EFFECT FROM OPEN BURNING AT GREATER MEKONG SUB-REGION NATIONS TO THE PM10 CONCENTRATION IN NORTHERN THAILAND: A CASE STUDY OF BACKWORD TRAJECTORIES IN MARCH 2012 AT CHIANG RAI PROVINCE

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Abstract

This paper presents the open burning in the Greater Mekong Sub-Region nations to the increased PM10 concentration in Northern Thailand. Thailand, Myanmar, and Laos were chosen as case studies, and 2009, 2010, and 2012 were chosen as the year for case studies. Hotspots detected by MODIS (Moderate Resolution Imaging Spector radiometer) Rapid Response System were used to represent opened burning in the region. Hotspots were filtered through fire confidence with confidence levels of 80% or more. The spatial analysis by GIS was used as the main tool for analyzing the location of opened burning at study sites. It was found that hotspots in the region and PM10 concentration at thirteen stations in Northern Thailand, including Chiang Mai (2 stations), Chiang Rai (2 Stations), Lampang (4 stations), Mae Hong Son, Nan, Lampun, Phrae, and Phayao were highly correlated. The result of this study showed that most affected areas from burning at the regional level were highly related to PM10 measurement at four stations including Mae Hong Son, Mae Sai, Chiang Rai and Nan Stations. Accordingly, the coefficient of determination was very high ($0.83 \leq R2 \leq 0.99$). The highest coefficient of determination was found at Mae Sai, followed by Mae Hong Son, Nan and Chiang Rai Stations. The burning in short-range at 50-80 km was most influenced on the increasing PM10 concentration. Daily backward trajectories in March 2012 were calculated using the Hybrid Single-Partical Lagrangian Integrated Trajectory (HYSPLIT4) model to roughly examine possible transport pathways of smoke emitted to Chiang Rai Station. The result showed that the southwesterly transport pattern which passed the south of Myanmar, Mae Hong Son and Chiang Mai was found most frequently.

Keywords: hotspot, PM10, MODIS, short-range, HYSPLIT, backward trajectories

Introduction

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. The unprecedented smoke haze that blanketed all areas in the northern highland region of Thailand is a recent problem that the local people have to face every year. Moreover, the smoke haze situation directly affects the air quality in many areas, including Chiang Mai, Chiang Rai, Mae Hong Son, Lampang, Lampun, Phrae, Nan and Phayao.

A report from the Pollution Control Department, Thailand (2012) indicated that in each year the level of PM10 measured at various stations in Northern Thailand started to rise above the standard level set by the Pollution Control Department (120 µg/m3) by February and the highest level of PM10 was detected in March. The PM10 situation was especially severe in 2012 when all stations had PM10 values that exceeded standards continuously over several days, especially at Mae Sai and Mae Hong Son Stations, where PM10 values exceeded standards over several periods as well. It was found that the highest 24 hour average PM10 value at Mae Sai Station was 357.46 µg/m^3 on March 19, 2012, and the highest 24 hour average PM10 value at Mae Hong Son Station (T66_MH) was 354.79 µg/m3 on March 20, 2012. PM10 values at both stations were almost 3-4 times of the standard level or over 100 on the air quality index (AQI). When the AQI goes over 100 it means there are direct effects on the health of the local people (Pollution Control Department, 2012), especially at risk groups such as children under 5 years of age, elderly people over 60 years of age, and those with respiratory problems.

Forest fires and agriculture burning affect the air quality and create a smoke haze and dust particles in the atmosphere. It creates particular matter less than 10 microns (micrometers) in diameter, or PM10, which are small particles that cause irritation or stinging to the eyes and make breathing difficult. Air pollution also affects the business sector as it was found that there were a smaller number of tourists travelling to Chiang Mai when the province was experiencing air pollution and smoke haze. This, in turn, directly impacts on provincial and regional economy (Rayanakorn, 2010).

PM10 is considered the most significant air pollutant that contributes to serious air pollution during the dry season, especially in Northern Thailand. Major sources of PM10 are open burning (Manomaiphiboon et al. 2009) and internal combustion exhaust from traffic. However, traffic density seems to be constant for the whole year, while open burning is mostly performed during the dry season, which coincides with the peak of the annual haze episode in the upper northern region of Thailand (Somporn Chantara, 2012; Kim Oanh, 2011). The open burning in this region consists of forest fires and the burning of agricultural waste. These activities definitely emit a variety of air pollutants in the forms of both particulates and gases. In the case of Chiang Mai, 50% - 70% of PM10 came from forest fires and the burning of agricultural residues, 10% came from diesel engines, and the remainder came from dust that blew over from another source (Manomaiphiboon et al. 2009).

The majority of research about haze in Northern Thailand focused on the impacts from haze, such as health impacts and economics losses due to reduction in tourist numbers. They also focused on finding answers for abnormal increases in PM10 from January to April, and done only on 1 – 2 years basis. Although most research concluded that open burning is an important contributor of particulate matter pollution in Chiang Mai during the dry season (January-April and October-December), especially in March, but Thailand is not the only country that conducts burning during the dry season (from January to April). Significant burning is also conducted in Laos and Myanmar (Bach and Siriomongkonlertkun, 2011). Moreover, most GMS countries experience the highest amount of burning during March of each year. This is in accordance with the increasing PM10 values in the upper northern region of Thailand during the same period. The available research still lack of overall studies at the national level, and the studies on the relationship between regional burning in nearby areas and their impacts on the concentration of PM10 in Northern Thailand. These kinds of study possibly will reduce arguments and questions that may arise from news coverage concerning the haze problem from various perspectives. An example of arguments is that the smoke haze in Northern Thailand is caused by burning activities originated in neighboring countries, which much creates confusion and misunderstanding among the public. This research therefore aimed to create true understanding about this problem.

This research was conducted in order to test if regional burning influenced the increases in PM10 at every station in the Northern Thailand. Thailand, Myanmar, and Laos were chosen as case studies, with a focus on the burning season (January to April) of each year. Thus, this research aimed to study the relationship between regional burning and PM10 concentration during the burning season, based on PM10 data available in 2009, 2010, and 2012 (except for 2008 and 2011 due to the decrease of smoke haze problem during these two years, Northern Meteorological Center, 2012). PM10 data were collected from 13 monitoring stations in Northern Thailand, 4 stations in Lampang, 2 stations in each Chiang Mai and Chiang Rai, and a station in each Mae Hong Son, Nan, Lampun, Phrae, and Phayao. In addition, hotspots data detected by the MODIS (Moderate Resolution Imaging Spector radiometer) Rapid Response System was used in this research to represent burning points in the region. Hotspots were filtered through fire confidence with confidence levels of 80% or more. The Spatial data analysis by GIS was used as the main tool for analyzing the location of burning at study sites. Simple Regression Analysis was used to determine the correlation between the number of hotspots in the region and PM10 concentration. Finally, the conclusions from the research would be considered in order to provide policy recommendations on open burning issue for the regional level.

Materials and Methods

Hotspots data counted in this research were gathered from the website of NASA's Earth Observatory (http://earthobservatory.nasa.gov/Natural Hazards/) and Web Fire Mapper (http://maps.geog.umd.edu/). In Web Fire Mapper, each detected fire represented the center of 1 km pixel, which might contain one or more active burning fires in a short period of time (1-2 hours). As MODIS satellite images for Thailand are available only 1 or 2 times per day, the short-lived fires happened at other time during a day would not be detected using satellite images. The fire detection might also be affected by cloudiness. Thus, the hotspot counting based on the available satellite images could be underestimated. Nevertheless, the hotspot counting was still considered as an effective way for monitoring the burning sites over the large study area.

The data of PM10 (particles with aerodynamic diameters less than 10 µm which are defined as respirable particulate) at the thirteen PM10 monitoring stations in Northern Thailand were collected by the Pollution Control Department of Thailand. To demonstrate the impacts of open burning in the regional level of Northern Thailand, correlations between the hotspots counted on MODIS and the PM10 levels detected at each station were analyzed. The short-range transport of air pollutants, defined within 100 kilometers (Glossary of Environment Statistics, 1997), employing by GIS application was brought to study as well. An interval of each 10 kilometer distance was tested to assess the impacts of hotspots on PM10 in each of three stations with the highest PM10 level detection.

The Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT4) model, available at http://www.arl.noaa.gov/ready/hysplit4.html, was used in calculating the backward trajectories from the PM10 monitoring station which could be used to roughly represent the travel pathways of smoke from the origin of open burning. The model was run by using the "Final Run" meteorological data archives (FNL) of the Air Resource Laboratory, National Oceanic and Atmospheric Administration, USA. In principle, the HYSPLIT model is used for long range transport study and the starting level should be in the free atmosphere. For this research, the starting time was selected at 12:00 am Thailand Local Standard Time, taking into account that the people normally burn during 10:00-14:00 (11), and total run time was about 24 hours. The starting coordinates were selected at Chiang Rai station (19.9092 latitude and 99.8234longitudes).

Results and Discussion

- **PM10 Situation**

As the data on monthly PM10 concentrations are only available mainly in Thailand, the concerning data used in this research were obtained from Thailand's Pollution Control Department (http://www.pcd.go.th). The monthly PM10 data were gathered from 2007 to

2012 at all 11 stations in Northern Thailand (2 stations each in Chiang Mai and Chiang Rai, and 1 station each in other provinces including Phrae, Nan, Lampun, Lampang, Phayao, and Mae Hong Son). However, in 2008 and 2012 there were frequent rainfalls in the dry season, so the data of these two years were excluded from the analysis. In the researched years, the seasonal characteristics of PM10 in Northern Thailand were seen clearly. The monthly PM10 values remained very low and fairly unchanged, approximately 30 µg/m3, in the rainy season (typically from May to December). However, the values sharply increased in the burning season (from January to April) to an average value of 93 µg/m3 and significantly reached a peak of about 141 µg/m3 in March, which was higher than the standard PM10 level set for Thailand of 120 µg/m3. The spatial variations of mean PM10 concentrations and their standard deviation (SD) were illustrated in Table 1. It was found that concentrations of PM10 collected in the burning season (January – April) were significantly higher than those in non-burning season (May – December). Moreover, average PM10 concentrations at each station were found to be very much similar.

The increase in PM10 in the burning season was about 3 times higher than that in the non-burning season in Northern Thailand. The highest PM10 values were detected at three stations, Mae Sai (Chang Rai2), Mae Hong Son, and Chiang Rai (Chiang Rai1), which all share borders with Myanmar and Laos as indicated in figure 1.

Table1: PM10 Statistics in Northern Thailand, Averaged over the Four Years

PM10 Station	**Burning season**			**Non-burning season**	
	January to April		March	May to December	
	Average PM10 (µg/m^3)	SD	Average PM10 (µg/m^3)	PM10 (µg/m^3)	SD
Chiang Rai2*	151.64	±80.12	262.86	-	-
Mae Hong Son** *	99.86	±65.16	187.32	25.74	±8.55
Chiang Rai1***	98.57	±49.50	163.15	15.88	±12.20
Nan ***	79.30	±36.015	125.22	26.60	±11.48
Chiang Mai1	80.72	±36.42	126.15	28.25	±9.07
Chiang Mai2	84.61	±36.17	129.25	34.63	±10.49
Lampang1	96.97	±34.42	122.68	31.02	±12.69
Lampang2	76.01	±25.015	99.73	28.21	±9.40
Lampang3	81.28	±36.68	119.82	26.98	±6.32
Lampang4	79.43	±30.055	96.45	26.80	±9.42
Lampun ***	96.41	±34.11	127.53	32.59	±17.14
Phrae**	94.43	±31.73	123.29	30.75	±16.34
Phayao **	93.58	±22.12	143.05	30.30	±28.85
Average	93.29	±39.81	140.50	28.14	±12.66

Note: * data available in 2012 only
** data available in 2010 and 2012
*** data available in 2009, 2010 and 2012.

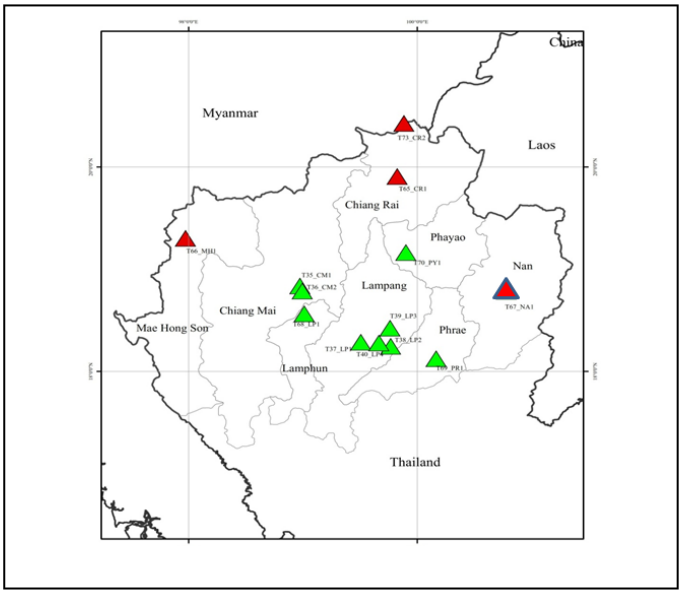

Figure1: The Location of PM10 Stations in Northern Thailand

From the research, the increase in PM10 values during the dry season coincided with open burning that were part of agricultural activities and forest fire that occurred during the dry season. This is in accordance with statistics from the Forest Fire Control Division, Department of National Parks Wildlife and Plant Conservation, which showed that fires commonly occurred during the dry season and peaked in March of each year as indicated in figure 2. In the rainy season and at the beginning of the dry season each year, PM10 values in the air were generated from other anthropogenic sources, such as internal combustion exhaust from traffic that seemed to be constant in every year.

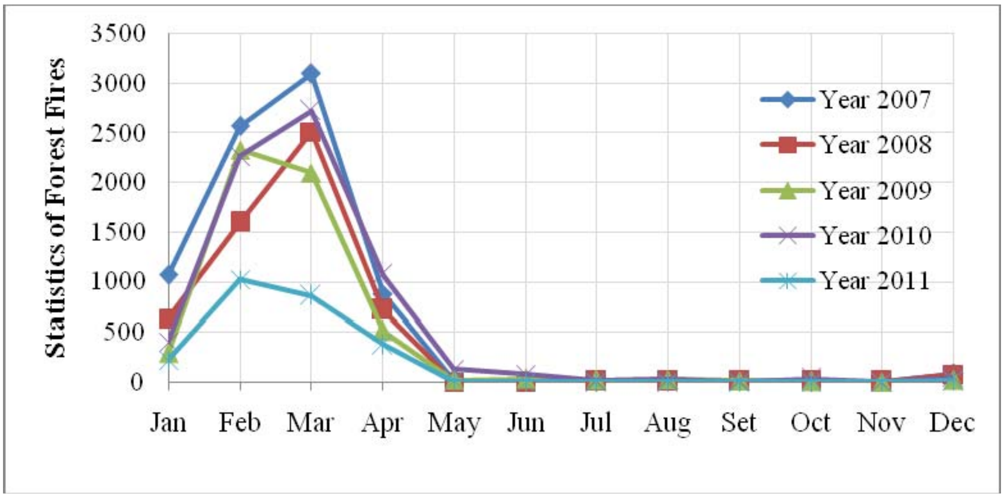

Figure 2: Statistics of Forest Fires (Northern Thailand) in 2007-2011
Source: the Forest Fire Control Division, Thailand

- **Hotspot Situation**

The daily number of hotspots at the regional level was obtained from the of NASA's Earth Observatory (http://earthobservatory.nasa.gov/NaturalHazards/) at the Web Fire Mapper (http://maps.geog.umd.edu/), then selected for fine confidence of 80% or more, and overlaid with geographic boundaries by GIS to attain hotspot number in each country or each zones of interest. The hotspot data collected from 2007, 2009, 2010 and 2012 (from January to April in 2012) at the regional level, including Thailand, Laos, and Myanmar, showed a very high yearly average of 63,795 hotspots. About 80% of them occurred in the burning season (from January to April) with a peak in March at 70%. The total hotspot number in the four years (2007, 2009, 2010 and 2012) was 255,177. The highest number or 50 % of all was in Myanmar, followed by 36% in Laos and 14% in Thailand as indicated in Figure 3.

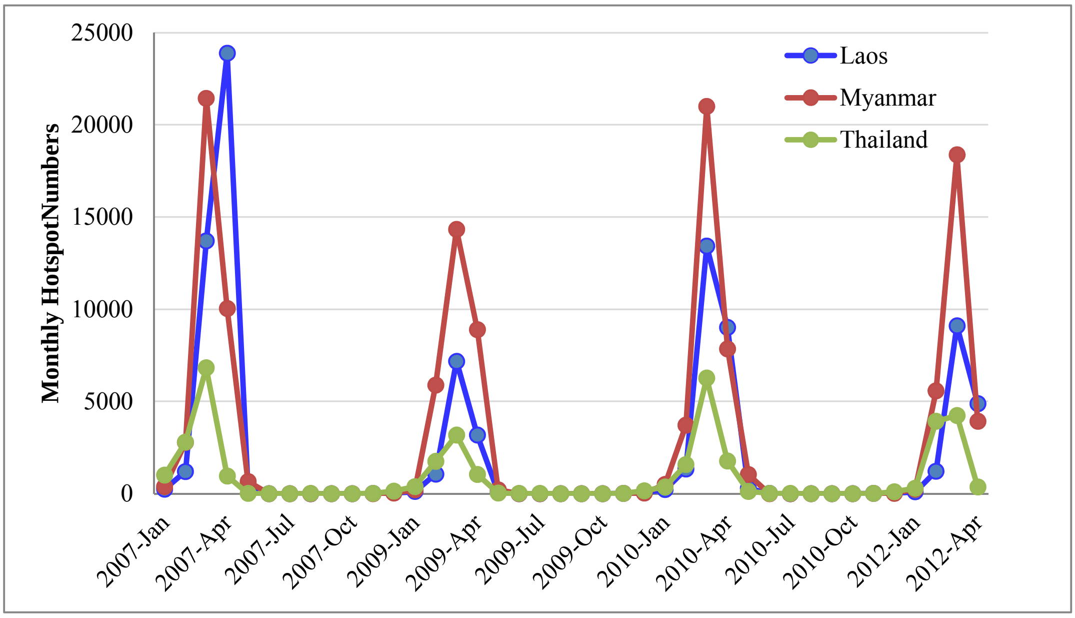

Figure 3: Monthly Hotspot Number Distribution at the Regional Level
(2007, 2009, 2010 and 2012)

The reason why the forms of hotspot occurrence in this regional level were similar each year was due to the culture of people in the Greater Mekong Sub-Region countries, who mainly conducted agricultural activities (Sirimongkonlerkun and Phonekeo, 2012). Therefore, it could be said that the number of hotspots of each country changed in May onwards was the consequence of the lifestyle of people in the GMS countries. From May until the end of January of each year, people would begin to collect harvests. After the harvest season, most agriculturists would conduct burning to eliminate rice stubble, in order to prepare crop lands for the next cultivation session (Sirimongkonlerkun and Phonekeo, 2012). This in turn resulted in the increasing of hotspots during this period each year. The occurrence of hotspots from February to April could therefore come from the preparation of crop lands for cultivation. In Northern Thailand, the majority of hotspots generally occur at altitudes of

400 – 600 meters from mean sea level (Donthri et al. 2012 and Sirimongkonlerkun and Phonekeo, 2012) that are mostly highlands and forest areas where local residents often conduct agriculture, especially corn. Normally, burning would begin in February, so the rate of change of hotspots from January to February would be higher when compared with other months during the burning season. Burning activities were conducted much more in March, while the lack of fire breakers in the areas was resulting in fires spreading and becoming major forest fires. Accordingly, the highest number of hotspots was found in this month each year. Likewise, statistics showed that forest fires occur most frequently in March of each year).

From the analysis of the relationship between hotspots in the regional level-- Myanmar, Laos, and Thailand--and PM10 concentration at each station in Northern Thailand, the majority of burning was significantly related to changes in PM10, except for the case of Lampang, Phayao, and Phrae stations where the correlation coefficient was very weak ($0.19 \leq R^2 \leq 0.56$). However, it was found that stations along border areas, Mae Sai, Mae Hong Song, Chiang Rai and Nan, had very high coefficient of determinants ($R^2 \geq 0.9$). The coefficients of determinant for these stations were 0.99, 0.92, 0.83 and 0.89, respectively. It implied that the average monthly hotspot number for each case accounts for 83-99% of the variation in average monthly PM10 concentration. The scatter plot for each relationship was provided in Figure 4.

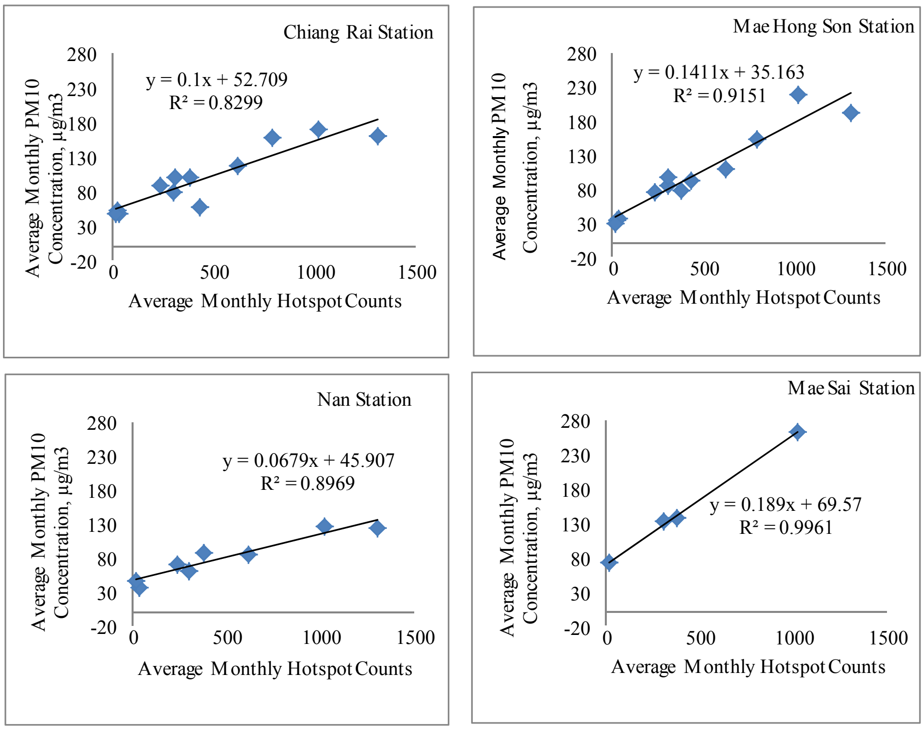

Figure 4: Correlation between the average monthly hotspot number in the regional level and average monthly PM10 concentration at four stations.

Additionally, in order to find out the minimum range of the burning point to PM10 monitoring station that started to significantly correlate with the change of PM10 values, the connection between the number of hotspot and PM10 concentration at these 4 stations were brought to study. Using GIS technique in this step, buffers were made at a radius of 10 km of each station. It was found that short-range burning of a radius of 50-80 km was the most influence on the increases of PM10 concentration. Moreover, hotspots which occurred in this range were originated from both within Thailand and neighboring countries. For instance, at Chiang Rai station, the burning at a radius of 80 km of the station was found significantly influence the increases of PM10 concentration. While considering in each administrative region, number of hotspot was found to occur in Thailand the most, followed by Laos and Myanmar. The hotspot counts in these three countries were 1,587, 705, and 544 respectively. The total number of hotspot in Thailand consisted of 1265 hotspots occurred in Chiang Rai and the rest were in other provinces such as Lampang, Chiang Mai, and Payao as shown in Figure 4. As a result, there was a high possibility that smoke haze problem in Chiang Rai mostly caused by burning activity within Thailand itself.

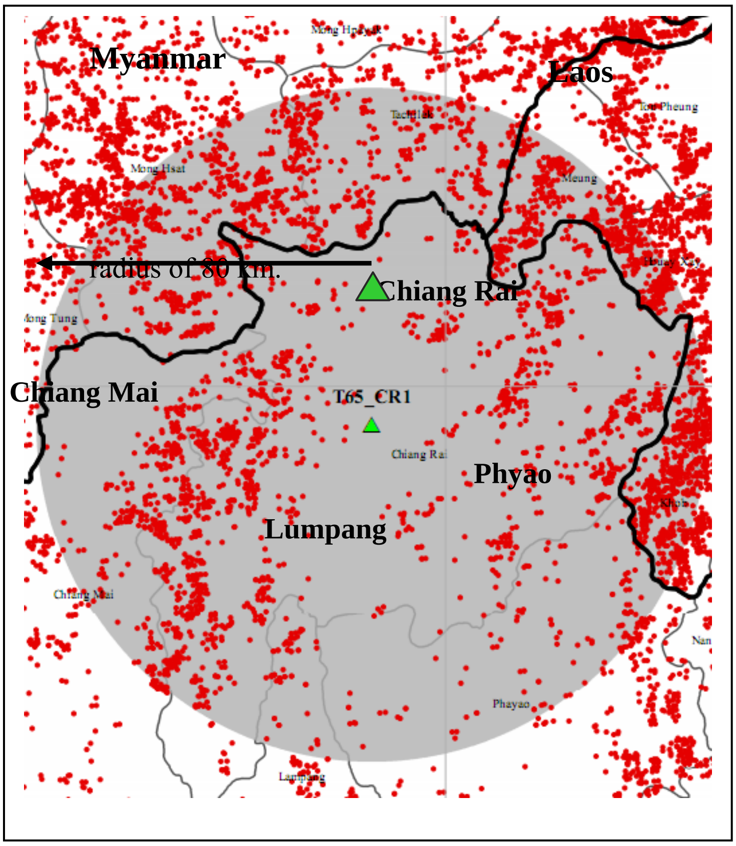

Figure 4: The Hotspots within a radius of 80 km of Chiang Rai station (Gray Circle)

- **Daily backward trajectories in March 2012 to Chiang Rai**

The high emission from emission sources at upwind regions and the meteorological conditions can contribute to the air pollution at a local area (Kim Oanh and Leelasakultum, 2011). Additionally, many researches have supported that smoke haze problems in some provinces of Northern Thailand such as Chiang Mai were influenced by open burning from the long-range upwind regions (Yasanga,et.al, 2010). In this research, daily backward trajectories in March 2007 and 2010, from PM10 station in Chiang Rai, were brought to analyze. Using the HYSPLIT4 model, it was found that the main of the backward trajectories patterns were southwesterly moved pass the Southern Myanmar, Mae Hong Son and Chiang Mai where hotspot were frequently and mostly found as indicated in Figure 5.

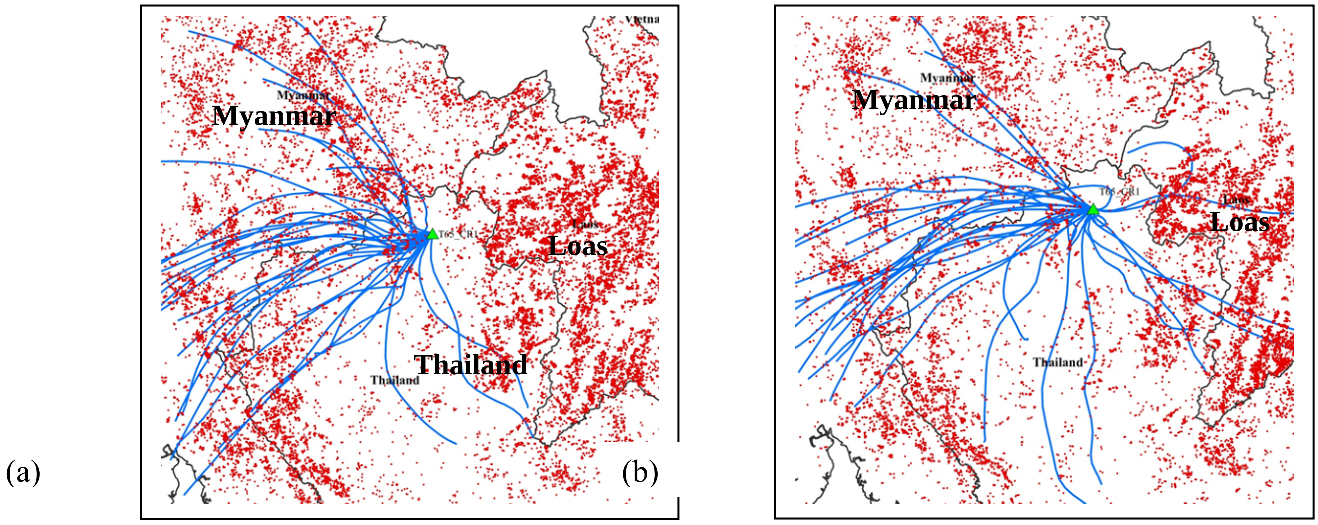
(a)
(b)

Figure 5: a) Daily backward trajectories and hotspot in March 2007
b) Daily backward trajectories and hotspot in March 2010

Consequently, it could be said that smoke haze problem in Chiang Rai was influenced by burning from the upwind regions where PM10 was steadily accumulated until reaching PM10 station in Chiang Rai. Upwind regions in this case included Myanmar and some provinces in Thailand which were Mae Hong Son and Chiang Mai.

Conclusions

The number of regional hotspot correlated reasonably with the PM10 concentration in the border areas, especially at Mae Sai, Mae Hong Son and Chiang Rai stations since the coefficients of determinant for these stations were 0.99, 0.92 and 0.83 respectively. However, burning at short-range, within a radius of 50-80 km of the stations, was found start to influence the increases of local PM10 concentration at border areas. In the case of Chiang Rai, the burning range that significantly increased PM10 concentration was within a radius of

80 km of Chiang Rai station. As a result, hotspots occurred in this range were mostly caused by open burning within Thailand. Although the analysis of backward trajectories, simulated through the use of the HYSPLIT model, demonstrated that air mass movement in March mostly found in the southwest direction which moved pass burning points in Myanmar and some provinces of Thailand before reaching Chiang Rai station, it might brought only a minor effect to Chiang Rai. Therefore, smoke haze problem in Chiang Rai could mainly have caused from burning activities in Chiang Rai itself. To combat with this problem, it should seriously start with the local solution first and after that; seek for cooperation with neighboring countries to establish further mutual plan.

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