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Effects from Open Rice Straw Burning Emission on Air Quality in the Bangkok Metropolitan Region

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ABSTRACT: In Thailand and many other Asian countries, where rice is the major crop, open burning of rice straw after harvesting is a common practice. This activity releases a large amount of air pollutants, which can cause serious effects on the ambient air quality, public health and climate. In this study, the number of hotspots, which represents open fires, detected on the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite images over the Pathumthani were counted. The results show high numbers of hotspots during the rice straw burning season. Good correlation was obtained between hotspots numbers and the levels of air pollutants, including carbon monoxide and particulate matter, measured at the Rangsit ground based air quality monitoring station of the Pathumthani province. Forward trajectories were calculated using the HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT4) model to roughly examine possible transport pathways of smoke emitted from the rice straw burning in Pathumthani. The results show that during the intensive burning season (November-April) smoke plumes from rice straw burning in Pathumthani can be transported to Bangkok following the Northeast monsoon. Emission from open rice straw burning therefore may contribute significantly to air pollution levels in the surrounding areas including Bangkok.

KEYWORDS: air pollution, rice straw open burning, forward trajectory, hotspot, satellite imagery

INTRODUCTION

In many countries in Asia, open burning for agricultural land clearing is commonly practiced. In particular, open burning of rice straw after harvesting in Southeast Asia is intensive during the dry season, which may contribute significantly to the ambient air pollution. In Thailand, where rice is the major agricultural product, the area of annual harvested rice paddies, including both the major crop (growth season: May-October) and minor crop (November-April), is about 9.6 million hectare[1]. Based on our questionnaire survey, over 90% of the rice paddies during the high harvesting season (November-December) are burned. The intensive burning period of rice straw from both crops lasts from November to April of the following year[2].

Open burning of rice straw in the field is of the incomplete combustion in nature hence a large amount of pollutants are emitted, including toxic gases (carbon monoxide (CO), volatile organic compound (VOC), and carcinogenic polycyclic aromatic hydrocarbons) and fine/inhalable particles [2, 3, 4]. Smoke from biomass burning has been shown to be potentially toxic [5, 6, 7]. After release into the atmosphere, these pollutants disperse to the surrounding areas, and may undergo chemical and physical transformation and eventually adversely affect human health. Rice straw burning has been linked to increased asthma attacks in children in a prefecture in Japan[8]. Intensive burning of agricultural wastes in many Asian countries may substantially contribute to the formation of the Atmospheric Brown Cloud that affects the local air quality, atmospheric visibility and Earth climate[9].

Assessment of the impacts of the open rice straw burning on the air quality, however, is challenging as these fires normally occur sporadically, during short time periods, in small rice paddy plots which spreads over a large area. Satellites are proved to be a useful tool for monitoring of the biomass fires[10]. Satellite imagery can provide information on the dryness of the vegetation, location and size of major fires and smoke plumes, energy release by fires, and air pollutants in the smoke plumes.

This study has been designed to provide a casual link between the rice straw open burning and the ambient air quality in Pathumthani, the intensive burning area of the Bangkok Metropolitan Region (BMR), using both satellite and ground based monitoring data. The trajectory modeling was used to investigate possible pathways of the emission and potential impacts on the air quality in the neighboring areas.

Materials and Methods

Hotspots were counted using the information from the website of NASA's Earth Observatory (http://earthobservatory.nasa.gov/NaturalHazards/) and Web Fire Mapper (http://maps.geog.umd.edu/). In Web Fire Mapper, each fire detection represents the center of a 1 km pixel, which may contain one or more active burning fires. It is noted that rice straw burning in Thailand is mostly on small plots (much less than 1 km each side) and also for a short period of time (1-2 hours). The MODIS satellite images for Thailand are available 1 or 2 times per day. Hence, short-lived fires happen at other time periods during a day will not be detected using satellite imagery. The fire detection may also be affected by cloudiness. Thus, the hotspot counting based on the available satellite imagery may underestimate the fire spots in the area. Nevertheless, the hotspot counting is still considered as an effective way for monitoring the burning sites over this large study area. An example of the hotspots that appeared in Pathumthani on a burning day is given in Figure 1.

The ambient monitoring data for CO and PM_{10} (particles with aerodynamic diameters less than 10 µm which are defined as respirable) at the Rangsit automatic monitoring station were collected from the Pollution Control Department of Thailand. The station is located in Pathumthani province which has the major rice production in the BMR[1]. To demonstrate the impacts of rice straw burning on local air quality, correlations between the hotspots counted on MODIS and the ambient air pollution levels were analyzed.

The HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT4) model, available at http://www.arl.noaa.gov/ready/hysplit4.html, is used to calculate the forward trajectories which can be used to roughly represent the travel pathways of smoke from rice straw burning. The model is run 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. However, the rice straw burning happens at the ground level therefore the starting level of the forward trajectory calculation should correctly be assumed at 0 m level. The friction from the Earth's surface may affect the trajectory results in this case. To examine the magnitude of this effect attempts were made to run the model at different starting heights from the ground (0 m) level to 100 m above ground. The results show that the trajectory pathways calculated at the same starting time for different starting levels between 0 and 100 m. are not significantly different (Figure 2 a). The vast rice fields in the area with a full openness to the air flow would introduce a small friction from the Earth's surface hence the low starting levels might not significantly affect the resulting trajectory pathways. Thus, the starting level at the ground where the rice straw burning takes place can be used to represent the trajectory for the lower part of the planetary boundary layer. This low starting level is considered to be more suitable for the transport distance of the most interest in this study, 50-100 km, which is equivalent to the distance from

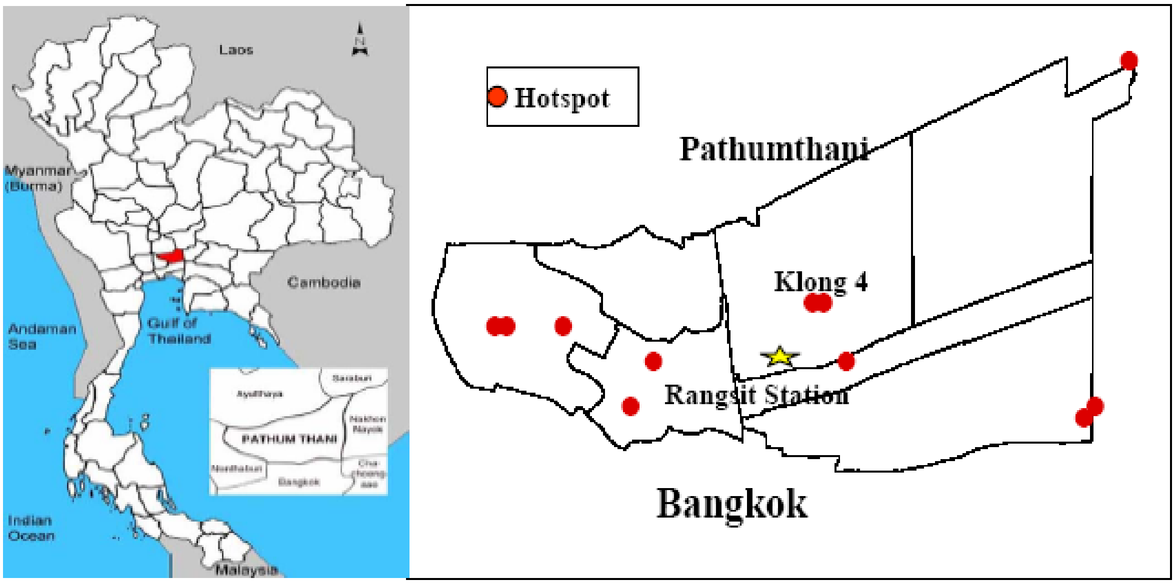

Fig1. The hotspots (circled) appear on MODIS on 17 Feb. 2004 (Source: http://maps.geog.umd.edu/) acquisition time at 1:40 pm (6:40 UTC)

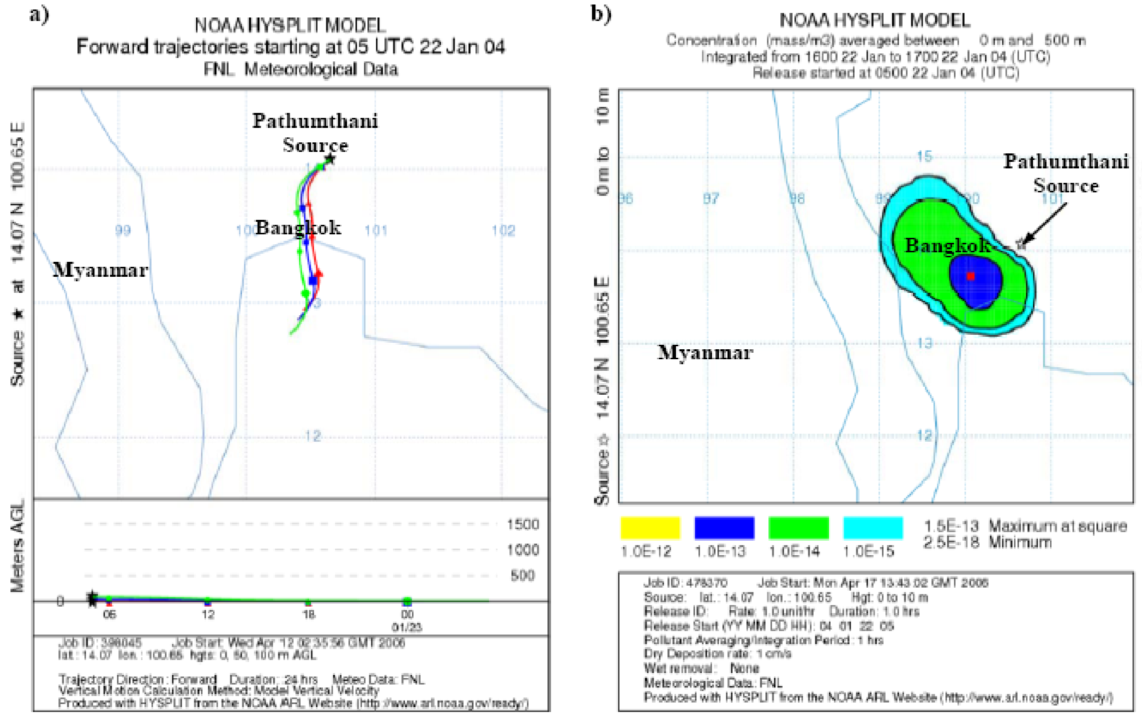

Fig 2. Transport of emission from rice straw burning on the experiment day, 22 January 2004, in Pathumthani: a) Forward trajectory at different starting levels (0, 50 and 100 m) at 12:00 am (5:00 UTC); and b) Concentration contours of the released puff after 12 hour dispersion from the region source (arbitrary unit)

Pathumthani to the Bangkok city. The starting time was selected at 12:00 am Thailand Local Standard Time taking into account that the farmers normally burn their fields during 10:00-14:00, and total run time was about 48 hours (2 days). The starting coordinates were selected at Klong 4 (14.07° latitude and 100.65° longitude), which is the centre of the Pathumthani province where more rice fields are located.

Results and Discussion

Hotspots counted and ambient air pollution

The numbers of hotspots observed over Pathumtani province during 1 year period (April 2003-April 2004) is shown in Figure 3. Higher numbers of hotspots were observed during the rice straw burning period (from November to April next year) while lower numbers of hotspots were observed during the rainy months (May

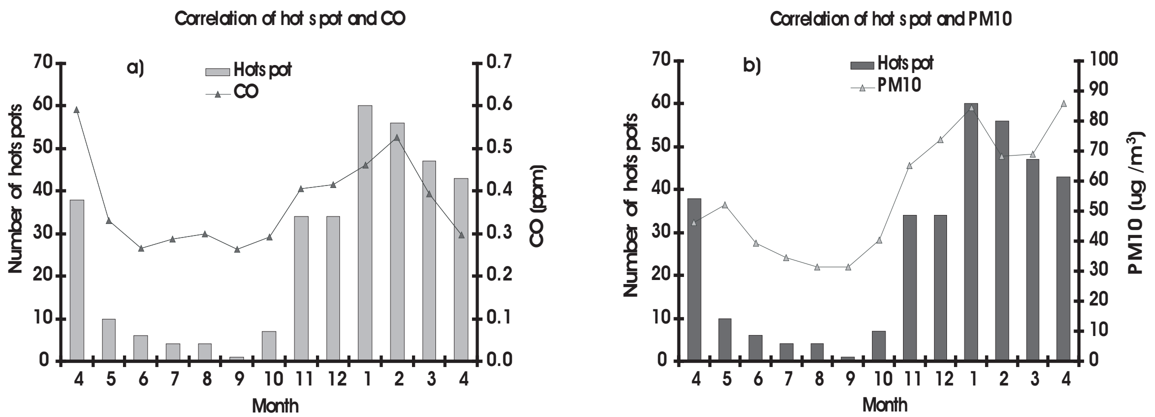

Fig 3. Correlation between hotpots and monthly average air pollutant concentrations during April 2003 – April 2004; a) CO and b) PM_{10}

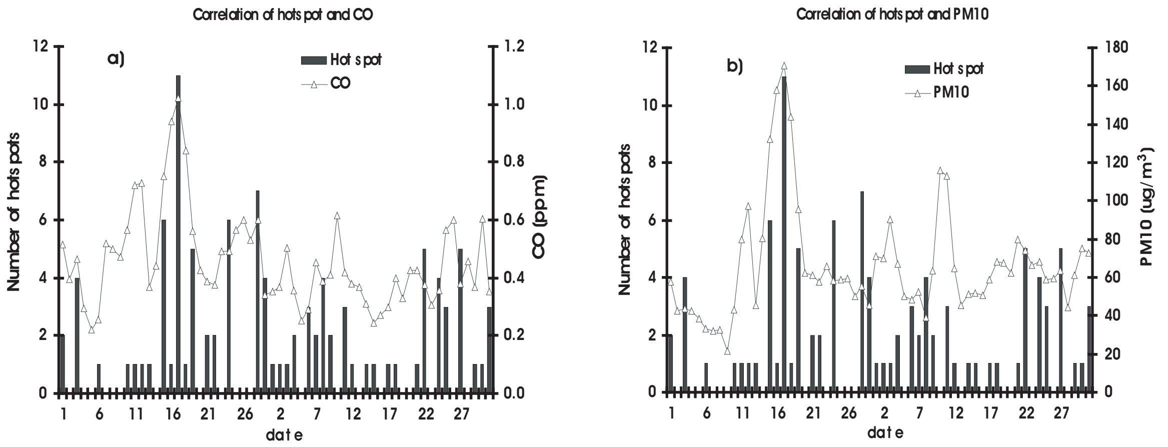

Fig 4. Correlation between hotpots and daily average air pollutant concentrations during February 1, 2004 to March 30, 2004; a) CO and b) PM_{10} (use a plot)

to October). During the burning period, the monthly average concentrations of CO and PM_{10} at the Rangsit station are much higher than those during the rainy months (Figures 3a and 3b). The plot of time series of daily hotspot number and daily average CO and PM_{10} concentrations during the intensive burning period, from February 1 to March 31, 2004 are presented in Figures 4a and 4b, respectively. The correlation plots between the monthly hotspot counts, and monthly average CO and PM_{10} concentrations are presented in Figures 5a and 5b, respectively, which show the linear relationship with R^2 of 0.56 for CO and 0.77 for PM_{10}. It is noted that the correlation between the number of hotspots and the PM_{10} concentration is better than the correlation between hotspots and CO, which is perhaps due to generally low levels of CO measured at the station (mostly less than 1 ppm). The traffic along the Paholyothin Highway, which is around 800 m to the west of the station, should contribute significantly to the measured air pollution levels. However, the emission intensity of the traffic on the road is not expected to change significantly from a day to another. The windrose constructed based on hourly wind for 1 year (Figure 6, inset) shows a low frequency of the westerly wind, i.e. less transport of the road emission directly to the station. It is considered that the highly fluctuating air pollution levels from day to day are likely caused by short term and intensive emission activities such as biomass burning.

Air pollution levels during the dry months in Bangkok are much higher than the wet months[11] which may be attributed to a number of factors. More stable atmosphere under the influence of the high pressure ridge extended from China to Southeast Asia[12], lack of intensive wet removal processes, and more intensive photochemistry [13] are some of the reasons leading to a high build-up of air pollution in BMR during the dry season. Open burning of biomass, especially the rice straw after harvesting would add more pollutants on the already high pollutant levels during the dry season.

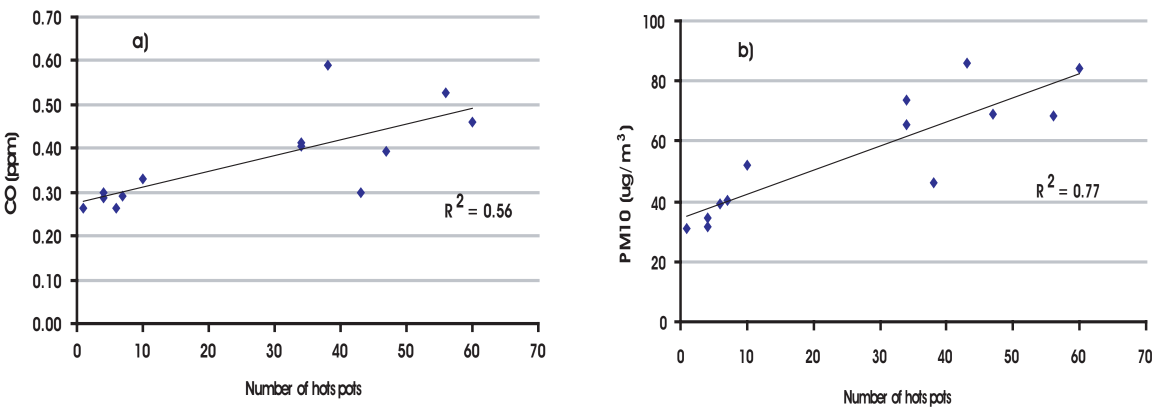

Fig 5. Correlation between monthly hotspot count and monthly average air pollutant concentrations during April 2003 – April 2004; a) CO and b) PM_{10}

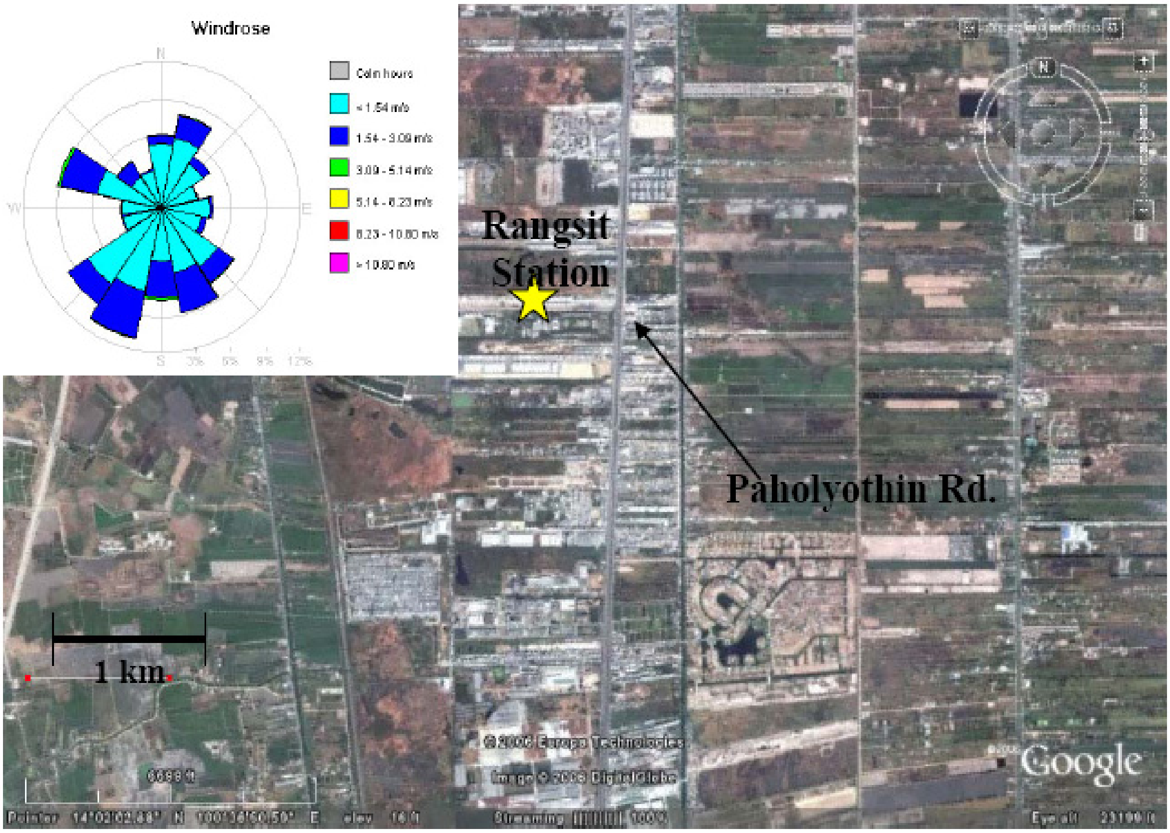

Fig 6. Yearly windrose (April 2003- April 2004) and the map showing location of the highway and the Rangsit station

The good correlations between hotspots and CO/PM_{10} concentration also suggest that open burning of rice straw during the dry season is an important emission source, leading to high air pollution levels in Pathumthani. The receptor modeling results conducted at the Asian Institute of Technology for BMR also show a substantial contribution of biomass burning (around 25-30%) to the fine particle levels (particles with aerodynamic diameters less than 2.5 ìm - $PM_{2.5}$) in the region during the dry season[14, 15, 16]. In particular, the study conducted for the particulate matter at a site in Pathumthani[15] shows that the biomass burning contributes above 35% to $PM_{2.5}$ and above 15% to the coarse particle ($PM_{10-2.5}$) mass.

Transport pathway of rice straw burning smoke

The forward trajectories produced by the HYSPLIT4 model for each day of 12 months in 2004 are presented in Figure 3. During the period when the Northeast monsoon prevails, i.e. October to December, the air masses originated from the Klong 4 rice growing area would travel toward the Bangkok city. Thus, there is high possibility that the smoke plumes from the burning rice paddies in the area would be carried toward Bangkok. The time that the air masses take to travel from the source region to the Bangkok city center is around 12 hours. In January-March the air masses trajectory directions vary but on many days of these months they also travel toward Bangkok. During the dry season, when the Northeast monsoon is prevalent[12], the intensive burning of rice paddies in Pathumthani, that are located in the upwind direction to Bangkok, would enhance the transport of emitted pollutants toward the city.

For illustration, the concentration contours from a burning emission puff produced by HYSPLIT is also presented in Figure 2b, which show the maximum concentration over Bangkok city 12 hours after release. Note that in this figure we did input an assumed emission rate in an arbitrary unit with the purpose to get the puff transport pathway only and not actual concentration levels.

For the wet season, when the burning is not intensive, the pollutants would mainly disperse toward the Northeast region following the Southwest monsoon. It is worth mentioning that even with the low trajectory staring levels the general trajectory patterns obtained for 12 months of 2004 do reflect the typical monsoon

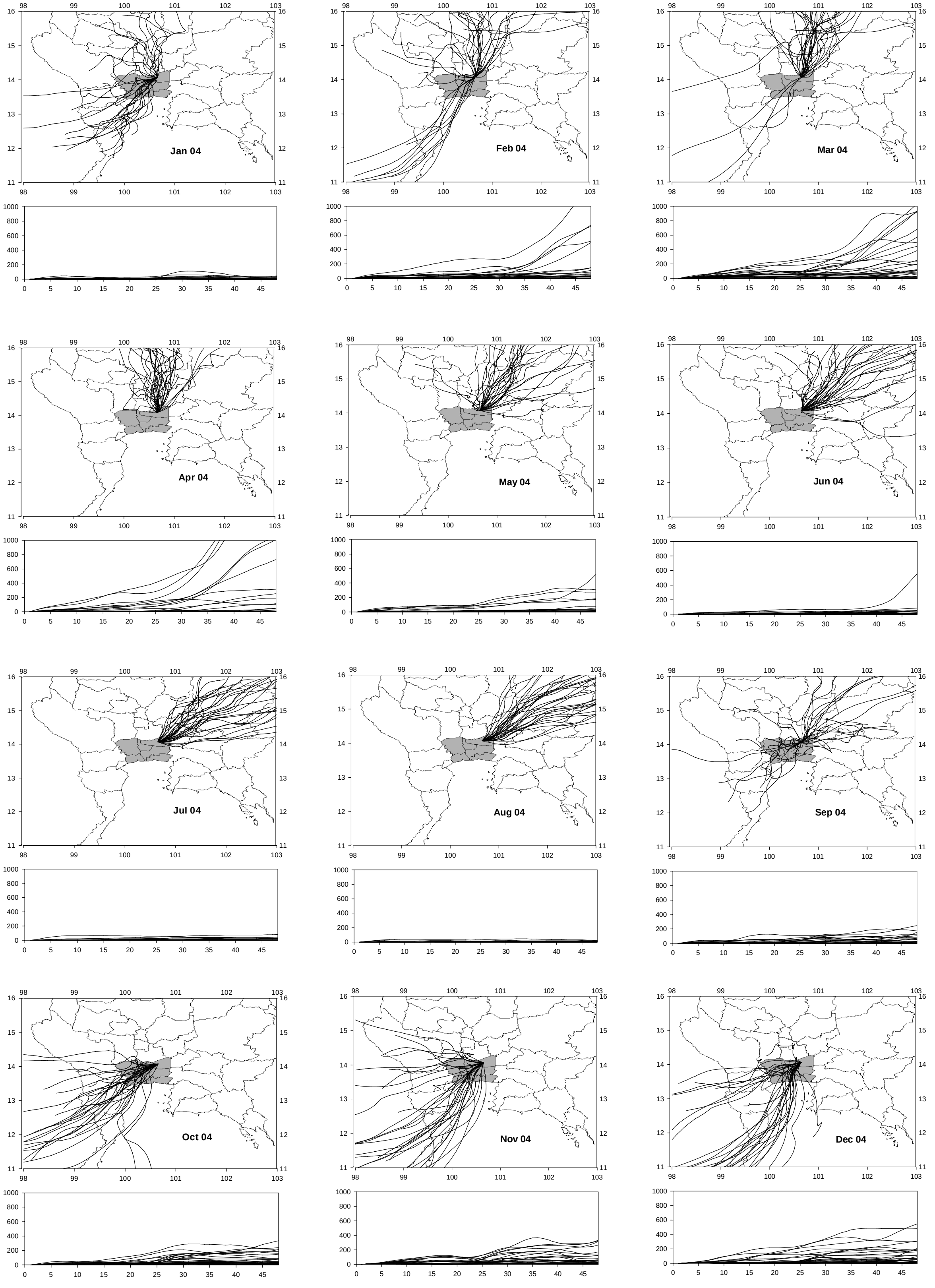

Fig 7. Forward trajectories in January – December 04

characteristics of the area (Figure7).

The correlation between air pollutants and hotspot counts as well as the HYSPLIT forward trajectories obtained in this study and also receptor modeling study[15] suggest that the smoke from rice straw burning may contribute significantly to air pollution levels in the BMR especially in Bangkok city where many intensive sources such as traffic are present.

Conclusions

During the dry season more hotspots were detected over Pathumthani which are the results of more intensive burning of rice paddy fields. Correlation between the number of hotspots and the air quality in the station near the rice field suggests that the emission from rice straw burning can affect the air quality in the area significantly. Smoke from the rice straw burning in Pathumthani is frequently transported toward Bangkok city following the Northeast monsoon during the dry season when the burning is intensive. This may contribute significantly to the already high air pollution in Bangkok in the dry season. More sophisticated dispersion models should be used with refined emission data to provide better quantitative estimates of contribution from rice straw burning to the air pollution and potential health effects in BMR. To reduce the negative impacts of rice straw burning, realistic regulations on burning should be formulated and enforced.

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