Satellite Data for Detecting Trans-Boundary Crop and Forest Fire Dynamics in Northern Thailand

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Abstract

Haze and smoke problems with adverse socio-economic and health impacts have become emerging new "disaster" issues over the last few years, especially in Northern Thailand. Among various main causes are forest fires, slash-and-burning, and waste residues burning from within Thailand and neighboring countries such as Myanmar and Laos. Although real-time remote-sensed data are usually used for fire detection and monitoring, there is an equal important need to assess the fire causes and impacts over time and space, then identify suitable prevention and mitigation strategies at relevant spatio-temporal scales. This study aims to analyze available remote-sensed data to better understand spatial and temporal distribution patterns of fire occurrences among these countries and also within Thailand. Our initial findings reveal that, over the period from 2006 to 2010, the frequency of fire occurrences varies from country to country. Namely, it is highest in Myanmar, and modest in China, Thailand, Cambodia, and Laos, but low in Vietnam. However, monthly distribution analysis clearly shows a common peak across these countries during the period from February to April, which clearly indicates trans-boundary and accumulative nature of the fire issue. Our further temporal analysis at local levels, from overlay techniques, indicates that fire occurrences are subject to change over time and space, hence fire risk maps must be dynamic accordingly. Overlay with other relevant data such as forest cover and landuse can be conducted to detect distribution patterns of different fire types for initially developing spatial management strategies to minimize total fire occurrences. Further in-depth research is planned to assess various socio-economic and health impacts to identify most sensitive areas for priority remedy actions, as well as responses to these issues by different stakeholders to identify gaps to be addressed, based on these patterns identified, then finally followed by alternative options and interventions to be identified to manage these trans-boundary fires and haze problems. Technical cooperation needed is also discussed for developing more comprehensive multi-temporal geospatial database at various geographical scales for different use purposes related to haze and forest fire monitoring across the South East Asia region.

1. Introduction

Remote-sensed data in one form or another for forest fire detection have become more and more important for fire management at various geographical scales from global to regional and local. Among various forms, MODIS data appear to be easily accessed to and hence more useful for preliminary applications. Therefore, MODIS data have been extensively used recently, in combination with other relevant instruments, for various purposes. The primary purpose is of course for real-time detection, followed by (i) estimation of burning areas, (ii) assessments of various fire impacts, such as emission and PM10, (iii) estimation of ground-based PM10, and (iv) ground-based validation. For example, first, MODIS is frequently used for estimating burning areas, such crop residue burning area in the contiguous United States (McCarty et al., 2009) for several years (2003-2007) and elsewhere as in Thailand. Second, with regard to fire impact assessment, MODIS sensor aboard the Terra and Aqua satellites is used with experimental data, and statistical data for estimation of forest fire emission (Junpen et al., 2011) during some years (2005-2009) on an annual basis for Thailand. MODIS data is used along with meteorology data, for emission estimation and PM10 analysis in Northern provinces of Thailand surrounding Chiang Mai province for some specific time periods (Oanh and Leelasakultum, 2011), and for analyzing smoke plume highs (Mazzoni et al., 2007) over North America during the summer of 2004. Third, other MODIS products in terms of optical thicknesses (AOTs) have been extensively used for estimating ground-based PM10, but with varying results. For example, MODIS AOT data are able to present the amount of PM10 over large spatial scales that there is no ground stations air quality monitoring (Amanollahi et al., 2011), or to improve the insight in PM distributions in Europe in combination with models and ground-based measurements (Schaapa

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et al., 2008). However, MODIS products for AOTs may have weak correlation with PM10, which can be improved by taking into account other meteorological variables such as mixing heights and winds (Dinoi et al., 2010). Forth, ground-based validation for MODIS products is also conducted elsewhere, including validation for burned area mapping on a regional scale in Mediterranean areas over a six year period (2001–2006) from June to September, when most of the forest fires occur (Gomez and Martin, 2011) in Southern European countries. In addition, there are also some constraints to use such satellite-derived fire products, as pointed out by Trigg and Roy (2007), taking Africa as an illustrative example. Because of real-time detection nature, MODIS products are, however, rarely used for both long-term monitoring purposes, especially on trans-boundary contiguous regions where forest fires and crop residue burnings occur at the same time duration for a couple of peak months and in all neighboring countries with similar upland forest conditions and farming cultures. Greater Mekong sub-region (GMS) is such a case, where the Northern Thailand can be seen as a central region where forest and crop burnings are seen clearly from within the region throughout neighboring countries as easily detected from satellite data some critical points in time. Consequently, haze and smoke problems with adverse socio-economic and health impacts have become emerging new "disaster" issues over the last few years, especially in Northern Thailand. In this preliminary, we have attempted to utilize available MODIS fire data to better understand spatial and temporal distribution patterns of fire occurrences among these countries and also within Thailand, to serve as benchmarking indicators for continuous monitoring, and also to detect possible spatio-temporal changes for better management of fire and burning issues, particularly from the original sources, rather than along the pathway (e.g. estimation of PM10 by AOT) or at the end of the pipe (e.g. reduction of health and visibility risks from haze and smoke after occurrence). The main purpose of this study is to detect fire patterns over the last four years of data availability at several geographical scales, from regional (GMS) to national and local. The local scale here is selected for Chiang Mai province in Thailand for demonstrative purposes. The data is extracted from MODIS Fire Information System (FIS) developed at the Asian Institute of Technology (AIT), Bangkok, Thailand. It acquires MODIS satellite data from MODIS sensors aboard Terra and Aqua Satellites on a daily basis. The data are archived for the purposes of research on the global environmental change monitoring and management/prevention of disasters of different types in the Southeast Asian region. The MODIS FIS is based on MODIS Active Fire Product (MOD14) Production Code, version 4.3.2, developed by NASA and automatically generates fire pixels or hotspot information with other physical parameters (including occurrence time and location) which would be useful to establish a better understanding of the fire occurrence phenomenon. The generated information is stored in a database, which could be accessed with ease via Internet. Details of the system, the associated algorithm producing the fire pixels information, and database access through the Internet are also described. The physical parameters in MODIS fire pixels are stored in a database designed to provide facilities for continued archiving and data retrieval. Also being web based, the database could conveniently be accessed via the Internet. The most inconvenient truth is, however, that only a limited number of records can be accessed to and downloaded at a time. Therefore, it is really time-consuming to manually select and download all fire records of interest, especially when we need data over a long period of time and for a number of countries involved. Such technical issues can provide an opportunity for regional cooperation to overcome the current shortcomings.

2. Fire Patterns at the Regional Level

The huge data from the FIS is extracted for the full four years from August 2006 to July 2010 for the six countries in the GMS including Thailand, Myanmar, Laos, Vietnam, China, and Cambodia. At this regional level, the analysis is based on fire counts for every month during that period with the default values assumed of fire occurrence from the FIS for simplicity. An outlined flowchart for our MODIS data processing for convenient reading is provided in Figure 1, with the corresponding results shown in Figure 2 and Figure 3. There are several important characteristics that we can see clearly from Figure 2. First, there is no apparent indication of a declining trend over the period for all the six countries. It implies a persisting situation of fires at both regional and national levels. Secondly, a simple comparative analysis from the magnitude of fire occurrences among those countries reveals that frequency of fires can be ranked in the three categories: highest in Myanmar; moderate in China, Thailand, Cambodia, and Laos; and low in Vietnam. In fact, frequency of fires in Myanmar alone is comparative with that in all other countries combined together. Figure 3 shows the monthly distribution of fire occurrences averaged over the last four years.

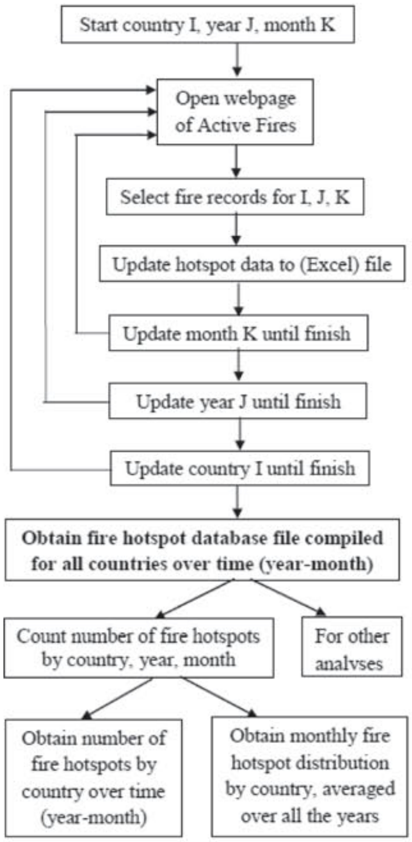

Figure 1: Flow chart for compiling fire hot spot database (across countries and over time), and generating fire distribution by country, year, and month

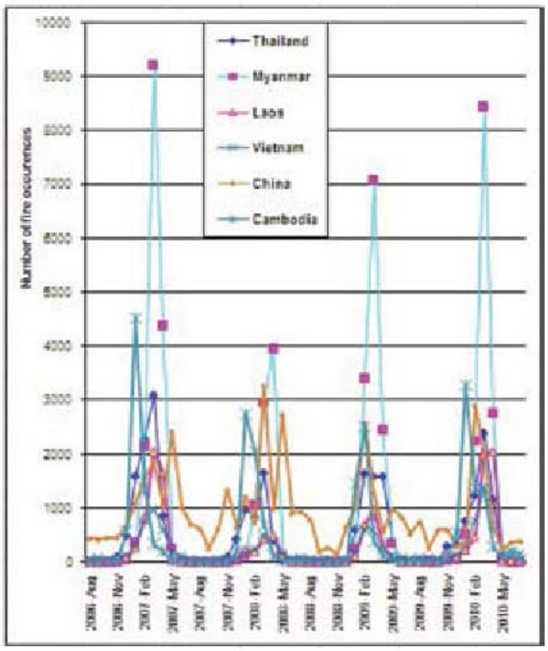

Figure 2: Fire occurrence in the GMS (2006-2010)

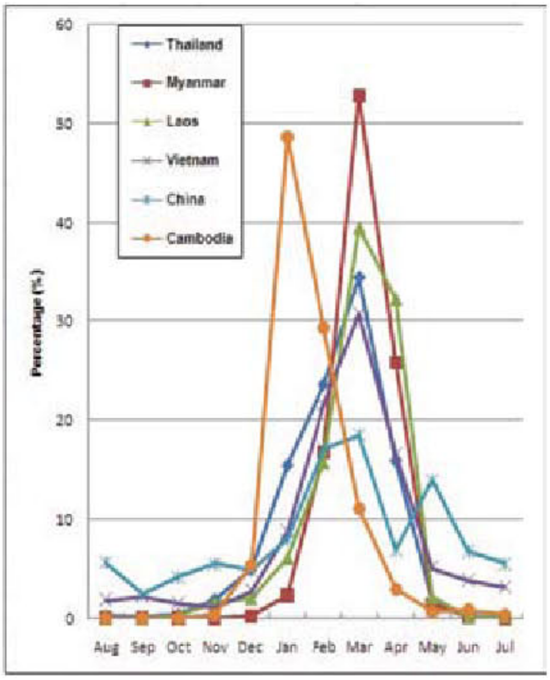

Figure 3: Monthly distribution of fires (2006-2010)

It is interesting to observe here that a single peak in March is common for all the five countries except for Cambodia, which clearly indicates trans-boundary fire nature. In particular, there seems to be an additional minor peak in May for China. These specific features can be explained partially by weather and climate patterns. For example, most fires occur in the dry season, and especially by the end of the dry season (before the rainy season starts). In these five countries, fires occur frequently in March, and this single month accounts for from 20% (in China), to 30% (in Vietnam), 35-40% (in Thailand and Laos), and to more than 50% (in Myanmar). A location map based on fire locations from the FIS and country boundary data, then generated by GIS overlay techniques, through a flow chart of data processing as outlined in the upper part of Figure 4, is provided in Figure 5 for better visualization. If we go further to the south (namely in Malaysia and Indonesia), the fire peaks will move to later months (September and November) as can be seen in Figure 6.

3. Fire pattern in Thailand

Having detected general spatio-temporal patterns of fire occurrences in the GMS countries, we now focus more on Thailand as we have more additional data available.

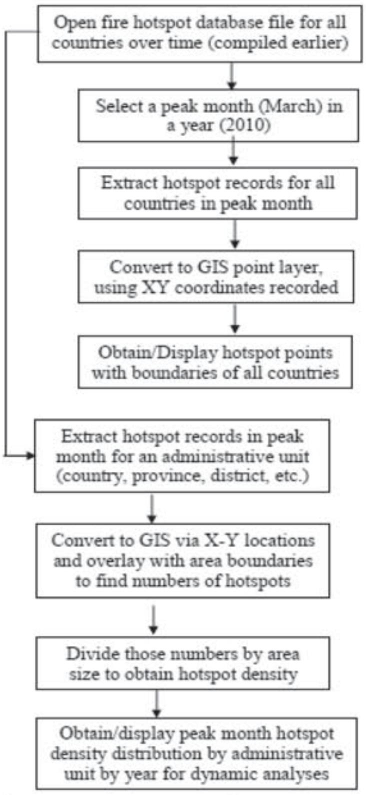

Figure 4: Flow chart for temporal and GIS data processing at different geographical scales

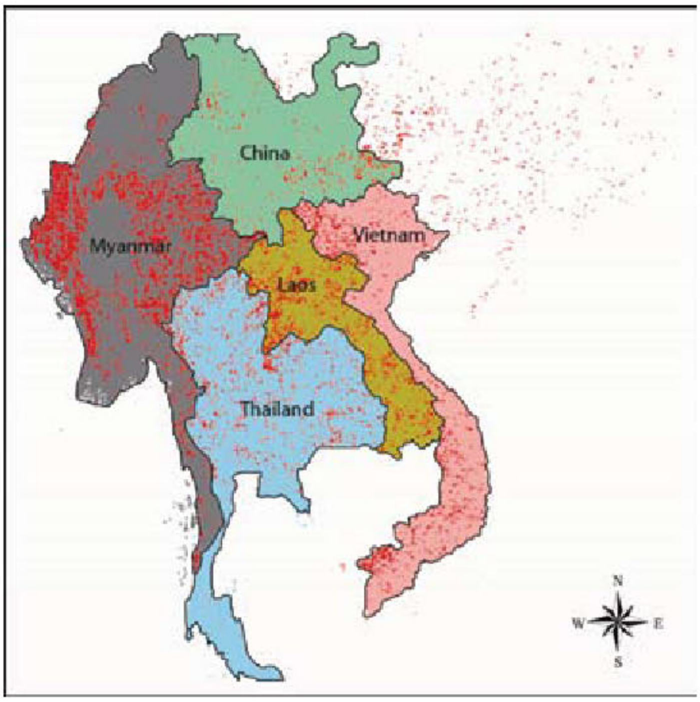

Figure 5: Fire location in peak month (March, 2010) in the GMS countries

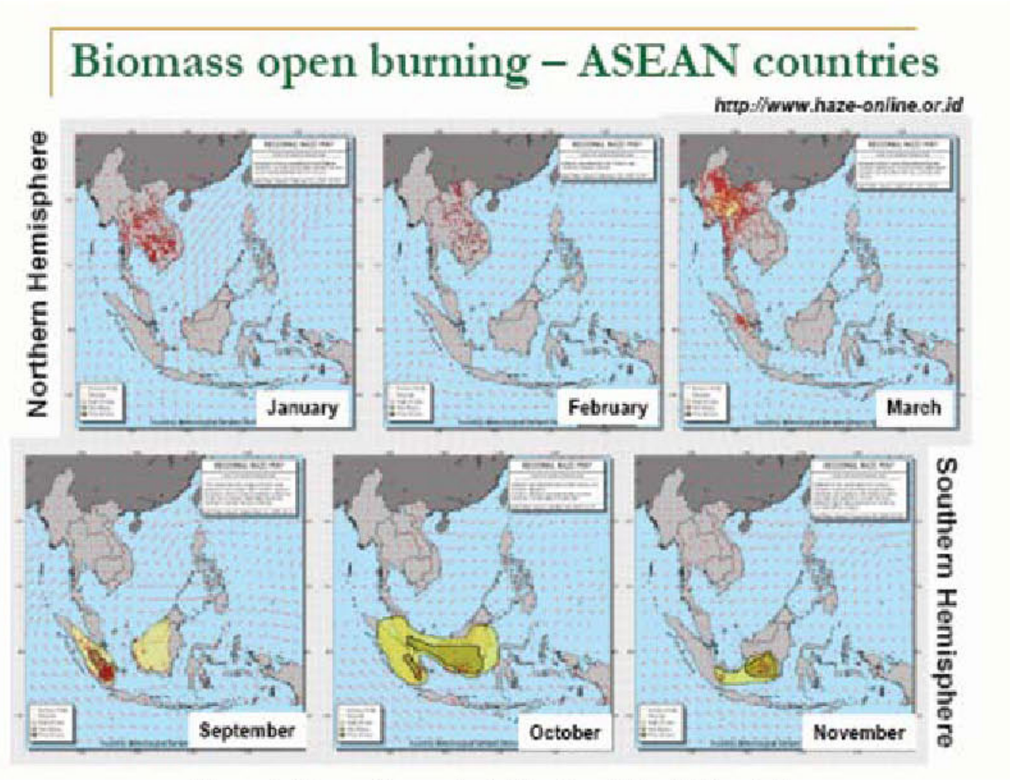

Figure 6: Fire peak months in North and South Hemisphere

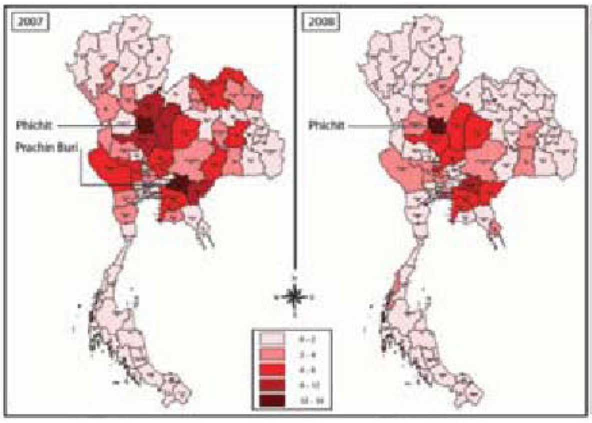

Figure 7a: Hotspot density in March (2007 to 2008)

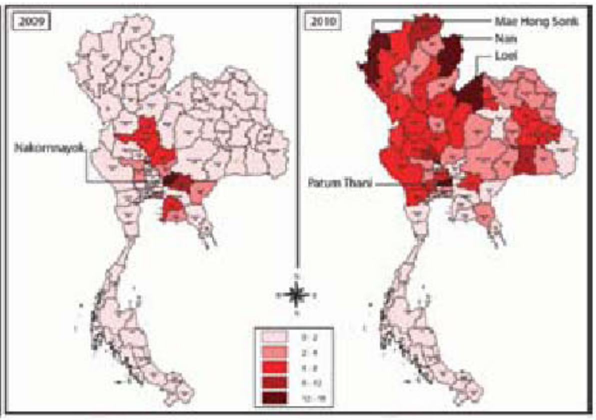

Figure 7b: Hotspot density in March (2009 to 2010)

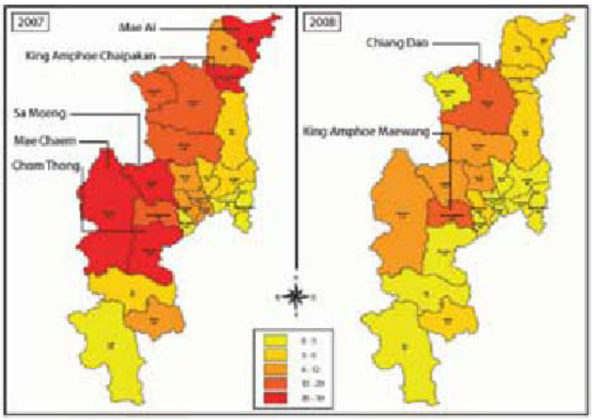

Figure 8a: Hotspot density (Chiang Mai, March 07/08)

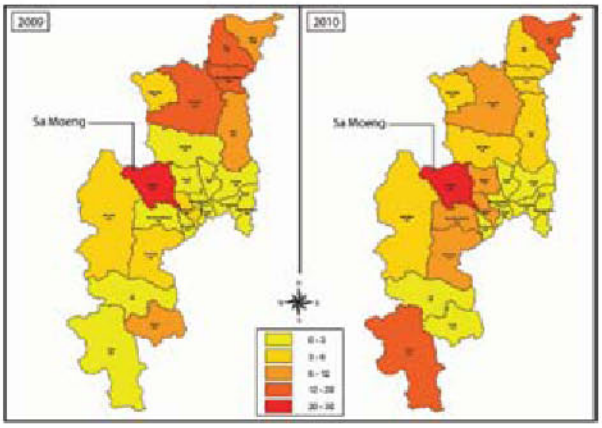

Figure 8b: Hotspot density (Chiang Mai, March 09/10)

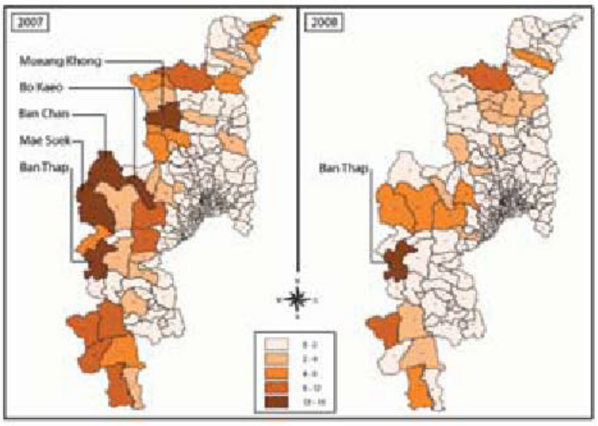

Figure 9a: Hotspot density (Chiang Mai, March 07/08)

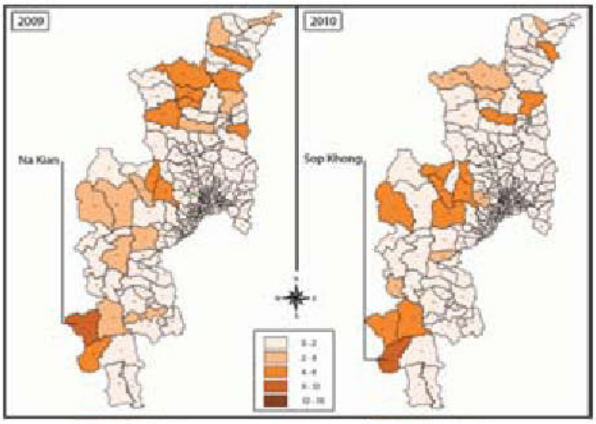

Figure 9b: Hotspot density (Chiang Mai, March 09/10)

However, for a comparative purpose among different administrative units (province, district, and sub-district), we use fire density (that is calculated as total number of fires divided by the total area of the administrative unit under consideration), rather than absolute number of fire occurrences in each administrative unit. The similar procedures as in the previous section are adopted with overlaying techniques, as shown in lower part of Figure 4. Hotspot density maps for the peak month (March) in each year (from 2007 to 2010) at provincial, district, and sub-district levels that we have developed from the FIS, administrative boundaries and areas are shown in Figures 7a, 7b, 8a, 8b and 9a and 9b, respectively, where the color scales are carefully designed to be the same for all the maps for better comparison purposes. It is interesting to observe more clearly from provincial to sub-district levels that hotspot densities are not unchangeable from one year to another, or from one administrative unit to another. This finding seems to be different from the common sense that hotspots are normally persisting elsewhere. Therefore, possible changes of hotspots in both time and space that are similar to non-point source processes add more challenges for effective fire control and management. It is noted that the peak of fire occurrences in March (and its peak of PM10) is also reported in other local studies earlier, for example in Chiang Mai government site in 2007 and 2008 (see Amnauylawjarurn et el., 2010), and in Nan province in 1998 (see Hoarse, 2004). In order to understand different kinds of fires (forest fires, agricultural fires, etc.), it is also important to overlay fire data with landuse data. However, because of time constraints and data accessibility difficulties, this task has not been completed yet, and will be pursued later.

4. Causes and Responses

To comprehensively control and manage the fire and haze problem, it is necessary to address it from its root causes to impacts and solutions, besides real-time detection and monitoring. Although in this paper, we are unable to manage to investigate various causes yet, there are useful secondary data available that can help provide some initial insights on possible causes to start with. For example, analysis (Hoare, 2004) of the causes of smoke in Nan province shows that the major three causes of fire in areas close to the provincial centre include "Urban fringe" burning; Roadside burning; and Lowland farmers' burning. The first two causes are each estimated to account for about 30% of the smoke problem. This burning contributes to human health problems and closure of the provincial airport by smoke. However, there is no Provincial Administration program developed to reduce this smoke problem. Another study for Chiang Mai (Charoenmuang, 2007) provides various causes of forest fires (from October 2003 to September 2005) including hunting and field burning together with various kinds of opening burning such as garbage burning, leaf and branch burning, weed burning, and field burning. While the impacts of fires and associated haze and smoke problems have been increasing to alarming levels over the last few years, especially as reported in many provinces in Northern Thailand, there are still no effective responses to the issue yet. Apparent solution approaches from national and local levels are seen to be more on awareness and monitoring, together with organizing various training workshops or some regional brainstorming workshops with public participation of all key stakeholders. The main focus is still more on forest fire detection and control, or on preventive (end-of-the-pipe) measures to cope with haze impacts on public health. At the national level, Thailand is very active in generating and providing hotspot data on-line for free access. For example, the Department of National Parks of Thailand has been providing since a few year ago a long list of Thailand daily hotspots maps from Terra or Aqua MODIS (http://www.dnp.go.th/forestfire/hotspot/hotspotmap.htm) along with statistical data on burned areas classified by province, and major landuse type (agriculture, forest protection and conservation). Additional efforts are made to summarize hotspots from a daily basis to monthly and yearly bases, for monitoring purposes. However, almost no related in-depth fire research is reported, except for the two reports on fire behaviors and fuel characteristics that were already made a long time ago in 2003 (see details in http://www.dnp.go.th/forestfire/Eng/research.htm). At the sub-regional level, the responses seem to be rather active recently. For example, the Sub-regional Ministerial Steering Committee on Trans-boundary Haze Pollution in the Mekong Sub-Region (MSC Mekong) convened for the first time on 25 February 2011 in Krabi, Thailand, attended by Environment Ministers/representatives from Cambodia, Laos, Myanmar, Thailand and Vietnam and Deputy Secretary-General for ASEAN Socio-Cultural Community. More details can be read at ASEANWEB (http://www.aseansec.org/25935-.htm). The Meeting discussed various initiatives to mitigate land and forest fires and to control smoke haze pollution. One of the important outcomes from the Meeting is endorsement and agreement to work towards a sub-regional target of (i) reducing cumulative hotspot count not exceeding 75,000 hotspots (based on 2008 data) to be achieved by

2011; and (ii) reducing cumulative hotspot count not exceeding 50,000 hotspots (based on 2006 data) to be achieved by 2015. The individual MSC Mekong countries also agreed to set their respective national targets for hotspot count reduction in order to achieve the regional/sub-regional targets. In addition, there has been some technical cooperation on PM10 monitoring at the regional level, which is initiated by Thailand. For example, Thailand has mobilized their mobile air quality monitoring units to Laos and Myanmar during the dry season of 2010, and also committed to provide such cooperation in 2011. Another approved bilateral project is seen between Thailand and Laos, which includes the installation of one fully equipped air quality monitoring station and one PM10 high volume air sampler in Laos by Thailand. It should be noted here also that although there is an ASEAN Agreement on trans-boundary haze pollution that was signed several years ago by member countries, its effectiveness to control the pollution is still far from satisfactory because of lacks of full understanding of the problems and lacks of specific measures to deal with these complicated trans-boundary issues. In summary, the target to reduce hotspot count at the sub-regional level has been set, and is to be set at national levels. However, an emerging challenge issue of how to achieve such targets has not been addressed in sufficient details. Likewise, no regional cooperation is initiated yet on monitoring of land and forest fires, which are the root cause of air quality problems.

5. Conclusions and Ways Forward

Based on the huge data available, we have attempted to do the data mining to detect spatio-temporal patterns of fire occurrences at different geographic scales. Although there are still questions of data reliability (without ground-truthing yet) and resolution, that need further research, our preliminary findings clearly show that fire occurrences in different countries are likely to be very different in magnitude and their local impacts are also likely to be combined from both local sources and trans-boundary fires and burnings from neighboring countries, depending on other meteorological factors such as cloud cover, mixing height, and wind (speed and directions). However, if a common approach is used for comparative studies, it clearly can help indicate good and reliable tendencies in relative terms. Another interesting finding is that hotspot densities at local levels (districts and sub-districts) are not unchangeable in both time and space, which makes fires much more difficult to manage and control. However, due to time and data constraints, more detailed analyses, including cross-checking with other possible sources and field data, have not been conducted yet. A plan for further study is already made to conduct such in-depth analyses and also look at both pathways and impacts from the original fire sources to important impact receptors, and finally to identify possible solutions (and alternatives) to deal with these complicated trans-boundary problems, especially from its root causes and from regional to national and local scales. It is worthwhile recognizing that, as mentioned from the beginning, the processing tasks of available huge data for detecting spatio-temporal pattern at various geographical scales are really time-consuming in deed, which is further illustrated through our data processing flowcharts (as seen in Figures 1 and 4). However, such technical issues can provide an opportunity for regional cooperation to further compile, develop and update the fire database to go beyond the current version of access to a limited number of fire records at a time, to a much more comprehensive on-line database that can provide, at a time, all fire information needed for long-term and multi-country purposes. Furthermore, it will be even more useful if such a database can also update ground validation for any area in the region when field monitoring data are available, and to incorporate other relevant meteorological variables as well as related air quality indicators and other socio-economic and ecological impacts for continuous monitoring purposes (from the sources to impacts). In addition, if all related research results and insights (as our findings in this study) can be provided in the same database (besides data), its usefulness and impact will be much more enhanced toward more comprehensive understanding of the complicated issues, which in turn helps to develop more appropriate short-term measures as well as long-term management strategies to address successfully the trans-boundary fire issues in general, and to achieve the targets set to reduce hotspot counts in particular.

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