Seasonal Variability of Biomass Open Burning Activities in the Greater Mekong Sub-Region

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Abstract

The seasonal variability of biomass open burning activities in the Greater Mekong Sub-region (GMS) with focus on carbon monoxide (CO) and total particulate matter or aerosol (TPM) emissions was investigated in order to document the characteristics of this significant source of air pollutants in the region. This assessment was performed using remote sensing data on fire hotspots detected by ANDES in combination with ground observations and data on vegetation land-use of the GMS region. We prepared monthly gridded emissions maps, to identify vegetation types subject to open burning and the corresponding spatio- temporal distribution. The results obtained showed that the major types of vegetation subject to open burning in the GMS region are forests and paddy fields. We also found that vegetation fires mostly take place during the dry season with a peak occurring during January - April. The quantification and spatio-temporal distribution of emissions from forest fires and rice residue burning could serve as important information to support decision making on control strategies that should be formulated at the national level to reduce emissions from biomass open burning and thereby to comply with the ASEAN Agreement on Transboundary Haze.

Key words: biomass open burning, emissions, Greater Mekong Sub-region, seasonality

1. Introduction

Biomass burning is defined as the combustion of the world's living and dead vegetation, including grasslands, forests and agricultural lands following harvest, for land clearing and land-use change. Biomass burning is not limited to one area but is a global phenomenon. It has been recognized as a key driver of global change (Levine *et al*., 1995). Biomass burning is recognized to be one of the major sources of gaseous and particulate emissions to the atmosphere (Yamasoe *et al*., 2000). It contributes to global environmental change by affecting local, regional and global air quality as well as by disrupting rainfall patterns.

In Southeast Asia, interest in biomass open burning effectively started in 1997/1998 when a severe haze episode occurred as a result of wildfires in Indonesia, which were enhanced by the climatology phenomenon known as the El Niño-Southern Oscillation (ENSO), which occurred in that year. The resulting haze covered the entire area of Sumatra and Kalimantan, and extended via long-range transport up to Malaysia, Singapore and the Southern part of Thailand. The severity of this disaster was recorded by UNEP as one of the most damaging in history for the member countries of the Association of Southeast Asian Nations or ASEAN. The environmental, economic and social impacts resulting from these fires, and the resulting transboundary haze pollution, were profound. The total economic losses in terms of forest destruction, health care due to respiratory disease, land and airtransportation disturbances, and impacts on agricultural production, tourism activities and other economic endeavors were estimated at US$9.3 billion (ASEAN Secretariat, 2004).

Transboundary haze pollution, which leads to severe air quality problems, occurs during the dry season in both hemispheres (Crutzen & Andreae, 1990; Andreae, 1991). In the northern hemisphere the peak period is usually observed during January to March in the region covering Cambodia, Lao PDR, Myanmar, Thailand and Vietnam, and in the southern hemisphere during August to October, with transport of haze from Indonesia up to the southern part of Thailand. To remediate this regional air quality issue, ASEAN approved the establishment of the ASEAN Agreement on Transboundary Haze on the basis of voluntary participation and ratification. Once a

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member country decides to ratify it, it is expected to develop and implement a National Master Plan on Open Burning Control and an Open Burning Control Plan of Implementation. Although in Asia biomass open burning particularly concerns China, India, Indonesia and countries of the Mekong River Basin Sub-Region includeing Thailand, Cambodia, Lao PDR and Vietnam (Streets *et al*., 2003), there is still a lack of reliable, up-to-date information concerning biomass open burning emissions in the Asian region. This is particularly the case for the Greater Mekong River Basin Sub-region (GMS), so regional air quality modeling and monitoring remain to be developed to better evaluate the impacts of those emissions on the regional air quality and climate.

To contribute to mitigation of their emissioins in Southeast Asia of the above issue, information on the spatial and temporal distribution of biomass open burning in the GMS region has been obtained using a combination of remote sensing data and ground-based observations, and Geographic Information System (GIS) vegetation land cover map. Monthly 12 km × 12 km gridded emission maps have been produced focusing on CO and total particulate matter (TPM) to characterize the spatio-temporal distributions of vegetation fires and related quantitative emissions.

2. Methodology

2.1 Vegetation land cover

A Geographic Information System (GIS) map was developed for the GMS incorporating a database of digital land use maps for each of the countries of the region. The map is displayed in Fig. 1. The geographic data and corresponding attributes were collected for the base Year of 2000 from governmental agencies responsible for land development, land use and national statistics. Based on the information collected, land cover maps were created for Thailand, Cambodia, Lao PDR, Vietnam and Myanmar at a 1,250,000 scale. These maps were used as a base GIS layer to classify emissions from biomass open burning. Three major types of vegetaion were reported on the maps which include: forests, paddy fields and bushes.

From Fig. 1, it can be observed that paddy fields are mostly located in the central part of Cambodia, in the central and northeastern part of Thailand, in the northern part of Vietnam along the border with China and in the southern part of Vietnam. In the case of Lao PDR, the main vegetation of the country is forest, while land dedicated to rice cultivation is still limited and spread throughout the country. A summary of the land area of each type of vegetation is reported in Table 1.

From the above information, one can see that Thailand, with 170,157 km^2, has the largest area of forest, followed by Lao PDR, Cambodia and Vietnam. However, with regard to the ratio of forest land to total land area, Cambodia and Lao PDR, are largely ahead in the region with about 60% of the country covered with forest. As for paddy fields, Thailand and Vietnam possess the highest coverage with 15%-20% of their national land dedicated

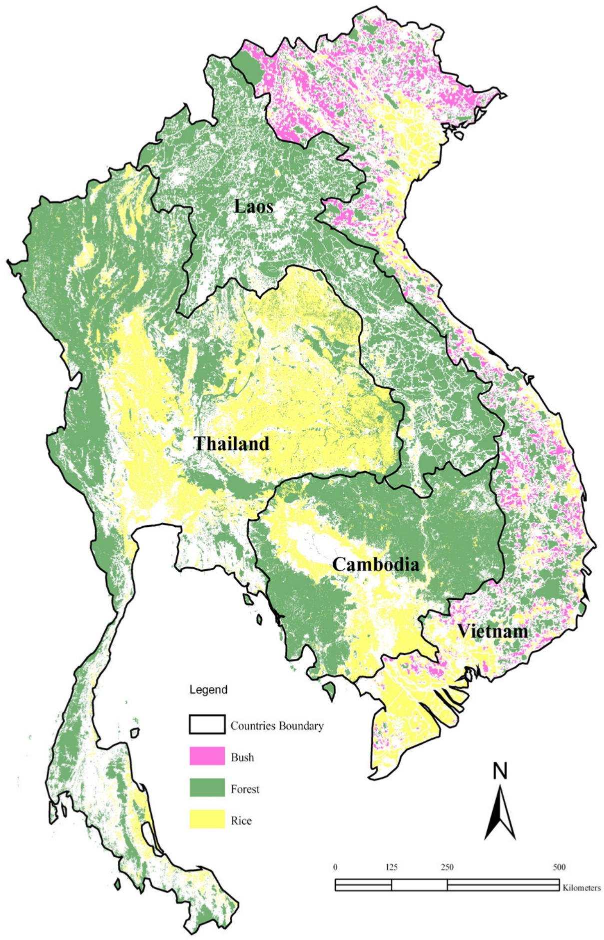

Fig. 1 GMS vegetation map (2000).

Table 1 Land surface of forest and paddy fields in the GMS region.

Type	Thailand	Cambodia	Lao PDR	Vietnam	Total in GMS
Forest					
km^2	170,157	108,990	142,602	58,613	480,362
Mha	17.02	10.90	14.26	5.86	48.04
(% NL)	(33%)	(61%)	(60%)	(18%)	
Paddy					
km^2	105,754	17,024	2,556	48,611	173,945
Mha	10.58	1.70	0.26	4.86	17.39
(% NL)	(21%)	(9%)	(1%)	(15%)	
National area					
km^2	514,361	181,035	236,80	331,033	1,263,229
Mha	51.44	18.10	23.68	33.10	126.32

to rice cultivation, which indicates their position as major world producers of rice.

2.2 Biomass open burning activities

2.2.1 Assessment of biomass burning activities using satellite data

Biomass burning activities in the GMS region were investigated using remote sensing data. This method provides information about the geographic position of and temporal changes in biomass burning activities. In this study, information on fire hotspots was retrieved from a satellite launched under the Asia-Pacific Network for Disaster mitigation using Earth observation Satellite (ANDES) research program. The Defense Meteorological Satellite Program-Operational Linescan System (DMSP-OLS) sensor enables the detection of areas where temperatures higher than a threshold, qualified as the reference temperature of open burning (>150°C), are observed and identified as hotspots. The resolution of the satellite sensor is 2.7 km × 2.7 km, which is considered a coarse resolution but is sufficiently fine to indicate the location of fires and enable estimation of the area burnt and related emissions. Based on the sensor resolution, it was assumed that the size of any fire hotspot was equal to 2.7 km × 2.7 km and therefore that the corresponding area was subject to burning. The ANDES hotspot data were collected for the Year 2002, since during that year there was no major interruption in satellite data record; and therefore hotspots were collected for the whole year to enable assessment of temporal changes in open burning activities in the GMS region.

The daily data of fire hotspots were first processed into monthly data in the form of a GIS map, in order to investigate the seasonal variability over a year. An example of a monthly hotspot map is given in Fig. 2. Each hotspot was classified according to the type of vegetation where it was located, by overlaying the monthly hotspot map with the land cover map illustrated in Fig. 1. This overlay of information enabled the qualitative and quantitative assessment of the type of biomass subject to open burning and estimation of related emissions. In order to systematically geo-reference the position of the hotspots, a grid map with a resolution of 12 km × 12 km was developed, supporting the development of a systematic emissions map, easy to use for monitoring or modeling biomass burning emissions. The emissions calculation equation was incorporated into the GIS to compute the emissions for each 12 km × 12 km grid based on land cover type. Monthly emissions maps of CO and TPM from forest fires and paddy field burning were then obtained, enabling us to investigate the areas and time periods of biomass open burning activities.

2.2.2 Assessment of areas burnt and related emissions

Properties of smoke emissions from biomass open burning vary highly under the control of two main parameters: (1) fuel characteristics and (2) combustion conditions. These parameters are dependent on the following: density of biomass fuel, fraction of biomass burnt, moisture content, biomass type, combustion phase (ignition, flaming or smoldering), completeness of combustion, wind conditions, etc. (Garivait, 1995; Reid *et al.*, 2005). Taking smoke properties into account, the emission of a compound from biomass burning can be determined based on a series of equations originally developed by Seiler and Crutzen (1980) which represents the relationship between the combustion process and its emissions, as follows:

$$E_x = M_{biomass} \times EF_x \qquad \text{(Eq.1)},$$

where E_x is the emission of compound x (g), $M_{biomass}$ is the mass of biomass subject to burning and expressed on a dry mass basis (kg), and EF_x represents the emission factor of compound x (g/kg biomass).

For forest fires, the mass of biomass, $M_{biomass}$, can be estimated as follows:

$$M_{biomass} = A \times L \times FB \qquad \text{(Eq. 2)},$$

where A is the area burnt (ha), L is the biomass load or dry matter density (kg/ha), and FB is the fraction of biomass burnt (burning efficiency).

Currently, data on the area burnt, A, are obtained either from observations at ground level, by aircraft or by remote sensing; while data on L and FB are generally from surveys and/or field experiments.

In the case of crop residue burning, the amount of biomass burnt can be determined using a modified version of the expression given in the IPCC revised guidelines (1996) and also similar to that used by Hao and Liu (1994) or Streets *et al.*, (2003), as follows:

$$M_{biomass} = A \times P \times N \times D \times F \times FB \qquad \text{(Eq. 3)},$$

Where A is the area of rice cultivation (ha), P is the crop yield (kg/ha), N is the crop-to-residue ratio (no unit), D is the fraction of dry matter (no unit), F is the fraction of dry matter crop residue left unused in the field and FB is the fraction of biomass burnt (burning efficiency). Data related to A and P can be obtained from national statistics and those to N, D, F and FB from surveys.

In order to characterize emissions from biomass open burning with an emphasis on forest fires and rice residue burning in the GMS region, data related to the parameters identified in Equations 2 and 3 were collected from several sources, as detailed in Table 2. These parameters, in combination with information on areas of vegetation

Table 2 Estimates of tropical forest biomass and crop residues burnt in Asia.

	Biomass load range (kg/m^2)			Burning efficiency
Tropical Forest	10[a]			0.2[b]
Crops	Residue-to-crop ratio	Dry matter fraction	Dry matter burnt in field	Burning efficiency
Rice	1.76[c]	0.85[d,e,f]	25%[d,e]	89%[e]

[a]IPPC (1996); [b]Levine (2000); [c]Koopmans and Koppejan (1997), [d]Hao and Liu (1994); [e]Streets *et al.*, (2003); [f]OEP (1990)

subject to open burning as detected in the form of fire hotspots by ANDES (see Fig. 2), were used to quantify the amount of biomass burnt and related emissions over time and space.

For the calculations of emissions, a review study by Andreae and Merlet (2001) provides a compilation of pollutant-specific emission factors for various types of vegetation subject to burning including tropical forests and crop residues. Those emissions factors were sourced from a critical review of research works performed over the past few decades on emission factor measurements worldwide. In this study, the focus is on emissions of CO and TPM. The EF for CO was retrieved from Andreae and Merlet (2001), but that of total particulate matter (TPM) was collected from Levine (2000), since in that research work the studied emissions were obtained from experiments representative of burning conditions in Asia (Table 3).

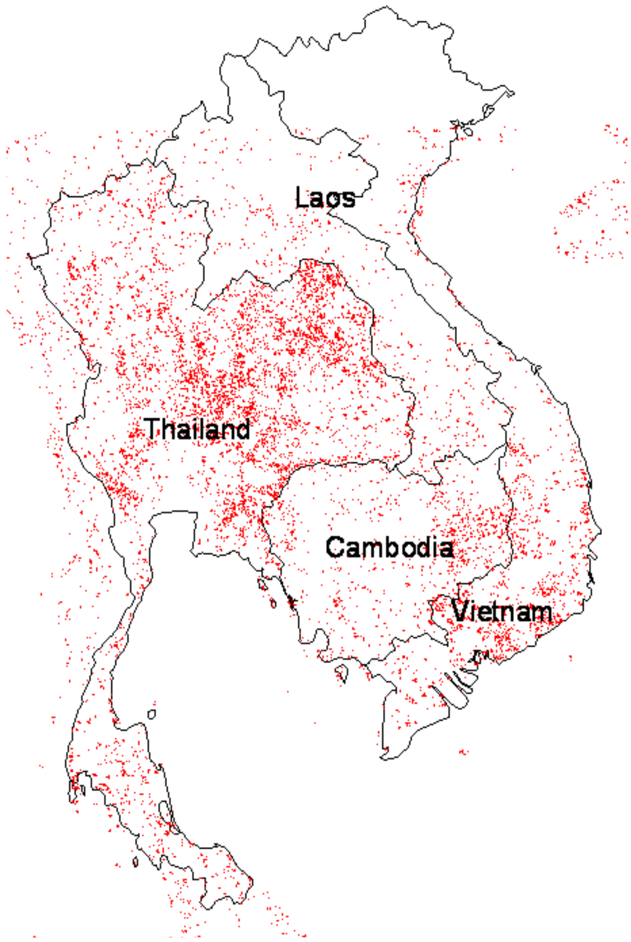

Fig. 2 Monthly fire hotspots map (2002).

Table 3 Emission factors of CO and TPM vs. biomass type (g/kg of dry matter).

Biomass type	Tropical forest	Agricultural residue	Reference
CO	104 ± 20	92 ± 84	Andreae and Merlet (2001)
TPM	20	10	Levine (2000)

3. Results and Discussion

3.1 Biomass open burning activities

The biomass open burning activities observed by ANDES satellite for Thailand, Cambodia, Lao PDR and Vietnam, are reported in Fig. 3, in terms of fire counts.

Results from Fig. 3 indicate that the peak season of forest fires in the GMS region occurs during the dry season running from October to April. In Thailand, Cambodia and Vietnam, the peak value is found in February, while for Lao PDR this is observed in April. The highest record is from Thailand, where more than 2,600 fires were counted in February 2002.

Regarding paddy field burning, the peak season is observed during the period of January – April in Thailand, Lao PDR and Cambodia. In Vietnam, however, a different pattern is observed with frequent burning activities occurring throughout the year. In addition, based on the intensity of paddy field burning, Thailand and Vietnam are far ahead. The particular seasonal pattern of paddy field burning observed for Vietnam seems to confirm an agro-intensification of rice production in this country.

Based on the fire count data retrieved from ANDES with satellite sensor resolution of 2.7 km × 2.7 km, the corresponding area of vegetation burnt (forest and paddy field) was quantified. The results are reported in Table 4.

Those results show that among the investigated countries, Thailand has the highest area of vegetation burnt with regard to forest and rice residues. In Vietnam, the total surface of paddy fields burnt is comparable to that of forests. These results indicate that slash-and-burn is a common practice in Vietnam and Thailand and both countries are experiencing an intensification of rice cultivation with an increased number of crops harvested per year, *e.g.*, 2-3 crops per year in the case of Thailand, in particular in the central part of the country and where irrigation is available.

3.2 CO and TPM emissions

Following the assessment of areas of forest and paddy field burnt in each country of the GMS, the corresponding amounts of biomass burnt were estimated using Eq. 2 and Eq. 3 and data from Table 2. On the basis of this information, emissions of CO and TPM were estimated using Eq. 1 and the emissions factors reported in Table 3. The results obtained at the level of the GMS region, were represented in the form of monthly gridded emissions maps of CO and TPM as shown in Figs. 4 and 5, respectively. These two figures seem identical since they are derived from the same hotspots map (see example illustrated in Fig. 2). The gridded emission maps help to visualize the locations where the numbers of fire counts, and hence the emissions intensities are high.

From Figs. 4 and 5, and based on the vegetation land use map, it is observed that for Thailand and Cambodia, forest fires largely contribute to emissions of pollutants during March and April, while open burning of paddy fields is particularly active during the period of January-February, particularly in the central and the

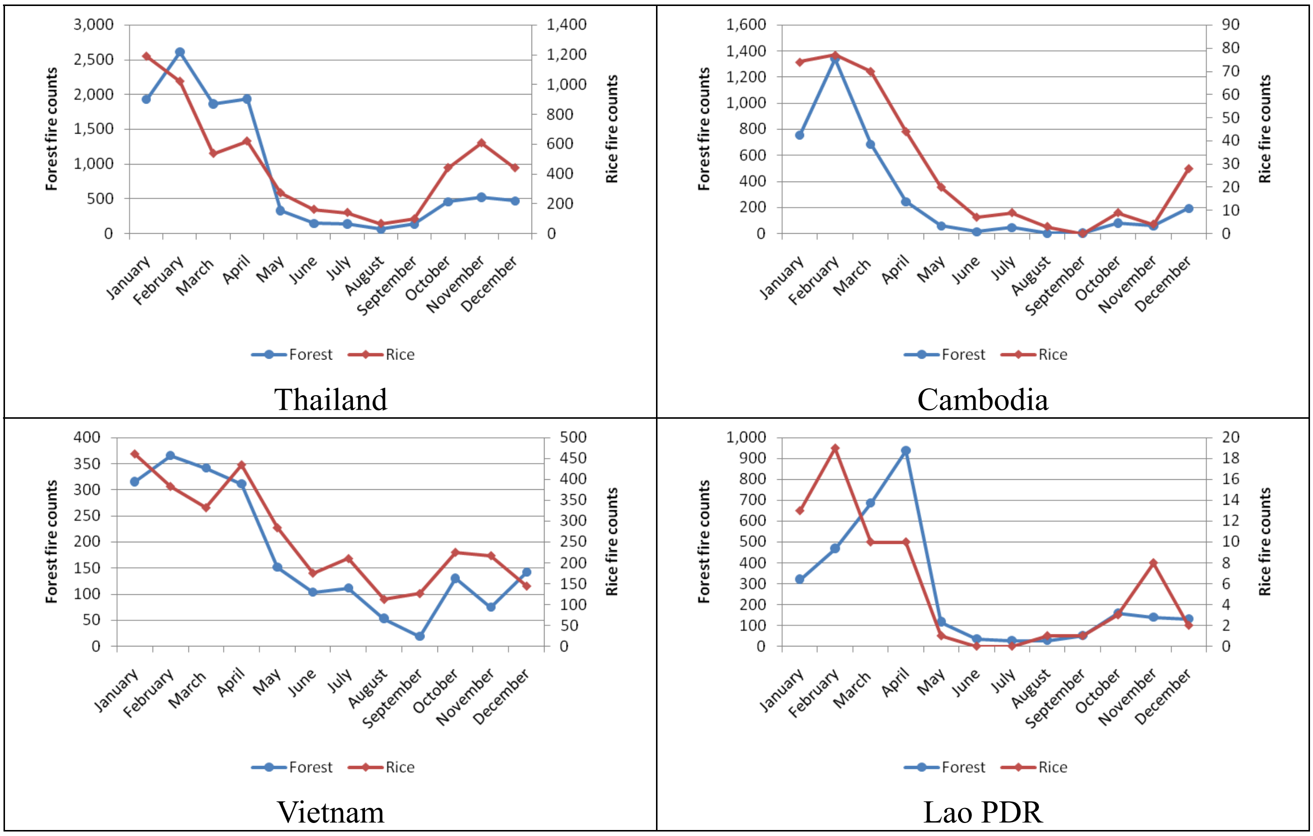

Fig. 3 Monthly fire counts related to forest fires and paddy field burning in the GMS region for the year 2002.

Table 4 Area burnt per type of biomass and country in 2002.

	Thailand	**Cambodia**	**Vietnam**	**Lao PDR**
Area of forest burnt (km^2)	29,431	13,752	6,360	10,174
Area of rice burnt (km^2)	11,568	1,153	5,414	175

northeastern regions of Thailand and in the central part of Cambodia around the Mekong delta.

In the case of Lao PDR, as paddy fields and forest coexist, and the land area where rice is cultivated is very limited, the burning is observed spread throughout the country with very low intensity or frequency. Finally, for Vietnam, only rice fields in the south along the border with Cambodia are affected by burning and are characterized by a similar intensity throughout the four months studied, confirming a possible intensification of rice farming in this region.

The first two months of the year (January and February) is the period corresponding to a dry wintery season in the GMS region, and therefore to a period where high pressure and cold air masses from China cover the northern and northeastern part of Thailand, and the northern part of Cambodia, Lao PDR and Vietnam. This weather condition contributes to a poor dispersion of the pollutants that are emitted in the atmosphere, and therefore to a higher ambient concentration of pollutants. This is notably the case for particulate matter, the ambient concentration of which can exceed national standards. Dry weather conditions also favor fast propagation of vegetation fires. Hence, it would be particularly necessary to control field burning of rice residues during January - March, notably in Thailand and Vietnam, the top two rice producers in the GMS region.

4. Conclusion

Seasonal changes related to biomass open burning in the GMS region have been observed via the fire hotspots detected by ANDES-DMSP-OLS and processed to generate emissions maps. The corresponding GIS database developed as part of these investigations has served to identify the types of vegetation subject to open burning and spatio- temporal distribution in the GMS region for the Year 2002.

The results obtained show that Thailand and Cambodia are the two countries where forest fires occur most frequently. On the other hand, paddy field burning occurs mainly in Thailand and Vietnam, the two top rice producers in the region. The peak period of such burning activities runs from January to April, with a peak during

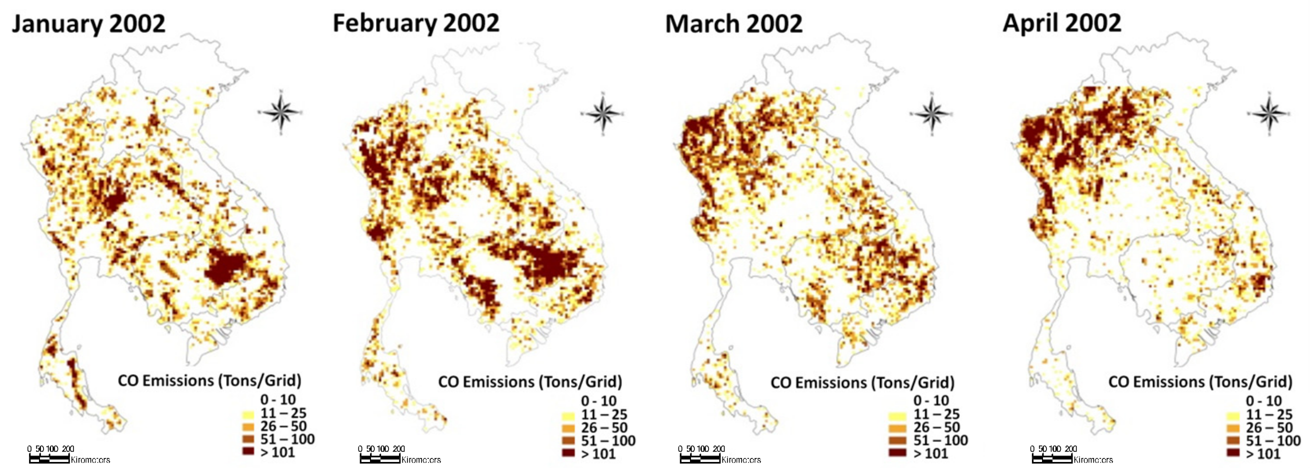

Fig. 4 Monthly gridded CO emissions maps during January -April (2002).

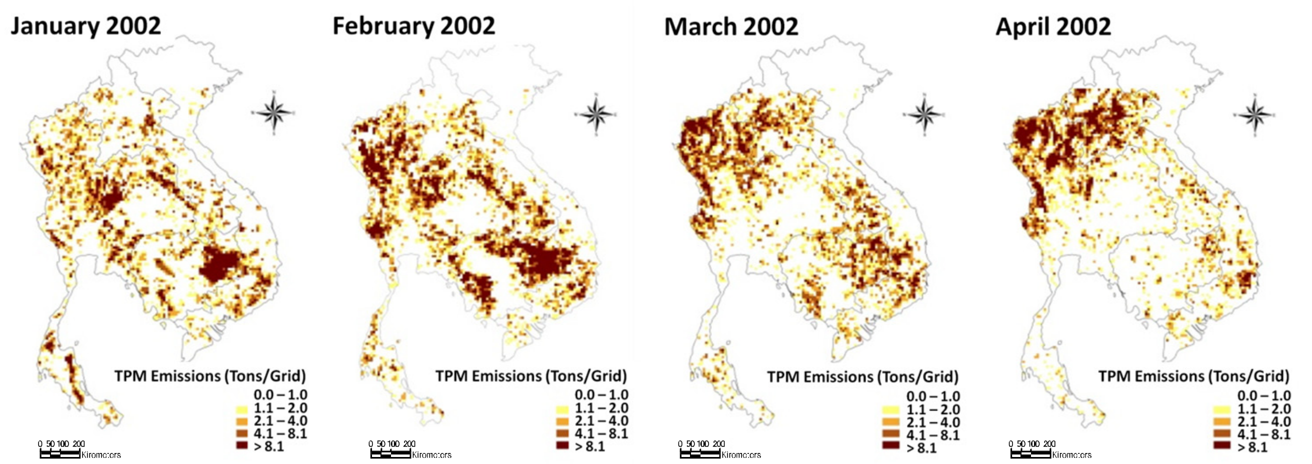

Fig. 5 Monthly gridded TPM emissions maps during January - April (2002).

January and February for paddy field burning, and March and April for forest fires. As this period corresponds to a time of atmospheric stability, it is necessary to discourage such open burning activities. In particular, slash and burn agricultural practices are of concern and should be controlled, notably in Thailand and Vietnam where there is an intensification of rice cultivation. This would enable the reduction of impacts on air quality and support the ASEAN Agreement on Transboundary Haze.

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