Assessment of Long-range Transport Contribution on Haze Episode in Northern Thailand, Laos and Myanmar

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Abstract. The objective of this research is to study the hotspot occurrence pattern in January to April and Long-range Transport Contribution on Haze Episode in the areas sharing borders between northern Thailand, Laos and Myanmar. Hotspots or active fire detected by Moderate Resolution Imaging Spectroradiometer (MODIS) onboard of Terra and Aqua satellites, provided by NASA’s Fire Information for Resource Management System (FIRMS) were used to represent open burning locations in the region. The daily backward trajectories in March 2014 to 2016, obtained from PM10 measurement station in Chiang Rai province was brought to analysis using the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT4) model. In the result, the hotspot occurrence has similar patterns. Highest number of hotspot was found in March, April, February and January, or 51, 31, 12 and 5 percent of the total number, respectively. The highest hotspot number was found in Myanmar, then Laos and Thailand, or 51, 28 and 21 percent, respectively. Backward trajectories patterns mainly moved across the south-western part of the study area, where hotspots were frequently occurred. Consequently, smoke haze problem in the province was influenced by burning at the upwind regions where PM10 was steadily accumulated until reaching the station. Obviously, the smoke problem in northern Thailand and its neighbours is boundless. Therefore, solving this regional problem by reduce burning activities in one country is insufficient. Collaboration between countries is necessary. Active sustainable land use, reduce burning activities after harvesting and maintain the sustainability of the natural resources and environment should be conducted

1. Introduction
Thailand recently experiences one of the worst air pollution episodes. For example, the elevated smoke haze plus particulate matter (PM10) significantly blanketed Northern Thailand during March, 2007. In the meantime, Laos and Myanmar also faced the same situation. Smoke haze pollution regularly occurs in this region in March annually coinciding with the annual dry season when forest fires and agricultural burnings occurred intensively[1]. The unprecedented smoke haze that covers all areas in Northern Thailand was the problem that local people have to endure every year since 2007. The smoke haze situation directly contributes poor air quality in many areas causing adverse health impact to the residents. Usually, the main causes of this smoke haze are forest fires, open burnings and exhaust pollution from vehicles Kruasuwanet al., 2014, [2]. According to Rayanakorn [2], it was found that 50 – 70 percent of small dust particles comes from open burning which included forest fires and agricultural burning or the burning off at farmlands while 10 percent comes from diesel engines, and the remainder is dust that blown over from another source. In addition, it is found that some areas have been affected by air pollution originated by forest fires occurred in neighbouring countries [3], [4] and [5]. This problem has direct impact to air quality that cause the value of particles with
aerodynamic diameters less than 10 µm (PM$_{10}$) has value exceeds the standard value of the Pollution Control Department (PCD) which is 120 microgram per m$^3$. This high PM$_{10}$ value has direct impact to the health of local people in particularly to the children younger than 5 year old and elders older than 60 years old. The value exceeds the standard has direct impact to respiratory system of the local people [5], [6]. However, the smoke-and haze problem that occurred in dry season (February - April), in particularly in March yearly has the source from the open biomass burning in high-elevated area [7] and[8] has conducted a research on the relationship of biomass burning with the elevation in Chiang Mai province using the hotspots that represents open fires, detected by MODIS as the open burning data. The result show that the area that high number of hotspots was found is the high-elevated area with the elevation of 401-600 m from the mean sea level. This result matched with the research conducted by [9] that high number of hotspots was found in Chiang Rai province is in the high-elevated area within logged forest area at the elevation of 401-600 m from the mean sea level. The logged forest area was used land preparation of the maize production. Burning in high elevated area may not impact to the urban area. However, long-range transport of air pollutants refers to the atmospheric transport of air pollutant within a moving air mass in a distance greater than 100 kilometres [10].

Among GMS countries, Thailand is the only country that monitors PM$_{10}$ levels under the supervision of the Pollution Control Department (PCD), Ministry of Natural Resources and Environment. Monitoring stations were established at 8 Northern provinces, including Chiang Mai, Chiang Rai, Mae Hong Son, Lampang, Lamphun, Phrae, Nan and Phayao. Therefore, Thailand is seriously aware of the change of PM$_{10}$ concentrations, especially during smoke haze episodes. Once it was found that, every PM$_{10}$ monitoring station in the northern region of Thailand had 24-hour average PM$_{10}$ levels that exceeded set standards for several days. As a result, Thailand’s authority initiated to seek for mutual cooperation among 5 GMS countries to solve the problem of trans-boundary smoke haze. Then a working team on forestry and haze was also established for the Greater Mekong Sub-Region. The team was comprised of representatives from Cambodia, Laos, Myanmar, Vietnam, and Thailand. Importantly, these GMS countries agreed to work by aiming at the target of hotspot reduction. For instance, the goal to have cumulative hotspot counts not exceeded 50,000 (based on the data of 2006) was set to be achieved by 2015.

However, long-range transport of air pollutants refers to the atmospheric transport of air pollutant within a moving air mass in a distance greater than 100 kilometres [10]. The air pollutants emitted at a location could circulate the globe within a few days to weeks depending on meteorological conditions. In many cases, air pollutants were found thousands of kilometres away from their emission sources. While air pollutants were travelling around the globe, their impacts on human could be ranged from local to global. Therefore, through the trans-boundary transport phenomena, the air pollutants emitted within a state or country could evidently introduce adverse effects on other states or countries. Some research show that the relationship between hotspots and PM$_{10}$ found that increase in hotspot increases PM$_{10}$, while long-range transport of pollutant air masses also impact local PM$_{10}$ levels the relationship between hotspots and PM10 found that increase in hotspot increases PM$_{10}$, while long-range transport of pollutant air masses also impact local PM$_{10}$ levels [1], [11] and [12]. Most of the researchers use Hybrid-Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model from the Air Resources Laboratory (ARL) of the National Oceanic and Atmospheric Administration (NOAA) (the web-based version is available at http://www.arl.noaa.gov/ready/hysplit4.html [13]. HYSPLIT is one dispersion model type, which can compute the advection of air parcels, or its trajectories. When a source location emits pollutant parcel into the atmosphere, the trajectories of those can pinpoint how pollutants flow through the atmosphere. Most of the researchers use HYSPLIT as tool to study on the possibility of the movement of PM$_{10}$. This is also an important tool for studying the possibility of the movement of PM$_{10}$ from distant source to the urban area as [14] used the HYSPLIT Model to determine the dispersion path way of smoke from biomass burning in Pathumthani. The resulted showed the pollutant from Pathumthani could transport to neighbouring area especially, the Bangkok Metropolitan Region. Sathavarodom [15] showed the possibility of Asian Dust reaching Thailand using ambient air monitoring data (PM$_{10}$ and SO$_2$), the 10-day backward air mass trajectory from HYSPLIT4 model, 3 MODIS imagery during November 2001 and April 2002. The resulted show that the air mass from
China was not transported to Thailand or other Southeast Asia countries during those days. Manomaiphiboon et al., [16] used Trajectory Modelling for examination of potential fire emissions for a March 2007 haze episode in UNR of Thailand. Pongkiatkul and Kim Oanh [17] attempt to use both trajectory analysis and monitoring data to assess the potential contribution of long-range transport to particulate air pollution (PM$_{10}$) in the Bangkok Metropolitan Region and [18] identify back trajectories of air masses arriving in Chiang Mai and Bangkok into distinct transport patterns by cluster analysis. Two-day backward trajectories at an altitude of 500 m in Chiang Mai and Bangkok were calculated between June 2008 to May 2009 using HYSPLIT Model developed by the Air Resources Laboratory of National Oceanic and Atmospheric Administration (NOAA). By the way, the air pollutants emitted at a location can normally circulate the globe within a few days to weeks depending on meteorological conditions. In many cases, air pollutants were found thousands of kilometres away from their emission sources. While air pollutants were travelling around the globe, their impacts on human could be ranged from local to global. Therefore, through the trans-boundary transport phenomena, the air pollutants emitted within a state or country can evidently introduce adverse effects in other states or countries.

Based on the review of the existing research listed above, the idea of this research is to study the pattern and trend of open burning conducted in Greater Mekong Sub-Region countries, particularly in the study period of 2014, 2015 and 2016, by using Thailand, Laos, and Myanmar as a case study. Hotspot data detected by MODIS sensors on board of Terra and Aqua satellites and provided by NASA’s FIRMS website was applied in this research to represent burning locations in the region. The Spatial data analysis by GIS was used as the main tool for analysing the location of burning at study sites. And use the HYSPLIT model for study the possibility of PM$_{10}$ movement to measurement station in Chiang Rai or the possible of the long-range transport contribution on haze episode in northern Thailand. The result from this study will be obvious information for planning and management of the smoke and haze problem due to open biomass burning in high-elevated area with concerned parties.

2. Methods

Hotspots or active fire data counted in this research were gathered from FIRMS website (https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms). Each hotspot or detected active fire represented a 1-kilometer pixel, which might have contained one or more active burning fires in a certain period of time, either short or long-lived fires. As MODIS satellite images for Thailand are normally available only 1 or 2 times per satellite (either Terra or Aqua) and per day or night time, then the short-lived fires happened at other time during a day would not be detected. Moreover, the fire detection could be affected by cloud cover as well. Accordingly, 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.

Active fire or hotspot data obtained from the FIRMS website is in the format of spatial data which included several physical parameters designed by NASA, in particularly, latitude, longitude, detection date and time, brightness temperature, fire power and fire detection confidence which range from 0 to 100 percent. Thus, in order to apply the downloaded active fire data, it was necessary to create a spatial database for the data which are monthly and yearly grouped for each country. The process of the database development was conducted using Geographic Information System (GIS) tools. For analyzing long-range transport contribution on haze episode, the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT4) model, available at http://www.arl.noaa.gov/ready/hysplit4.html, was used. This online tool calculates the backward trajectories from the PM$_{10}$ monitoring station. The output 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, and total run time was about 24 hours.
3. Results and Discussion

3.1. Pattern and Trend of Hotspot Occurrence in Three Countries

The general scenario of hotspot occurrence in three countries during the study period is described as following. Total of 747,477 hotspots were found. These countries has similar occurrence pattern in term of hotspot number, in which the highest number of hotspot was found in March, April, February and January, or 51, 31, 12 and 5 percent of total number of hotspot, respectively.

Figure 1. Hotspot occurrence number in Thailand, Laos and Myanmar in the period of January – April of 2014–2016

Fig. 1 shows the hotspot occurrence numbers in country level. The highest number of hotspot was found in Myanmar, following by Laos and Thailand, or 51, 28 and 21 percent, total number of hotspot, respectively as shown in Fig. 2.

Figure 2. Hotspot occurrence pattern in Thailand, Laos and Myanmar in the period of January – April of 2014–2016
The important factor for the similar pattern of hotspot occurrence in this regional level is the agricultural activities of the local people in the Greater Mekong Sub-Region countries [18]. Therefore, it can be concluded that the obvious decreasing number of hotspot in three countries from January of each year, people usually begin to collect harvests. After the harvest season, most agriculturists will conduct burning to eliminate crop residues, in order to prepare lands for the next cultivation session. As a result, hotspots increase to highest number to the most during this period each year. In Northern Thailand, the majority of hotspot generally occurs at altitudes of 400 – 600 meters from mean sea level [18]. Those are mostly highlands and forest areas where local people often conduct agriculture, especially corn. Normally, agricultural burning is begun in February, so the increasing rate of hotspot from January to February will be higher comparing with other months during the burning season. Burning activities are conducted regularly in March, when the highest number of hotspots is found, with the lack of making fire breakers resulting in fires.

3.2 Long-range transport Pathway of Maize Straw Burning Smoke
The daily backward trajectories produced by HYSPLIT4 model for March of 2014-2016 are presented in Figs. 3 - 5. It can be seen that, most of backward trajectories patterns were moved in southwest direction across the southwestern part of Chiang Rai Province such as Mae Suay and Wiang Pa Pao districts before moving to PM$_{10}$ measurement station located in urban area. The study also shows that most of the air mass movement moved across the area having intensive fire region. It is possible that PM$_{10}$ that exceed standard is due to the movement of the air mass over the area and consequently moved to the urban area. This study is consistent with the study made by Yasanga et al. [18] that related to the study of the smoke and haze problem in Chiang Mai province, which show that PM$_{10}$ exceed standard value was were influenced by open burning from the long-range upwind regions. Another study by [19] also showsthat when PM$_{10}$ peaked, the air mass arriving at the Songkhla and Phuket passed over the intensive fire region in Sumatra Island. Therefore, we can see that the smoke and haze problem or the problem of PM$_{10}$ exceed standard value in Chiang Rai city has high possibility due air mass movement rough PM$_{10}$ from burning area in elevated area to Chiang Rai city [20]. Therefore, the solution to the smoke-and-haze problem in Chiang Rai province need to be conducted together with the utilization of the land in high elevated area to reduce the problem sustainably.

Figure 3. Backward trajectories patterns in March 2014

Figure 4. Backward trajectories patterns in March 2015
4. Conclusions
The pattern of open burning occurrence in Thailand, Laos and Myanmar is identical with the significant increasing rate of hotspot from January to February. Hotspot in these countries is also found peak in March annually. Therefore, the government should develop the policy aiming to lessen open burning, especially in February to March, which is considered as a main factor that causes smoke haze problem in the region.

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