Assessment of Long-range Transport Contribution on Haze Episode in Northern Thailand, Year 2007

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Abstract

The haze episode over northern Thailand has been an almost yearly occurrence and becomes severe during the prolonged dry period with elevated PM₁₀ concentrations. This study aims to assess contribution of long-range transport on occurrence of haze episode in Northern Thailand. PM₁₀ concentrations and hotspot data as well as meteorological conditions of Chiang Mai station during 2004-2007 were analyzed. It was found that the PM₁₀ concentrations were positively correlated with number of hotspots. On the other hand the PM₁₀ concentrations were found to have negatively correlation with wind speed, especially in 2004 (r = -0.476), 2007 (r = -0.442) and 2009 (r = -0.445). The 3-day backward trajectories of air mass arriving at Chiang Mai in year 2007 were analyzed using hybrid single particle langrangian integrated trajectory (HYSPLIT) model and grouped by cluster analysis. The air mass for whole year (335 days; 100%) was classified into 4 groups. A major direction came from western continents of Thailand, in which 64% was found to be associated with air mass trajectories during the haze episode (February to April). At this period (86 days, 100%), air mass was classified into 6 groups, and the major direction still originated from western side (75%). Dry season in Thailand normally ranges from November to April. In this study, air mass data of January-April and November-December 2007 (170 days, 100%) were clustered into 6 groups. The origin of backward trajectories during these periods was mainly local (57%). The air masses in wet season (165 days) were also classified and most of data (55%) mainly started from the Indian Ocean because of southwest monsoon influence. The results revealed that haze episode in Upper-Northern Thailand mainly originated from the western continent in association with local activities. Therefore, potential sources of air pollution in that area should be considered.
Keywords: Long-range transport; Back trajectory; Cluster analysis; Air pollution; PM$_{10}$

1. Introduction

Air pollution is one of the most important environmental issues which are still to be solved and has far-reaching impacts on the sustainable development of the terrestrial biosphere and exposure to polluted air causes adverse human health effects. Previous studies have linked elevated levels of air pollutants to many human health problems such as low birth weight and birth defects, infant mortality, child asthma, increased hospital admittance, increased allergy cases, lung disease, respiratory and cardiovascular disease and mortality displacement. Therefore, characterizing air pollution distribution and understanding its causes and variations in megacities has become an urgent issue for policy makers (Wang et al., 2004). Particulate matter (PM) is still a major problem in almost all Asian countries with concentrations exceeding 300 $\mu$g.m$^{-3}$ in many cities (Baldasano et al., 2003)

Meteorological factors may affect visibility in several ways. Sunlight, for example, significantly affects visibility by promoting secondary aerosol formation. Atmospheric photochemistry produces the major visibility-reducing aerosols, i.e. sulfates, nitrates, and oxyhydrocarbons. Wind speed and atmospheric stability affect visibility because they determine atmospheric dispersion and therefore concentrations of aerosol particles. In general, as the wind speed increases, visibility improves, as the wind-induced atmospheric mixing results in lower aerosol concentrations. During periods of atmospheric stagnation (associated with slowly moving high pressure systems), vertical mixing is suppressed, aerosol concentrations increase, and visibility is reduced. The resultant haze may cover hundreds of thousands of square kilometers. It is not uncommon to have a major portion of the Midwest, Southeast, or the East Coast covered by a “blanket of haze” (Godish, 1997).

Smoke haze due to forest fires and agricultural burning is a recurring environmental problem in Southeast Asia. Thailand has experienced one of its worst hazes in March 2007, 8 provinces in northern Thailand have been blanketed in smoke and dust for two weeks after forest fires and agricultural burning in northern Thailand and neighboring Myanmar and Laos. On the 14th of March, the province of Chiang Rai was declared a disaster zone, while the nearby province of Chiang Mai, the largest city in northern Thailand reported hazardous levels of air pollution (Bangkok (AFP), 2007).

Air quality has become a big problem and has been steadily deteriorating over the past ten years of Chiang Mai. Airborne fine particles in recent years have increased and started to exceed the national ambient air quality standards (NAAQS) (120 $\mu$g.m$^{-3}$ for 24-hr average of PM$_{10}$) in all monitoring stations in the dry season (February to March) (PCD, 2009). The geographical features of Chiang Mai City’s located in the Chiang Mai–Lamphun intermontane basin and is surrounded by high mountain ranges that results in the same air being re-circulated, accumulate more pollutants every time. Therefore, sources of air pollutants are also needed to be identified. Kim Oanh and Leelasakultum (2011) reported that an emission inventory (EI) conducted by the Pollution Control Department, Thailand for Muang district of Chiang Mai (not include the surrounding area of Chiang Mai province) evaluated the total particulate matter emission to be 700 tones of which 89% came from
forest fires, 5.4% from solid waste burning and 2.3% from agriculture residue field burning. Point sources (industry) contributed only 0.08%, mobile sources 2.6% and other sources 0.56%.

Without evidence to the contrary it was widely believed that once polluted air was transported for some distance downwind, the enormity of the atmosphere and dilution processes associated with it reduced pollutants to background levels. However, elevated levels of pollutants may occur hundreds to thousands of kilometers downwind of large point sources and areas producing urban plumes. This phenomenon is known as long-range transport (Godish, 1997). The knowledge of possible long-range transport contribution will help shed understanding on the nature of air pollution at a location, in order to formulate optimal abatement strategies. However, difficulties may arise when attempting to quantify this long-range transport contribution and to identify its source regions (Pongkiatkul et al., 2007). A simple back-trajectory model is normally applied to track the origin of air masses (Stein et al., 2000; Zeng et al., 2003). The Hybrid Single-Particle Langrangian Integrated Trajectory model Version 4 (HYPLIT4) is a useful air trajectory model, which is widely applied for long-range transport studies (Draxler and Hess, 1997).

2. Methods

2.1 PM<sub>10</sub> data and Air Quality Monitoring station

Data of 24 hr-PM<sub>10</sub> concentrations monitored at the Air Quality Monitoring (AQM) stations in Chiang Mai province (City Hall (CH) and Yupparaj Wittayalai School (YP) stations) and Nakhonsawan province (Nakhonsawan station (NS) as control site) was obtained from Pollution Control Department (PCD), Thailand. The locations of these stations are shown in Figure 1. The YP station was situated at a city center of Chiang Mai. It was surrounded by diverse urban facilities (e.g. public transport, school, grocery and government office) and has high population density as well as high traffic volume (1,532-2,308 vehicles per hours) (Na Nongkhai, 2004). This site was classified as a roadside based on Pollution Control Department (PCD) criteria. The CH station was located northwest of the city, approximately 6 km from the YP station. Community and traffic density was less dense in comparison with the inner city. The NS station was situated in Nakhonsawan Technical College surrounded by residential area. PM<sub>10</sub> concentrations were measured continuously using 1400a Taper Element Oscillating Microbalance (TEOM) (Rupprecht & Patashnick, USA) at 3 m height in range 0 – 1000 µg.m<sup>-3</sup>. TEOM mass detectors or microbalances utilize an inertial mass weighing principle. A TEOM detector consists of a substrate (usually a filter cartridge) placed on the end of a hollow tapered tube. The tube with the filter on the free end is oscillated in a clamped-free mode at its resonant frequency. This frequency depends on the physical characteristics of the tube and the mass on its free end. A particle laden air stream is drawn through the filter where the particles deposit and then through the hollow tube. The frequency of oscillation was measured and recorded by the microprocessor; the change in frequency was used to calculate the mass of particulate matter deposited on the filter (Teflon coated with glass fiber filter surface). The air flow rate at 16.67 L min<sup>-1</sup> is sampled through the sampling head and divided between the filter flow (3 L min<sup>-1</sup>) and an auxiliary flow (13.67 L min<sup>-1</sup>). The filter flow is sent to the instrument’s mass transducer, which contains the
analyze fraction of particulate. The inlet is heated to 50°C prior to particles being deposited onto the filter in order to eliminate the effect of condensation or evaporation of particle water (Washington State Department of Ecology Air Quality Program, 2004; Patashnick et al., 2002).

![Figure 1. Location of the air quality monitoring stations; CH and YP in CM province and NS in Nakhonsawan province.](image)

2.2 Hotspot data

The hotspot data are provided by Fire Information for Resource Management System (FIRMS) (Domain; minX: 77.368, minY: 6.782, maxX: 122.193, maxY: 29.107). FIRMS integrates remote sensing and GIS technologies to deliver global MODIS (or Moderate Resolution Imaging Spectroradiometer) hotspot/active fire locations to natural resource managers and other stakeholders around the World. FIRMS was developed by the University of Maryland with funds from NASA. The hotspot/fires are detected using data from the MODIS instrument, on board NASA’s Aqua and Terra satellites, using a specific fire detection algorithm that makes use of the thermal band detection characteristics of the sensor. Each hotspot/active fire location represents the center of a 1km pixel (approximately) flagged as containing one or more actively burning hotspot/fires within that pixel. (NASA/University of Maryland, 2002)

2.3 Meteorological data

Thai Meteorological Department (TMD) provided data on rain precipitation, wind speed and wind direction used in this study. Most of the data were daily averages. Three meteorological factors were used as input data for cluster analysis.

The climate of Thailand is under the influence of monsoon winds of seasonal character i.e. southwest monsoon and northeast monsoon. The southwest monsoon which starts in May brings a stream of warm moist air from the Indian Ocean towards Thailand causing abundant rain over the country, especially the windward
side of the mountains. Rainfall during this period is not only caused by the southwest monsoon but also by the Inter Tropical Convergence Zone (ITCZ) and tropical cyclones which produce a large amount of rainfall. May is the period of first arrival of the ITCZ to the Southern Part. It moves northwards rapidly and lies across southern China around June to early July that is the reason of dry spell over upper Thailand. The ITCZ then moves southerly direction to lie over the Northern and Northeastern Parts of Thailand in August and later over the Central and Southern Part in September and October, respectively. The northeast monsoon which starts in October brings the cold and dry air from the anticyclone in China mainland over major parts of Thailand, especially the Northern and Northeastern Parts which is higher latitude areas. In the Southern Part, this monsoon causes mild weather and abundant rain along the eastern coast of the part. The onset of monsoons varies to some extent. Southwest monsoon usually starts in mid-May and ends in mid-October while northeast monsoon normally starts in mid-October and ends in mid-February.

2.4 Trajectory analysis

Backward trajectories arriving at the receptor were calculated using the hybrid single particle langrangian integrated trajectory (HYSPLIT) model. The 3-day backward trajectories were available online at http://ready.arl.noaa.gov/HYSPLIT.php. To minimize the fraction effect from the Earth’s surface and to represent wind in the lower boundary layer (Begum et al., 2005), the air masses arriving at 1000 m above ground level (AGL) were chosen. The results from preliminary study on the effects of different starting levels in Thailand indicated that the air masses trajectories obtained for the start level of 1000 m agreed with those obtained for the 500 m start level on 70% of the days during the period from January 2002 to December 2004. It means that the air masses arriving levels may be at least considered to be within a layer of 500–1000 m (Pongkiatkul and Kim Oanh, 2007). The input data to HYSPLIT available 4 times a day (0, 6, 12, and 18 UTC), for total of 358 days during the period from January to December 2007.

2.5 Statistical analysis

The Pearson correlation of seasonal hotspot number and daily PM$_{10}$ concentrations in year 2007 was calculated. Air mass trajectories from each day were clustered to determine the main trajectories direction arriving to receptor using hierarchical clustering method. SPSS package version 17 was used for all data analysis.

3. Results and discussion

3.1 PM$_{10}$ concentrations during 2004-2009

PM$_{10}$ concentrations of the three AQM stations; CH, YP and NS, from 2004 to 2009 were analyzed. In this work the whole year season was basically divided into dry (6 months) and wet seasons (6 months). Dry season includes 2 periods (January-April and November-December), while wet season starts from May to October.

Monthly rainfalls recorded at Chiang Mai meteorological station in years 2004-2009 together with PM$_{10}$ concentrations measured at the AQM stations were plotted in Figure 2. Patterns of PM$_{10}$ levels were
almost the same for every year. In dry season the PM$_{10}$ concentrations were obviously higher than those in wet season. Remarkably in March 2004 and 2007, the levels of PM$_{10}$ at Chiang Mai stations were higher than those of other years. Amount of rain precipitation obviously affected to ambient PM$_{10}$ concentrations, which were high in dry season and low in wet season. Noticeably, the PM$_{10}$ concentrations increased at the beginning of dry season (November) and became highest in March before decreasing by the end of April. Their patterns were almost the same for all stations.

Figure 2. Monthly average PM$_{10}$ variation and rainfall in Chiang Mai, 2004-2009.
Haze episode in northern Thailand often occurred from February to April. It was found to associate with high levels of PM$_{10}$ concentrations. From the plots (Figure 3), PM$_{10}$ concentrations were high in March. The highest PM$_{10}$ concentrations were found in year 2007 (396.4 µg m$^{-3}$ at YP station and 317 µg m$^{-3}$ at CH station).

![Figure 3](image-url)  
Figure 3. 24 hr-PM$_{10}$ variation during February-April, 2004-2009 obtained from 3 AQM stations; NS, CH and YP.
Numbers of days those PM$_{10}$ concentrations exceeded 24 hr national standard (120 µg m$^{-3}$) at CH and YP stations are plotted in Figure 4. As described, PM$_{10}$ concentrations were high in March of every year, consequently high numbers of days were found in this month. Exception was found in year 2005, in which February presented the highest values for both stations. At the CH station in March, the numbers of days those PM$_{10}$ concentrations exceeded the standard in a descending order were 2004 (27 days, 87%) > 2007 (23 days, 74%) > 2009 (14 days, 45%) > 2005 (8 days, 26%) > 2006 (6 days, 19%) > 2008 (4 days, 13%) while those at YP station were 2004 (30 days, 97%) > 2007 (19 days, 61%) > 2009 = 2006 (14 days, 45%) > 2008 (7 days, 22%) > 2005 (6 days, 19%). The highest percentage of numbers of days for both CH and YP stations were in March 2004 as presented in Figure 4. The PM$_{10}$ data was found to relate with burnt forest area in northern region, which was also highest in 2004. (Department of National Parks, Wildlife and Plant Conservation, Thailand). However, the cumulative percent of PM$_{10}$ concentrations at these two stations were highest in year 2007 (Figure 5). High PM$_{10}$ concentrations in March obviously affected to cumulative percent of PM$_{10}$. Kim Oanh and Leelasakultum (2011) reported that weak wind and strong inversion, was most associated with haze episodes with the highest daily PM$_{10}$ concentrations in Chiang Mai during 2001–2008. These meteorological conditions dominated during the severe haze episode in March 2007. Local sources including open biomass burning were also highest during March 2007 while the traffic emission presented stable pollutant emission for whole year. Therefore, year 2007 was selected for analysis of contribution of long-range transport on haze episode in Upper Northern Thailand.
Figure 4. Numbers of days that PM$_{10}$ concentrations higher than the Thailand’s standard (24 hr.) in Chiang Mai, 2004-2009.
3.2 PM$_{10}$ levels and wind speed

Wind speed and PM$_{10}$ concentrations at the CH station during February to April, 2004-2009 were analyzed to find out their correlations (Figure 6). It was found that the correlations between wind speed and PM$_{10}$ concentrations were all negative. Moreover, those correlations were stronger in year 2004 ($r = -0.476$) than those in 2007 ($r = -0.442$) and 2009 ($r = -0.445$). The values were almost the same with the study in Athens, Greece, which reported the correlation of -0.43 (Chaloulakou et al., 2003). This observation demonstrated clear relationship between PM$_{10}$ concentrations and wind speed. The strong negative correlation implied that wind speed is an important factor of PM$_{10}$ concentrations. Strong wind flushes pollutants out of the Chiang Mai basin, while calm wind allows air pollutants to accumulate in the basin.

Figure 5. The cumulative percent of PM$_{10}$ concentrations in Chiang Mai, 2004-2009.

(a) CH

(b) YP
3.3 Relationship between PM$_{10}$ and hotspot number

In order to assess the contribution of long-range transport on haze episode in this area, the CH station was selected as a representative of Chiang Mai province. The location is more appropriate due to less effect from local sources such as traffic and communities. Therefore, its PM$_{10}$ data was analyzed for further detail.

Figure 6. The correlation between wind speed and PM$_{10}$ concentrations in Chiang Mai during February-April, 2004-2009.

Figure 7. Variation between hotspot number and daily PM$_{10}$ concentrations 2007.
PM$_{10}$ concentrations obtained from the CH station as well as hotspot data in 2007 were plotted as shown in Figure 7. The results revealed that those data series were much higher in dry season than those in wet season. Both hotspot number and daily PM$_{10}$ concentrations were high during January to April and they were highest in March. In dry period, fires are set for the most part in northern Thailand to clear land for subsequent cultivation by burning of agricultural waste. In addition, topography of northern Thailand in association with high number of open burning and meteorological conditions (temperature inversion) in dry season, air pollutants are accumulated in the mountain valleys and can be hardly escaped. Therefore, high concentrations of particulate matter and other harmful substances are reached.

Moreover, numbers of hotspot and PM$_{10}$ concentrations were analyzed to find out correlation of each period (Table 1). The analysis showed that their correlations were positive. The whole year data were well correlated ($r = 0.722$). The correlations in dry season were relatively strong (0.532-0.659) while in the wet season it was relatively low ($r = 0.330$).

**Table 1. Pearson correlations of hotspot number and PM$_{10}$ concentrations, Year 2007.**

<table>
<thead>
<tr>
<th>Periods</th>
<th>Number of days (N)</th>
<th>Pearson correlation ($r$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole year</td>
<td>Jan-Dec</td>
<td>337</td>
</tr>
<tr>
<td>Dry season</td>
<td>Jan-Apr, Nov-Dec</td>
<td>172</td>
</tr>
<tr>
<td></td>
<td>Feb-Apr</td>
<td>86</td>
</tr>
<tr>
<td>Wet season</td>
<td>May-Oct</td>
<td>165</td>
</tr>
</tbody>
</table>

**3.4 Classification of air mass trajectories**

The 3-day backward trajectories of air masses arriving at Chiang Mai from January to December 2007 were determined. Classification of air mass trajectories were performed for whole year (2007) and also for each season: wet season (May-October) and dry season (January-April and November-December). Moreover, those of haze episode (February-April) were mainly considered.
The data for whole year (335 days; 100%) were analyzed by cluster analysis. Air mass trajectory can be classified into 4 clusters and percent of data in cluster 1, 2, 3 and 4 were 64%, 18%, 17% and 1%, respectively (Figure 8). The trajectory directions of all clusters were found to be in almost the same direction, which were southwest and northeast of the receptor. The 1st cluster (southwest of the receptor) was a major direction of air mass. The origin of trajectory in cluster 1 was in southern Myanmar continent and directly move northeast arrived the receptor. The cluster 2, 3 and 4 were similar in terms of length. For cluster 2, the trajectory started from Indian Ocean and entered inland at the south of Myanmar before arriving Chiang Mai in the same direction with cluster 1. Air mass of cluster 3 originated from the south of China passing the Pacific Ocean, entered inland at the northeast of Vietnam and move through Laos and the receptor in the east. The last cluster started from the south of China and moves southwest through northern part of Laos to reach Thailand.

Figure 9. 3-day backward trajectories of clusters for dry season 2007 (January-April and November-December).

Back trajectories of the data of dry season (170 days including January-April and November-December) were grouped into 6 clusters as shown in Figure 9. 57% of the data were in cluster 1 (local area). Cluster 2, 3, 4, 5 and 6 contain 18%, 14%, 5%, 5% and 1%, respectively. The cluster 2 came from Indian Ocean and entered inland at southern Myanmar before arriving Chiang Mai. Air mass of cluster 4 started from Indian Ocean and arrived at the receptor in the south. Directions of air mass of cluster 3, 5 and 6 were the same as northeast monsoon direction. Cluster 3 and 5 originated at the south of China through Vietnam and Laos. Direction of cluster 6 was closed to cluster 3 but with longer pathways over the Pacific Ocean with clean air mass.

Air mass trajectories during haze episode (February to April) were run again to analyze pattern of air mass direction. They can be clustered into 6 groups as shown in Figure 10. All of air mass trajectories were presented distinct difference in terms of both direction and origin area. The frequency of all backward trajectories (86 days; 100%) were highest in the cluster 1 (75%) which came from southern Myanmar, while the
cluster 2 still originated from Myanmar at the southeast (15%). Moreover, the wind direction (Figure 11) during this period was well associated with this result which mostly started from western Thailand. The percent of air mass trajectories in cluster 3, 4, 5 and 6 were 4%, 2%, 2% and 2%, respectively. The air mass of cluster 3 started over Pacific Ocean through Vietnam and Laos arriving to Thailand. Cluster 4 originated over Indian Ocean and travel over Myanmar to the receptor while cluster 5 still started from Indian Ocean but entered inland at the south of Myanmar to Thailand. The last cluster started at the south of China through Vietnam and passing Laos before arriving to Thailand.

Figure 10. 3-day backward trajectories of clusters for dry season (February-April) 2007.

The clustering of air mass in wet season (165 days) was grouped into 4 clusters (Figure 12). The trajectory of air mass in cluster 1 (55%) and cluster 3 (3%) originated from the Indian Ocean because of southwest monsoon through Myanmar and northern part of Thailand. The percent of data in cluster 2 were 41%. The air mass of cluster 2 started in the boundary of Vietnam and travel over Laos before arriving at the receptor.

Figure 11. The windrose during February-April 2007.

The clustering of air mass in wet season (165 days) was grouped into 4 clusters (Figure 12). The trajectory of air mass in cluster 1 (55%) and cluster 3 (3%) originated from the Indian Ocean because of southwest monsoon through Myanmar and northern part of Thailand. The percent of data in cluster 2 were 41%. The air mass of cluster 2 started in the boundary of Vietnam and travel over Laos before arriving at the receptor.
in the east while for cluster 4 (1%) came from China and directly move to northern Laos before arriving at Thailand.

![Figure 12. 3-day backward trajectories of clusters for wet season (May-October) 2007.](image)

4. Conclusions

Haze episode in northern Thailand during March to April of almost every year was found to associate with the levels of daily PM$_{10}$ in Chiang Mai. During 2004-2009, PM$_{10}$ concentrations were high in dry season especially in March 2004 and 2007, which coincided with the strong correlation of hotspot number and daily PM$_{10}$ concentrations. On the other hand, PM$_{10}$ concentrations and wind speed were negatively correlated.

From cluster analysis, air mass trajectory mainly originated from western continent of Thailand during February to April 2007, while air mass trajectory in overall dry season (January-April and November-December) mainly came from local. In conclusion, major air masses in dry season came from the western continent of Thailand as well as local, which indicated potential sources of aerosols and pollutants to northern Thailand during haze period. However, more data in other years i.e. 2004 (episode year) and 2008 (background year) should also be applied to assess long-range transport contribution to air pollution in Chiang Mai to compare and confirm these results.

5. Acknowledgements

Financial supports from the Network Center for the Acid Deposition Monitoring Network in East Asia (EANET), Asia Center for Air Pollution Research (ACAP) and the Graduate School of Chiang Mai University are gratefully acknowledged. We also thank Pollution Control Department (PCD), Thailand, Fire Information for Resource Management System (FIRMS) and Thai Meteorological Department (TMD) for providing observation data and the NOAA Air Resources Laboratory (ARL) for the HYSPLIT dispersion model.
6. References


