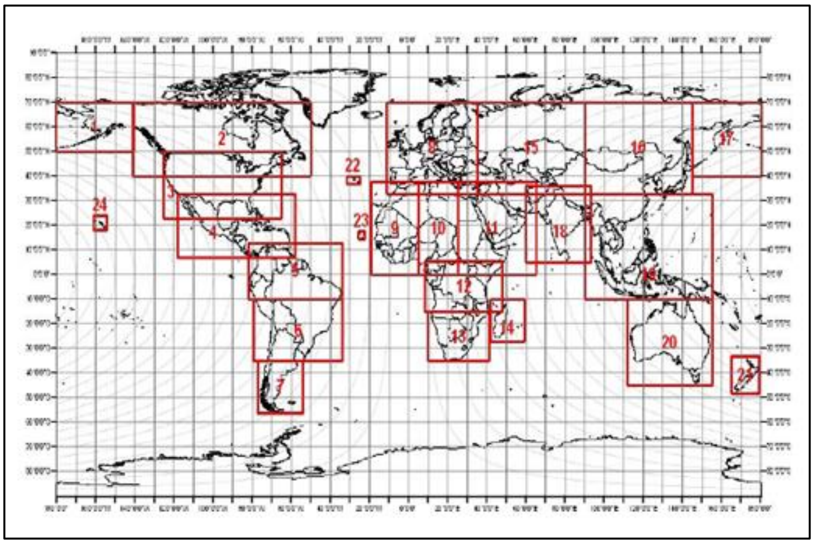


Figure 2.5 Regions and bounding coordinates of the Geotiff format subsets

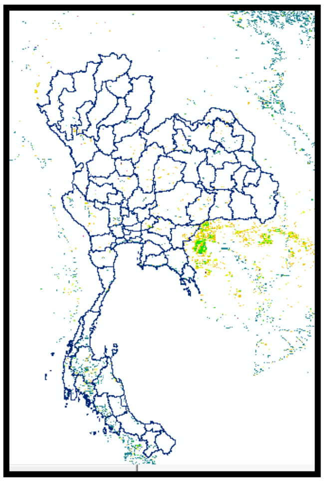


Figure 2.6 Bounding coordinates of the Geotiff format subsets in Thailand (Roy and Boschetti, 2009)

CHAPTER 3
MATERIALS AND METHODOLOGY

3.1 Vegetation Cover Subject of Biomass Open Burning in Thailand Assessment

Nowadays, there are 2 main methods that used to assess the source of a burning: ground observation method and satellite information method. Ground observation is done by survey of related-officer. The information also obtains from the report of local people. Satellite information provides the active fire from the interpretation of satellite data. Currently, active fire product and burned area product from MODIS onboard on TERRA and AQUA satellite are widely used for monitoring of burning. The sensor that mostly used is active fire product (MOD 14) 1 km × 1 km resolution as know fire hotspot because of this satellite information has medium spatial resolution that suitable for all biomass open burning (as forest fire, savanna fire, and agricultural fire). It also has high temporal resolution that suitable for dairy estimation.

This study uses the MODIS Active Fire Product (MOD14) developed by NASA. The active fire data covering the forest fire and agricultural burning in the year 2013 came from NASA LANCE Fire Information for Resource Management System (FIRMS) (Producer) (Producer), University of Maryland, Information for Resource Management System (Distributor). The data is available on-line http://earthdata.nasa.gov/data/nrt-data/firms..

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. The 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) developed by NASA for the global detection of fires (Kaufman and Justice, 1998) and suitable for day time detection (Giglio et al., 2003; Justice et al., 2002). 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 (Giglio et al., 2003).

The methodology to classify the sources of biomass open burning is described below:

(1) To download the active fire product during 2013, the data obtained from MODIS Active Fire Data, NASA LANCE Fire Information for Resource Management System (FIRMS) (Producer), University of Maryland, Information for Resource Management System (Distributor) which available MODIS Hotspot/Active Fire Detections data set available on-line http://earthdata.nasa.gov/data/nrt-data/firms and Geo-informatics and Space Technology Development Agency (GISTDA) Public Organization, Thailand which available on-line (http://fire.gistda.or.th/) (GISTDA, 2013).

(2) The data is obtained in a Microsoft Excel file format that included number of id, date of fire detection, satellite overpass time, day or night time for fire detection, name of satellite, fire position on latitude and longitude, Fire Reflectance Band2, Fire Brightness Temperature Band 21, Fire Brightness Temperature Band 31, Fire Power, and Fire Confidence (0-100%). Then all of these data is inserted into Geographic Information System (GIS) program for setting the active fire database. This study focuses on 75-100% fire confidence active fire.

(3) To classify the types of active fire by overlying the active fire on the land cover data and focusing only on the overlap on forest land and agricultural land. This study used land use information in 2007 from the Land Development Department (LDD), Thailand.

3.2 Estimation of Burned Area in Thailand using MODIS burned area product (MCD45A1)

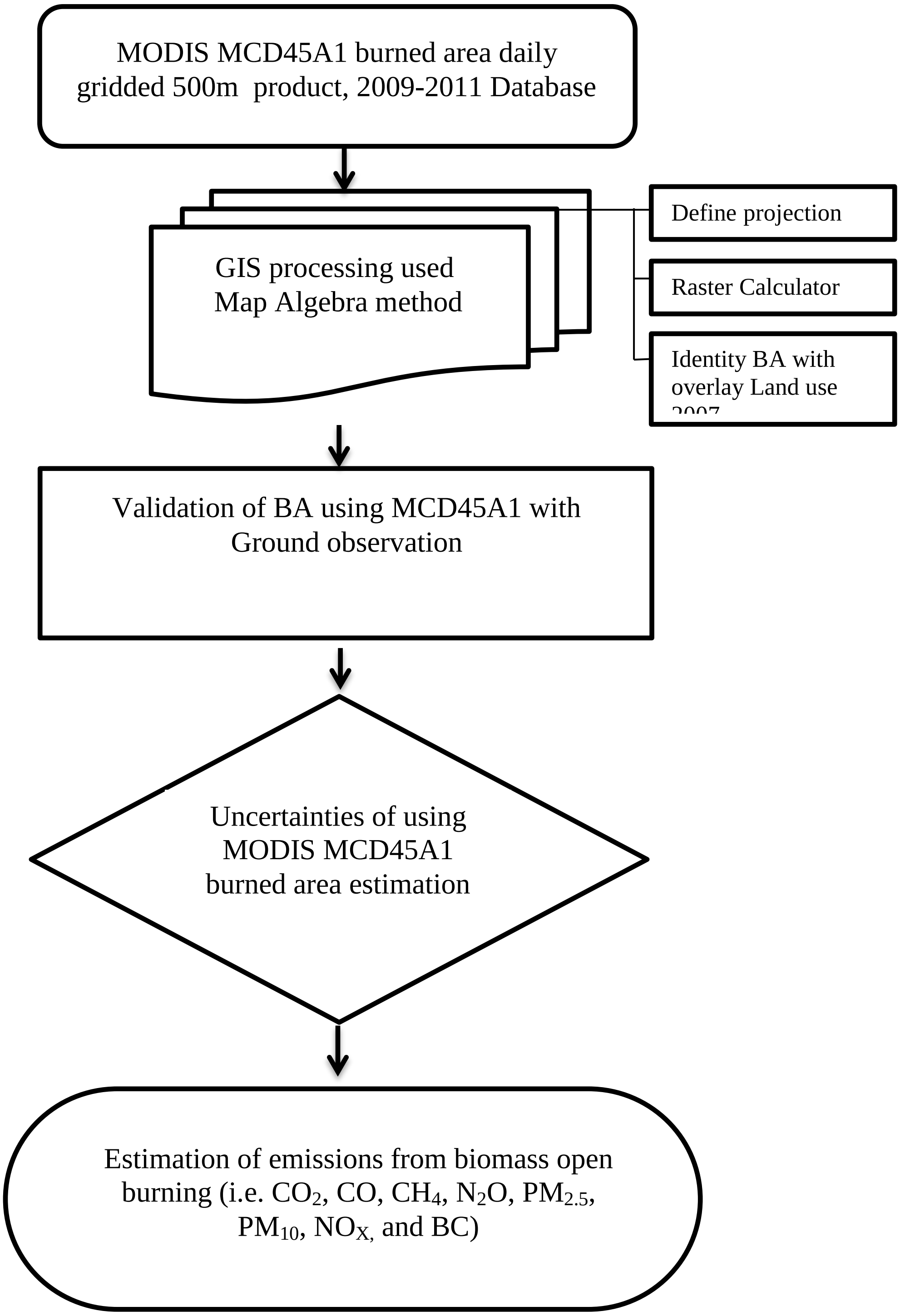


Figure 3.1 Flow chart of methodology for assessment of spatial and varied derived from MODIS Burned Area Product (MCD45A1)

3.2.1 Description of MODIS Burned Area MCD45A1 Product

This section explains some of the standard technical terms used in the documentation of the standard MODIS products. The global MODIS Collection 5 burned area product (MCD45A1) on the Terra and Aqua satellites, has specific features for monitoring a bidirectional reflectance model based on a change detection approach. It is applied independently to each gridded MODIS pixel to take advantage of spectral, temporal and structural changes that characterize vegetation fire. The MODIS burned-area product is available as a monthly Level 3 gridded 500m product containing per-pixel burning, quality information, and tile-level metadata. Additionally, we can download from an ftp server, which is maintained by the University of Maryland, mostly to provide support to the science users who need to download systematically large volumes of data. The website for this download is: http://modis-fire.umd.edu/. In order to obtain a username and password for the server, we can request permission to use the server and fill in a user online form for statistical purposes.

In this study the format type we use is Geotiffs, following a naming convention similar to the official MCD45A1 that was obtained by mosaicing, resembling and re-projecting several tiles of original product, the processing such as filename of the product. In addition to burned area product (MCD45A1), System (EOSDIS), and Core System (ECS), there are a set of specific products which have the advantage of identifying burned area and analyzing data, such as finding the percentage of land pixels detected as burned, the percentage of pixels in each of "BA pixel QA' categories, and the number of pixels detected in each direction in time (forward, backward or both). We can use geographic information system software to display, subset, and classify the data of the burned area for Thailand. The data to show a given month in Julian days is either in distinctly independent colors or in the same color, depending on our settings.

3.2.2 Materials and Methods

- **Data collection**

This study uses burned area product (MCD45A1) Collection 5, which covers a period from 2009 to 2011. It was developed by the MODIS Rapid Response Project; NASA/GSFC (Producer), from the University of Maryland, Information for Resource Management System (Distributor) The data is available online at http://ba1.geog.umd.edu/TIFF/. Our area of study was located in South East Asia (SEA). We can subset the data to the whole of Thailand. Therefore, the burned area product

(MCD45A1) summary of methodology for assessment of spatial and varied burned area is shown in Table 3.1 Assessment of burned area using burned area product (MCD45A1) used GIS program to analyze burned areas.

Table 3.1: The summary of methodology for assessment of spatial and varied burned area

Input data	Data processing Steps
– Burned area of MCD45A1 product input data to GIS program. – Land use map 2007 to GIS program. – Calculation of estimate emissions from biomass open burning after – validation of BA.	– Input all of Burned data into GIS Software (ArcGis ver.9.3) – Classify area of interest (SEA window) – and then focus the subset within Thailand – Using spatial analyst tool to ArcGis 9.3 – To Raster calculator for maintaining the burned dates – Reclassify raster-discarding burn dates – Create Vector layer from Raster layer – Calculate raster burned area by Spatial analyst Tool – Overlay and intersect the burned area that identifies cover forest and agricultural land – Create distribution of burned area (A) during period 2009-2011 – Estimation of emissions by trace gases

- **Land cover characterization**

The area burned of biomass open burning is classified by type of fire: forest fire and agricultural fire. The classification is done by overlaying the Burned Area (BA) data on a land use map (LDD, 2007) of 2007, developed by the Land Development Department (LDD) using GIS program. The overlay is shown in Figure 3.1. For burned area estimation, this study uses resolution 0.5km x0.5km of pixels as a representative of burned area of forest fire and agricultural burning. The result of the spatial and temporal variations of the burned area is presented in a map of burned areas from year 2009 to 2011.

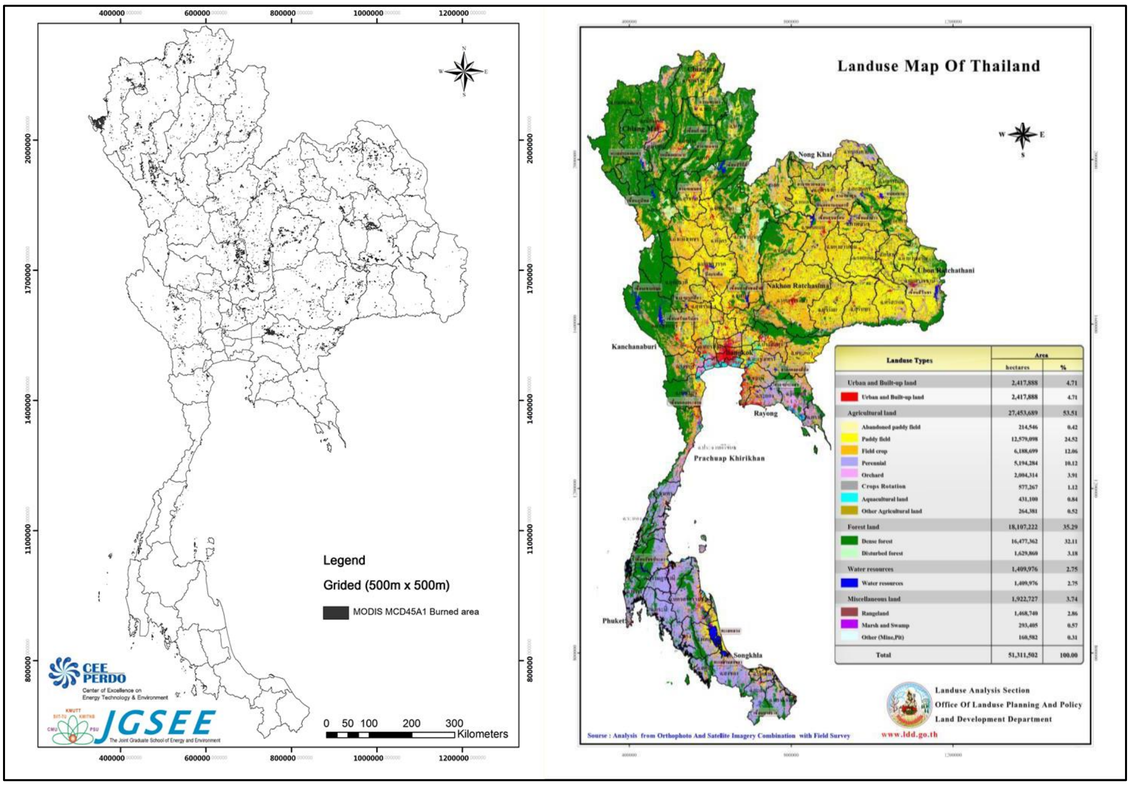


Figure 3.2 MCD45A1 Burned area classification with Landuse map using GIS system (LDD, 2007)

- **Data analysis**

(1) The The burned area product (MCD45A1) data is available online at http://ba1.geog.umd.edu/TIFF/. Our area of study waslocated in SEA. The data is subset to the whole of Thailand. The data during 2009-2011 was obtained from the Information for Resource Management System (Distributor) University of Maryland.

(2) The data provides the burned areas in Julian days (day 001-365) for any given month during 2009-2011. Then all of the data are input to a Geographic Information System (GIS) program. Firstly, to define the projection of all burned areas of Thailand, as World Geodetic Systems (WGS) 1984 UTM Zone 47N projected coordinate systems and WGS 1984 datum on geo-processing framework, such as spatial analysis tools, was used. These are applications in which we created, edited, and managed burned area data sets from 2009-2011 within Thailand. This study focused on the most confidently detected pixels, regardless of direction in time.

(3) To classify and match the type of burned area with land use that covers the whole of Thailand, and particularly, focusing on forest land and agricultural land. This study uses land use data for year 2007 from the Land Development Department (LDD), Thailand Agricultural land.

(4) To analyze the spatial distribution of the burned area occurrences on forest land and agricultural density mapping between 2009-2011. Generally, the burned area was at a resolution of 0.5 km ×0.5 km. This study creates and shows the result of spatial distribution size of the burned area from 10 km × 10 km per grid/100 km^2 which is able to clearly able to present the density of burned area, and to prepare for estimation of air pollutants. Moreover, appropriate spatial resolution for the setting of a forest fire management plan by identification of type of burned area overlaid with land use (base year 2007 (LDD, 2007)) from burned area product (MCD45A1) uses a geo-processing tool. The geo-processing tool provides the ArcGis program into a grid map, and then presents the results in terms of density of burned area per grid map by trace gases.

- **The map of emissions estimated from biomass open burning in grid (ton per 10,000 ha)**

The spatial and temporal variations of biomass open burning emissions are represented in a grid density emission map. The emissions in each grid estimated from the biomass open burning emissions equation is shown in Equations 3.3 and 3.4 from (IPCC, 2006). The biomass open burning area was obtained by burned area from the burned area product (MCD45A1) with burned area that has an adjusted factor for each of the burned pixel before input of the entire BA to calculate the emission estimation. The estimations consist of biomass density, combustion efficiency, and emission factors, which will use the information from Table 3.2 to 3.4.

The emissions map represents the cumulative emissions for forest fire seasons from 2009-2011. We focus on the emissions emitted in the grid area. The size of the grid area was 10 km × 10 km /(10,000 ha) and represented a sufficient resolution for the implementation of forest fire control. It was also appropriate to clearly display the air pollutants for the whole of Thailand.

3.3 Validation of burned area with ground observation

At present, the data from the MODIS sensor on the TERRA and AQUAR satellites has the capability to find the burned area of biomass. For this study, the burned area was determined using the burned area product (MCD45A1) estimation of area burned, and validated with the ground observation measurement method. The methodology of burned area estimation from biomass burning is as follows:

- To select the validated site from FHS information from Geo-Informatics and Space Technology Development Agency (GISTDA) during January to March 2012, the number of validated sites was about 90 sites, including 30 sites for forest land, 20 sites for paddy field, 20 sites for sugarcane-field, and 20 sites for corn-field. The validated site of the forest fire was in Chiangmai, whereas the validated site of agricultural burning was in Ayutthaya, Phetchabun, Lopburi and Nakhonratchasima. The validation was done during December, 2012 to March, 2013.
- To track the contour of burned areas in the validated site by using a global positioning system (GPS) Gamin60SX units
- To measure the topography characteristics, as altitude and slope, by measuring altitude in the center, upper and lower areas of the sampling plot by using a global positioning system (GPS) associated with SRTM to provide digital elevation data (DEMs) 30 m also. These data was used to calculate the percent of the slope. The percent of the slope was calculated from the distance of the vertical (v) height divided by the distance of the horizontal length (h)

$$\text{Percent of slope} = v/h \times 100\% \qquad (3.1)$$

- To assess the adjusted factor for each area by using a simple linear regression analysis between the burned area derived from ground observation (y) and the burned area derived from MCD45A1 (x).The slope of the linear regression was the adjusted factor, as shown in Equation 3.2.

$$y = bx \qquad (3.2)$$

3.4 Estimation of Biomass Open Burning Emissions

- **Materials and Methods**

(1) Equation of emission estimation

In this study, we use the estimation equation of biomass open burning emissions from IPCC, (2006). From the equation, we find that open biomass burning emissions is the relationship between the amount of burned fuel (BF) and emission factor (EF) as shown in Equation 3.3. The amount of burned fuel is derived by the relationship between area burned (A), mass of fuel available for combustion (M), and combustion factor (CF) as shown in Equation 3.4.

$$E = A \times EF \qquad (3.3)$$

$$A = BA \times BF \times CF \qquad (3.4)$$

Where: E = amount of emissions from fire, tones of each air emission e.g., CO_2, CO, CH_4, N_2O, BC etc.

A = amount of burned fuel, (tons dry matter burned)

EF = emission factor, (g of gas kg^{-1} dry matter burned)

BA = burned area, (ha)

BF = biomass fuel available for combustion, (tons ha^{-1}). This includes biomass, ground litter and dead wood.

CF = combustion factor (dimensionless kg/kg)

- **The amount of burned fuel (A)**

The amount of burned fuel is given by the area burned and the density of the fuel present in that area. The fuel density includes biomass, dead wood and litter, which vary as a function of the type, age and condition of the vegetation. Moreover, the type of fire affects the amount of fuel available for combustion.

- **Emission factor (EF)**

The emission factors were obtained from the study of (Andrea and Merlet, 2001) by choosing the emission factors of tropical forests and agricultural residue burning. The emission factor used in this study was found to be a suitable factor for Thailand from various case studies in terms of biomass open burning in Thailand as shown in Table 3.2.

Table 3.2 Emissions factor of tropical forests and agricultural residues

Vegetation type	Emission factor of forest and agricultural residue burning (g kg^{-1} dry matter burned)							
	CO_2	CO	CH_4	N_2O	PM_{10}	$PM_{2.5}$	NO_x	BC
Tropical forest	1580	104	6.8	0.2	11.4	9.1	1.6	0.66
Agricultural residues	1515	92	2.7	0.07	13.0	3.9	2.5	0.69

Sources: Andrea and Merlet, (2001) reported that the value of *EF* as CO2, CH4, N2O, NOx, PM2.5, PM10, BC, etc. for agricultural open burning by extrapolation from the best value.

- **Burned Area (BA)**

In this study, we use the satellite data from the burned area product MODIS-MCD45A1 with a 0.5km × 0.5km spatial resolution to estimate the burned area during 2009 to 2011which obtained from ftp://ba1.geog.umd.edu/TIFF/. The data was assessed for the size of burned area and classified for the type of fire by using GIS. The classification based on the land use information from Land Development Department (LDD) of 2007. Then, the burned area was multiplied with the adjusted factor to assess the actual burned area.

- **Biomass fuel available for combustion (BF)**

This study collected the value of the mass of fuel available for combustion from the previous study and selected the country specific value. The average biomass density used in this study was 3.76 tons/ha for forest (Junpen and Garivait, 2011), 2.37 tons/ha for rice field (Garivait, 2012), 6.20 tons/ha for corn and 2.47 tons/ha for sugarcane (Andrea and Merlet, 2001). The estimation method for each biomass type is summarized in Table 3.3.

Table 3.3 Biomass fuel of tropical forest and agricultural residues

Biomass Fuel (tonns/ha)			
Forest[a]	Rice paddy[b]	Corn[c]	Sugarcane[c]
3.76	2.37	6.20	24.70

[a]Junpen and Garivait, 2011,[b]Cheewaphongphan and Garivait, 2012,
[c]PCD, 2005

- **Combustion factor (CF)**

The combustion factor is a determination of the proportion of the real combusted fuel, which varies as a function of the size and construction of the fuel load, the moisture content of the fuel and the type of fire. The average of combustion factor used in this study was 0.79 for forests (Junpen and Garivait, 2011), 0.87 for rice fields (Cheewaphongphan and Garivait, 2012), 0.20 for corn and 0.39 for sugarcane (PCD, 2005). The estimation method to quantify the combustion factor for each type of field is summarized as in Table 3.4.

Table 3.4 Combustion Factor of tropical forest and agricultural residues

Combustion Factor			
Forest[a]	Rice paddy[b]	Corn[c]	Sugarcane[c]
0.79	0.87	0.20	0.39

[a]Junpen and Garivait, 2011,[b]Cheewaphongphan and Garivait, 2012,
[c]PCD, 2005

- **Assessment of the emission estimation**

After the completion of the second process, we substitute the results of each factor into Equation 3.3 and 3.4 for the assessment of the emissions from biomass open burning. Then, we input the value mass of fuel available for combustion, area burned, combustion factor, and amount of emissions from fire into GIS software for calculation of all factors and creation of an air pollutant map of each trace gas. To represent the emission perform to the spatial distribution by emission grid density in 100 km^2 per grid. The result is represented in a map that patterns the result into the pixel area format. Thus, a pixel represents an emission for each vegetation by type of Greenhouse Gas (GHG) and air pollutant; the amount of CO, CO_2, CH_4, N_2O PM_{10}, $PM_{2.5}$, NO_x and BC. The GHG emissions and air pollutants are related to making the inventory emission map for biomass open burning in Thailand from 2009-2011. The results of this study were compared to the result of the Global Fire Emissions Database version 3 (GFEDv3.1), which provides monthly biomass burning data based on MODIS burned area (ECCAD, 2013).

4.4 Biomass Open Burning Emissions

This chapter details the assessment of the spatial distribution of agricultural burning and forest fires from biomass open burning emissions by trace gases in Thailand. The gaseous emissions consist of major greenhouse gases which are carbon monoxide (CO), carbon dioxide (CO_2), and minor greenhouse gases such as methane (CH_4), nitrous oxide (N_2O) and particulate matter ($PM_{2.5}$) particulate matter (PM_{10}), nitrogen oxides (NO_x) and black carbon (BC). From 2009 to 2011, the results are illustrated as the total yearly emissions by spatial distribution of trace gases emissions. Furthermore, the results can use the database of greenhouse gas emissions for wildfires in Thailand.

4.4.1 Total Emission estimation using burned area products (MCD45A1)

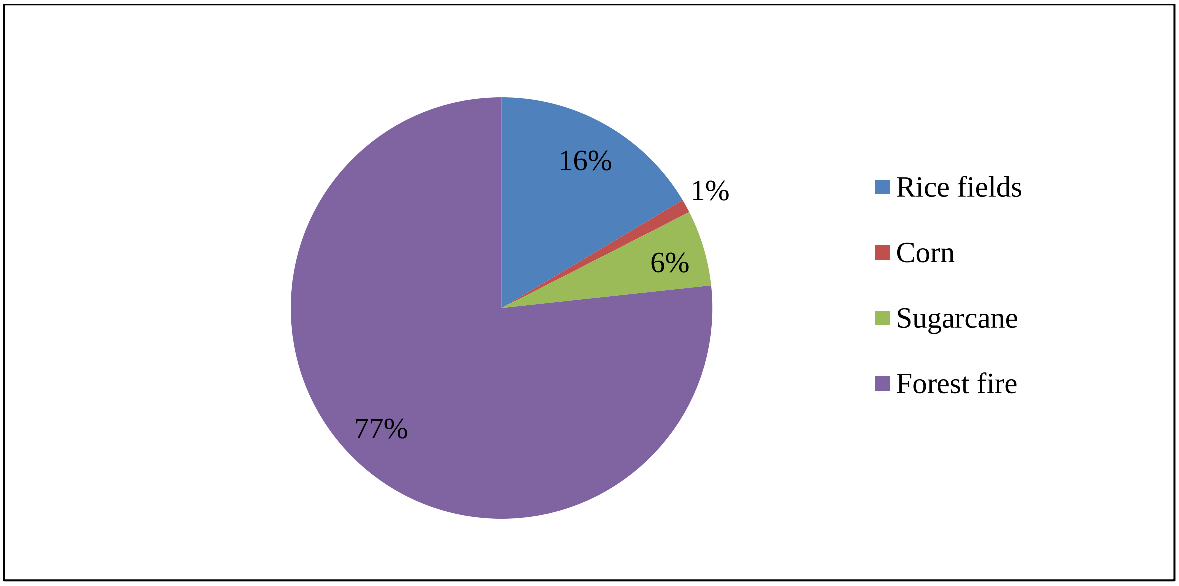
Regarding the estimation of emissions from biomass open burning emissions using (MCD45A1) in Thailand from 2009 to 2011, we found the total emissions of CO_2, CO, CH_4, N_2O ,$PM_{2.5}$, PM_{10}, NO_x and BC to amount to 2,150,077 tons, 163,175 tons, and 7,704 tons, 221 tons, 10,469 tons, 16,571 tons, 2,841 tons and 1,014 tons, respectively. Considering the distribution of biomass open burning cumulative emissions, we found that over 3 years, greenhouse gases and particulate matter were most emitted in March. Especially from 2009-2010, the amounts of emissions are shown in Table 4.9. Considering a trend of change in air pollutant emissions, it was similar to a trend of change in forest fire and agricultural residue of each year, as discussed. Whereas in year 2011, there was a natural disaster of mega flooding that covered Thailand and the emissions are less than other years.

Considering the distribution of biomass open burning emissions in year 2009, we found that the emissions of CO_2, CO, CH_4, N_2O , $PM_{2.5}$, PM_{10}, NO_x and BC amounted to 815,212 tons, 62,184 tons, and 2,845 tons, 82 tons, 93,886 tons, 6,245 tons, 1,105 tons and 386 tons, respectively. In 2010, we found that the amounts of CO_2, CO, CH_4, N_2O, $PM_{2.5}$, PM_{10}, NO_x and BC were about 984,890 tons, 72,554tons, and 3,684 tons, 106 tons, 4,988 tons, 7,484 tons, 1,226 tons and 457 tons, respectively. In 2011, we found at emissions of CO_2, CO, CH_4, N_2O ,$PM_{2.5}$, PM_{10}, NO_x and BC amounted to 349,975 tons, 28,437 tons, 1,165 tons, 33 tons, 1,595 tons, 2,841 tons, 511 tons and 171 tons respectively. The greatest amount of emissions was during February to April. The information on annual emission is shown in Table 4.9.

Taking into consideration the percentage of emissions by source, It was found that forest fires had emitted the largest amount of emissions of about 77%, followed by the burning of rice fields (16%), sugarcane fields (6%), and corn fields (1%) in the year 2009. For other years, it had the similar trend as the year 2009. The information of the percentage of source of $PM_{2.5}$ in the year 2009 -2011 is shown in Figure 4.17- 4.19 respectively.

Table 4.9 Annual accumulation of biomass open burning emissions estimation using burned area estimation from burned area product (MCD45A1) in 2009-2011

Year	Open biomass burning emissions, E (tons of trace gases)							
	CO_2	CO	CH_4	N_2O	$PM_{2.5}$	PM_{10}	NO_X	BC
2009	815,212	62,184	2,854	82	3,886	6,246	1,105	386
2010	984,890	72,554	3,684	106	4,988	7,484	1,226	457
2011	349,975	28,437	1,165	33	1,595	2,841	511	171
Total	2,150,077	163,175	7,704	221	10,469	16,571	2,841	1,014



.**Figure 4.17** Share of $PM_{2.5}$ emissions from Forest Fires and agricultural open burning in 2009, Thailand

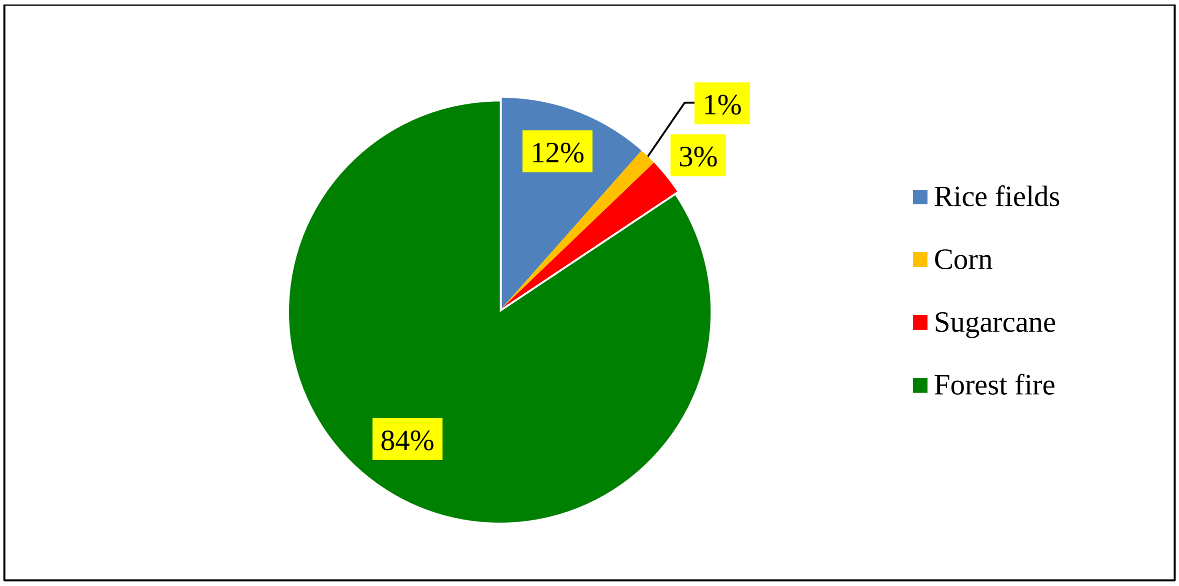


Figure 4.18 Share of $PM_{2.5}$ emissions from Forest Fires and agricultural open burning in 2010, Thailand

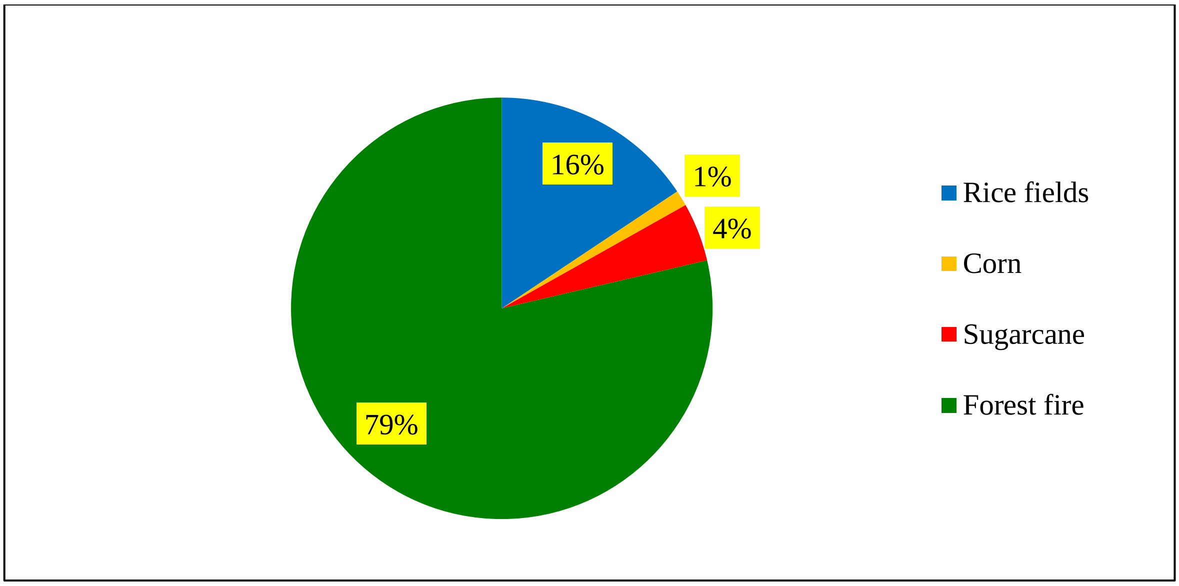


Figure 4.19 Share of $PM_{2.5}$ emissions from Forest Fires and agricultural open burning in 2011, Thailand

4.4.2 Spatial distribution of biomass open burning emissions

The amount of forest fires and agricultural burning emissions are related to the amount of burned area. For example, for 2010, if the CO_2 grid burned area has the highest density (more than 150 ha/10,000 ha), they will emit the emission more than 1,500 tons of CO_2 /10,000 ha (the dark red color). In the grid burned area that has low densities of forest fire and agricultural burning (burned area less than 50 ha/10,000 ha), the amount of emissions emitted will be less than 500 tons of CO_2 /10,000 ha (the light red color). The spatial distributions of the annual map of each trace gases, i.e. CO_2, CO, CH_4, N_2O ,$PM_{2.5,}$ PM_{10}, NO_x and BC, for 2010 are shown in Figure 4.20 to Figure 4.27, respectively.(see more in 2009 and 2011 is show in appendix B)

The highest emission density was found in the forest areas located in the northern, the western, and the upper northeastern regions, and also found in the paddy fields that located in the central and the northeastern regions.

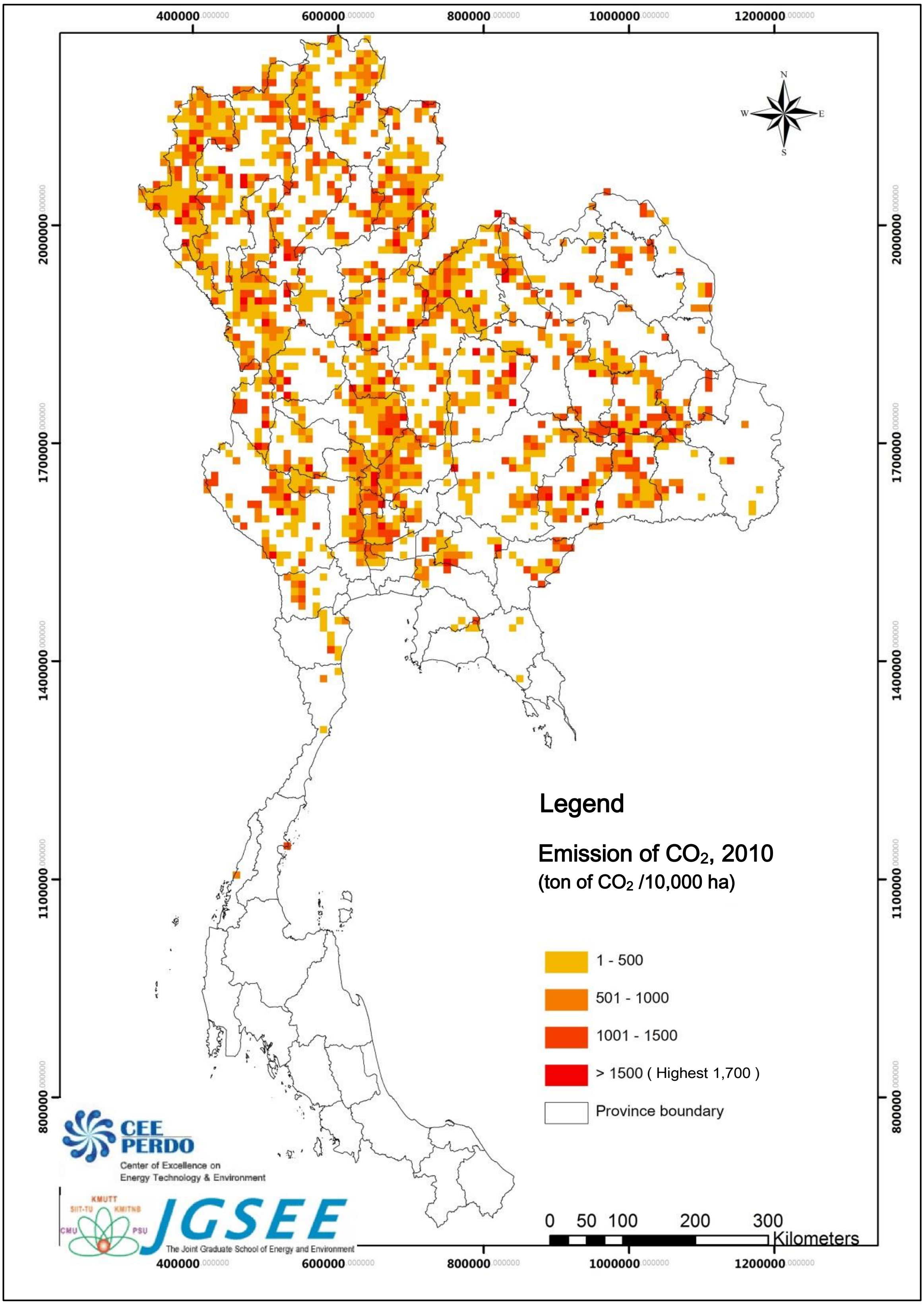


Figure 4.20 Spatial distributions of CO_2 from biomass open burning in 2010

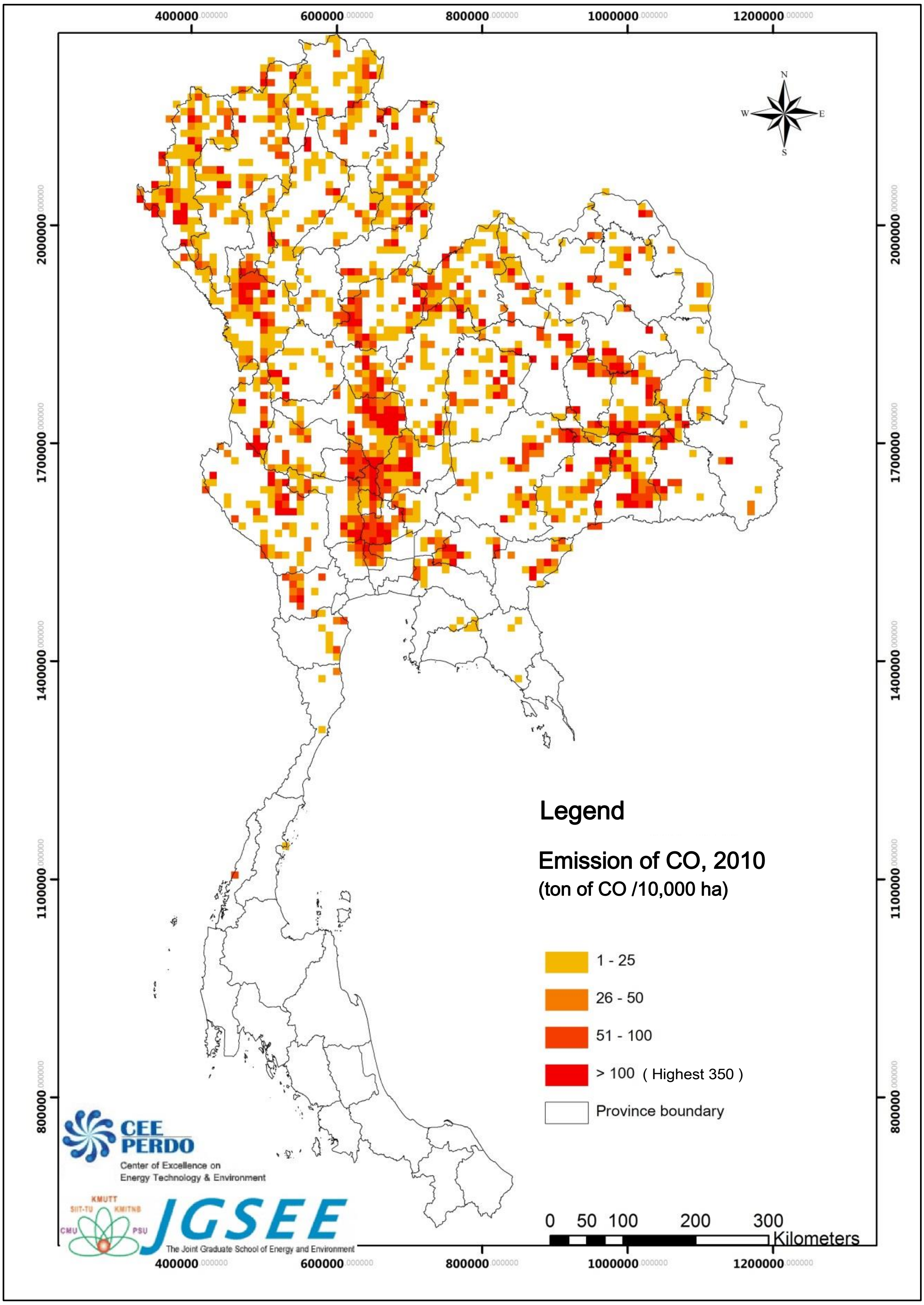


Figure 4.21 Spatial distributions of CO from biomass open burning in 2010

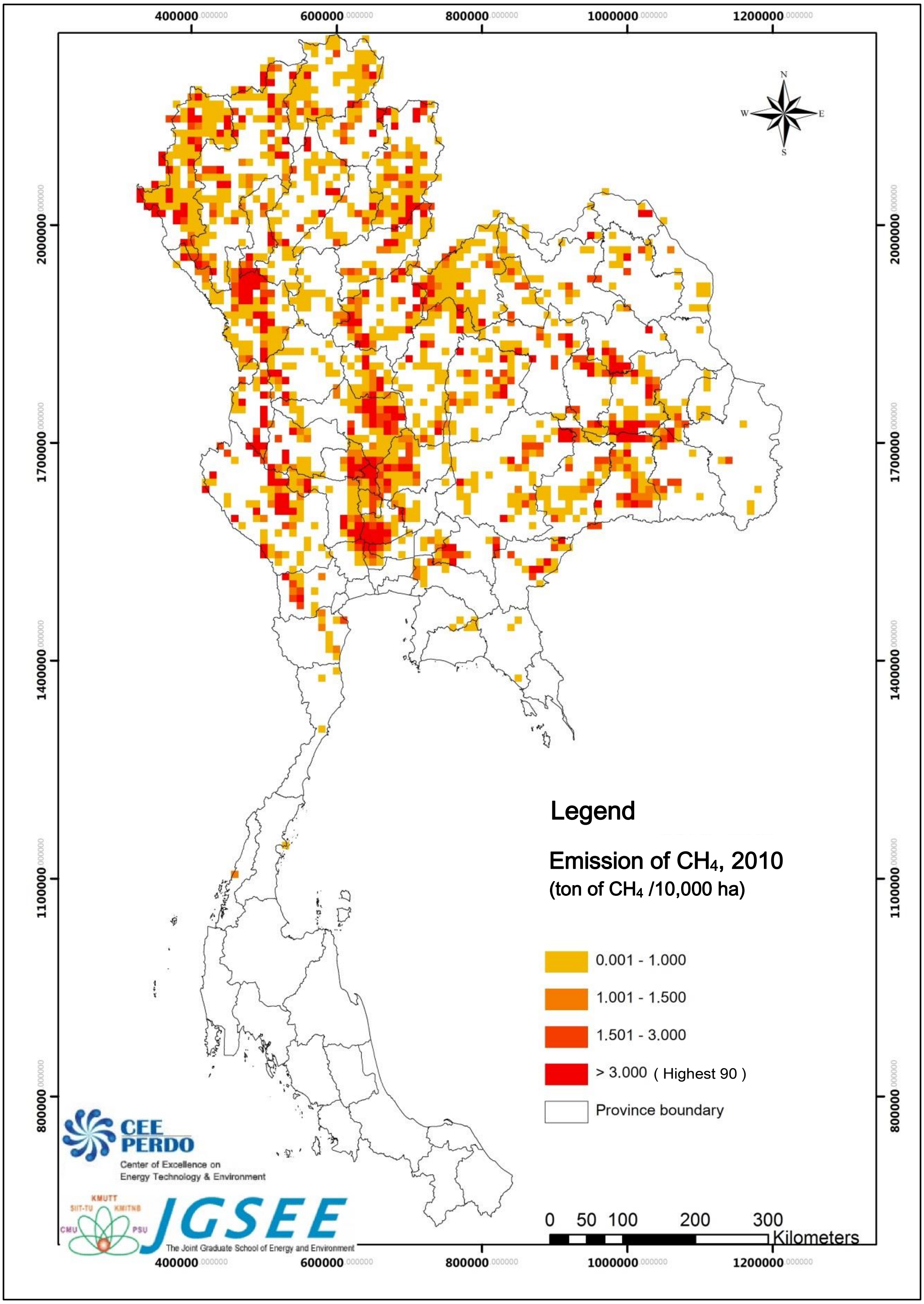


Figure 4.22 Spatial distributions of CH_4 from biomass open burning in 2010

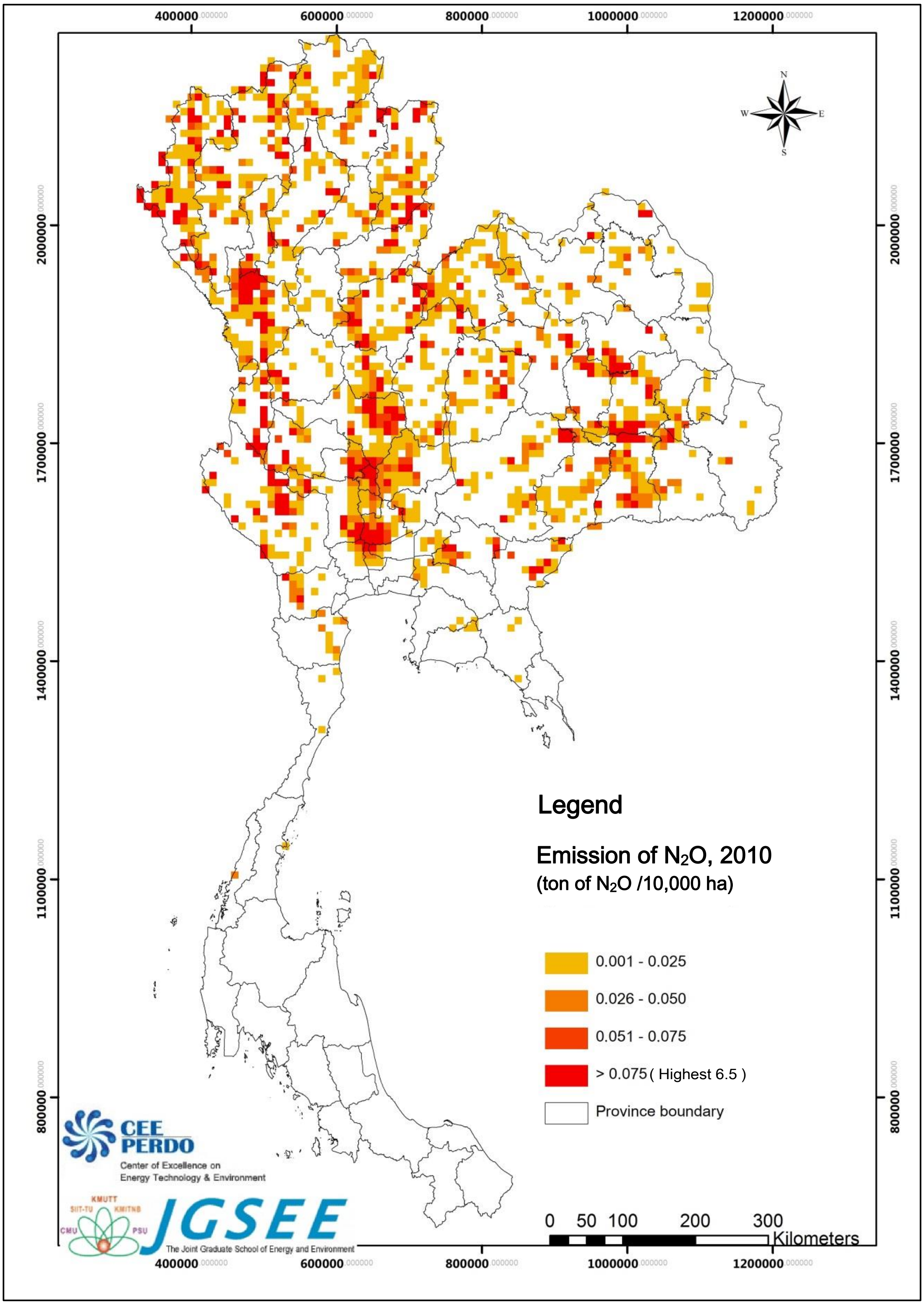


Figure 4.23 Spatial distributions of N_2O from biomass open burning in 2010

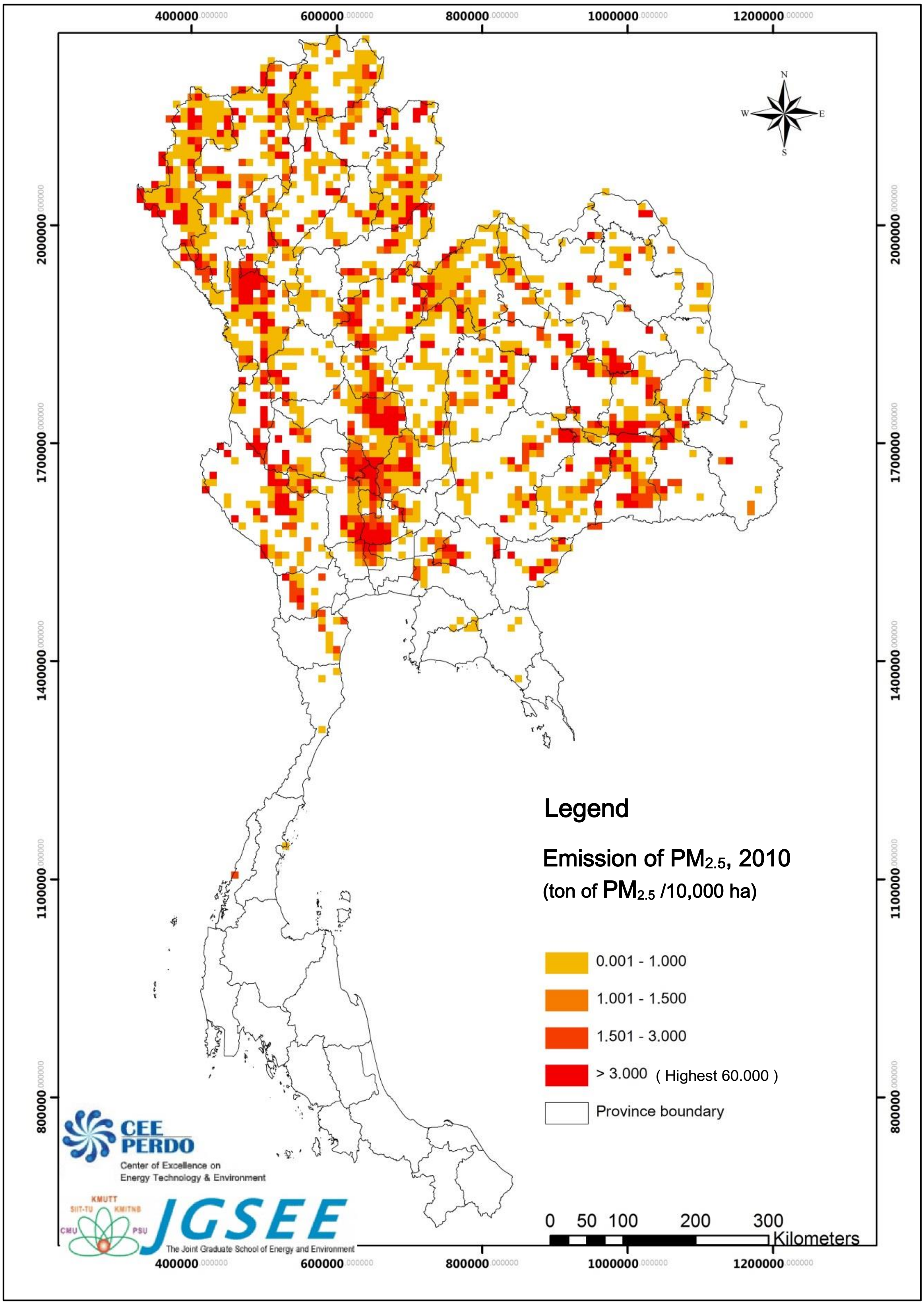


Figure 4.24 Spatial distributions of $PM_{2.5}$ from biomass open burning in 2010

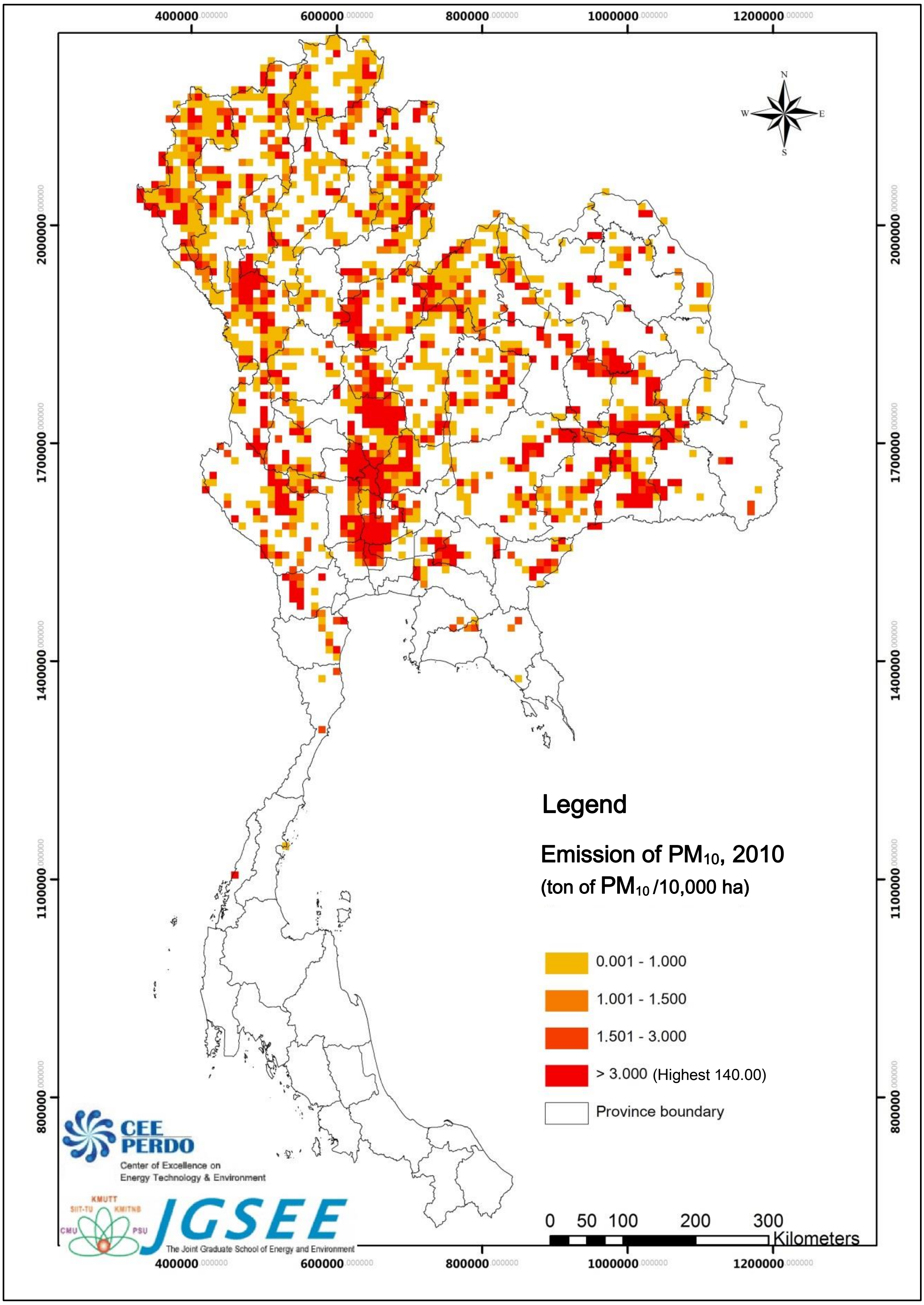


Figure 4.25 Spatial distributions of PM_{10} from biomass open burning in 2010

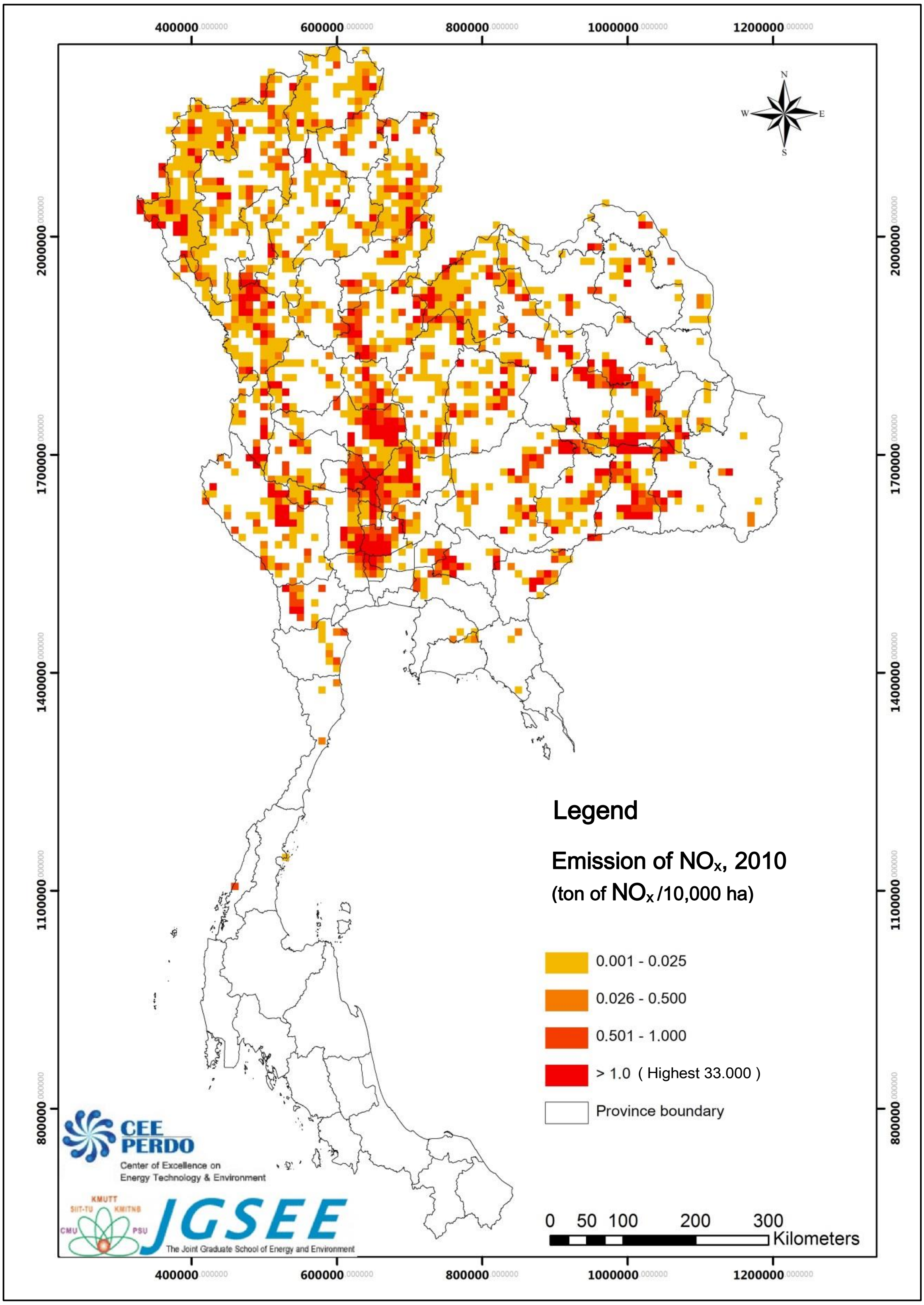


Figure 4.26 Spatial distributions of NO_x from biomass open burning in 2010

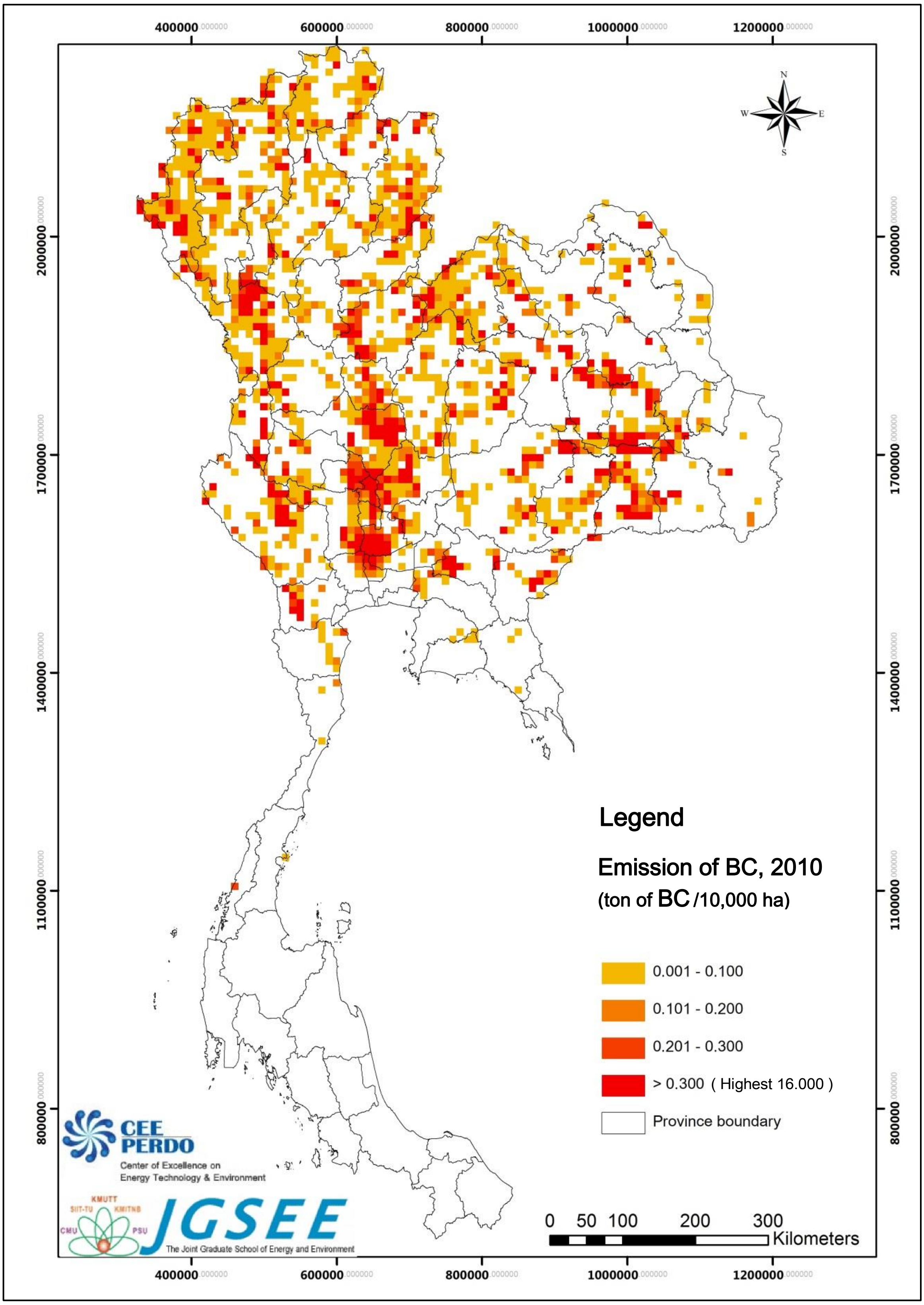


Figure 4.27 Spatial distributions of BC from biomass open burning in 2010

4.4.3 Comparison of emissions estimated with other Satellite Data Products

The GFEDv.3.1 obtained monthly biomass burning base on MODIS burned area which is aggregated resolution from 500m to 50km. These emission estimates was combining with burned area data from MODIS direct broadcast algorithm with a biogeochemical model (CASA-GFED) which is calculated fuel load and combustion completeness for each month (Giglio et al, 2003) and compared with MODIS burned area product base on burned area algorithm detects the approximate date of burned resolution about 500m by located the occurrence of repaid changes in the daily surface-reactance time series data even though those of all product the same retrieval algorithm MODIS sensor onboard the Terra and Aqua satellites (Choi et al, 2013; ECCAD, 2013). The comparison of total biomass open burning gridded emissions estimated distribution derived from GFEDv3.1, and this study in year 2010 for (a) for year 2010 , CO emission estimated for Thailand was approximate 2,769,000 tons of CO from GFEDv3.1 compared with this study using MCD45A1 was approximate 81,181 tons of CO. The results of this study were found to be lower than GFEDv3.1 in forest burning with a range of 16 to 52 times, and in agricultural burning with a range of 5 to 57 times. The results are shown in Table. 4.10

Table 4.10 Comparison of the total biomass open burning emissions derived from GFED v3.1 results in Thailand in 2010 with results from this study.

Emissions	The total of open biomass burning emissions in year 2010 (tons of trace gases)					
	GFED v3.1		This study		Forest Ratio[a] (times)	Agriculture Ratio[b] (times)
	Forest	Agriculture	Forest	Agriculture		
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 fraction between Forest burning emissions derived by GFED v3.1 and this study
[b]Ratio is the fraction between Agriculture burning emissions derived by GFED v3.1 and this study

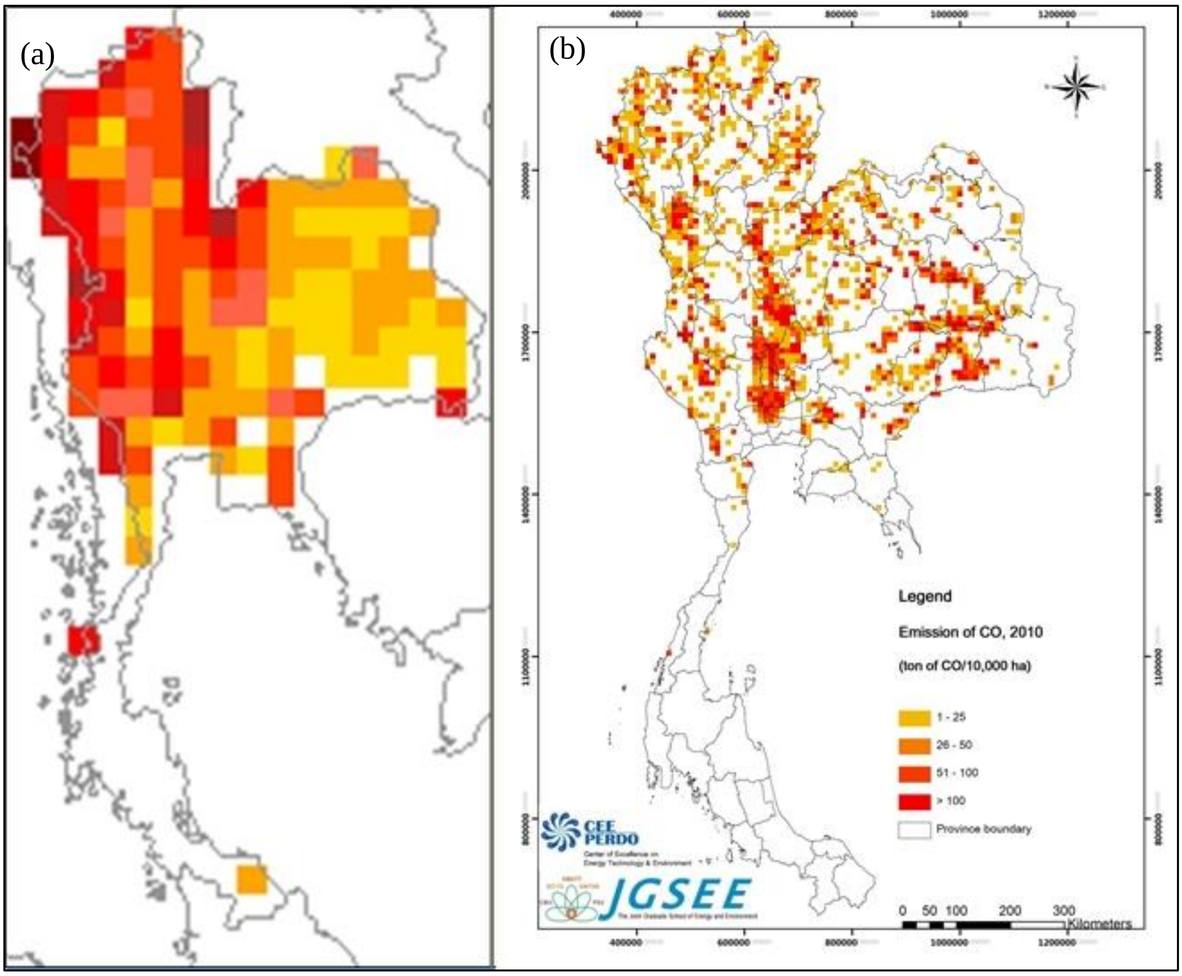


Figure 4.28 Comparison of total biomass open burning gridded emissions estimated distribution derived from GFED v3.1, and this study in year 2010 for (a) GFED v3.1 and (b) MCD45A1 from this study, Thailand

The comparison of the size of gridded emissions from GFED v.3.1 obtained emitted on a global scale resolution at 50km × 50km or 2,500 km^2 per grid. The GFED v.3.1emission gridded data were bigger than 25 times as compared to MCD45A1 estimated emissions. We assumed emissions of CO at 10km ×10km or (100 km^2 per gridded emission) while is the size of the gridded map was a suitable resolution for forest fire management plans in country and regional scales (Garivait et al, 2007). There are two main causes of this large difference as follows: (1) the methodology of the estimated burned area and (2) the selection of fire activity data. Firstly, the main of forest fire area in Thailand is somewhat smaller than the pixel of the regional burned area product. Secondly, the assumption of this study is based on surface fire which do not affect the stand trees and the forest conversion (Janpen, 2011) In addition, there are factors such as the use of biomass load that different possibilities is to evaluate the emission from the GFEDv3.1 using the biomass load factor used in the valuation of land cover-specific conversion factors (Giglio et al, 2006). This study used the country specific conversion factors (i.e. Combustion Factor (CF) Biomass Load (BL) for Thailand. The evaluation algorithm method is rubbing from the satellite data. That means, the biomass load used only the above ground biomass, which does not consider the amount of surface fuel true , neither nor this study used burned area at a resolution of 10 km and use surface fuel to be used from the factor from the literature survey study in country specific each type of biomass burning used in Thailand and the values obtained from the measurement and research in the field actually calculate the amount of air emissions. Therefore, the evaluation of air emissions in the Global Scale (i.e. GFAS v1.0 and GFED v3.1) it is the value of a different emission estimated larger than 25 times, so there is a significant difference compared to the results of this study. The results are shown in Figure 4.28.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Vegetation cover subject of open burning

The analysts of the active fire product from MODIS found that during 2013, the overall number of active fires on forest land and agricultural land was about 12,452 fire hotspots. The highest of number of active fire was in forest land, followed by paddy field, other land, corn and sugarcane respectively. In the other land, it includes settlement land, abandoned land, and disposal site. This study excluded this land because the material burned is an inorganic matter which is not biomass. So, this study focuses only on the biomass burning in the forest, paddy field, sugarcane, and corn. The information of active fire classified by area is shown in Table 4.1.

Table 4.1 Number of active fires detected by MODIS, and forest fires and agricultural burning areas in 2013

Vegetation Cover	Number of Active Fires (FHS)	Percent of FHS (%)
Forest land	5,817	46.7
Paddy field	2,945	23.7
Other land	2,661	21.4
Corn land	563	4.5
Sugarcane field	466	3.7
Total	12,452	100

4.2 Estimation of Burned Estimation Using Burned Area Product (MCD45A1)

4.2.1 Temporal distribution of Burned Area (MCD45A1)

The results from analyzing the burned area from detection by burned area product (MCD45A1) occurring from 2009 to 2011 are shown. After the data was collected and the burned area was estimated the using burned area product (MCD45A1) from 2009 to 2011, we classified and identified the type of burned area which covers the land use map using a land use map from the Land Development Department (LDD) from 2007. The results show the annual burned area product (MCD45A1) of the whole country ranged from 3,327.23 km^2 (332,723 ha) in 2009, to 4,106.36 km^2 in 2010 (410,636 ha), and to 1,444.19 km^2 (144,419 ha) in 2011. Moreover, the temporal span of total burned area from burned area product (MCD45A1) by month for 2009-2011, Thailand is shown in Table 4.2. The area consists of areas of burning which occurred on forest land, including evergreen forest, deciduous forest, and other forests. It also occurred on agricultural lands, such as rice paddies, corn fields, sugarcane, and other agricultural land. The graph of the total burned area from burned area product (MCD45A1) by month from 2009 to 2011, Thailand shows a higher burned area in February and March, whereas, during in June to September for 2009, May to October for 2010 and May to November for 2011, are no fire detection from MODIS burned area product (MCD45A1). The available data from burned area product (MCD45A1) is shown in Figure 4.1.

Table 4.2 Area of burning from burned area product (MCD45A1) classified by land use type for 2009-2011, Thailand.

Vegetation type		Burned area (ha)[1]		
		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 detected during Jun-Sep 2009, May-Sep 2010 and May-Nov 2011

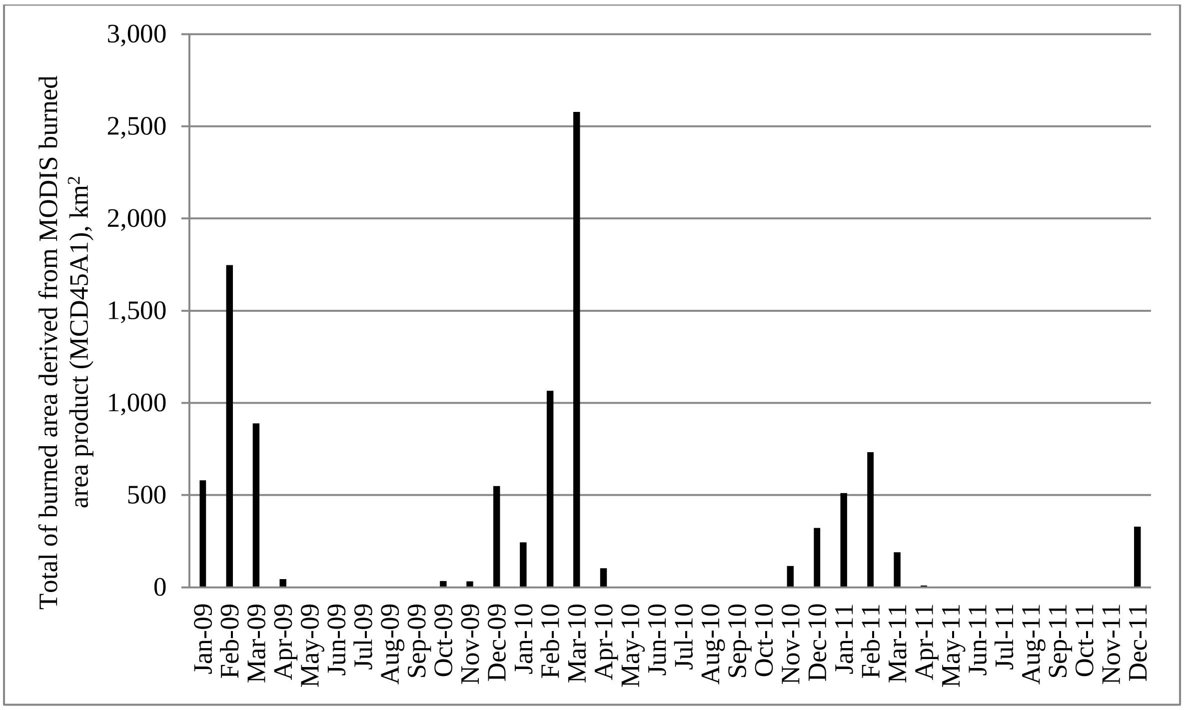


Figure 4.1 Total burned area from burned area product (MCD45A1) by month for 2009-2011, Thailand.

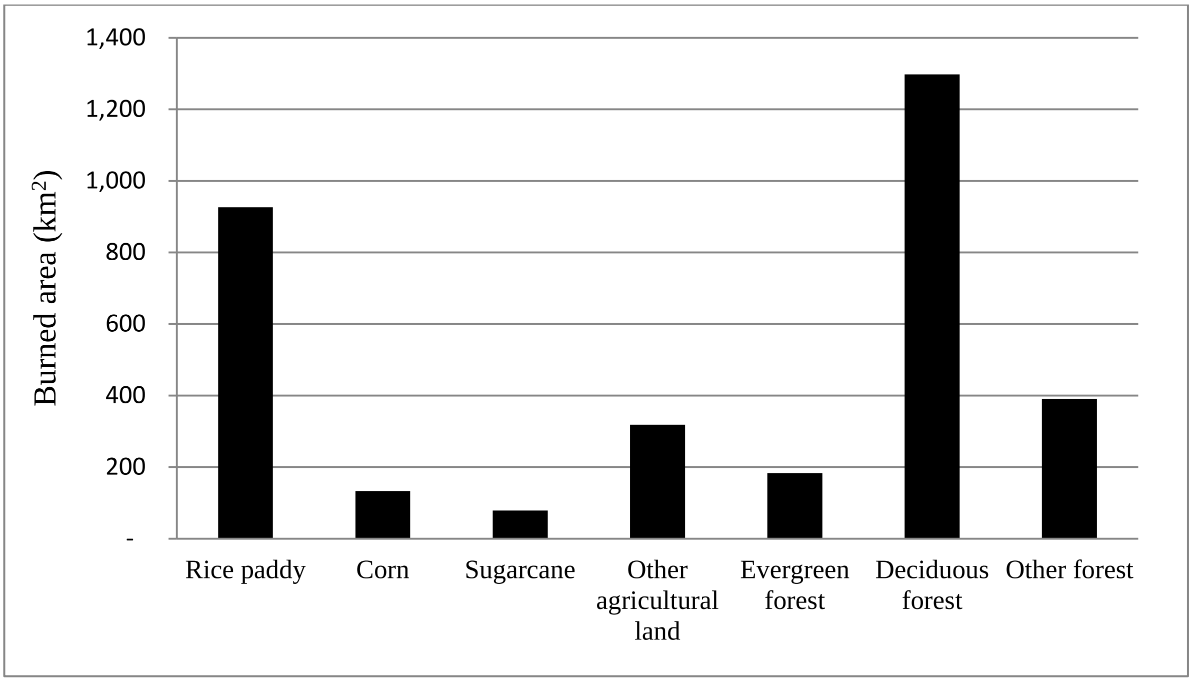


Figure 4.2 Burned areas from burned area product (MCD45A1) by land use type for 2009, Thailand

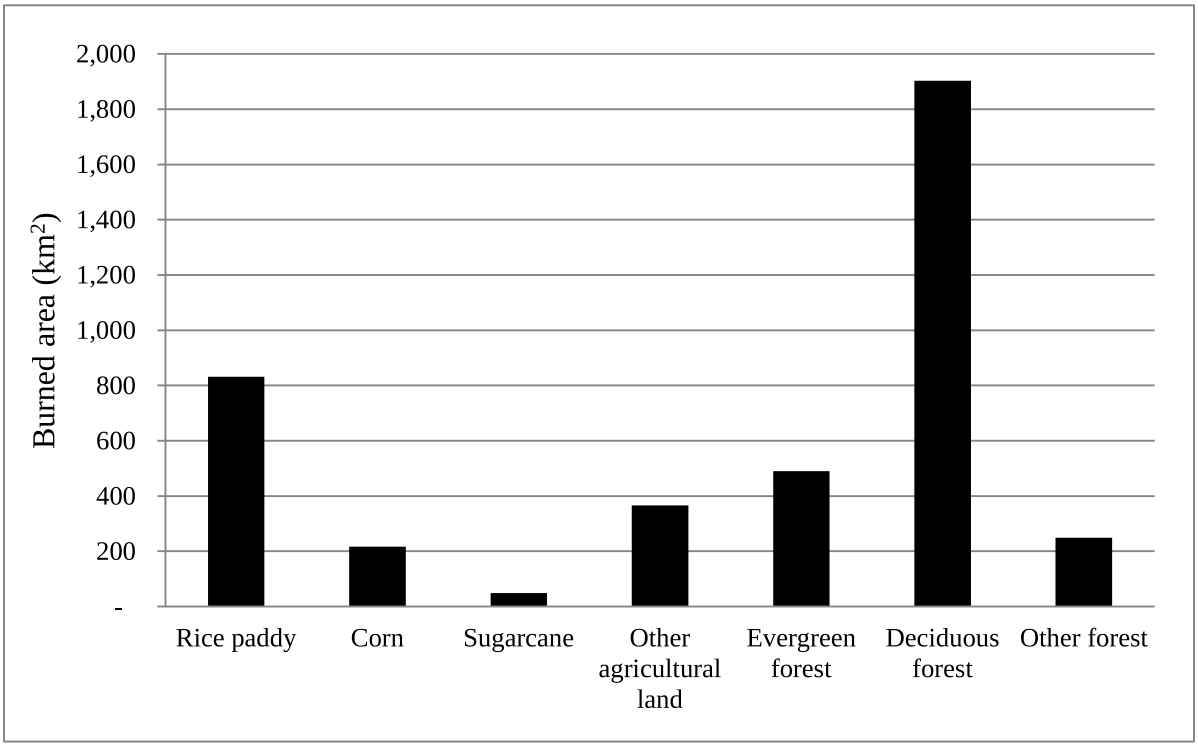


Figure 4.3 Burned areas from burned area product burned area product (MCD45A1) by land use type for 2010, Thailand

In 2009, the display of the BA from the burned area product (MCD45A1) was classified by land use type in Thailand. The land types consist of BA in Forest Land (evergreen forest, deciduous forest and other forest), and also in agricultural land (rice paddy, corn field, sugarcane field and other agricultural land). The main sources come from deciduous forest, rice paddies, and other forest, respectively. The data is shown in Figure 4.2. In 2010, the display of the BA from burned area product (MCD45A1) is classified by land use type in Thailand. The land types consist of BA in Forest Land (evergreen forest, deciduous forest and other forest), and also in agricultural land (rice paddy, corn field, sugarcane field and other agricultural land). The main sources come from deciduous forest, rice paddies, and evergreen forest, respectively. The data is shown in Figure 4.3.

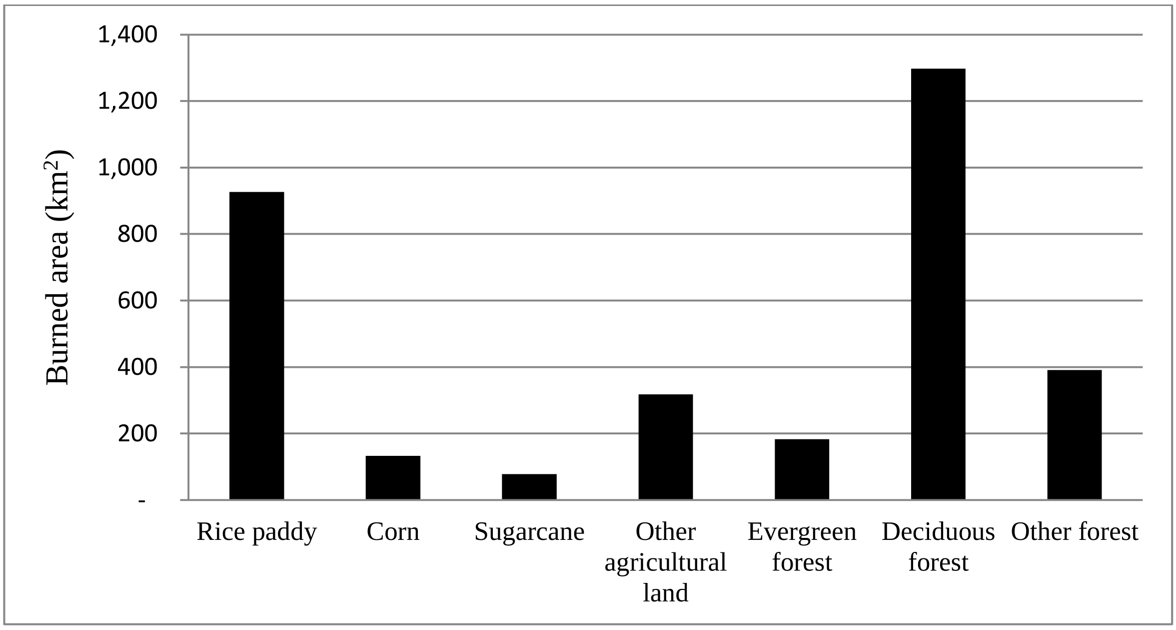


Figure 4.4 Burned areas from burned area product (MCD45A1) by land use type for 2011, Thailand

In 2011, the display of the burned area the from burned area product (MCD45A1) is classified by land use type in Thailand. The land use type consists of BA in both Forest Land and Agricultural Land. The main sources of burned area came from rice paddies, deciduous forest, and other forest. A higher burned area is shown in 2011 when compared with previous years, as shown in Figure 4.4.

4.2.2 Spatial Distribution of Burned Area (MCD45A1)

The objective was to assess the spatial distribution of burned area by month, and to sum the yearly totals for each occurrence from 2009-2011. The spatial distribution of burned area occurring from 2009 to 2011 is displayed in a annual temporal distribution. The occurrence of burned area in forest and agricultural land occurred during December, and then it increased until March. It occurred during the winter season. Perennial trees shed their leaves, which fall to the ground and support the accumulation of surface fuel on the land. In 2009, in the middle of the forest fire season (which is between January to March), the highest total of burned area was detected by the burned area product (MCD45A1). Additionally, that the spatial distribution fraction of burned area by resolution grid size 10 km × 10 km for 2009 to 2011, was the most of area burned area small than 0.5 km^2 shown on the density map. The results of burned area presented in forest land were from data collected in deciduous forests, while the main source for agricultural land were rice paddies. The information of the burned area is shown in Figures 4.5 to 4.8

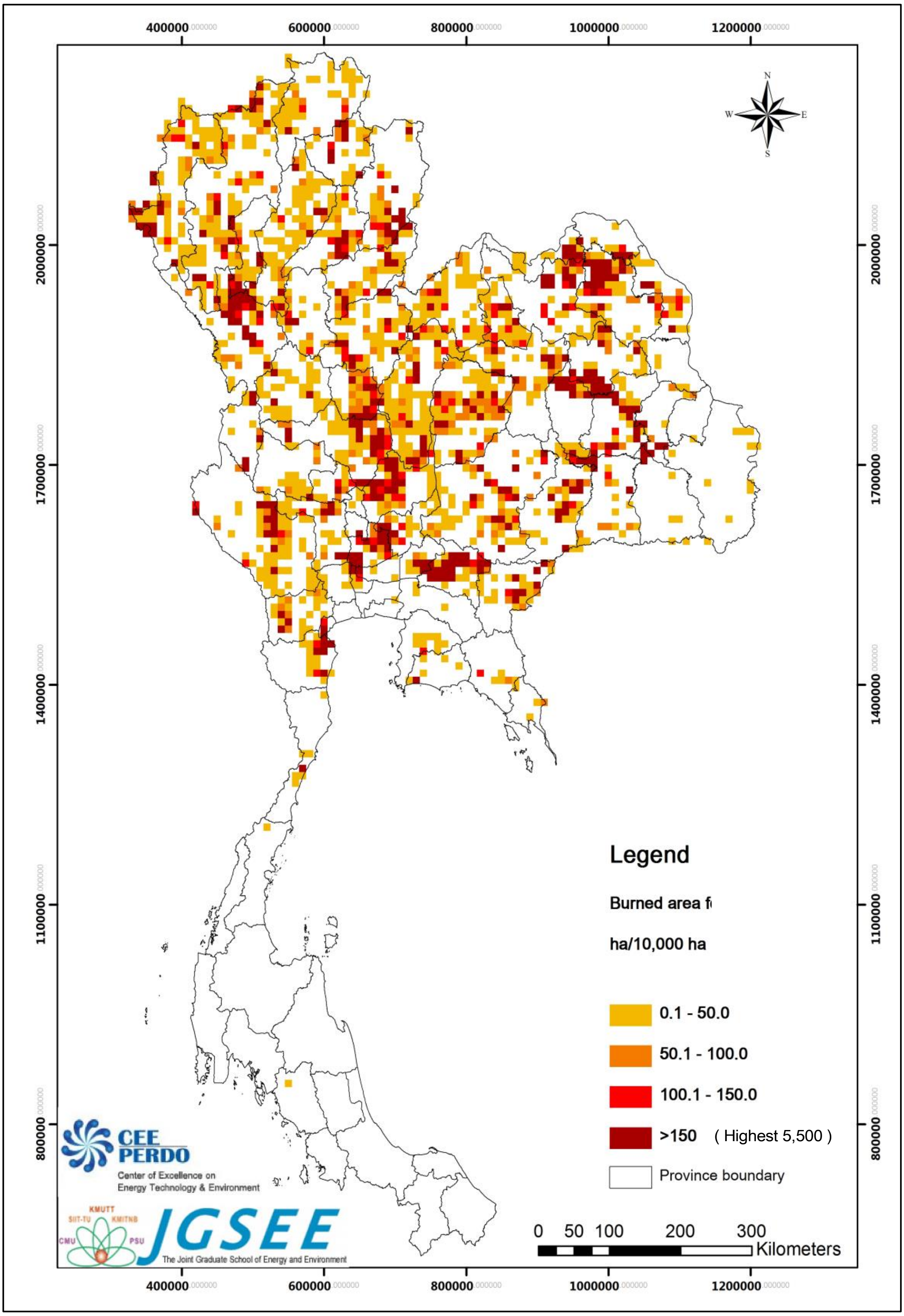


Figure 4.5 The map of fractions of burned areas from burned area product (MCD45A1) in 2009.

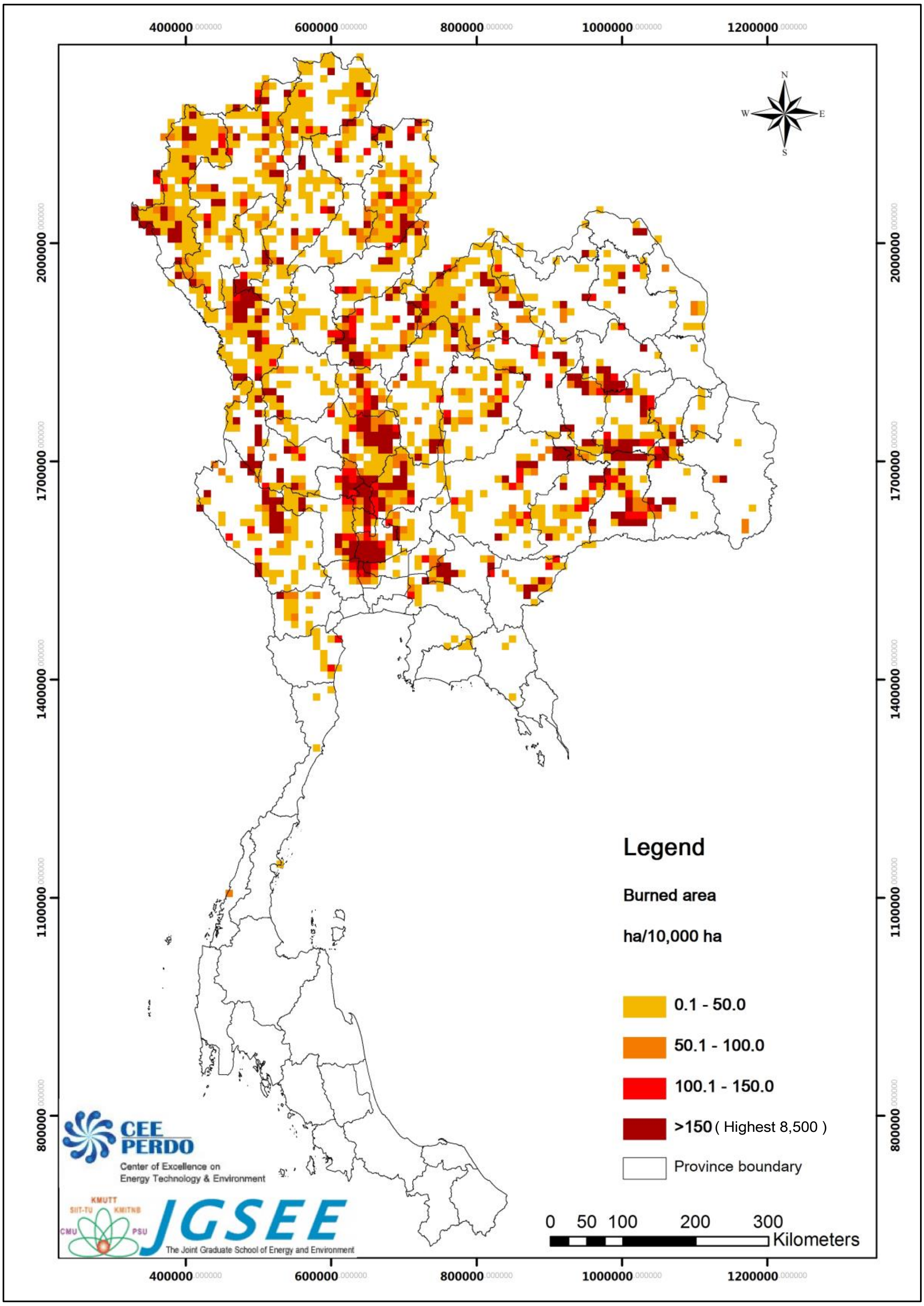


Figure 4.6 The map of fractions of burned areas from burned area product (MCD45A1) in 2010.

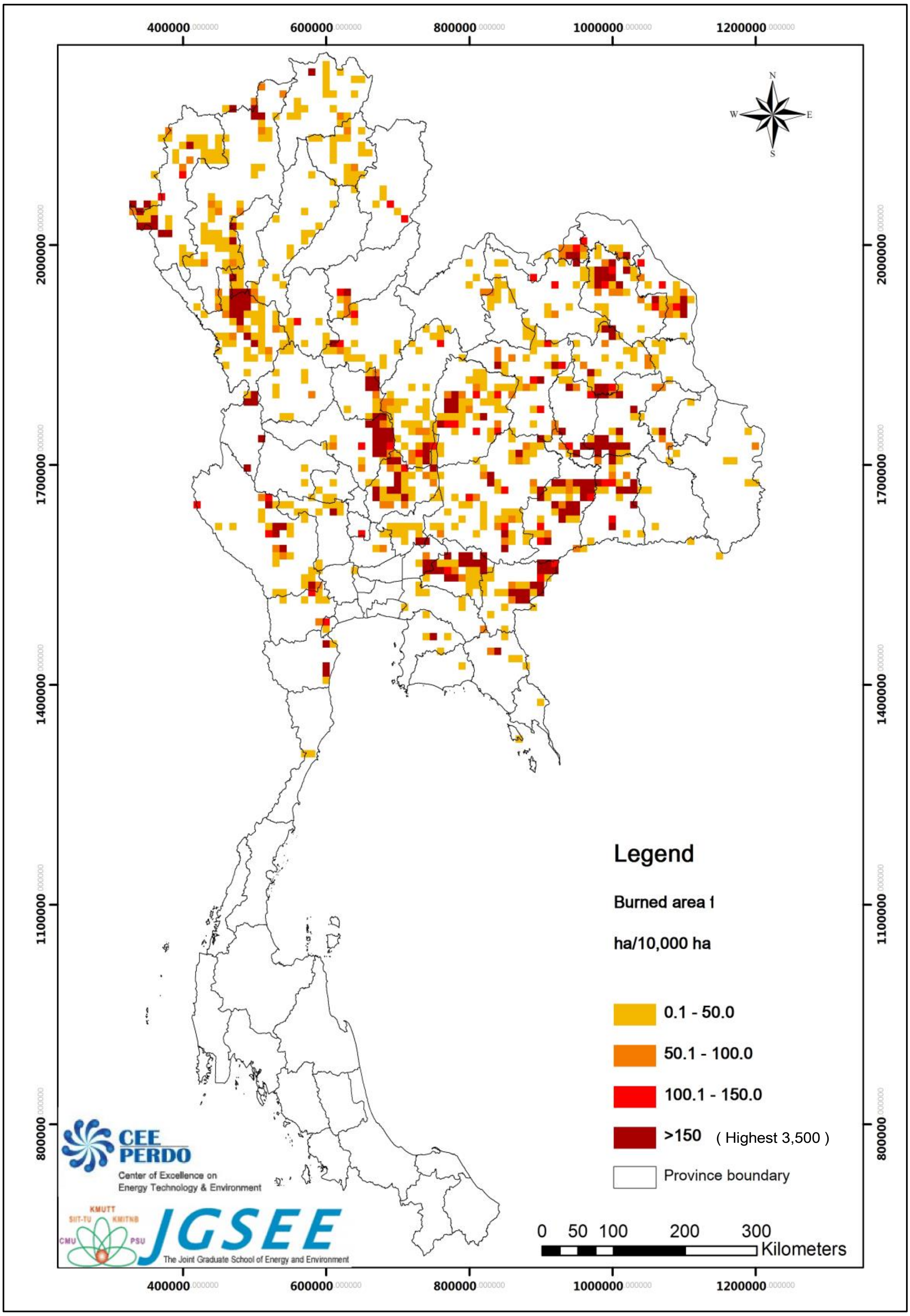


Figure 4.7 The map of fractions of burned areas from burned area product (MCD45A1) in 2011

Considering the temporal distribution of the burned areas from MCD45A1 for the year 2009-2011 (unit: km^2), it was found that the peak period of forest fires was between January and April with a maximum in March (as shown in Figure 4.1). The result is similar to the report from the Forest Fire Control Division National Park. The period between February and April is when it is important to pay attention to forest fires (FFCD, 2009). The total burned area from MCD45A1 by month from 2009 to 2011, Thailand will see higher burned areas in March, whereas from May to October the burned area (BA) is not shown by available data from MCD45A1. The burned area from MCD45A1 is classified by land use type in Thailand and consist of BA in forest land; (evergreen forest, deciduous forest and other forest), and also in agricultural land (rice paddies, corn fields, sugarcane fields and other agricultural land). Therefore, the main sources come from deciduous forest, rice paddies, and evergreen forest, respectively.

Figure 4.8 is shows that also a large amount of burned areas occurred in deciduous forests that are situated in northern Thailand, along the western border with Myanmar and the Huai Kha Khaeng Wildlife Sanctuaries. Within the cores of the deciduous forests, high area slope topography made it difficult to control the forest fires. Most forest fires are burned continuously throughout the day and night and quickly become a large fire that is easily detected by satellite imagery. Moreover, the highest density of burned area was found in the central and northeastern part of Thailand. The area corresponds to rice paddy fields which farmers usually burned after harvesting their rice.

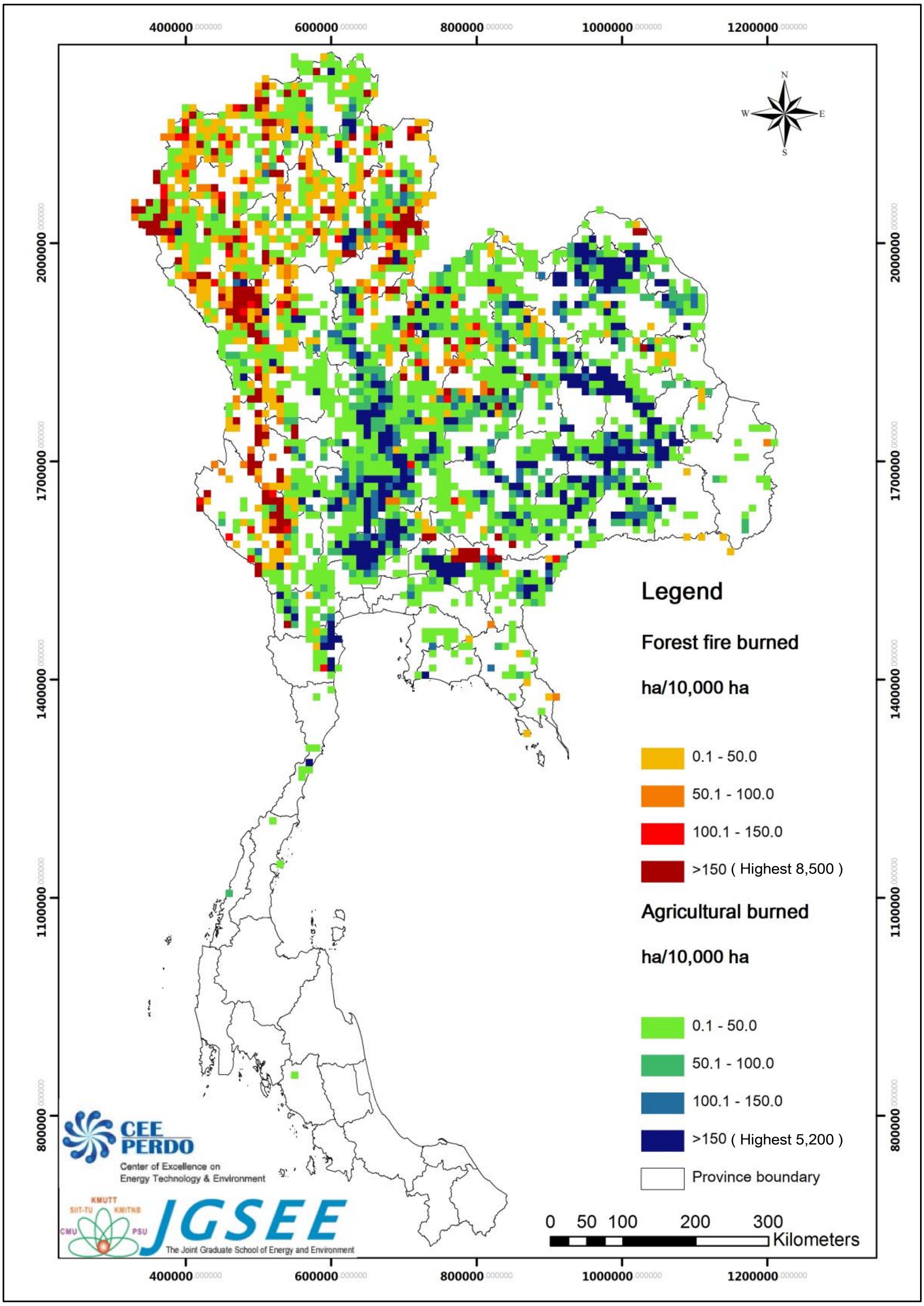


Figure 4.8 The map of fractions of burned areas from burned area product (MCD45A1) of agricultural and forest fires during 2009 -2011.

4.3 Estimation of Adjustment Factor for Burned Areas Estimated Using MCD45A1 Product

4.3.1 Result of Ground Observation

The ground survey at the studied burning sites after having obtained the burned areas from the organization of burned area product (MCD45A1) data between January and March, 2013 was combined using active fire data from fire hot spot (FHS) to help determine where the fires had occurred. We are able to download daily data, which is provided by Geo-Informatics and Space Technology Development Agency (Public Organization) and NASA LANCE Fire Information for Resource Management System (FIRMS) MODIS active fire data. The results from our study showed the higher burned area occurred in relation to time. We focused on going to the experiment site study by motor bicycle and walking, and after that we received results from our site study at Ayutthaya, Lopburi, Phetchabun and Nakhonratchasima provinces. These provinces have continued to find area of burning in agricultural burning from 11 to 13 January, 19 to 20 February, and 20 March, 2013. Forest fire control officers at Chiangmai province on 9 to 14 March, 2013 checked records of amount of area burned from forest fire.

A ground survey was conducted to find the burned areas of biomass burning in agricultural and forest areas. It was done via selection of 20 sampling plots for agricultural area of each type; corn, sugarcane, paddy rice, and 30 sampling plots for forest area. Then we measured the forest fire area by using GPS and imported all of the burned area datasets to GIS software and conducted mappings of burned area, such as checking the records of the amount of area burned from agricultural and forest area. Based on the mappings of forest fire and agricultural areas, and checking 20-30 sampling plots, we found the burned area using burned area product (MCD45A1) data and observation. We found that the burned area derived from MCD45A1 was larger than the burned area from observation in the range of 0.099-0.978 for paddy field, 0.250-0.978 for corn, 0.174-0.930 for sugarcane, and 0.000-1.000 for forest. The information of the burned area derived from MCD45A1 and observation of paddy field, corn, sugarcane, and forest is shown in Tables 4.3-4.6 respectively.

Table 4.3 The burned areas from burned area product (MCD45A1) data collection and observations for the case of rice fields

No	Vegetation Type	Coordinates (UTM)		Burned area product (MCD45A1), km^2	Observation, km^2	Observation/ Burned area product (MCD45A1)
		X	Y			
1	Rice	639293	1569174	1.297	0.129	0.099
2	Rice	650538	1569756	0.846	0.782	0.924
3	Rice	651102	1597818	0.871	0.789	0.906
4	Rice	649712	1597305	1.080	0.982	0.909
5	Rice	648745	1598748	7.850	6.852	0.873
6	Rice	654479	1594331	0.450	0.440	0.978
7	Rice	656318	1594466	1.850	1.560	0.843
8	Rice	651765	1593520	0.230	0.220	0.957
9	Rice	645451	1570726	4.630	4.110	0.888
10	Rice	634879	1575537	1.640	1.240	0.756
11	Rice	637340	1573680	0.230	0.120	0.522
12	Rice	644938	1564447	0.470	0.450	0.957
14	Rice	686473	1608025	1.380	1.350	0.978
15	Rice	685746	1609302	2.170	1.680	0.774
16	Rice	675165	1609302	1.160	0.990	0.853
17	Rice	676607	1606243	0.930	0.870	0.935
18	Rice	654293	1555783	0.220	0.080	0.364
19	Rice	351911	1550936	0.210	0.160	0.762
20	Rice	625211	1578044	3.470	3.300	0.951

Table 4.4 The burned areas from burned area product (MCD45A1) data collection and observations for the case of corn

No	Vegetation Type	Coordinates (UTM)		Burned area product (MCD45A1), km^2	Observation, km^2	Observation/ Burned area product (MCD45A1)
		X	Y			
1	Corn	742870	1710589	0.921	0.468	0.508
2	Corn	739991	1709573	1.381	0.652	0.472
3	Corn	739790	1708927	0.453	0.131	0.288
4	Corn	737385	1709350	0.822	0.805	0.978
5	Corn	735658	1708867	0.544	0.326	0.598
6	Corn	744306	1710877	0.230	0.150	0.652
7	Corn	745592	1711766	0.710	0.220	0.310
8	Corn	745211	1713877	0.020	0.010	0.500
9	Corn	741242	1713861	0.230	0.190	0.826
10	Corn	744544	1715877	0.050	0.020	0.400
11	Corn	745295	1727466	1.380	1.250	0.906
12	Corn	739508	1736891	0.710	0.390	0.549
14	Corn	747042	1737552	1.390	0.600	0.432
15	Corn	745326	1739172	0.240	0.060	0.250
16	Corn	744226	1739047	0.240	0.160	0.667
17	Corn	745666	1741841	0.700	0.590	0.843
18	Corn	745237	1746289	2.340	1.000	0.427
19	Corn	748635	1750526	2.340	1.910	0.816
20	Corn	749540	1751977	0.690	0.570	0.826

Table 4.5 The burned areas from burned area product (MCD45A1) data collection and observation for the case of sugarcane

No	Vegetation Type	Coordinates (UTM)		Burned area product (MCD45A1), km^2	Observation, km^2	Observation/ Burned area product (MCD45A1)
		X	Y			
1	Sugarcane	708480	1724981	0.210	0.150	0.714
2	Sugarcane	709349	1711899	0.218	0.203	0.930
3	Sugarcane	709452	1711875	0.230	0.200	0.870
4	Sugarcane	709126	1721922	0.920	0.720	0.783
5	Sugarcane	712799	1715203	0.158	0.069	0.439
6	Sugarcane	713505	1717204	2.120	1.740	0.821
7	Sugarcane	715397	1704147	0.550	0.200	0.364
8	Sugarcane	720313	1713351	6.521	5.116	0.785
9	Sugarcane	720150	1713297	0.470	0.180	0.383
10	Sugarcane	718249	1713298	0.237	0.104	0.439
11	Sugarcane	724011	1707722	1.220	0.900	0.738
12	Sugarcane	731607	1696038	1.105	0.851	0.769
14	Sugarcane	736313	1708902	0.830	0.550	0.663
15	Sugarcane	697506	1671947	0.710	0.660	0.930
16	Sugarcane	699306	1671507	0.230	0.120	0.522
17	Sugarcane	698769	1706175	0.240	0.100	0.417
18	Sugarcane	820328	1609191	0.920	0.160	0.174
19	Sugarcane	819458	1608486	0.240	0.090	0.375
20	Sugarcane	820100	1607953	0.240	0.070	0.292

Table 4.6 The burned areas from burned area product (MCD45A1) data collection and observation for the case of forest fire areas

No	Vegetation Type	Coordinates (UTM)		Burned area product (MCD45A1), km^2	Observation, km^2	Observation/ Burned area product (MCD45A1)
		X	Y			
1	Forest	527643	2081900	0.220	0.120	0.545
2	Forest	528278	2081292	0.570	0.200	0.351
3	Forest	524114	2077630	0.230	0.017	0.074
4	Forest	524369	2076091	0.220	0.006	0.027
5	Forest	523793	2074378	0.240	0.014	0.058
6	Forest	522715	2073928	0.210	0.022	0.105
7	Forest	520536	2073113	0.232	0.011	0.047
8	Forest	521972	2073576	0.330	0.014	0.042
9	Forest	535713	2079175	0.700	0.560	0.800
10	Forest	530591	2075852	0.230	0.230	1.000
11	Forest	521955	2073513	0.000	0.010	0.000
12	Forest	530712	2075868	0.230	0.230	1.000
14	Forest	530845	2073142	1.630	0.810	0.497
15	Forest	528437	2076344	1.050	0.014	0.013
16	Forest	523463	2068787	0.220	0.018	0.082
17	Forest	453805	2010718	0.250	0.200	0.800
18	Forest	451508	2015731	1.250	0.500	0.400
19	Forest	506357	2158919	3.040	2.340	0.770
20	Forest	508326	2163901	0.210	0.120	0.571
21	Forest	507810	2154204	0.350	0.230	0.657
22	Forest	510865	2165265	1.120	0.510	0.455
23	Forest	521926	2156962	1.220	0.470	0.385
24	Forest	509761	2156962	2.100	1.960	0.933
25	Forest	510224	2165328	2.570	1.370	0.533
26	Forest	513465	2166387	1.240	0.580	0.468
27	Forest	511613	2167577	2.220	1.050	0.473
28	Forest	506453	2169959	0.930	0.880	0.946
29	Forest	499111	2173464	1.090	0.350	0.321
30	Forest	501691	2177499	0.240	0.200	0.833

4.3.2 Result of adjustment factor of burned area estimation

The preliminary 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 using satellite information. This study developed a linear equation to calculate the adjustment factor by using the information in Tables 4.3 to 4.6. The equation demonstrated that the adjustment factor is about 0.8677 for the burning of paddy field, 0.7700 for the burning of sugarcane field, 0.5255 for the burning of corn field with less than 5% slope, 0.6566 for the burning of corn field with 5%-10% slope, 0.6401 for the burning of forest with less than 15% slope, and 0.5275 for the burning of forest with higher than 15% slope. The burned area derived from MCD45A1 is multiplied by the adjustment factor for the actual of burned area estimation. The actual of burned area is used to calculate the emission from the biomass open burning. The information of adjustment factor is summarized as shown in the Table 4.7 and the description of the validation for each type of vegetation is shown in the following:

Table 4.7 The results of the Correlation Coefficient between the burned area product (MCD45A1) and ground measurements of biomass open burning in Thailand

Biomass burning type	Burned area slope correlation faction	Correlation Coefficient between MCD45A1product and ground observation in this study	R^2	Confidence (%)
Rice area	No slope	0.8677	0.9765	97.65%
Sugarcane area	No slope	0.7700	0.9808	98.08%
Corn area	Slope ≤ 5%	0.5255	0.7647	76.47%
	Slope 5-10%	0.6566	0.7254	72.54%
Forest fire area	Slope ≤ 15%	0.6401	0.7991	79.91%
	Slope > 15%	0.5275	0.8750	87.50%

This study, found the results of the adjustment factors of burned areas. The data was assessed for the size of burned area and classified for the type of fire by using GIS. The classification based on the land use information from Land Development Department (LDD) of 2007. Then, the burned area was multiplied with the adjusted factor to assess the actual burned area is shown in Table 4.8

Table 4.8 The results of MCD45A1 burned area product was multiplied with the adjusted factor to assess the actual burned area.

Vegetation type		Burned area (ha)		
		2009	2010	2011
Forest	Evergreen forest	10,684	28,606	3,386
	Deciduous forest	75,777	111,097	28,606
	Other forest	22,827	14,537	8,290
	Total	109,287	154,240	40,282
Agriculture	Rice paddy	80,349	72,193	49,719
	Corn	7,861	12,826	2,482
	Sugarcane	6,006	3,696	2,310
	Other agriculture	22,417	25,801	7,613
	Total	116,633	114,516	62,125
All Total		225,921	268,756	102,407

Case I: open burning of paddy field on January 13th -15th 2013, and March 20th, 2013 at Ayutthaya.

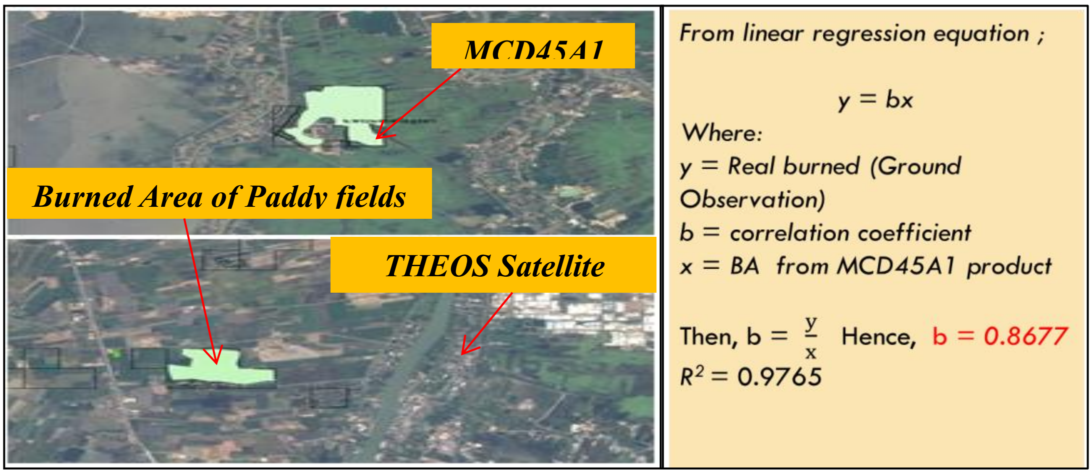


Figure 4.9 Validated location of burning of paddy field

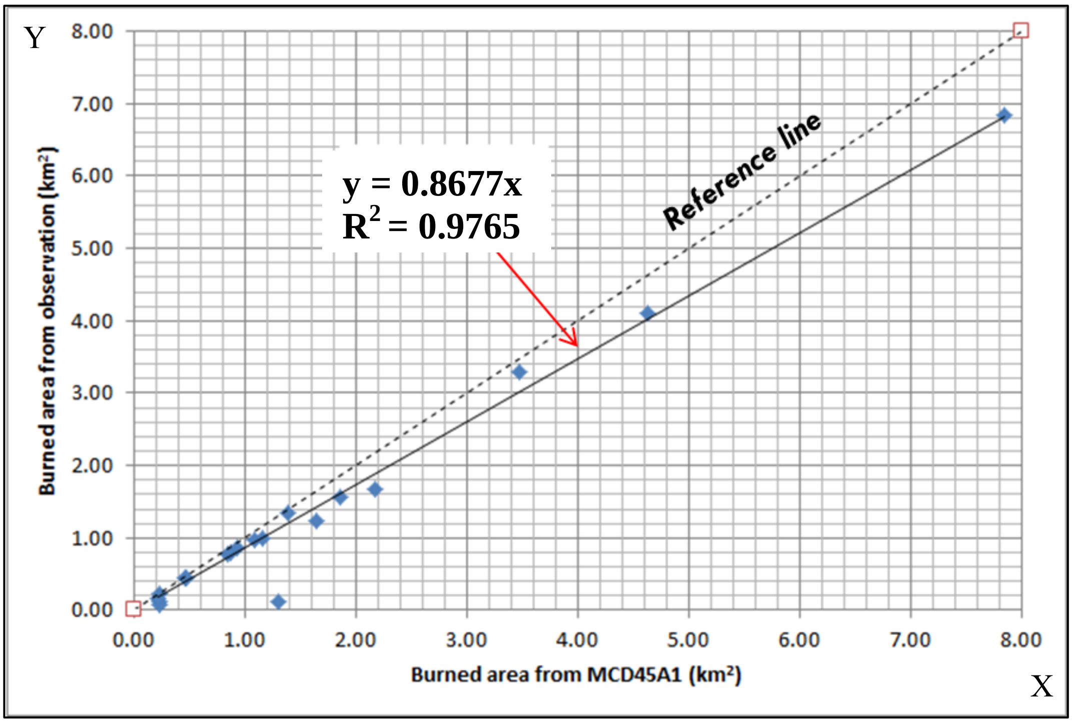


Figure. 4.10 Ground observation measurement method and relationship between the burned area products (MCD45A1) with ground-truthed of paddy fields.

Considering the accuracy and reliability of the results, it can be seen that there is a similar behavior to burning of waste biomass of rice farms, while almost all in the holding area of paddy per household size area is not very large. Also, cultivation and harvesting shares arable land into many small sections that are easy to prepare for planting and harvesting. When it's time to prepare the new planting areas, farmers burning biomass residues in rice paddy fields are not of large areas as well. The burned area will be smaller than the smallest pixel size of the burned area from MCD45A1 pixel size of 25 ha (156.25 Rai) and the validated location of burning of paddy field is show in Figure 4.9.

Figure 4.10, shows the relationship of the size of the burned area in the paddy field between the ground observation and the data obtained from the satellite MODIS burned area product (MCD45A1) is shown. The total of 20 sampling plots shows that burned areas from burned area product (MCD45A1) information is larger than the actual burned area for every area (with all the points below the curve at 45 degrees) and burned areas from MODIS burned area product (MCD45A1) correlating linearly with the size of the burned area measured by the actual equation; Y = 0.8677 X (R^2 = 0.9765).For the burned area, the actual size is equal to 0.8677 times the size of the area from the burned area product (MCD45A1) with a confidence 97.65 %. The data of burned areas from MCD45A1 is to be used to evaluate the release of air pollutants from the biomass open burning, particularly in the paddy fields. Such information suggests it be made modifiable by multiplying the adjusted factor equal to 0.8677 for the assessment of the burned area and the release of air pollution situation.

Case II: open burning of sugarcane on January 11th -13th 2013, and March 20th, 2013 at Phetchabun.

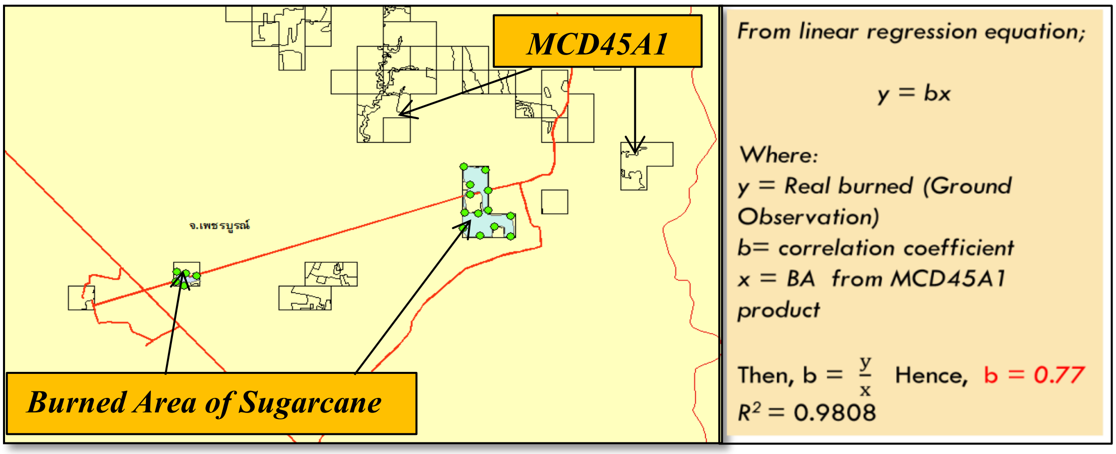


Figure 4.11 Validated location of burning of sugarcane

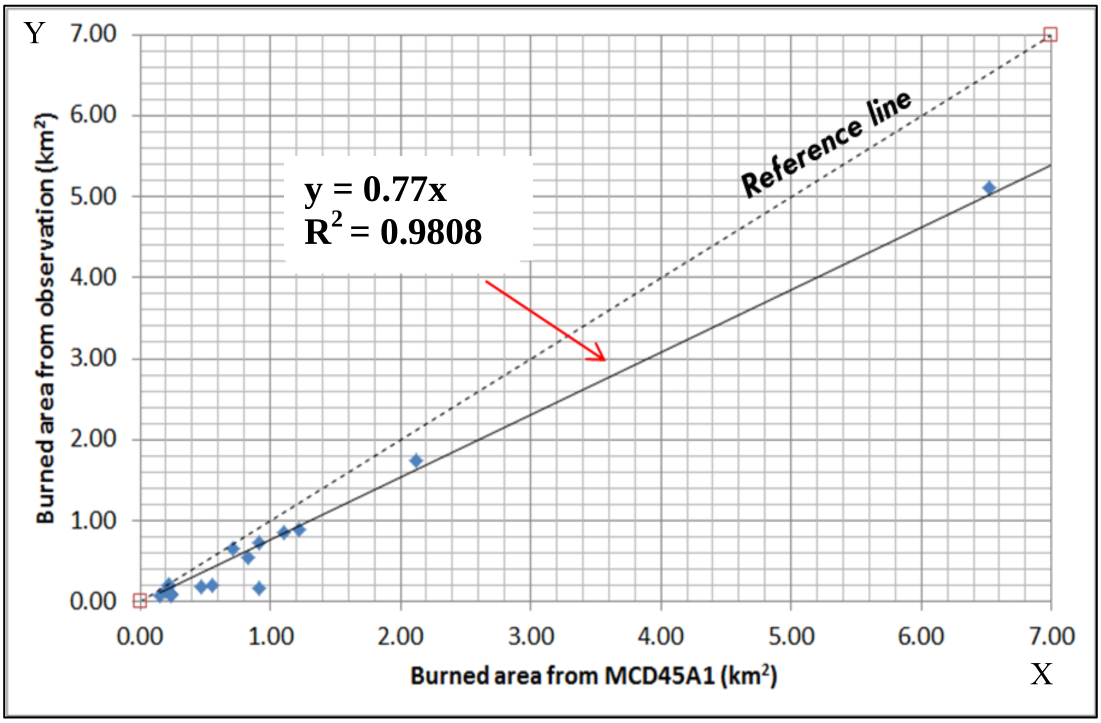


Figure 4.12 Ground observation measurement method and relationship between the burned area product (MCD45A1) with ground-truthed of sugarcane.

Considering the accuracy and reliability of the results, It can be seen that there is a similar behavior to the burning of sugarcane fields by farmers in Thailand. For almost all farmers holding areas of sugarcane field, the area size is not very large per household. Cultivation and harvesting of shares of arable land divided into many small areas are easy to prepare for planting and harvesting. When, it's time to prepare the new planting areas. Farmers burning biomass residues of sugarcane before harvesting are not of large areas as well. The burned area will be smaller than the smallest pixel size of the burned area from MCD45A1 per pixel size of 25 ha or (156.25 Rai) and the validated location of burning of paddy field is show in Figure 4.11.

Figure 4.12, shows the relationship of the size of the burned areas for sugarcane between ground observation and the data obtained from the satellite MODIS burned area product (MCD45A1). A total of 20 sampling plots on the graph shows that burned areas from burned area product (MCD45A1) information is larger than the actual burned area for every area (with all the points below the curve at 45 degrees). Burned areas from MCD45A1 correlate linearly with the size of the burned area that are measured by the actual equation; $Y = 0.770X$ ($R^2 = 0.9808$). i.e. for the burned area, the actual size is equal to 0.770 times the size of the area from burned area product (MCD45A1) with a confidence of 98.08%. So, the data of burned areas from the burned area product that is used to evaluate the release of air pollutants from the biomass open burning is applied to the sugarcane field. Such information should be made modifiable by multiplying the adjusted factor equal to 0.770 for the assessment of the burned area and release the air pollution situation possible.

Case III: Open burning of corn on January, 19th -20th, 2013 at Phetchabun.

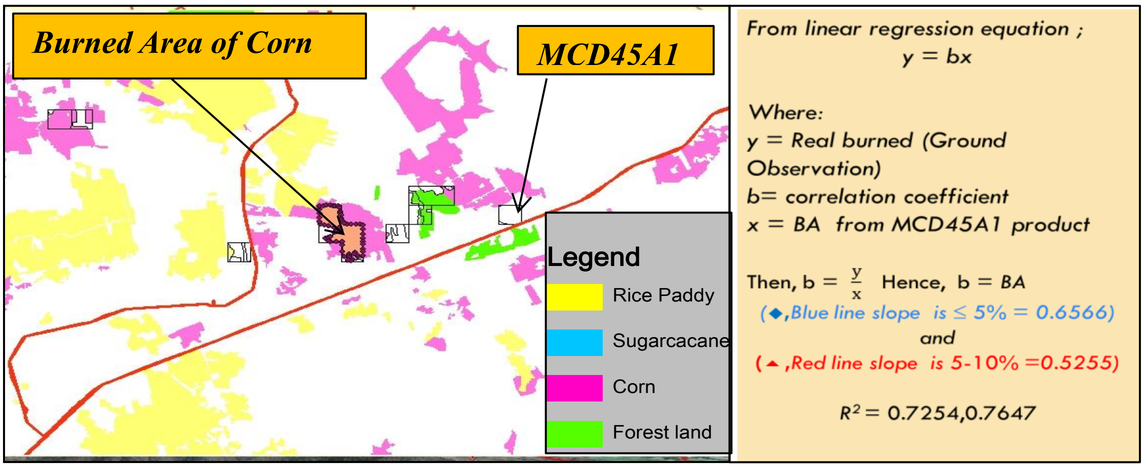


Figure 4.13 Validated location of burning of corn

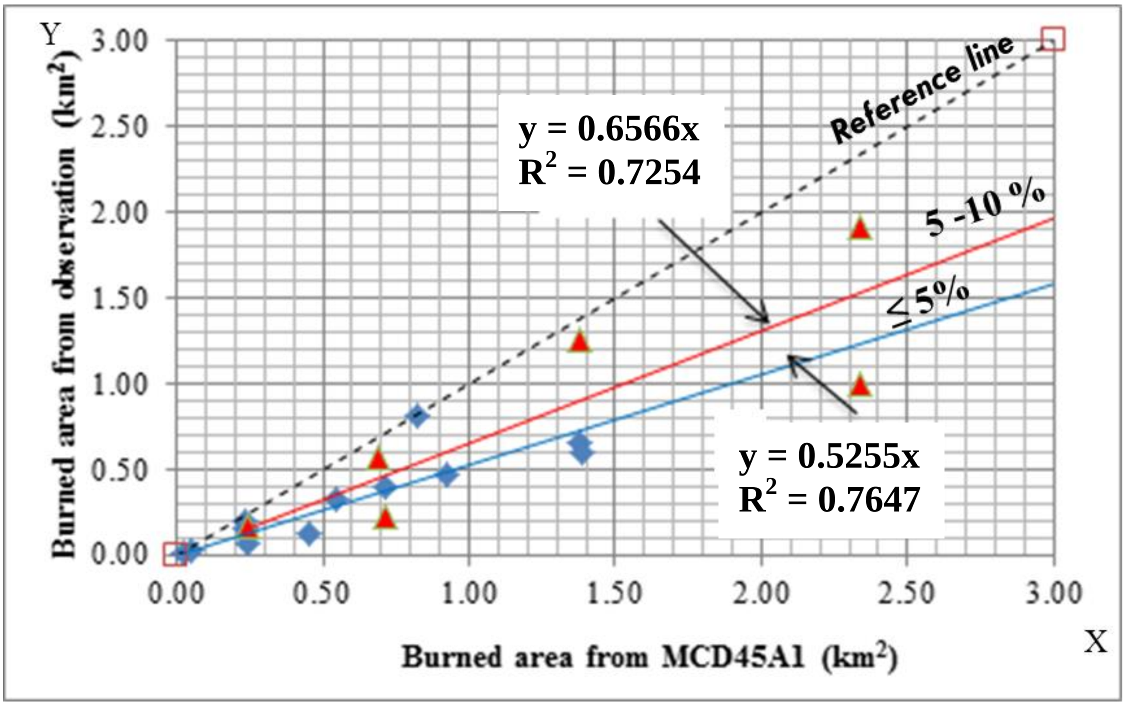


Figure 4.14 Ground observation measurement method and relationship between the burned area products (MCD45A1) with ground-truthed of corn areas. For terrain with slopes ≤ 5 percent shown by the blue line (◆) and for terrain with slopes ranges between 5 to 10 percent shown by the red line (▲).

It can be seen that the burning of biomass residues of corn is not very large and most farmers prefer plowing corn stubble to prepare the area for planting and the validated locations of the burning of paddy field is shows in Figure 4.13. Moreover, from Figure 4.14, the analysis shows the relationship of the size of the burned area between ground observation and data obtained from satellite MODIS burned area product (MCD45A1) for forest area. A total of 20 sampling positions in the graph show that burned areas from burned area product (MCD45A1) information is larger the actual burned area for every area (with all the points below the curve at 45 degrees). For the case of corn, we have the slope into a factor of corn burned result from the ground observation can be divided according to two groups of data. Which are show in the graph as the blue line and red line slopes, respectively. Burned areas from MCD45A1 correlate linearly with the size of the burned area to measure the actual equation. If the slope of the burned area range is ≤ 5 percent using equation Y = 0.6566X (R^2 = 0.7254), then the actual size of the burned area is equal to 0.6566 times the size of the area from burned area product (MCD45A1) with a confidence of 72.54%, and if the slope of the burned area ranges between 5 to 10 percentage points using equation Y = 0.5255X (R^2 = 0.7647), then the actual size of the burned area is equal to 0.5255 times the size of the area from burned area product (MCD45A1) with a confidence of 76.47%. The information should be made modifiable by multiplying an adjustment factor that follows slope condition, equal to 0.6566 and 0.5255, for the assessment of burned area in corn fields and releases of air pollution.

Case III: Open burning of forests on March 9th -14th, 2013, Chiang Mai.

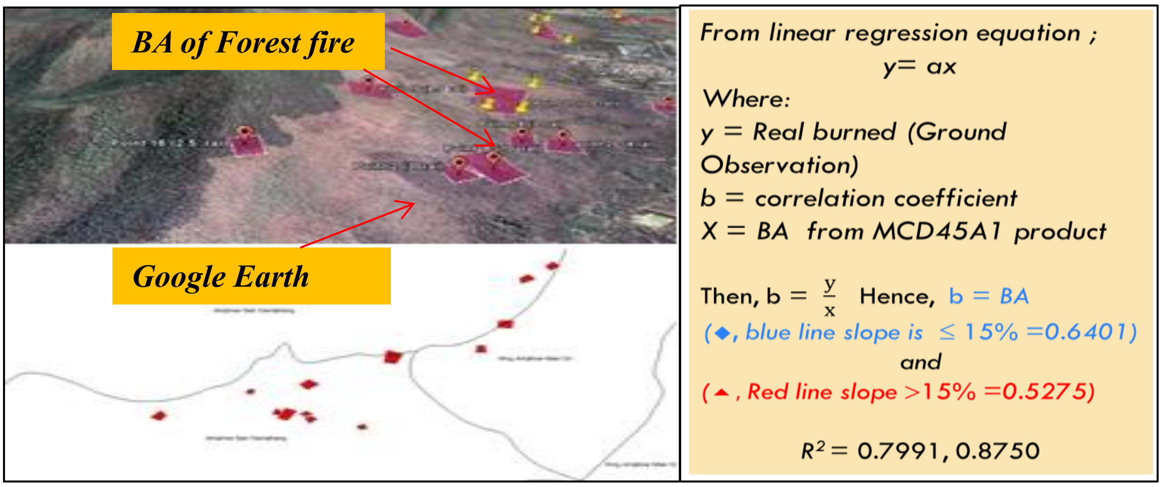


Figure 4.15 Validated location of burning of forest

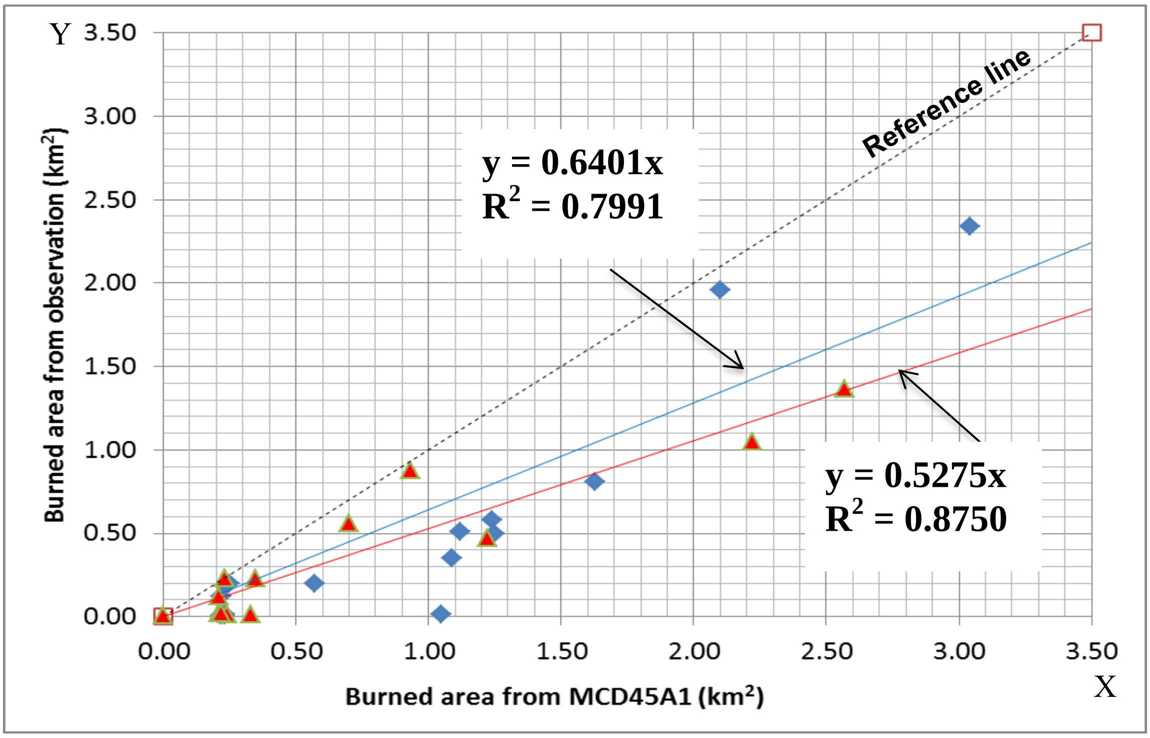


Figure 4.16 Ground observation measurement method and relationship between the burned area products (MCD45A1) with ground-truthed of forest area. For terrain with slopes at ≤ 15 percent shown by the blue line (◆) and and for terrain with slopes at > 15 percent shown by the red line (▲)

Considering the accuracy and reliability of the results, it can be seen that for forest fires the area in Thailand is not very large. Most forest fires occurred between January and April, with a period of higher fire occurrence in March. The burned area will be smaller than the smallest pixel size of the burned area from MCD45A1 pixel size of 25 ha or (156.25 Rai) and the validated location of burning of paddy field is show figure 4.15

Figure 4.16, shows the relationship of the size of the burned area between the ground observation and the data obtained from burned area product (MCD45A1). A total of 30 sampling positions on the graph shows that burned areas from burned area product (MCD45A1) information is larger than the actual burned area for every area (with all the points below the curve at 45 degrees). For the case of forest fire, we have the slope into a factor for support the crisis action. The Result shown that, from the ground observation field can be divided according to the sign of the slope of two groups of data. which are shown in the graph as the blue line and red line slope. Burned areas from MCD45A1 correlate linearly with the size of the burned area that is measured by the actual equation. If the slope of the burned area range $\leq$ 15 percent using equation Y = 0.6401X (R^2 = 0.7991), then the actual size of the burned area is equal to 0.6401 times the size of the burned area product (MCD45A1) with a confidence 79.91%, and if the slope of the burned area range $>$ 15 percentage using equation Y = 0.5275X (R^2 = 0.8750), then the actual size of the burned area is equal to 0.5275 times the area of the burned area product (MCD45A1) with a confidence 87.50%. The information should be made modifiable by multiplying an adjustment factor that follows slope condition equal to 0.6401 and 0.5275 for the assessment of burned area for forest fire, and releases of air pollution.

For all results of the cases of rice fields, sugarcane, corn and forest fires, a R-squared value of very close to 1 indicates that the x and y variables significantly influence the mean equation estimation and would be appropriate to use. It was found that the burned area product (MCD45A1) has a capacity for the detection of burned areas in rice fields greater than sugarcane fields, corn and forest fires.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this study, emissions from open biomass burning in Thailand were estimated for three consecutive years from 2009 to 2011. The results indicated that the burned areas detected in forest and agricultural lands were approximately 887,778 ha. The most significant burning occurred in 2010 with a total burned area of 410,636 ha. The total burned biomass was computed at 26,539 tons dry matter, which included burned forest biomass at 15,460 tons dry matter and burned agricultural biomass at 11,078 tons dry matter. The emissions from biomass open burning in Thailand were estimated for three continuous years from 2009 to 2011 were computed to be approximately 2,150,077 tons of CO_2, 163,175 tons of CO, 7,704 tons of CH_4, 221 tons of N_2O and 2,841tons of NO_X. They also emitted about 10,469 tons of $PM_{2.5}$, 16,571 tons of PM_{10} and 1,014 tons of BC.

In 2010, the biomass open burning emissions from this study were found to be lower than the results obtained using GFEDv3.1 for forest fires, with a range of 16-52 times, and for agricultural burnings with a range of 5-57 times. From field observations, it was found that the use of MCD45A1 product provided accurate and reliable information of the area burned. The improved emission inventory relies on the use of country-specific data on area burned by quantifying adjustment factors for each type of vegetation using ground-truthing technique. This led to a more accurate estimate of the burned area, and enabled to reduce uncertainties related to direct conversion of MCD45A1 product.

5.1.1 Burned area estimation

The results from the burned area product (MCD45A1), were comprehensive of the period from 2009-2011, and was been conducted for main locations in the whole of Thailand. The overlay of burned area from burned area product (MCD45A1) data is classified with land use map (LDD, 2007) for 2009 to 2011. The results show the annual burned area product (MCD45A1) of the whole country ranged from 3,327.23 km^2 (332,723 ha) in 2009, to 4,106.36 km^2 in 2010 (410,636 ha), and to 1,444.19 km^2 (144,419 ha) in 2011.

In 2009, the total was 3,327.23 km^2 and consisted of forest land at a total area of 1,871.78 km^2 (187,178 ha), including evergreen forests at about 183.10 km^2 (18,310 ha) or 5.50 %, deciduous forests at about 1,297.71 km^2 (129,771 ha) or 39.00 %, and other forests at about 390.97 km^2 (39,097 ha) or 11.75 %. The agricultural land had a total area of 1,871.78 km^2, and consisted of rice fields at about 926.38 km^2 (92,638 ha) or 27.84%, corn at about 132.83 km^2 (13,283 ha) or 3.99%, sugarcane at about 78.16 km^2 (7,816 ha) or 2.35%, and other agricultural land at about 318.07 km^2 (31,807 ha) or 9.56 %.

In 2010, the total was 4,106.36 km^2 and consisted of forest land at a total area of 2,642.57 km^2 (264,257 ha), including evergreen forests at about 490.22 km^2 (49,022 ha) or 11.94%, deciduous forests at about 1,903.15 km^2 (190,315 ha) or 46.35%, and other forests at about 249.20 km^2 (24,920 ha) or 6.07%. The agricultural land had a total area of 1463.79 km^2 and consisted of rice paddies at about 832.31 km^2 (83,231 ha) or 20.27%, corn at about 217.26 km^2 (21,726 ha) or 5.29%, sugarcane at about 48.31 km^2 (4,831 ha) or 1.18 %, and other agricultural land at about 365.92 km^2 (36,592 ha) or 8.91 % respectively.

In 2011, the total was 1,444.19 km^2 and consisted of forest land at a total area of 690.53 km^2 (69,053 ha), including evergreen forests at about 42.32 km^2 (4,232 ha) or 4.04%, deciduous forests at about 490.12 km^2 (49,012 ha) or 33.94 %, and other forests at about 142.12 km^2 (14,212 ha) or 9.84%. The agricultural land had a total area of 753.66 km^2, and consisted of rice paddies at about 572.98 km^2 (57,298 ha) or 39.67%, corn at about 42.32 km^2 (4,232 ha) or 2.93%, sugarcane at about 30.18 km^2 (3,018 ha) or 2.09%, and other agricultural land at about 108.18 km^2 (10,818 ha) or 7.49 %.

The area consists of areas of burning that occurred on forest land, evergreen forest, deciduous forests, and other forests. It also occurred on agricultural lands, such as rice paddies, corn fields, sugarcane, and other agricultural lands *(see Table 4.2)*.

5.1.2 Estimation of adjustment factors for burned area

Field observations for validation was done from January to March 2013, and the methods used by previous research studies for the simple linear regression method was used to find the adjusted factor for combining burned area product (MCD45A1) results with ground observation measurements. After that, we have an adjusted factor of forest fire and agricultural residues burning. For the case of rice paddy fields, the shown burned area product (MCD45A1) correlates linearly with the size of the burned area as measured by the actual equation, Y = 0.8677 X (R^2 = 0.9765), with the actual size equal to 0.8677 times the size of the area from MCD45A1 with a confidence of 97.65%.

For the case of sugarcane, burned areas from MCD45A1 correlate linearly with the size of the burned area as measured by the actual equation, Y = 0.770X (R^2 = 0.9808), where the actual size is equal to 0.770 times the size of the area from burned area product (MCD45A1) with a confidence of 98.08%. Nevertheless, In the case of corn and forest fire, one more slope condition adjustment factor is considered before assessment of burned area. Burned areas from MCD45A1 correlate linearly with the size of the burned area as measured by the actual equation; if the slope of the burned area range $\leq$ 5 percent using equation Y = 0.6566X (R^2 = 0.7254), it then the actual size of the burned area is equal to 0.6566 times the size of the area from burned area product (MCD45A1) with a confidence of 72.54%, and if the slope of the burned area ranges between 5 to 10 percent using equation Y = 0.5255X (R^2 = 0.7647), it then the actual size of the burned area is equal to 0.5255 times the size of the area from the burned area product (MCD45A1) with a confidence of 76.47%. The information should be made modifiable by multiplying an adjusted factor following a slope condition equal to 0.6566 and 0.5255 for the assessment of the burned area in corn areas.

Burned areas from MCD45A1 correlate linearly with the size of burned area as measured by the actual equation. If the slope of burned area range $\leq$ 15 percent using equation Y = 0.6401X (R^2 = 0.7991), then the actual size is equal to 0.6401 times the size of the area from the burned area product (MCD45A1) with a confidence of 79.91%. If the slope of the burned area range $>$ 15 percent using equation Y = 0.5275X (R^2 = 0.8750), then the actual size is equal to 0.5275 times the size of the area of the burned area product (MCD45A1) with a confidence of 87.50%. The information should be made modifiable by multiplying an adjustment factor that follows a slope condition equal to 0.6401 and 0.5275 for the assessment of the burned area in forest fire area. These have been done to ensure the accuracy and the confidence of the data (*see Chapter 4*).

5.1.3 Emissions of estimation from biomass open burning

The estimation of emissions from biomass open burning from 2009 to 2011 indicated that the amounts of CO_2, CO, CH_4, N_2O, and NO_x were about 2,150,077 tons, 163,175 tons, 7,704 tons, 221 tons and 2,841 tons, respectively. They also emitted particulate matter $PM_{2.5}$, PM_{10}, and black carbon (BC) which was about 10,469 tons, 16,571 tons and 1,014tons, respectively.

In 2009, we indicated that the amounts of CO_2, CO, CH_4, N_2O, and NO_x were about 815,212 tons, 62,184 tons, 2,854 tons, 82 tons and 1,105 tons, respectively. Additionally, emissions of particulate matter $PM_{2.5}$, PM_{10}, and black carbon (BC) were about 3,886 tons, 6,246 tons and 386 tons respectively. In 2010, the amounts of CO_2, CO, CH_4, N_2O, and NO_x were about 984,890 tons, 72,554 tons, and 3,684 tons, 106 tons, and 1,226 tons, respectively. Emissions of particulate matter $PM_{2.5,}$ PM_{10}, and black carbon (BC) were about 4,988 tons, 7,484 tons, and 457 tons, respectively. In 2011, we indicated that the amount of CO_2, CO, CH_4, N_2O, and NO_x were about 34,975 tons, 28,437 tons, 1,165 tons, 33 tons, and 511 tons, respectively. They also emitted particulate matter $PM_{2.5}$, PM_{10}, and black carbon (BC) at about 1,595 tons, 2,841 tons, and 171 tons respectively.

Each year, the highest occurrence of biomass open burning is during February to April. The spatial and temporal distributions of emissions are similar to the spatial distribution of the forest areas and agricultural areas being burned. The high emission density was found in the forest area that located in the northern, the western, and the upper northeastern region and also found in the paddy filed that located in the central and the northeastern region.

5.1.4 Comparison with other burned area product

The results of this study were found to be lower than GFEDv3.1 in forest burning with a range of 16 to 52 times, and in agricultural burning with a range of 5 to 57 times. The result comparison of the size of gridded emissions from GFED v.3.1 data were emission estimated larger than 25 time compared to MCD45A1 emissions estimated from this study. Researchers suggested that using adjusted factor from our study from ground validation was necessary to reduce the uncertainty of biomass open burning emission estimations in Thailand.

5.2 Recommendations for further research studies

(1) Limitations of time and budget. The number of sampling plots of ground observation plot was limited to go plots. If we were to improve the research of this study more sampling plots these accuracy could be require for reduce uncertainty of burned area emission estimation for Thailand in the future.

(2) This study assessed the adjustment factors of forest fire and corn by slope classification. Future studies should consider the other factors that affect the value of the

adjustment factor, for example biomass density, moisture content of biomass, forest type and other (wind speed, Slope direction).

Then we assume there are other factors, that would effect the assessment of the accuracy of BA and affect to assess emission estimation would be highly accurate.

(3) For the burned area product from MODIS, we should optimize the spatial resolution to 250 or less than this and compare with other burned area products with high spatial resolution imagery, such a LANDSAT, THEOS and SPOT satellite imagery.it cloud be increases the accuracy of detection of agricultural burning and forest fire.

(4) We recommend using the forest fire risk area map or ground observation by using small size grids, high spatial resolution and efficiently instrument sensor from satellite are obtain high accuracy.

REFERENCES

Akagi, S. K., Yokelson, R. J., Wiedinmyer, C., Alvarado, M. J., Reid, J. S., Karl, T., Crounse, J.D., and Wennberg, P. O. (2011), Emission factors for open and domestic biomass burning for use in atmospheric models, *Atmospheric Chemistry Physics*, **11**, pp. 4039–4072.

Andreae, M.O., Merlet, P. (2001), Emissions of trace gases and aerosols from biomass burning. *Global Biogeochem*, **15**, pp. 955-966.

T.C. Bond, and H. Sun,(2005) ,Can Reducing Black Carbon Emissions Counteract Global Warming, *Environmental Science. Technology*, **39**, pp. 5921-5926.

Chang, D., and Song, Y. (2010), Estimates of biomass burning emissions in tropical Asia based on satellite-derived data, *Chemistry Physics*, **10**, pp. 2335-2351.

Cheewaphongphan, P., Garivait ,S. (2012), Bottom up Approach to Estimate Air Pollution of Rice Residue Open Burning in Thailand, *Asia-Pacific Journal Atmospheric Science*, **49**, pp. 139-149.

C.P. (Mick) Meyer, Ashok K. Luhara, and, Ross M. Mitchell. (2008), Biomass burning emissions over northern Australia constrained by aerosol measurements: I-Modeling the distribution of hourly emissions, *Atmospheric Environment*, **42**, pp. 1629–1646.

C.O. Justice, L. Giglio, S. Korontzi, J. Owens, J. T. Morisette, D. Roy (2002) , The MODIS fire products, *Remote Sensing of Environment*, , pp. 244−262.

ECCAD, Emissions of atmospheric Compounds & Compilation of Ancillary Data, GFEDv3.1 (2010), available online: http://eccad.sedoo.fr. [Accessed January 2013].

FFCD-Forest Fire Control Division National Park, Forest fire description (2011a), available Online: http://www.dnp.go.th/forestfire/Eng/description.htm. [Accessed January 2012].

FFCD-Forest Fire Control Division National Park, Forest fire statistics (2011b), available Online: http://www.dnp.go.th/forestfire/2546/firestatistic%20Th.htm [Accessed January 2012].

Giglio, L., Randerson, J.T., Van Der Werf, G.R., Kasibhatla, P.S., Collatz, J.G., Morton, D.C.and Defries, R.S. (2010), Assessing variability and long-term trends in burned area by merging multiple satellite fire products, *Biogeosciences*, **7**, pp. 1171-1186.

Garivait, S., U. Parnmongkol, S. Wisitpanich, S. Bonnet, A. Gumnert, S. Jongkitwiwat, I. Sittirojanakul, C. Wiriyabuncha, and U. Chaiyo, (2007), *Monitoring and Assessment of Air Pollutant Emissions from Forest Fires in the Northern Region of Thailand*. National Research Council of Thailand, 128 pp.

Garivait, S., and Coauthors. (2005), *Monitoring and Assessment of Biomass Open Burning in Agricultural Areas/Lands in Thailand*, Pollution Control Department, 60 pp.

Geo-Informatics and Space Technology Development Agency (Public Organization), Thailand Fire Monitoring System, available online: http://fire.gistda.or.th [Accessed June 2012].

IPCC-The Intergovenmental Panel on Climate Changes (2006), *2006 IPCC Guidelines for National Greenhouse Gas Inventories 4*, The Institute for Global Environmental Strategies (IGES), Japan, 55 pp.

Jenkins, B. M. and Bhatnagar, A. P. (1991), On the electric-power potential from paddy straw in the Punjab and the optimal size of the power generation station, *Bioresource*, 37, pp. 35- 41.

Junpen, A., (2011), *Spatial and Temporal Variation of Biomass Open Burning Emission Estimation by Using Remote Sensing Information*. Thesis 's degree of Doctor of Philosophy in Environmental Technology, JGSEE, King Mongkut's University of Technology Thonburi, Thailand, 300 pp.

Justice, C.O., Giglio, L., Korontzi, S., Owens, J., Morisette, J. T., Roy, D. (2002), The MODIS fire products. *Remote Sensing of Environment*, 83, pp. 244−262.

Kadam, K. L., Forrest, L. H., and Jacobson, W. A. (2000), Rice straw as a lignocellulosic resource: collection, processing, transportation, and environmental aspects, *Biomass Bioenergy*, **18**, pp. 369–389.

Kaiser,J.W.,Schultz.,Marie,G.J.,Textor,C.,Sofiev,M.,Bartholome,E.,Leroy,M.,Engelen,R.J.,Hollingsworth,A. (2006), Observation Requirements for global Biomass Burning Emission Monitoring, *Eumetsat Meteorological Satellite conference*.

Kanokkanjana, K., and S. Garivait. (2010), Emission Factors of Particulate Matter Emission from Rice Field Residues Open Burning in Thailand, Proc., *Climate Thailand conference Nonthaburi*, Thailand, pp. 512-527.

Kaufman, Y. J., Justice, C. O., Flynn, L. P., Kendall, J. D., Prins, E. M., Giglio, L., Ward, D.E., Menzel, W. P., and Setzer, A. W., (1998), Potential global fire monitoring from EOS-MODIS. Journal of Geophysical Research, **103**, pp. 32215-32238.

LDD-Land Development Department, Geographic Information System Soil and Land use, available online: http://www.ldd.go.th/gisweb/.html. [Accessed January 2013].

MODIS data. (2009-2012), Burned area product, available online: ftp://.geoinfo.bal.geog.umd.edu/TIFF/. [Accessed 10 June 2012].

MODIS user manual, Burned area product, available online: http://modis-fire.umd.edu/Documents/MODIS_Burned_Area_Collection51_User_Guide_3.0.pdf [Accessed 10 June 2011].

MODIS Fire Hot Spot(FHS) (2013), NASA LANCE Fire Information for Resource Management System (FIRMS), available online: http://earthdata.nasa.gov/data/nrt-data/firms.[Accessed January 2013].

PCD-Pollution control department, Statistical of air quality, available online: http:// www.pcd.go.th [Accessed December 2009].

PCD-Pollution Control Department. (2005), *National Master Plan for open Burning Control,Pollution control Department*, Ministry of Natural Resource and Environment, Thailand, 26 pp.

Richard Smith, Matthew Adams, Stefan Maier, Ronald Craig, Agnes Kristina, and, Ian Maling. (2007), Estimating the area of stubble burning from the number of active fires detected by satellite, *Remote Sensing of Environment*, **109**, pp. 95–106.

Roy, D.P., Lewis, P.E. and Justice, C.O. (2002), Burned area mapping using multi-temporalmoderate spatial resolution data– a bi-directional reflectance model-based expectation approach, *Remote Sensing of Environment*, **83**, 263-286.

Roy, D. P., Boschetti, L., Justice, C. O., and Ju, J. (2008), The collection 5 MODIS burned area product-Global evaluation by comparison with the MODIS active fire product, Remote Sensing Environment, **112**(9), pp. 3690–3707.

Roy, D.P. and Boschetti, L. (2009), Southern Africa Validation of the MODIS, L3JRC, and GlobCarbon Burned-Area Products, IEEE T. Geosci. Remote, **47**(4), pp. 1032-1044.

Roy, D. P., Boschetti, L., Justice, C. O., and Hoffmann Anja. A. (2009), *The collection 5 MODIS burned area product- MCD45*, User Guide Version 2.0.

Seiler, W., Crutzen, P.J.(1980), Estimates of gross and net fluxes of carbon between the biosphere and the atmosphere from biomass burning. Climate, pp. 207-247.

T.C. Bond, and H. Sun, (2005),Can Reducing Black Carbon Emissions Counteract Global Warming,*Environmental Science. Technology*. **39**, pp. 5921-5926.

Zhang,Y., et al. (2012), Emission inventory of carbonaceous pollutants from biomass burning in the Pearl River Delta Region, China (PM_{10},sugarcane), *Atmospheric Environment*, **76**, pp. 189-199.

APPENDIXES

APPENDIX A: Forest and agricultural fires with ground observation

Figure A1 Burned areas collection from observational data for the case of rice fields

Figure A2 Burned areas collection from observational data for the case of corn

Figure A3 Burned areas collection from observational data for the case of sugarcane

Figure A4 Burned areas collection from observational data for the case of forest fire

APPENDIX B: The spatial distributions of emission estimation from biomass open burning for 2009 and 2011

- The spatial distributions of emission estimation from biomass open burning in grided ton/10,000 ha for 2009 and 2011 indicated that the amounts of CO_2, CO, CH_4, N_2O, and NOx and particulate matter $PM_{2.5}$, PM_{10}, and black carbon (BC) are shown in Figures B1 to B16.

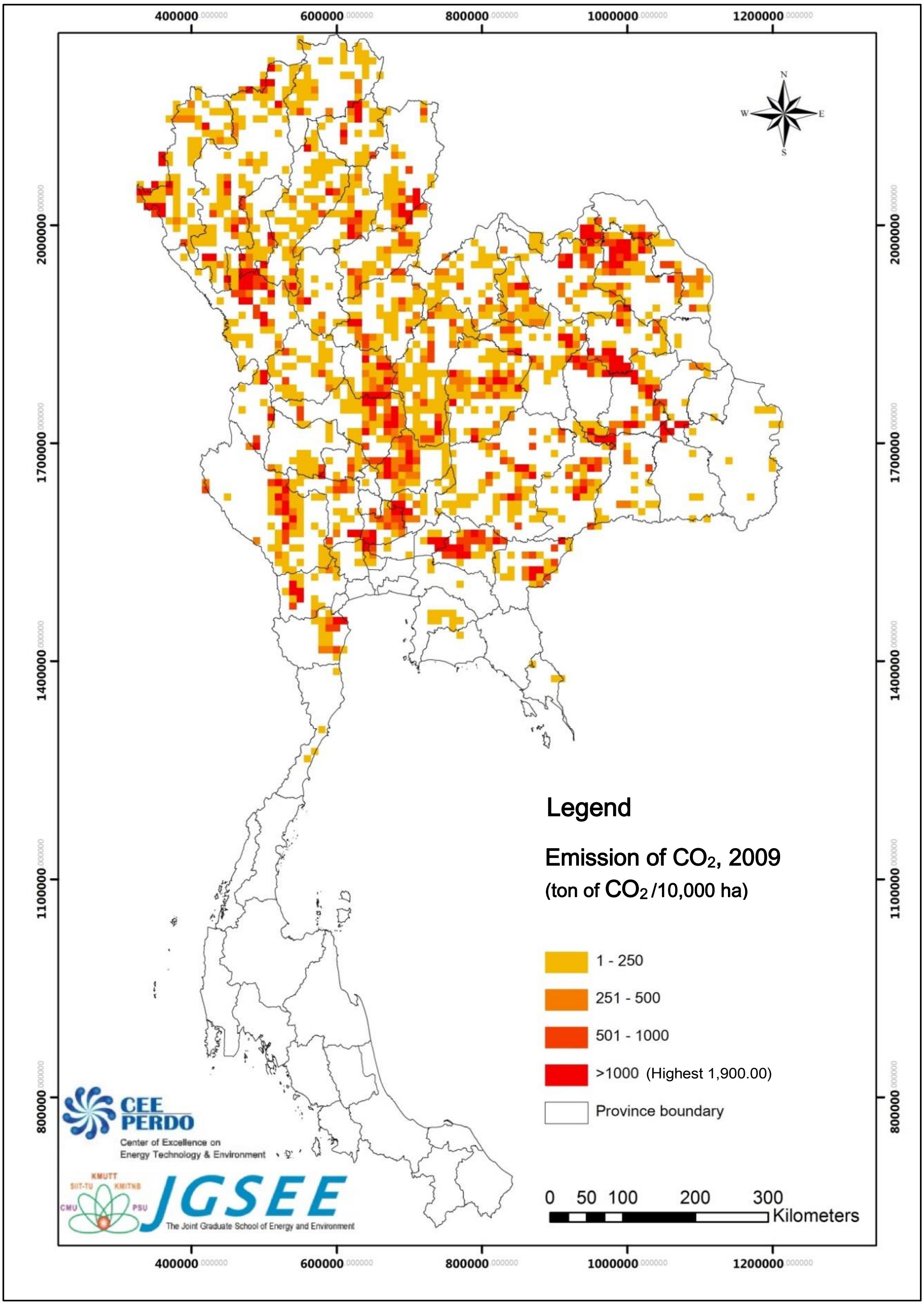


Figure B1 Spatial distributions of CO_2 from biomass open burning in 2009

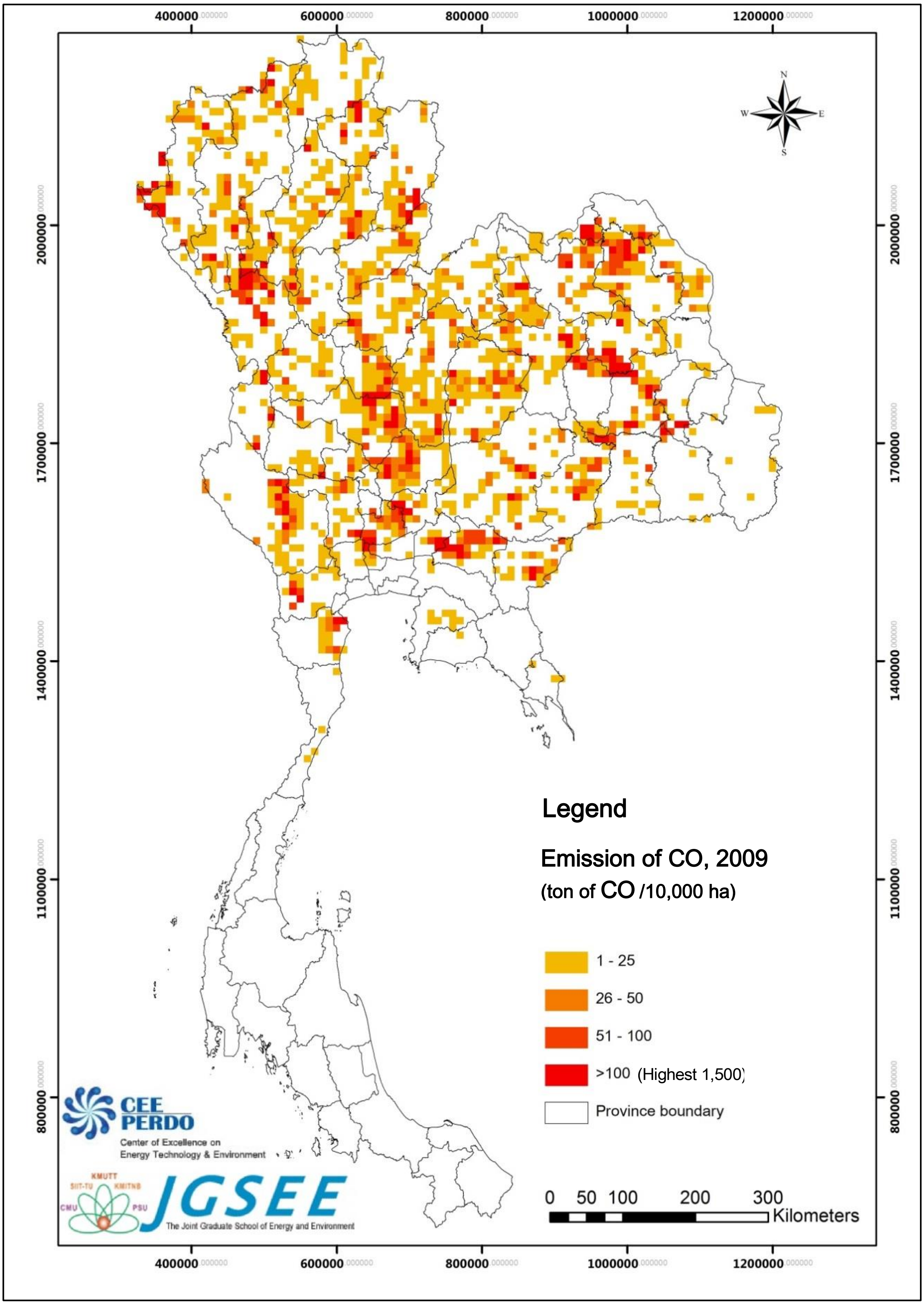


Figure B2 Spatial distributions of CO from biomass open burning in 2009

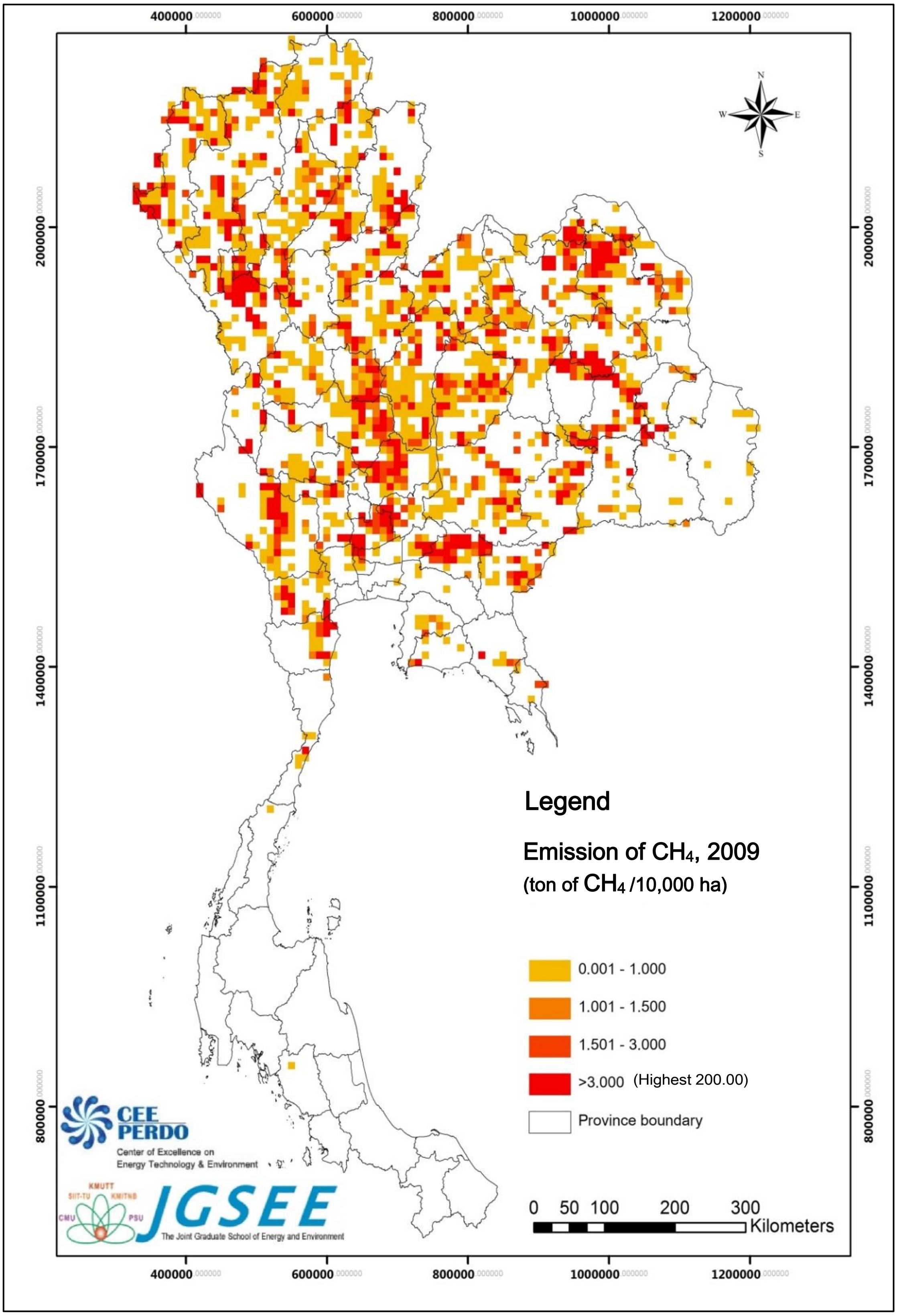


Figure B3 Spatial distributions of CH_4 from biomass open burning in 2009

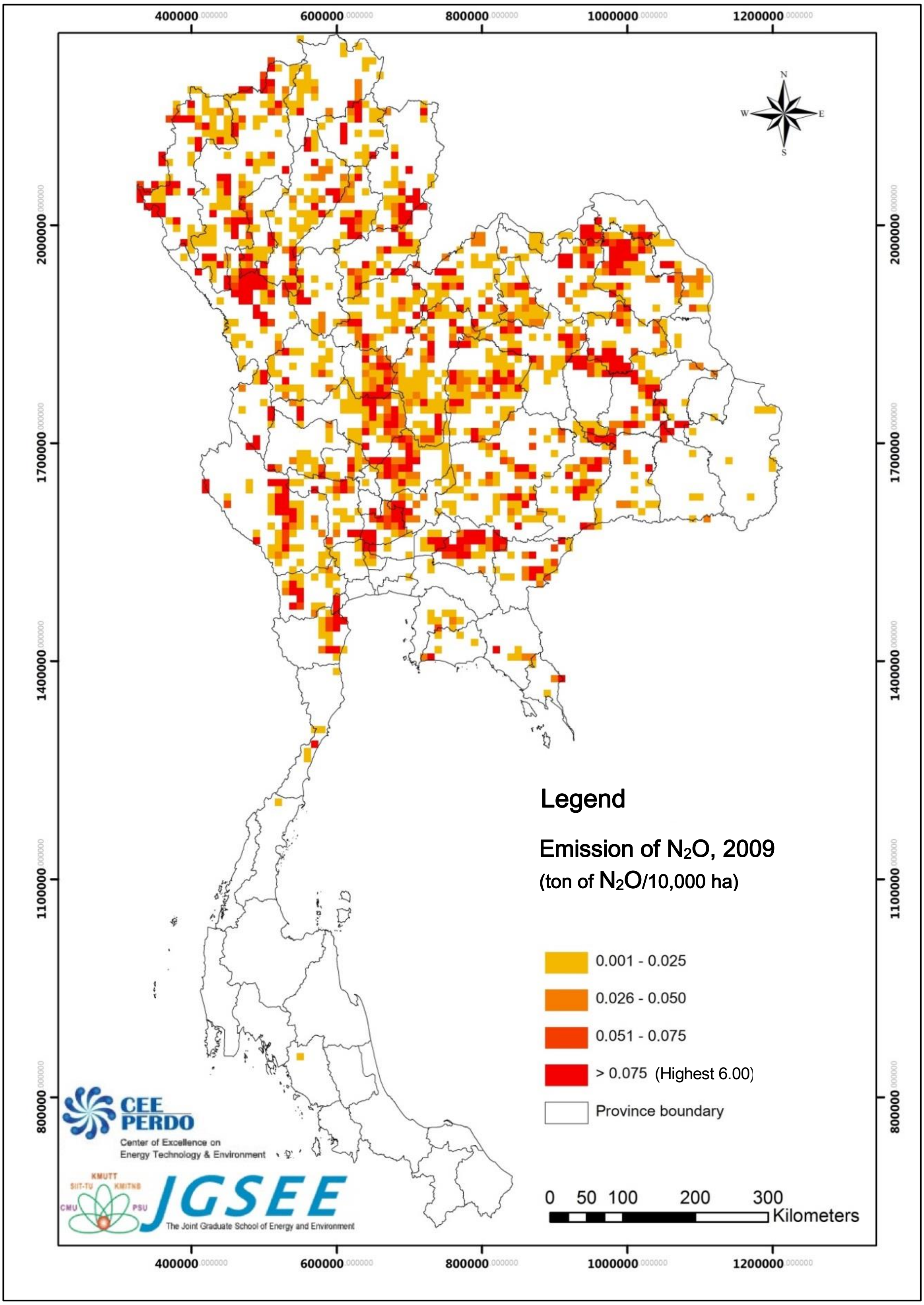


Figure B4 Spatial distributions of N_2O from biomass open burning in 2009

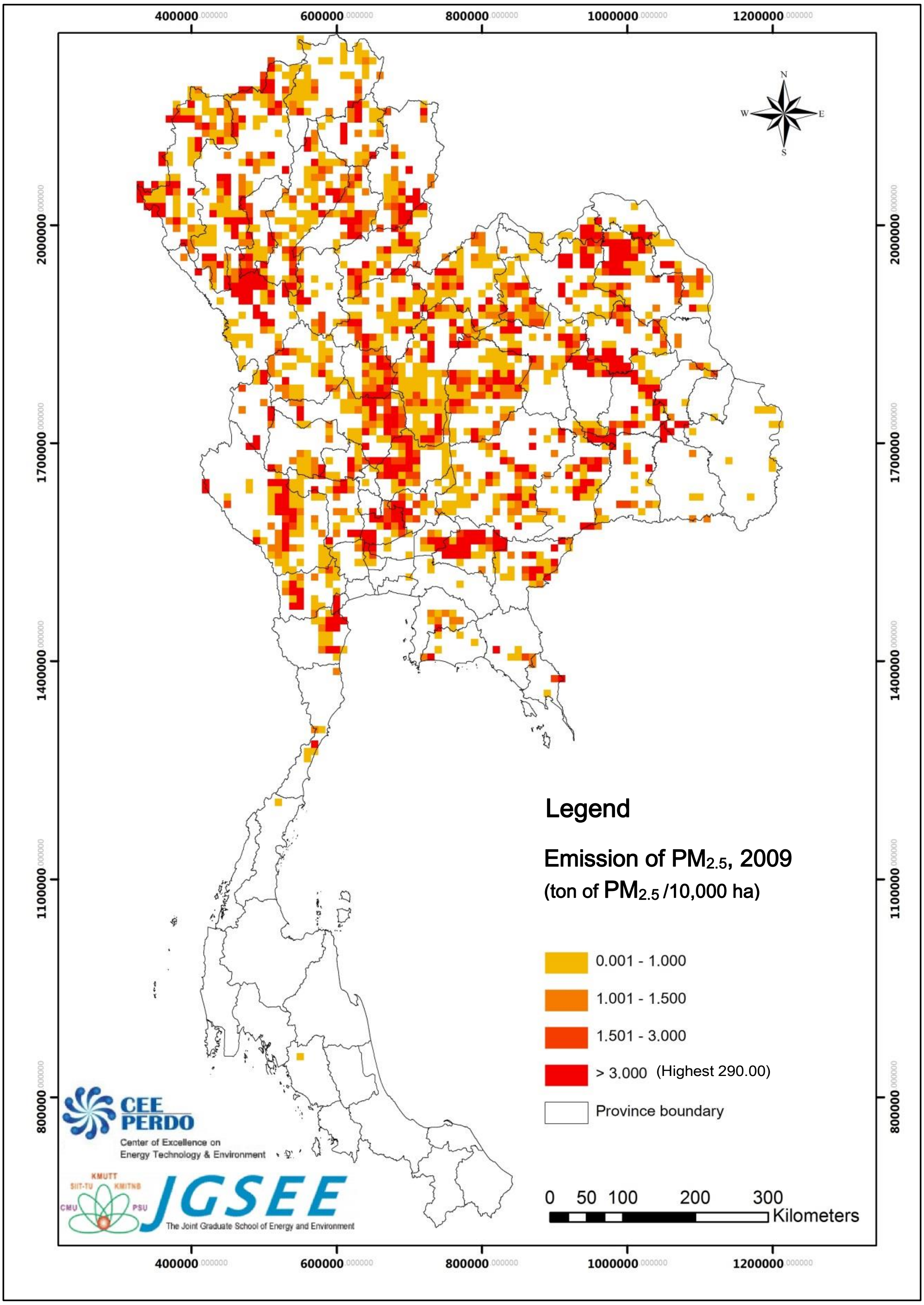


Figure B5 Spatial distributions of $PM_{2.5}$ from biomass open burning in 2009

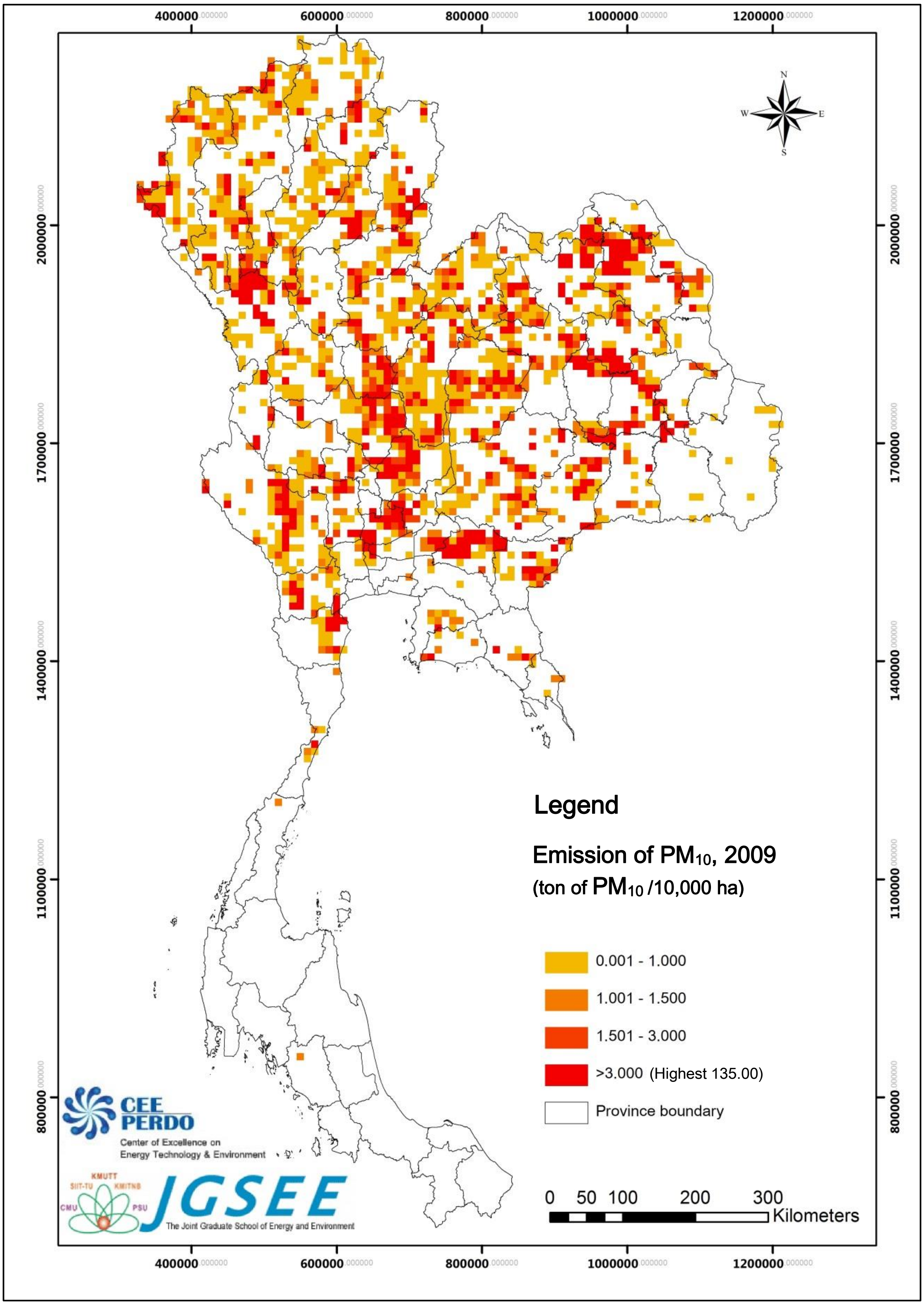


Figure B6 Spatial distributions of PM_{10} from biomass open burning in 2009

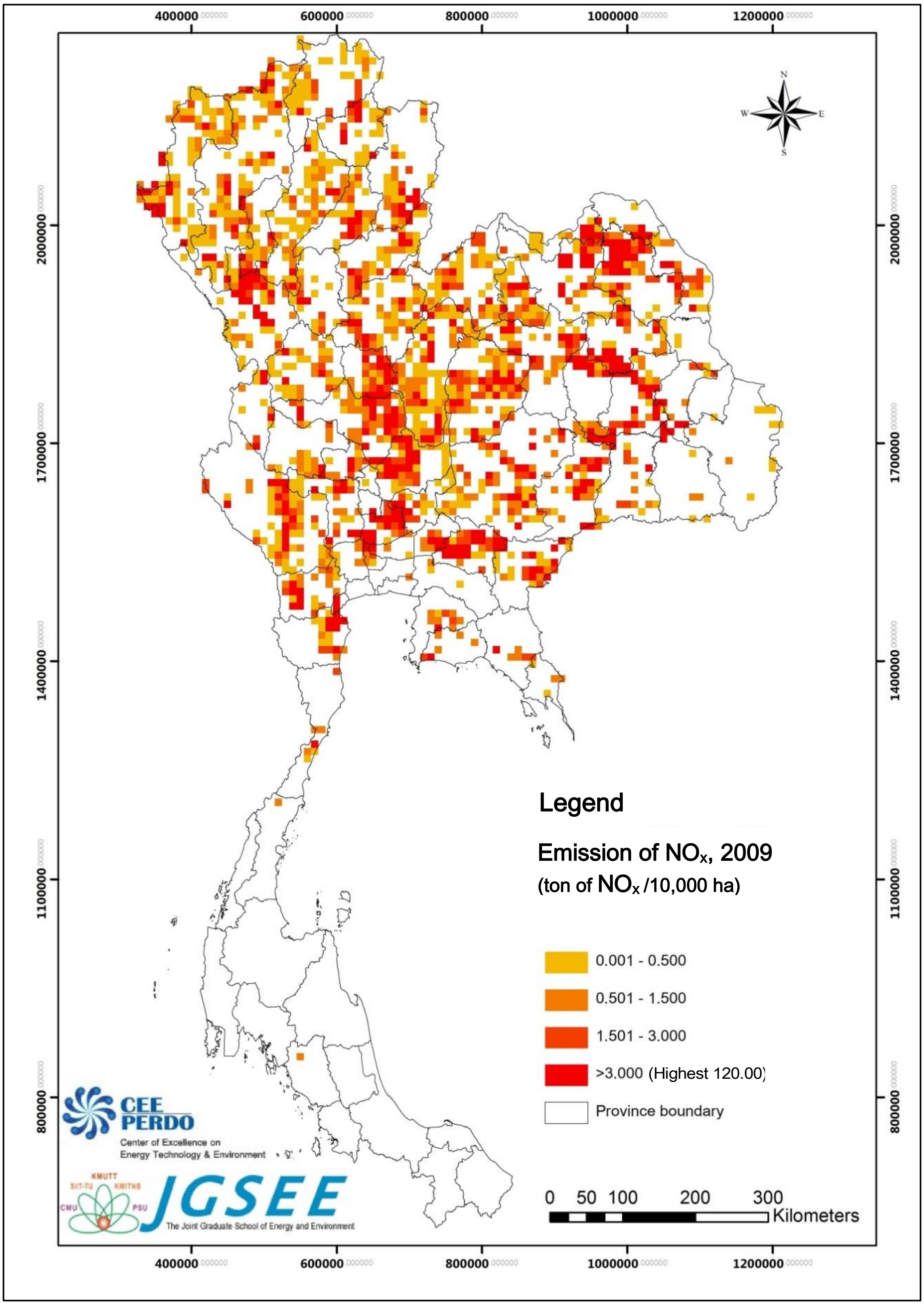


Figure B7 Spatial distributions of NO_x from biomass open burning in 2009

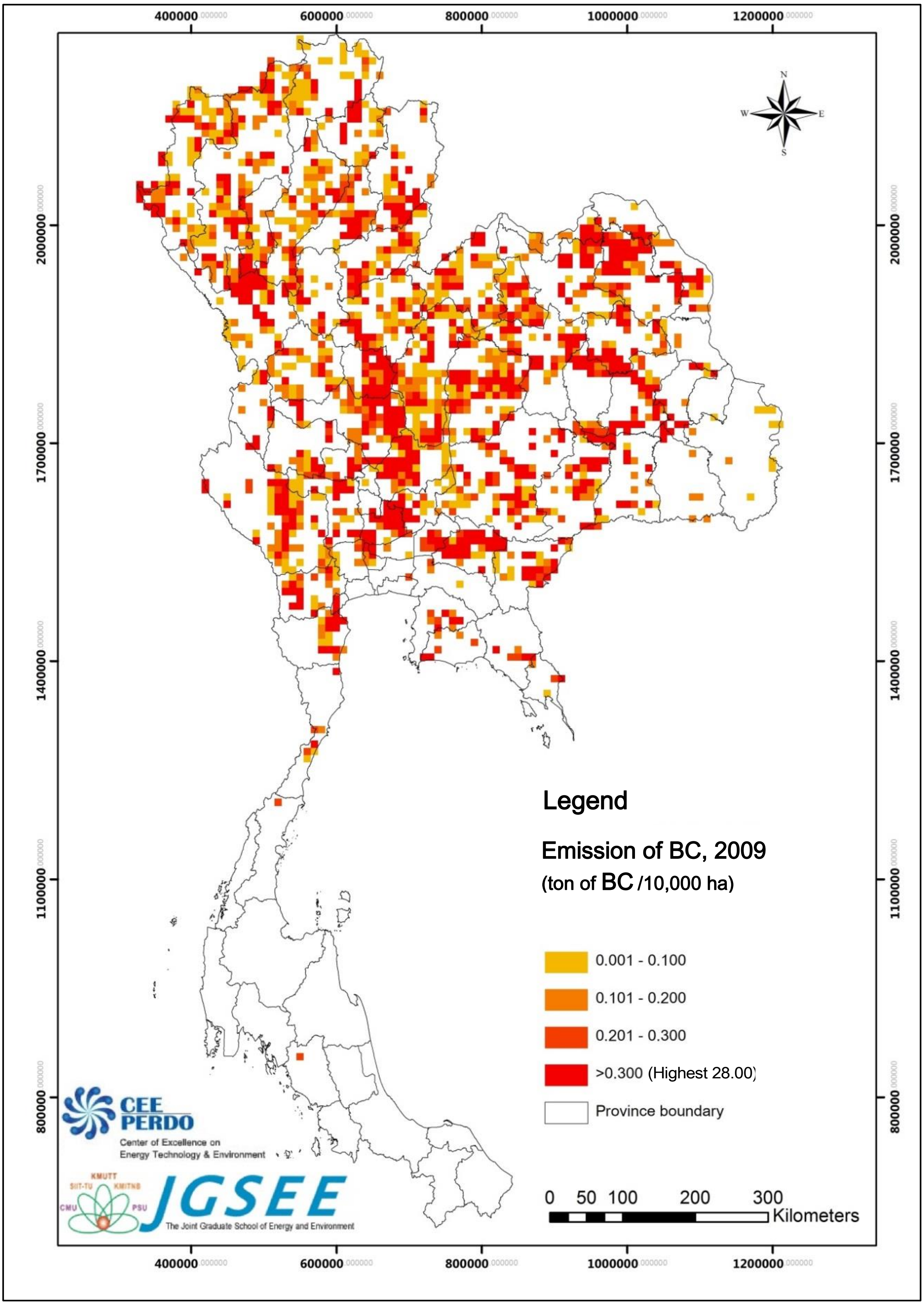


Figure B8 Spatial distributions of BC from biomass open burning in 2009

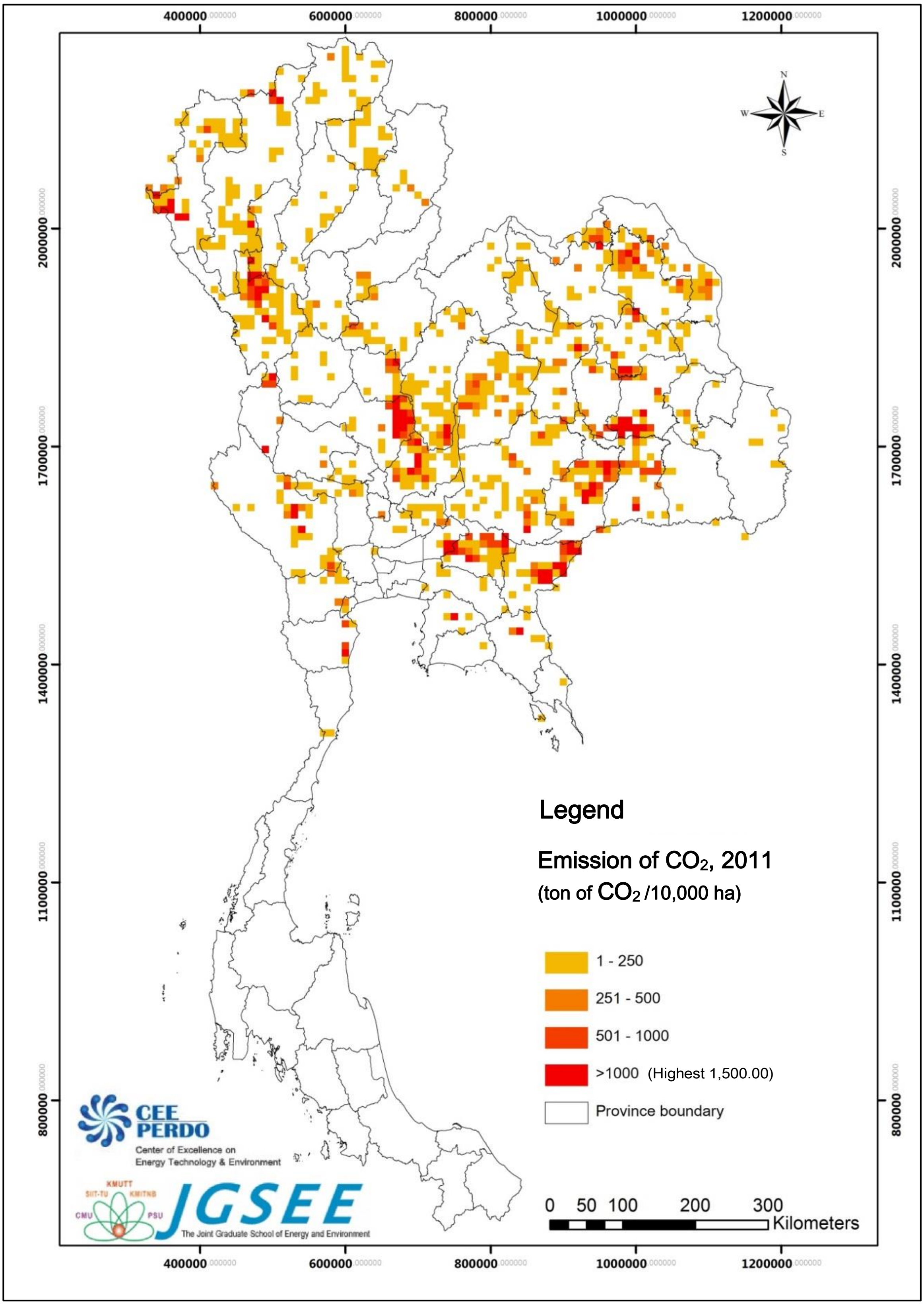


Figure B9 Spatial distributions of CO_2 from biomass open burning in 2011

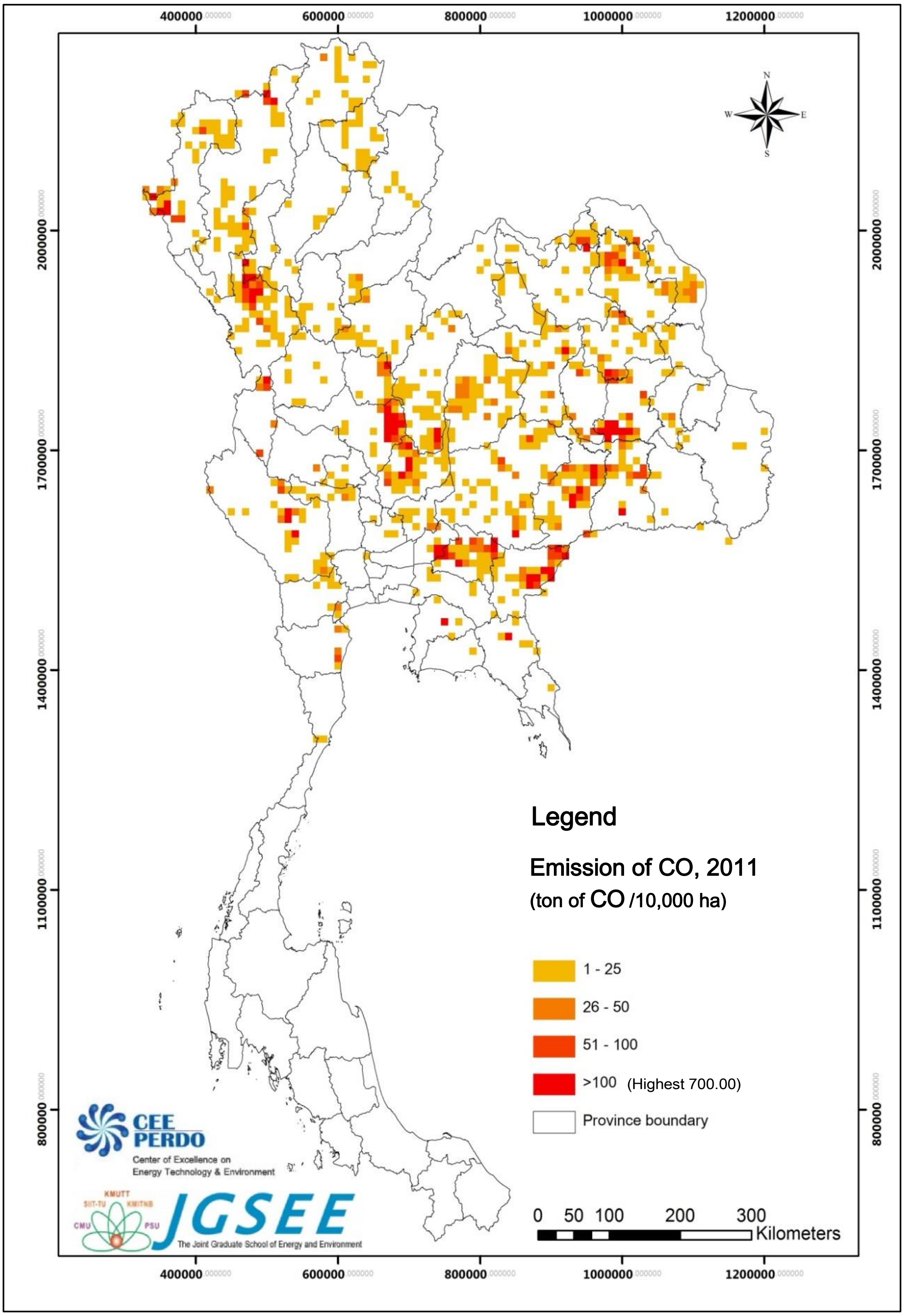


Figure B10 Spatial distributions of CO from biomass open burning in 2011

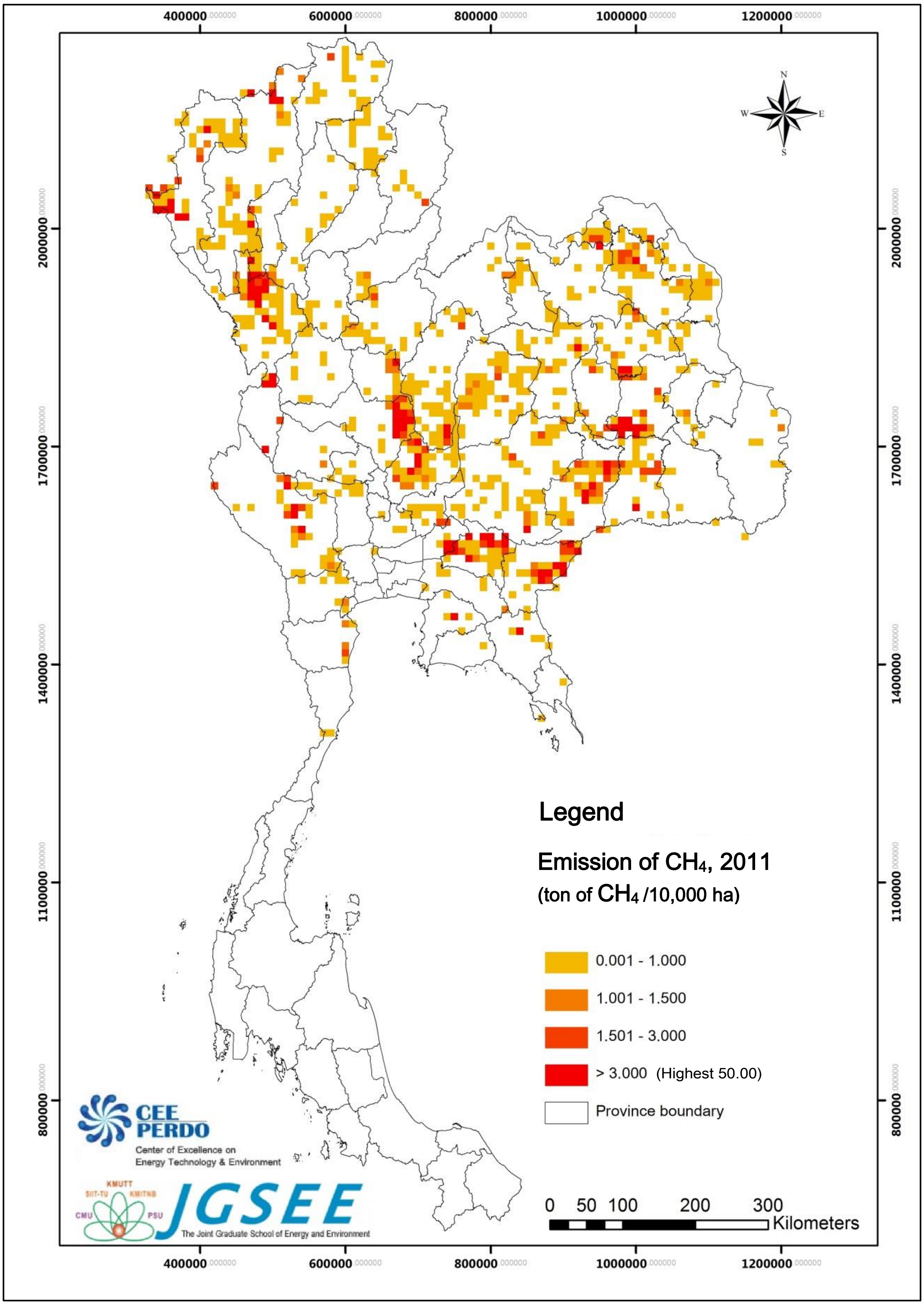


Figure B11 Spatial distributions of CH_4 from biomass open burning in 2011

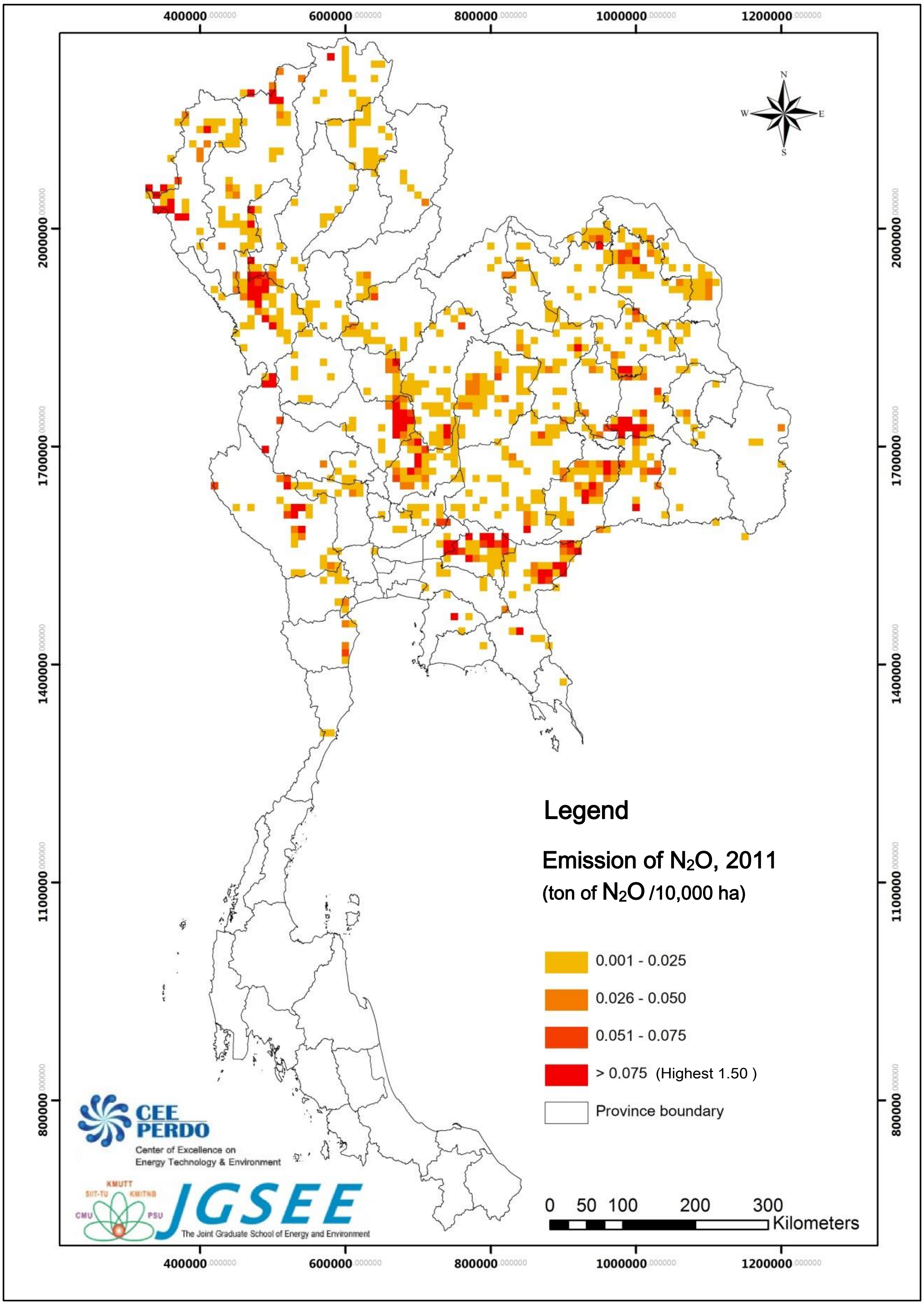


Figure B12 Spatial distributions of N_2O from biomass open burning in 2011

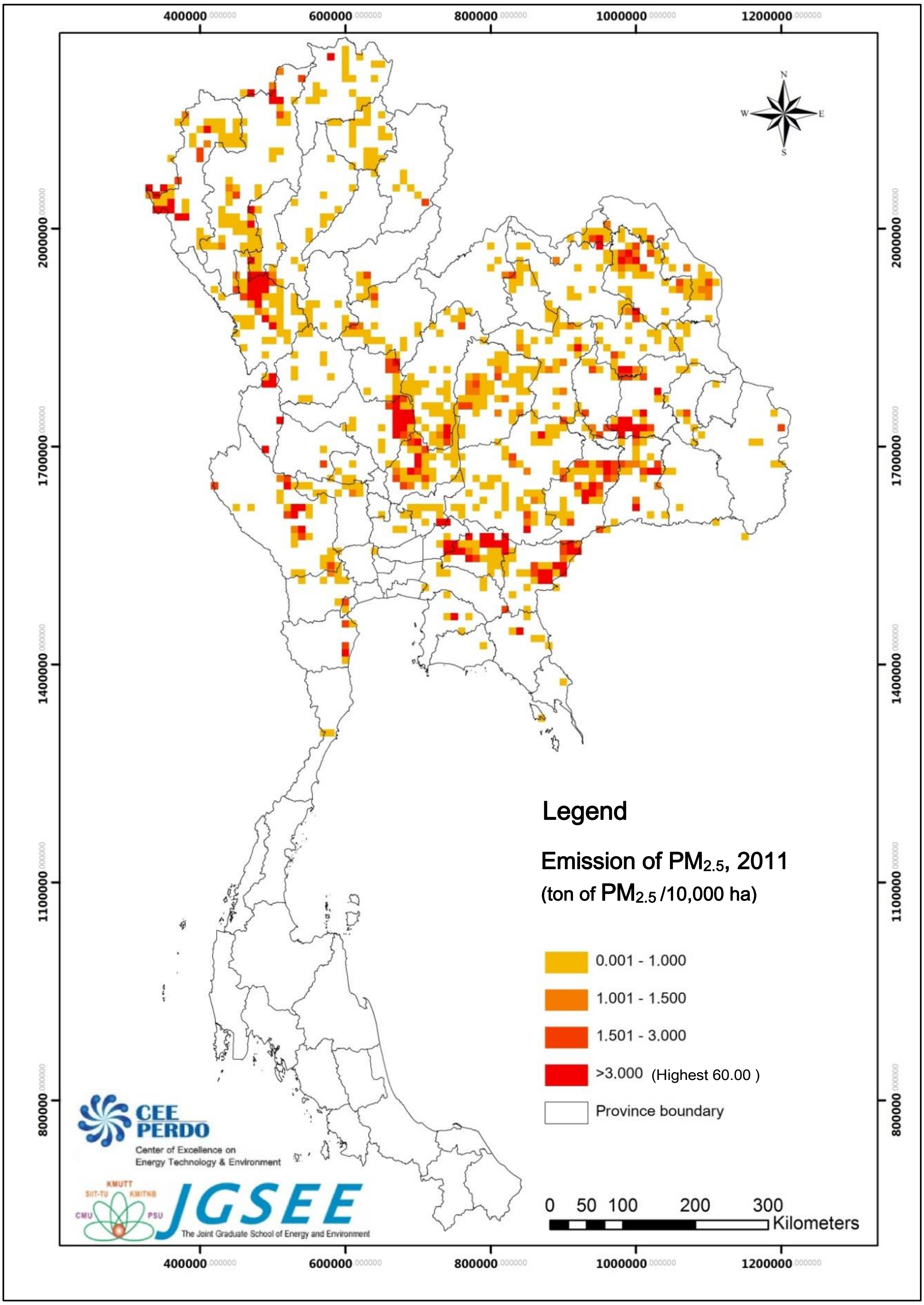


Figure B13 Spatial distributions of $PM_{2.5}$ from biomass open burning in 2011

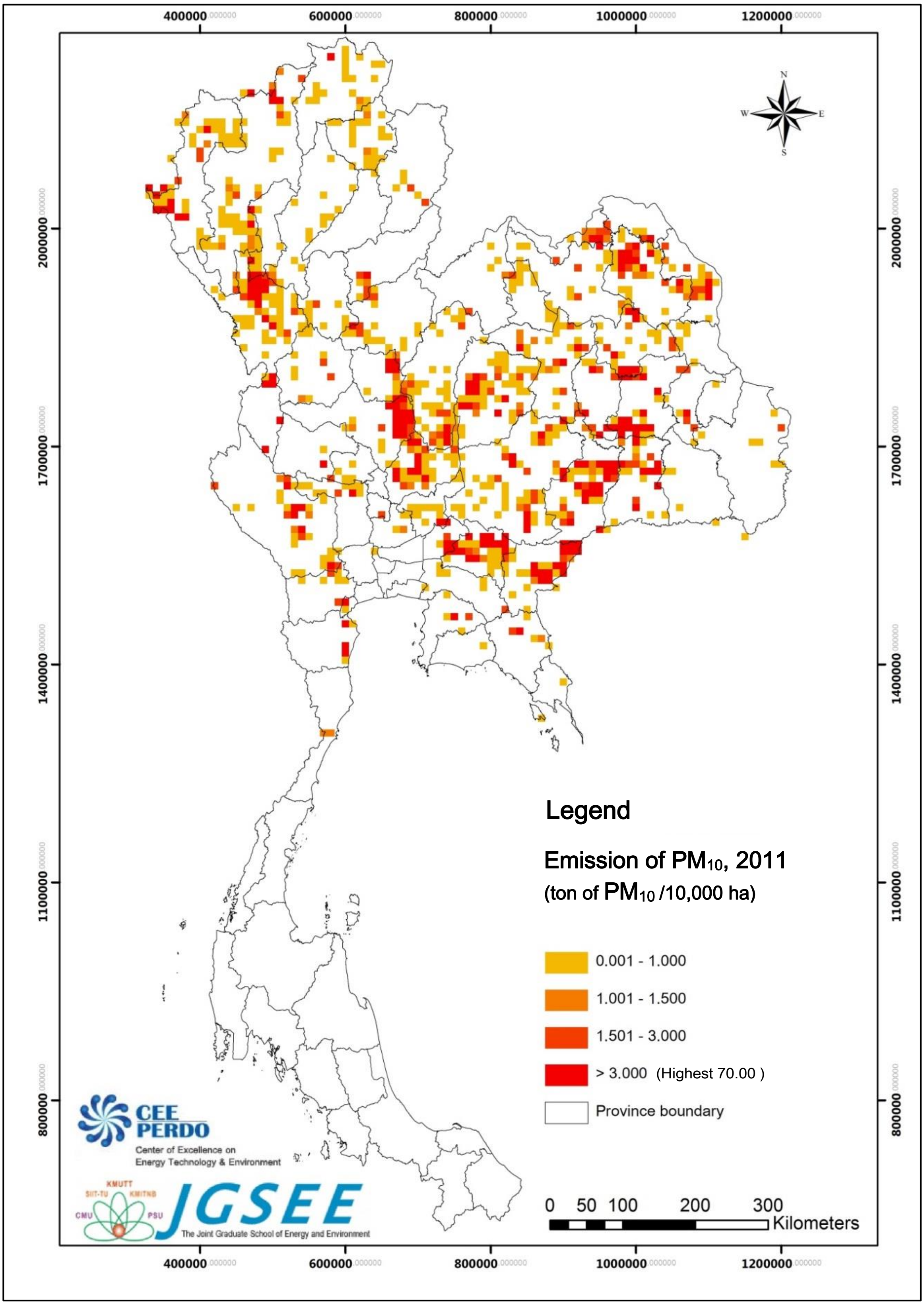


Figure B14 Spatial distributions of PM_{10} from biomass open burning in 2011

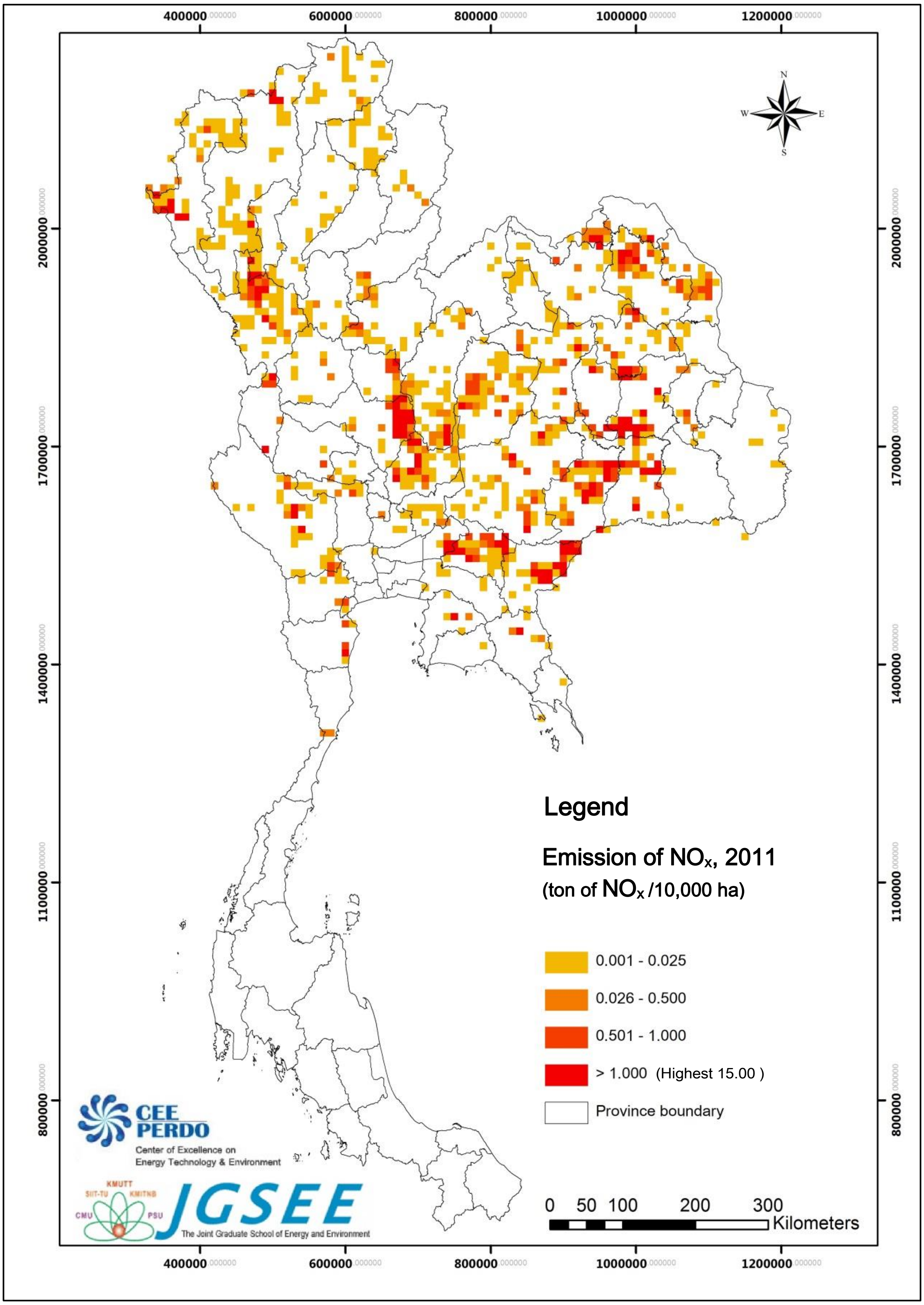


Figure B15 Spatial distributions of NO_x from biomass open burning in 2011

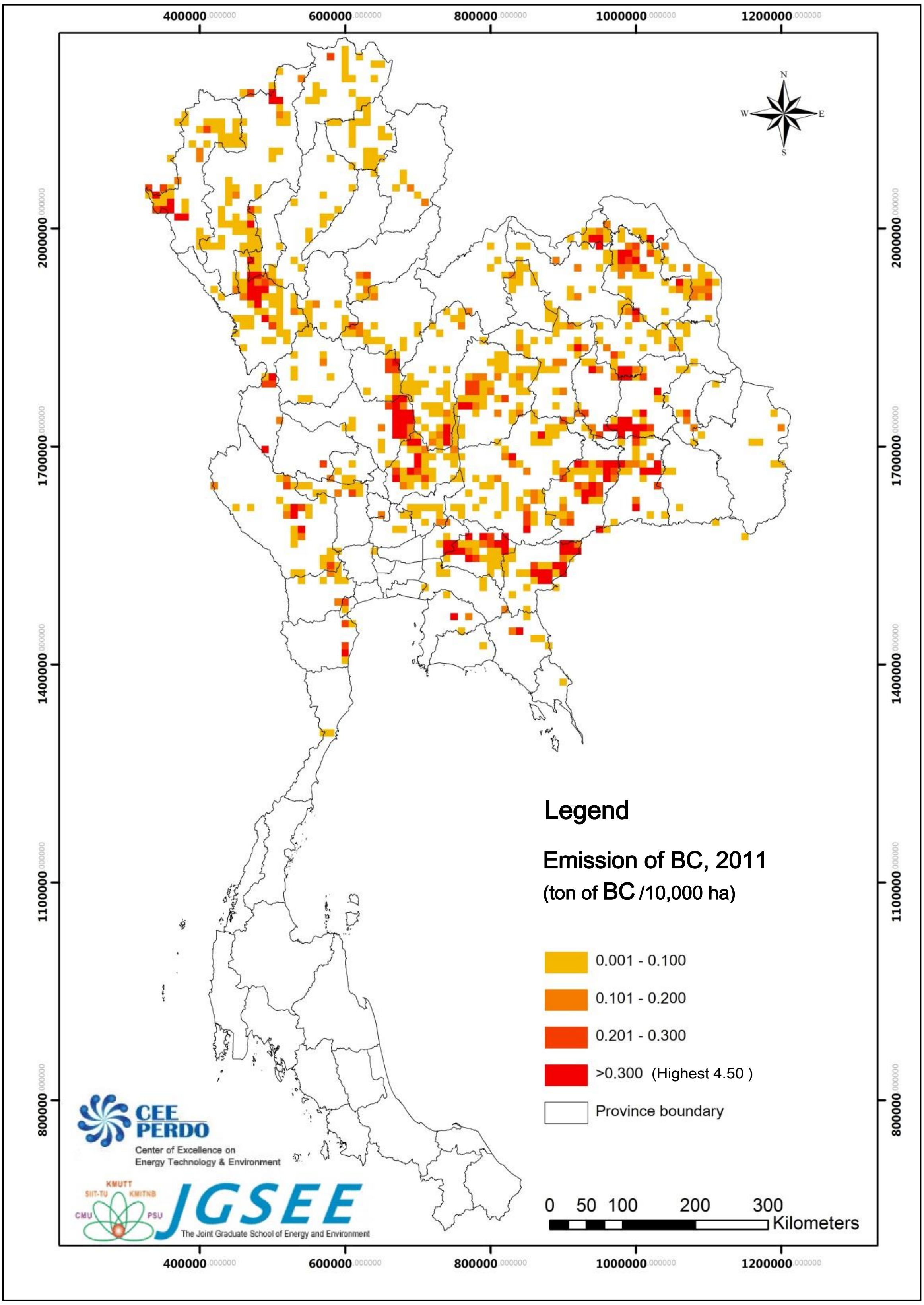


Figure B16 Spatial distributions of BC from biomass open burning in 2011