Songklanakarin J. Sci. Technol.
30 (4), 539-546, Jul. - Aug. 2008

Songklanakarin Journal
of Science and Technology

http://www.sjst.psu.ac.th

Original Article

Air quality in Southern Thailand during haze episode in relation to air mass trajectory

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Received 17 August 2007; Accepted 5 July 2008

Abstract

Southeast Asia haze with elevated particulate matter (PM_{10}) often blankets Southern Thailand during June-August period. During the haze period of August 2005, the highest 24h PM_{10} concentration was 92 µg/m^3 in Songkhla and 108 µg/m^3 in Phuket. Though the levels were still below the 24h PM_{10} National Ambient Air Quality Standard of 120 µg/m^3, they were considerably higher than the annual average levels of 32 µg/m^3 in Songkhla and 56 µg/m^3 in Phuket. The variation in daily PM_{10} levels during this period was largely dependent on the prevailing wind directions and the intensity of fire, expressed as the number of hotspots on NOAA satellite images, at the upwind regions. The backward trajectories obtained by HYSPLIT4 model revealed that on the days when PM_{10} peaked the air masses arriving at the cities passed over the intensive fire region in Sumatra Island. The peak PM_{10} levels were observed in Phuket on 16th and in Songkhla on 13th August 2005, i.e. during the same period when a large number of hotspots were seen in Sumatra Island of Indonesia (10th-16th August 2005). The PM_{10} level dropped when the wind changed direction from southwesterly to southeasterly hence the air mass trajectory did not pass the fire region. The transport time of air masses from the source region to Southern Thailand during this period was around 2-3 days.

Keywords: Southeast Asia Haze, particulate matter, Thailand, forest fire, transboundary

1. Introduction

Haze is one of the most basic forms of air pollution when tiny particles (sub-micron size range) in the air cause significant visibility reduction because they effectively scatter and absorb sunlight. Some haze-causing particles are directly emitted into the air. Others are formed when gases emitted into the air transforming into particles. These fine particles disperse around and are transported following the general wind direction, causing transboundary air pollution. The fine haze-causing particles are of particular health concern as they are respirable and may carry many adsorbed toxic substances on the surface.

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The smoke haze from forest fire causes deleterious effects to the nature, material property and human health. Due to their incomplete combustion nature forest fires emit smoke containing large amounts of fine particles, and toxic gaseous such as carbon monoxide (CO) and a range of hydrocarbons (HC) including the carcinogenic polycyclic aromatic hydrocarbons (PAHs) (Kim Oanh *et al.*, 2002 and 2005). These substances can be transported to great distances hence the effects on air quality can be felt both within a country border and transboundary. Exposure to “haze” air pollution can be substantial as it involves a large number of people over a large region. Haze also causes public transportation disruption and traffic accidents due to visibility reduction, which may result in life and economical losses. The light absorption and scattering properties of the haze particles would affect the solar radiation balance which may be linked to the earth climate change (Ward, 1998; Brauer, 1999; UNEP and C[4], 2002).

Several hundred million hectares of the world's forests and vegetation are annually consumed by wildfires and intentional fires for land use systems management (Qadri, 2001). Uncontrolled forest fire during the dry season in Southeast Asia causes smoke haze almost annually. The fires themselves may occur within a country but the effects are extended to other countries. Transboundary haze pollution from forest fires is one of the most severe regional air pollution problems in the Association of Southeast Asian Nations (ASEAN) region. The fire episode that hit the region during the El Nino drought of 1997-1998 has been particularly severe and most damaging in the recorded history. The most severe was the period from July to October 1997 when most parts of Indonesia, Singapore, Malaysia, southern Thailand, Brunei, and southern Philippines were badly affected. The causes and effects have been widely reported by many researchers (Nichol, 1998; Radojevic and Hassan, 1999; Muraleedharan *et al.*, 2000; Koe, 2001; Tan, 2004). During the most severe haze of 1997 the large and uncontrolled fires occurred in the peat areas of Sumatra Island (Qadri, 2001). Air quality index (AQI) readings remained in the hazardous range for long periods in September and October 1997 in Sarawak, with a recorded peak at 849. In Malaysia and Singapore people were informed when air pollution reached unsafe levels, and were warned to take appropriate protective measures (Pinto and Grent, 1999). The 24h PM_{10} level in Songkhla city, Southern Thailand during the 1997 haze was 218 $\mu g/m^3$ (Phonboon *et al.*, 1998).

The most recent serious regional smoke haze in Southeast Asia (SEA) was observed at the beginning of August 2005. The haze affected areas in Indonesia, Malaysia and Southern Thailand. The local authorities in Southern Thailand issued the warning of poor visibility and respiratory difficulties. Air quality monitoring network of the Pollution Control Department (PCD) of Thailand recorded a high concentration of potential harmful small particles in some areas (PCD, 2005a). As a matter of fact, during this period numerous peat conversion fires, slash-and-burn agriculture and vegetation fires were reported to take place on the Sumatra Island of Indonesia. Although fire-related haze phenomenon is a recurring problem in the SEA there is a lack of systematic studies on effects of haze in this highly populated area. Limited and fragmented data show that the effects can be serious (Qadri, 2001; Sastry, 2002; Varma, 2003; Phonboon *et al.*, 1999).

This study analyzes the air quality in Southern Thailand during the August 2005 haze episode in relation to the air mass trajectories arriving at the area. Monitoring data including particulate matter with the size less than 10 µm (PM_{10}) and the gaseous criteria air pollutants are considered. The Hybrid Single-Particle Langrangian Integrated Trajectory Model Version 4 (HYSPLIT4) is used to identify the pathways of air masses associated with high pollution concentrations in Southern Thailand.

2. Materials and Methods

In this paper, we consider the air quality in Southern Thailand during the 2005 haze episode in comparison with the non-haze period and in relation to meteorological conditions. The potential effects of long-range transport to the air quality in Southern Thailand were also investigated. The monitoring data were collected from the national ambient air quality monitoring stations of PCD during the period from June to August 2005. Data from the automatic monitoring stations in three southern cities were used, namely, Songkhla (Hat Yai district) (latitude 7°05'N, longitude 100°57'E), Phuket (latitude 7°88'N, longitude 98°38'E), and Surat Thani (latitude 9°14'N, longitude 99°27'E) together with the short-term data collected by mobile monitoring units for Satun and Trang cities. Each automatic station produces a range of specific criteria air pollutants (hourly and 24-hourly) using the beta attenuation and Tapered Oscillated Micro Balance (TEOM) for PM_{10}, non-dispersive infrared detection for carbon monoxide (CO), chemiluminescence for nitrogen dioxide (NO_2) and ozone (O_3), and UV-fluorescence for sulphur dioxide (SO_2). The instruments are daily calibrated by means of zero air and span gas using a built-in automated calibration system.

The relationship between the possible distant sources and air quality in the study area was analyzed using the air mass back trajectory. The hotspots representing fires available on the satellite images in SEA were gathered from the website of the National Environmental Agency of Singapore (NEA) (http://app.nea.gov.sg/cms/htdocs/article.asp?pid=1674) (NEA, 2005). In order to identify potential source areas and the pathways that give raise to the observed high air pollution concentration, HYSPLIT4 was run online at the NOAA ARL READY Website (HYSPLIT4, 1997) using the meteorological data archives (FNL) of Air Resource Laboratory (ARL). The 3-day backward trajectories were calculated at the starting levels of 1000, 500, and 100 m AGL (Above Ground Level) from each monitoring station. The starting time was 5:00 UTC (Coordinated Universal Time) that is equivalent to 12:00 noon Thailand local time, on the days that Songkhla and Phuket cities experienced of highest air pollution level (PM_{10}) during 12^{th} - 16^{th} August 2005.

3. Results and Discussion

3.1 Air quality and meteorology in Southern Thailand

Southern Thailand is located on the Malay Peninsula, which covers an area around 70,713 km² with a population of 8.5 million. The meteorological conditions are typical for tropical humid region with one wet and one dry season. The southwest monsoon season, which lasts from May to October, brings rain and squalls to the coastal areas of the Andaman Sea. There is another rainy period caused by the northeast monsoon generally during November to December,

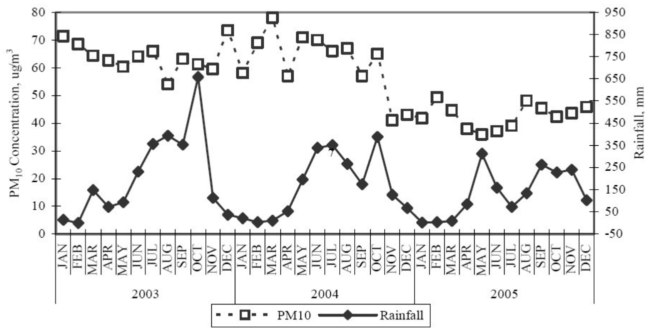
Table 1. Climatological data for the period 1971-2000 of Songkhla and Phuket cities (Extracted from TMD, 2003)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Songkhla (Hat Yai)												
Mean Rainfall (mm)	48.2	19.1	55.4	113.6	161.7	106.8	109.4	112.1	159.4	211.4	318.1	269.4
Mean Temperature (Celsius)	25.8	26.6	27.5	27.9	27.7	27.5	27.2	27.2	26.7	26.4	25.8	25.4
Prevailing direction	NE	NE	NE	NE	SW	SW	SW	SW	SW	SW	NE	NE
Mean Speed (m/s)	2.7	2.4	2.1	1.5	1.1	1.1	1.2	1.2	1.1	1	1.5	2.3
Phuket												
Mean Rainfall (mm)	21.7	30.3	59.2	135.4	282.6	244.0	283.5	293.5	382.8	305.0	173.8	59.4
Mean Temperature (Celsius)	27.9	28.6	29.2	29.3	28.5	28.3	27.8	27.9	27.3	27.3	27.4	27.4
Prevailing direction	E	E	E	E	W	W	W	W	W	W	NE	NE
Mean Speed (m/s)	1.6	1.5	1.4	1.1	1.1	1.4	1.4	1.8	1.4	1.1	1.2	1.8

which brings heavy rain to the coastal areas along the Gulf of Thailand. This area has higher relative humidity and lower average temperature than the rest of the country (TMD, 2003). These trends are clearly seen in Table 1 (values extracted from TMD, 2003) which shows average meteorological conditions over 30 years (1971-2000). Songkhla (on the Gulf of Thailand side) has higher rainfall in November-December while Phuket (washed by the Andaman Sea) has higher rainfall in August-October. Mean annual rainfall in Songkhla is around 1680 mm with 160 rainy days and in Phuket is 2270 mm with 170 rainy days. The prevailing wind and other meteorology conditions for Songkhla and Phuket cities are also presented in Table 1.

Monthly rainfall during the period 2003-2005 for the two cities are plotted in Figure 1(a,b) together with PM_{10} data. The minimum rainfall is observed for the period from January to April while higher rainfall is observed for mostly the rest of the year. Note that Phuket and Songkhla are located only around 500 km apart. However, they are washed by different seas, which partly determine the difference in meteorology. The monthly average PM_{10} during 2003-2005 in Phuket is higher than in Songkhla. The annual average PM_{10} in Phuket for the 3 year period was 56 $\mu g/m^3$ compared to 32 $\mu g/m^3$ in Songkhla. The observed PM_{10} levels in these two cities do not change much in a year. This pattern is different from that observed for Bangkok (the capital city) where air pollution is significantly higher during the dry season, November-March, and lower during the rainy season (Kim Oanh *et al*. 2006, Pongkiatkul and Kim Oanh, 2007). In Phuket there is somewhat higher PM_{10} during the drier period of December-March. However, a close examination of the monthly trends of PM_{10} and rainfall in Phuket revealed that the PM_{10} levels remain quite high during heavy rainfall months, i.e. October 2003-2005, June-July 2004, August-September 2005. In Songkhla there is no clear trend but the drier months (Feb-March) even show slightly lower PM_{10} levels. Since the wet removal is believed to be efficient for PM_{10}, higher levels of the pollutant during the rainy period suggest an increase in the source intensity. The local sources in the study area such as traffic and industry are believed to be more or less constant during the year. The local biomass burning should be lower during the rainy season. Thus, it was hypothesized that the higher pollution levels during the rainy period may be linked to long-range transported pollutants.

(a) Phuket city



(b) Songkhla city

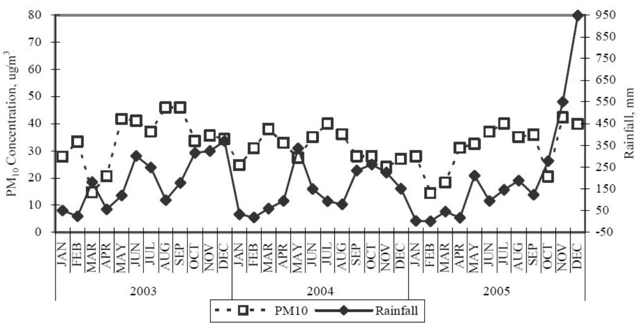


Figure 1. The PM_{10} monthly average variation and mean rainfall in 2003-2005 at (a) Phuket and (b) Songkhla cities

3.2 Air quality during the haze episode July-August 2005

The haze was reported to blanket parts of Southern Thailand at the beginning of August 2005 and lasted until the end of the month. During this period (1^{st} - 31^{st} August 2005)

Table 2. Air quality data during haze month and non-haze month of 2005

Station/Pollutant	PM_{10} 24 h-avg ($\mu g/m^3$)	SO_2 1 h-avg (ppb)		NO_2 1 h-avg (ppb)		CO 1 h-avg (ppm)		CO 8 h-avg (ppm)		O_3 1 h-avg (ppb)	
	Range	Range	Avg	Range	Avg	Range	Avg	Range	Avg	Range	Avg
(i) Haze month											
(1st-31st August 2005)											
Surat Thani	16-43	0-13	0.6	0-14	4.3	0-0.8	0.2	0-0.6	0.2	0-22	6.4
Phuket	34-108	0-1.5	0.4	0-28	8.3	0-2.5	0.4	0-1.8	0.4	0-32	8.9
Songkhla	18-92	0-11	1.9	0-13	4.4	0-2.1	0.7	0.2-1.5	0.7	0-40	7.7
Satun (16th - 31st August 2005)	20-55	-	-	-	-	-	-	-	-	-	-
Trang (16th - 31st August 2005)	14-31	-	-	-	-	-	-	-	-	-	-
(ii) Non-haze month											
(1st June – 31st July 2005)											
Surat Thani	14-35	0-8	1.6	0-13	2.8	0-0.7	0.2	0-0.5	0.2	0-23	5.6
Phuket	22-63	0-6.3	0.4	0-26	9	0-2.5	0.4	0-2.1	0.4	0-30	10.4
Songkhla	22-85	0-10	2.4	0-31	10	0-2.6	0.7	0.2-1.3	0.7	0-40	5.5
Satun (16th - 31st August 2005)	-	-	-	-	-	-	-	-	-	-	-
Trang (16th - 31st August 2005)	-	-	-	-	-	-	-	-	-	-	-
NAAQS	120	300		170		30		9		100	

elevated PM_{10} levels in Phuket and Songkhla were observed as compared to non-haze period (1st June - 31st July 2005) while at other cities, presented in Table 2, no significant difference in PM_{10} was observed. Other criteria pollutants (SO_2, NO_2, CO and O_3) presented in Table 2 show no significant difference between the haze and non-haze months. During the haze episode, the reported criteria pollutants at all sampling sites were not exceeding the Thailand National Ambient Air Quality Standard (NAAQS). As compared to the non-haze period, the increase in PM_{10} appears to be the most significant. Note that low ozone was observed during the haze period suggests that the photochemical activities were not enhanced and the increase in PM_{10} could mainly be due to the primary particles.

The Phuket station recorded the highest levels of 24h PM_{10} during the haze month, which ranged 34-108 $\mu g/m^3$ as compared to the non-haze month of 22-63 $\mu g/m^3$. Note that the variations of PM levels at Surathani presented in Table 2 during the haze month were larger and covered higher values (i.e. 16-43 vs. 14-35 $\mu g/m^3$), which also suggests the haze effects.

During the entire month of August 2005, there was only 1 pronounced peak observed on 13th August in Songkhla with 24h PM_{10} of 92 $\mu g/m^3$ and the high PM levels maintained until it reached normal level on 14th August. In Phuket, one high peak was observed on 16th August with the PM_{10} level of 108 $\mu g/m^3$, the highest at all sites in August 2005. Small peaks were also observed at Surathani on 16th and 17th (Figure 2). During this period the Pollution Control Department issued a warning in the southern provinces of Thailand of the forest fires haze. Data at Satun and Trang were available from the mobile stations only in the second half of the month and show high levels at Satun on 13th August and toward the end of the month, but at Trang no peaks were observed.

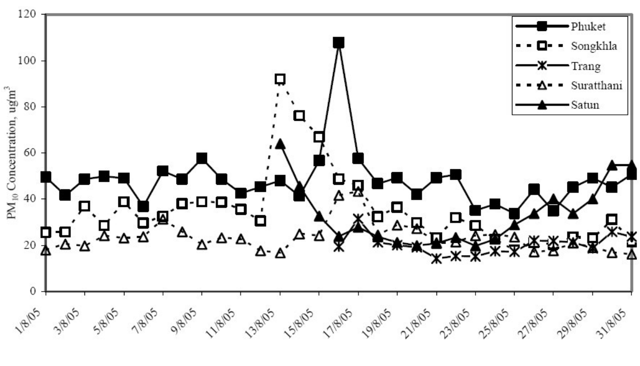


Figure 2. The 24h-avg of PM_{10} during 2005 haze episode at Surat Thani, Phuket, Songkhla, Satun, and Trang cities

The Air Quality Index (AQI) used in Thailand is based on the principle of the Pollution Standard Index (PSI) that employed by the US Environmental Protection Agency (EPA). AQI counts above 100 but below 200 are considered unhealthy; between 200 and 300 are very unhealthy; and between 300 and 500 are considered hazardous (PCD, 2005b). During the haze episode, the 24h PM_{10} concentrations was the highest among the criteria air pollutants hence the AQI is based only on this pollutant. The temporal variations of 24h PM_{10} and AQI at Surat Thai, Songkhla, Phuket, Satun, and Trang during August 2005 were analyzed and the highest AQI during 2005 haze period was 92 in Phuket, which implies a “moderate” health effect on population. For comparison, the AQI were in the range of “unhealthy” during

2003 and 2004 haze episodes with peak readings in Southern Thailand at 114 and 104, respectively.

3.3 Transboundary Transport during the Haze Episodes

Uncontrolled forest fire during the dry season in Southeast Asia causes smoke haze almost every year. The fires themselves may occur well within the national boundary of a country but the effects are also felt in other countries. Transboundary haze pollution from forest fires is one of the most severe regional air pollution problems in the ASEAN region (Qadri, 2001).

The dry season in Sumatra, Indonesia, starts from May and lasts until September (OCHA, 2005). During this dry season uncontrolled forest fire frequently occurs in the area. Haze in the SEA is often observed during this period. The haze episode in 2003, for example, recorded the peak of 24 h PM_{10} of around 150 µg/m^3 on 9th-10th June (note that Figure 1 presents only monthly average). In August 2004 the highest peak 24h PM_{10} in Phuket city was 128 µg/m^3.

In August 2005, the forest fires lit to clear land for plantation and mining on Sumatra Island were intensive. On the National Oceanic and Atmospheric Administration (NOAA 12) satellite images, derived from NEA of Singapore, numerous hotspots were detected in the provinces of Riau, North Sumatra and Nanggroe Aceh Darussalam of Indonesia. In Sumatra the highest numbers of transports were observed on 6-7 August 2005 (202 and 333 hot spots, respectively).

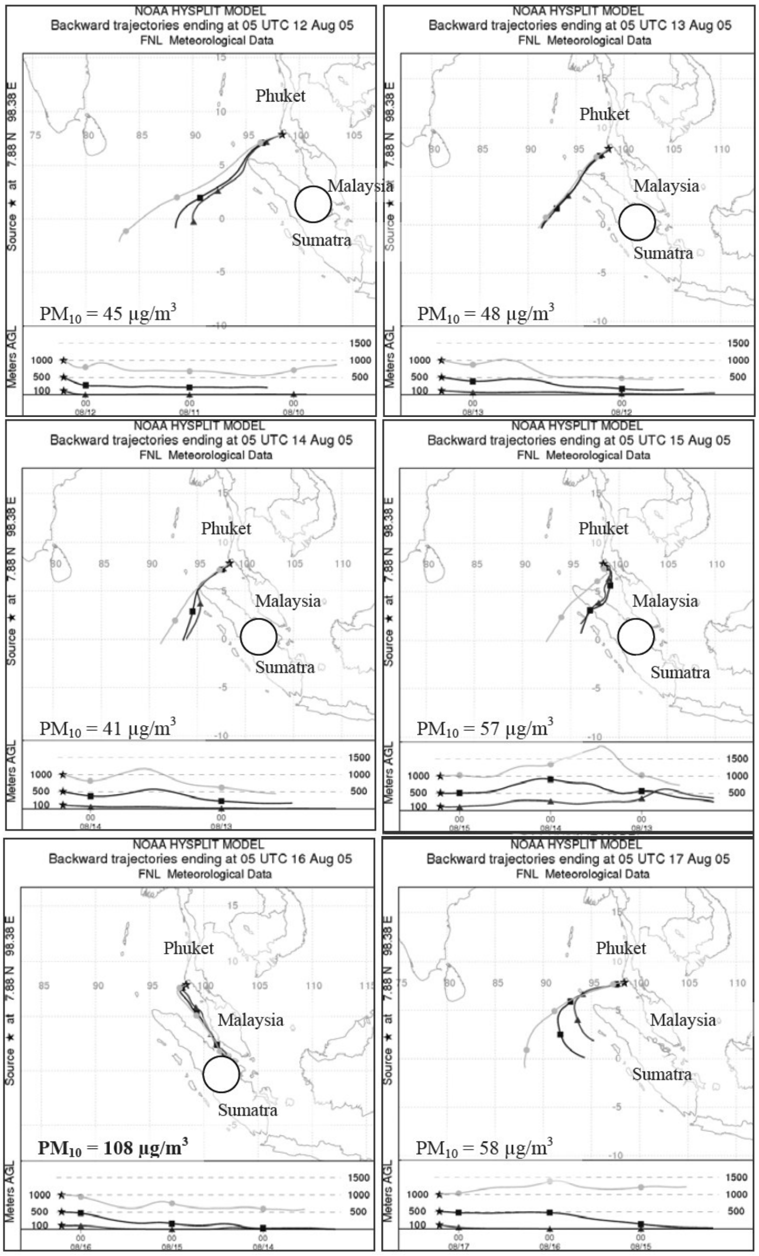


Figure 3. Air mass back trajectories during 12th-17th August 2005 at Phuket city.

The haze was observed in Peninsular Malaysia during this period (ASEAN, 2005). However, the smoke haze was not found to affect air quality in Southern Thailand due to the prevailing easterly wind component over southern Thailand. The backward trajectories of air masses arriving at the study area on these days did not pass Sumatra Island.

However, during the period of 10th-12th August 2005 the southwest monsoon was prevalent and the smoke haze was blanketing Southern of Thailand. Note that the numbers of hotspots detected over Sumatra during this period were generally smaller than the first period, i.e. 11 and 92, respectively. The smoke haze was nevertheless visibly observed in central Sumatra. On 15th August, the intensity of fire increased and NOAA 12 detected 286 hotspots in Riau of Sumatra Island. Visibility reading in Pekanbaru and Riau of Sumatra during the period dropped to 5-6 km. After 17th August the direction of the low-level wind over the southern part of west coast of Peninsular Malaysia shifted to south-easterly (ASEAN, 2005); also rain was reported over the fire region, and the haze over Southern Thailand declined.

The 3-day backward air masses trajectories were obtained on the days with high PM_{10} concentration, 12th-17th August 2005, at Phuket (Figure 3) and Songkhla (Figure 4). The backward trajectories at 1000, 500, and 100-m are presented in the figures.

In Phuket, from 12th-14th August the air mass trajecto-

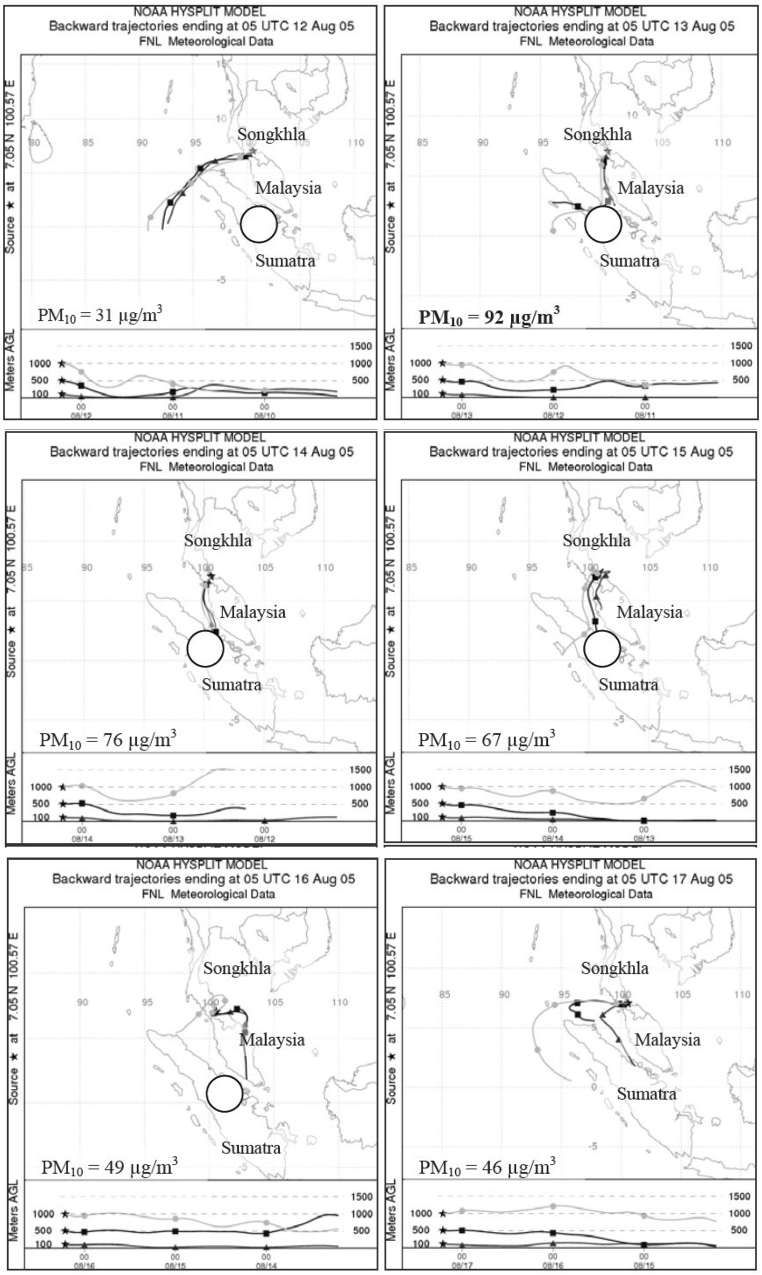


Figure 4. Air mass back trajectories during 12th-17th August 2005 at Songkhla city

ries were not passing the fire region (circle in Figure 3) and mainly starting over the sea. During this period the 24h PM_{10} was lower (41-48 µg/m^3). However, starting from 15th August the air mass changed the pathway and passed over the Sumatra Island. On 16th August it passed the intensive fire region. The PM_{10} level in the city was observed to increase from 15th, peaked on 16th August at 108 µg/m^3. The level dropped on 17th August due to heavy rain in the source region and no hotspot was observed. The air mass also had its origin changed toward the sea.

For Songkhla, the high levels of PM_{10} were observed on 13th August (peaked at 92 µg/m^3) when the air mass originated from the fire region in Sumatra (circle in Figure 4). The levels remained relatively high on 14th and 15th when Southerly wind brought the air mass from Sumatra. On 16th and 17th when the air mass did not pass the Sumatra island the PM_{10} levels dropped to normal range of below 50 µg/m^3.

It is noted that Phuket and Songkhla were under the influence of different air masses during the haze period therefore the peaks of PM_{10} appeared on different days in these 2 cities. The transport of haze during this period from the Sumatra fire region to Southern Thailand took approximately 2-3 days. The transport of the haze, as expected, strongly depends on the prevalent wind.

Although the forest fires in Sumatra and Borneo continued for the next few months in 2005, there was no other reported transboundary haze event in Thailand after August. This is mainly due to the shift in wind direction from the southwest to northeast monsoon (ASEAN, 2005). Compared to other recurring transboundary haze episodes in Southern Thailand the haze event in 2005 seemed to be less intensive.

The results suggest that the elevated PM_{10} observed in these locations was likely linked to the regional transport of the emission from distant sources. Forest fires in Sumatra Island appear to be the distant sources of concern. International cooperation is required to deal with this transboundary air pollution. The strong association between the local air pollution and the wind direction also helps in prediction of general trend of air pollution, especially during the haze periods. Meanwhile, back trajectory analysis based on the predicted meteorology can provide information to government agencies and public on potential haze episode occurrences so that measures can be taken in time to minimize the exposure to the toxic air pollutants.

4. Conclusions

The smoke haze event observed in August 2005 in the Southern Thailand appeared to be not intensive because all the 24h criteria air pollutants were within acceptable limits of the Thailand NAAQS. During this month, elevated levels of PM_{10} were recorded in the study area as compared to non-haze month of July. The highest AQI during August 2005 was reported to be within "moderate" range health category. The 3-day backward trajectories confirmed that the high PM_{10} events observed in Southern Thailand coincide with the air masses originated/passed over the intensive fire locations in Sumatra. The transport of haze from the fire region to Southern Thailand during this time took only 2-3 days. Further studies should be conducted which would apply 3D regional atmospheric dispersion models in order to quantify the major contributing sources and test different scenarios to develop control strategies for management of the episodic haze pollution in the area. Detailed analysis of PM_{10} composition during haze episodes would provide data for source apportionment by receptor modeling. Both dispersion and receptor modeling approaches will help to establish a comprehensive picture of cause and effects relationship in the haze events.

Acknowledgements

The authors are grateful to thank the Pollution Control Department of Thailand for air quality data.

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