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Active fire and hotspot emissions in Peninsular Malaysia during the 2002 burning season

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Abstract

Thermal emissions from vegetation fires in Peninsular Malaysia as monitored by the National Oceanic Atmosphere Administration (NOAA) satellite during the burning season from February to March 2002 had showed that the states of Perak, Selangor and Pahang exhibited higher burning activities compared to other states. The hotspots displayed patterns of clusters that were variable temporally and spatially. Incomplete and uncontrolled vegetation burning can be a potential polluter to the surrounding atmosphere. Estimates of the emissions and dispersion of pollutants such as particulates, sulfur dioxide, nitrogen dioxide, carbon monoxide and non-methane hydrocarbons were investigated. The emission estimates showed that comparatively, carbon monoxide ranked as the highest polluter, followed by particulate matter and non-methane hydrocarbons. Estimates of the greenhouse gases showed that carbon dioxide was much higher than either the emissions of nitrous oxides or methane.

Keywords: greenhouse gases, hotspots, particulates, pollutants, thermal emissions, vegetation fires

Introduction

Biomass burning that includes deforestation, agriculture fires, wood fuel use, and natural fires being less efficient than fossil fuel combustion can cause an impact on the land cover, bio-diversity, climate change, socio-economy, air quality and human health (UNEP, 1999). Biomass burning not only contributes to emissions of some greenhouse gases and chemically active gases (UNEP, 1999) but also to changes in the atmospheric composition. As a result of continuing emissions by biomass burning in addition to fossil fuel combustion as well as industry and agriculture, complex chemistry -aerosol and an irreversible future climate feedback may take place (Scholes *et al.*, 2003).

On a regional scale, uncontrolled biomass burning from the land clearing processes can result in transboundary haze, poor visibility and degradation of the local air quality between neighbouring countries such as these in Southeast Asia. During February and March of 2002, approximately 10,906 hectares of plantations and protected forest reserve land were destroyed that included hundreds of acres of peat land in Bengkalis, on the island of Riau, Sumatra (The Jakarta Post, 2002). The lack of personnel in the local forest department and the inaccessibility of the remote areas resulted in the suppression of surface fires, while undergrowth fires were left smoldering which in turn transported much of the widespread smoke.

The air quality level, measured by the Air Pollution Index (API) consequently recorded an unhealthy level of 200-300 in the Klang Valley and Kuala Selangor over the western coast of the

Malaysian Peninsula that was partly caused by the transboundary smoke during middle of March 2002 (*Berita Harian*, 2002a). Some burning was also detected in Malaysia even though the ban on agricultural and open burning was imposed by the Malaysian Department of Environment following the haze episode (*The Star Online*, 2002). A total of 543 hectares of land was burnt in Sepang in the state of Selangor in Peninsular Malaysia during February and March of 2002 (*Berita Harian*, 2002b). Of this, approximately 400 hectares of agriculture land and the fringe of forests were burnt by smallholder farmers near Sepang and Kuala Selangor on 15th February, while over one hundred hectares of peat land burnt during the dry conditions in February (*Utusan Malaysia*, 2002).

Remote sensing studies have been confirmed as a useful tool for fire monitoring over a global or large scale region (Scholes *et al*., 2003). Various satellites were utilized such as Landsat (Lim *et al*., 2004, Koutsiast and Karteris, 2000; Patterson and Yool, 1998), DMSP (Elvidge *et al*., 1997; 2001), NOAA AVHRR (Siegert & Hoffmann, 2000; Siegert *et al*., 2001), MODIS (Roy *et al*., 1999; 2002a; 2002b), SPOT (Liew *et al*., 1998), SPOT-VGT (Ershov & Novik, 2001), and IRS-WIFS (Barbosa *et al*., 2001). The NOAA AVHRR hotspots will be utilized in this study. The polar orbiting satellite carries an array of sensors which cover the earth at a resolution of approximately 1 km. The wavelength that can detect vegetation fires is the thermal infrared band, which lies within a spectral bandwidth of 3.55 to 3.93 μm.

It is granted that the coarse resolution of the hotspot within the spatial area of 1.1 km^2 is limiting in terms of the accuracy of detecting active fires. The exact numbers of fires within the detected hot spot cannot be verified, and may inherit many false alarms; while areas of fires may be underestimated or overestimated (Chen *et al*., 2001). Nevertheless, comparison between the hotspots from of the Along Track Scanning Radiometer (ASTR) and NOAA AVHRR satellites in Kalimantan for 1997/98 showed similar spatial accuracies (Siegert *et al*., 2001). Verification with field data showed that area burnt was slightly overestimated by the NOAA AVHRR data (Siegert *et al*., 2001).

Despite these strictures, the NOAA hotspots are deemed the best data available in investigating the afternoon burning patterns for the period from February to March of 2002. The Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) that captured the early afternoon burning was not available for the period considered. The Terra MODIS satellite during mid-morning overpass was unable to detect as many hotspots as compared to the NOAA hotspots during the same period (Mahmud, 2004), as the burning practice was preferred in the afternoon.

Daily NOAA AVHRR hotspot data were acquired from the Forest Fire Prevention Monitoring Project II (FFPMPII) based in Indonesia. The project is a collaborative effort with the Department of Forestry, Indonesia and the Japan International Cooperation Agency (JICA) where daily hotspot data is disseminated from their websites.

Objective

The objective of this paper is to investigate the spatial patterns of hotspots over Peninsular Malaysia during the short dry episode in February and March of 2002 when haze was detected over the western coast of Peninsular Malaysia. The National Oceanic Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) satellite monitored the hotspots.

Emission estimates and dispersion analyses of selected pollutants were then calculated from the spatial analysis to investigate the estimates of pollutants emitted to the atmosphere during the short duration of burning. The findings may assist policy makers and managers of fires in evaluating the trends of the burning and in adopting policies that may control or manage future fires.

Methodology

Spatial analysis in the form of first-order statistics describing the general spatial distribution was initially performed to examine the correlation tendencies of the hotspots with their neighbours. Information such as the center of distribution and the spread of fires were investigated in the form of centre mean and standard distance, respectively. Spatial autocorrelation, specifically the Moran Index, was also calculated to identify any spatial independence of the active fires. It is an index of covariation between different point locations and is similar to a product moment correlation coefficient, varying from – 1 to +1 (Levine, 2002).

A second -order spatial analysis of the nearest neighbour index was next applied to determine if the spread of hotspots was clustered, dispersed or randomly distributed. Parameters analyzed in this paper include the distance statistics such as the nearest neighbour index, which is a measure of the first-order randomness. The index compares distances between the nearest points and the distances that would be expected on the basis of chance. This is a useful measure for understanding the degree of clustering.

Further filtering was carried out to identify different groups of clusters of hotspots within Peninsular Malaysia through the nearest neighbour hierarchical spatial clustering (Levine, 2002). This technique utilizes a nearest neighbour method which specifies a threshold distance and compares that to the distances of all pairs of points. A minimum of five points per cluster was selected as the cluster threshold. Then, the pairs were grouped into a second- order clusters, and the process was repeated until convergence was achieved where all the incidents fell into a single cluster. The ArcInfo software performed the above calculations automatically.

Next, the air pollutant emissions from vegetation fires were calculated from information obtained by spatial analysis. In this investigation, only selected primary regulated pollutants such as particulates (TSP, PM_{10}, $PM_{2.5}$), CO, NOx, SOx and greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), nitrous dioxide (N_2O) and carbon (C) were considered. These pollutants were chosen as they can provide information on the local air quality and can be used as a guide, particularly for sensitive groups such as children, adults with respiratory diseases, adults with cardiovascular diseases, and children and adults who are active outdoors (Godish, 2004).

Average emissions were estimated from the emission equation and emission factors (EPA, 1995) from the formula:

$$E = P\ L\ A$$

where:
E = total emissions for pollutant
P = yield for pollutant (emission factor for a particular pollutant)
L = fuel loading consumed (mass of vegetation fuel / unit land area burned) A = area burned

A dispersion analysis was also performed to predict the dispersion of pollutant plumes from the active fires. The model utilized was the Hysplit (Hybrid Single Particle Lagrangian Integrated Trajectory) model, which was a part of the Program to Assess ASEAN Regional Transboundary Smoke (PARTS) programme. It computes air trajectories and dispersion of pollutants (Elvidge *et al*., 2002). Concentrations of pollutants were calculated based on the dispersion rate of vertical diffusivity, wind shear and horizontal deformation of the wind field (Draxler, 1999). The backward trajectory of a particle advected during the simulation was integrated in order to trace the origin of the particle from the source location.

Results

a. Spatial burn pattern of the hotspots detected by the NOAA satellite

The hotspots detected in Peninsular Malaysia for a total of 19 days were subjected to a simple spatial analysis to study the spread of the hotspots from a central mean. In total, 2,037 hotspots were detected throughout the period investigated. Spatial analysis displayed that the patterns of burn were clustered. Much of the burning in March was concentrated over the eastern -central region of Pahang, whilst the burning activities during February occurred over northwestern and northeastern peninsula.

The breakdown of burn activity according to the different states during the two months is shown in Figure 1. The state of Pahang displayed 601 hotspots, followed by Johor at 365 and Kedah at 235. Terengganu, Negeri Sembilan and Selangor also displayed a substantial number of hotspots. The fires in Selangor received media coverage due to their proximity to the capital of the country, but it was apparent that agricultural waste burning was prominent particularly over the northern states such as in Kedah. The burning of the peat in Pahang emerged as near continuous throughout the two months, with a prominence in March 2002.

Table 1 shows that the mean central locations were influenced by the extreme locations of hotspots located in the northern or southern - most tip of the peninsula. The average standard distance of 173 km in February was larger compared to that in March at 103 km. Nearly half of the eight events in February displayed standard distances of more than 200 km. The rest of the other events displayed standard distances of more than 100 km, implying a more clustered concentration of hotspots.

Table 1. The spatial centrographic statistics for the NOAA hotspots

Date	Centre mean		State	Standard distance (m)	Number of hotspots
	Longitude ^{0}E	Latitude ^{0}N			
01 Feb 02	102.13	3.82	Pahang	201.70	86
04 Feb 02	101.02	5.44	Perak	172.99	118
07 Feb 02	102.36	4.38	Pahang	182.21	69
08 Feb 02	101.43	4.89	Perak	200.16	70
15 Feb 02	101.58	4.20	Pahang	181.18	120
18 Feb 02	101.34	5.12	Perak	209.43	20
25 Feb 02	100.53	5.97	Kedah	75.89	38
26 Feb 02	100.66	5.73	Kedah	163.26	20
04 Mar 02	102.95	3.21	Pahang	106.94	110
05 Mar 02	102.51	3.97	Pahang	171.05	59
06 Mar 02	101.09	5.01	Perak	113.26	125
07 Mar 02	102.33	4.35	Pahang	199.97	133
08 Mar 02	103.57	2.41	Johor	117.73	237
11 Mar 02	102.70	3.02	Pahang	134.23	188
12 Mar 02	103.00	4.02	Pahang	148.01	433
13 Mar 02	102.87	3.45	Pahang	77.22	96
14 Mar 02	103.28	3.54	Pahang	27.08	25
15 Mar 02	103.19	3.51	Pahang	45.50	25
19 Mar 02	102.60	2.65	N.Sembilan	40.17	65

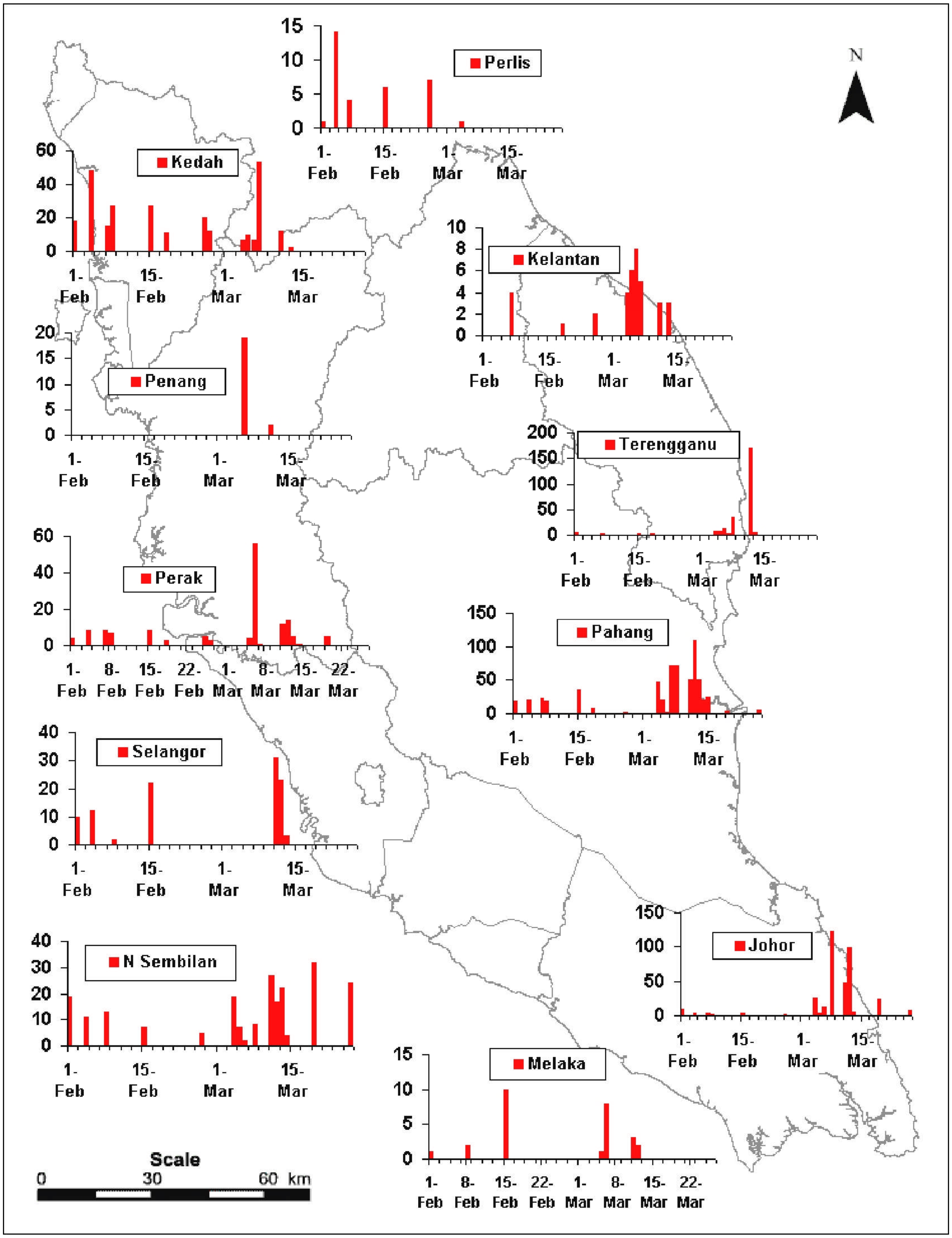


Figure 1. *The total number of hotspots over the peninsula according to the different states. The period of maximum burning was concentrated from 4 March to 15 March*

The mean number of neighbours within a specified distance was utilized for the purpose of clarifying non-randomness or clustering of points in relation to each other. The random distance shown in Table 2 is the mean distance of a hotspot from its nearest neighbour in a random distribution. The random distances for the 19 case studies ranged from the low value of 8.72 km on 12 March when a maximum of 433 hotspots was detected mostly over the states of Pahang, Selangor, Johor and Terengganu. Larger random distances as such over 40 km were exhibited when the hotspot density was low over the peninsula. As the random distances were all above the value of 1, the burning patterns for all the days examined showed a tendency of clustering. The nearest neighbour index and Moran index in Table 2 show that all of the distributions of hotspots displayed the tendency of clustering.

An index of dissimilarity which is a measure of relative change of concentration was performed to measure the difference between the daily consecutive paired of percentages of hotspot distributions. Only consecutive data were utilized to investigate the change in daily burning distributions. The results in Table 3 showed that the dissimilarity indices for the consecutive days investigated were fairly moderate over the states in Peninsular Malaysia, ranging from values of 30 to 50. This implied that the patterns of distribution were approximately 30 to 50% different over the various states from the previous day. The highest dissimilarity of 88% occurred from the 6^{th} to 7^{th} March. The hotpots on 7^{th} March were concentrated over the northwestern, central and eastern coast in the states of Kedah, Kelantan and Pahang, but none over the southern or southwestern part of the peninsula. This dissimilarity was particularly evident in the states of Johor, Melaka, Negeri Sembilan, Terengganu, and Penang.

Table 2. The spatial centrographic and second order analysis of the NOAA hotspots

Date	Standard distance (m)	Mean nearest neighbour distance (km)	Nearest neighbour index	Moran index	Distribution
01 Feb 02	201.70	6.08	0.31	0.51	cluster
04 Feb 02	172.99	6.79	0.41	0.66	cluster
07 Feb 02	182.21	8.86	0.38	0.98	cluster
08 Feb 02	200.16	5.93	0.27	0.60	cluster
15 Feb 02	181.18	4.28	0.26	0.51	cluster
18 Feb 02	209.43	13.03	0.36	0.35	cluster
25 Feb 02	75.89	7.09	0.24	0.75	cluster
26 Feb 02	163.26	3.83	0.09	0.81	cluster
04 Mar 02	106.94	6.16	0.36	0.63	cluster
05 Mar 02	171.05	6.86	0.29	0.86	cluster
06 Mar 02	113.26	5.73	0.28	0.61	cluster
07 Mar 02	199.97	3.57	0.23	0.48	cluster
08 Mar 02	117.73	2.25	0.22	0.73	cluster
11 Mar 02	134.23	5.03	0.38	0.63	cluster
12 Mar 02	148.01	2.01	0.23	0.71	cluster
13 Mar 02	77.22	4.78	0.26	0.63	cluster
14 Mar 02	27.08	7.57	0.21	0.50	cluster
15 Mar 02	45.50	7.57	0.21	Indeterminate	cluster
19 Mar 02	40.17	7.19	0.32	0.48	cluster

Table 3. The dissimilarity indices on selected days of the NOAA hotspots

Dates	Dissimilarity Index	States
7-8 Feb	37.86	Johor, Kelantan, Pahang, Perak,Terengganu, Perlis
25-26 Feb	40.00	Johor, Kelantan, Pahang, Perlis
4-5 Mar	34.21	Johor, Kedah, Pahang, Perlis
5-6 Mar	32.79	Johor, Negeri Sembilan, Pahang, Perak
6-7 Mar	87.58	Johor, Kelantan, Melaka, Negeri Sembilan, Perak, Terengganu, Penang
7-8 Mar	68.12	Kedah, Kelantan, Pahang, Perak
11-12 Mar	38.96	Johor, Kedah, Kelantan, Melaka, Negeri Sembilan, Pahang, Perak, Selangor, Penang
12-13 Mar	54.36	Johor, Melaka, Selangor, Terengganu
13-14 Mar	26.88	Johor, Kedah, Kelantan, Negeri Sembilan, Pahang, Selangor, Terengganu
14-15 Mar	20.00	Negeri Sembilan, Perak

b. Emission estimates

Emission estimates from vegetation fires occurring during February and March of 2002 over the Malaysian peninsula were calculated based on the various vegetation types. Fuel loading was estimated for different tropical vegetation types that include emissions due to burning from agriculture, forest and peat land. The emission factor for a given compound is defined as the amount of the compound released per amount of fuel consumed (Scholes *et al*., 1996) and from published information (Levine *et al*., 1996).

Open burning is allowed in Malaysia under the order of the Environmental Quality (Prescribed Activities) (Open Burning) Order 2000. Under the Environmental Quality Act and Regularities (EQA, 2002), limitations on the burning of various agriculture products are stipulated for sugar cane, pineapple stumps, paddy stalks or burning of plants from land clearing activities for replanting or planting.

Table 4 shows the estimated emission of pollutants detected from satellites for the different states in Peninsular Malaysia from February to March 2002. The largest area burnt in Pahang emitted the highest amount of pollutants, followed by the Johor state. The total emission of 335 tons $PM_{2.5}$ throughout the two months from the various states in the peninsula is of concern as these small particulates do enter the human respiratory system and may affect the health of the population, particularly within the states that were conducting the burning activities. A total of 313 tons of total particulates was estimated during the burning season. A high amount of 3,905 tons of gaseous carbon monoxide was released into the atmosphere. Oxides of nitrogen (NOx) and sulphur were also emitted, though at relatively lower amount than carbon monoxide or hydrocarbons. This low number was due to the relatively low content of sulphur and nitrogen (N_2) in the biomass. The release of NOx and N_2 was related to fuel composition and combustion types that mainly occur during flaming combustion (Scholes *et al*., 2003).

Emissions of greenhouse gases such as carbon dioxide, nitrous oxide and methane from agricultural waste burning and clearance of tropical forests were also estimated for this exercise. The calculated emissions of tropospheric ozone gases such as carbon monoxide, nitrogen oxides and nonmethane hydrocarbons are tabulated in Table 5. Other species emitted by tropical vegetation that include acetylene, ethane, ethane, propyne, propene, propane, isobutenes, tetrahydrofuran, benzofuran, methyl chloride (CH_3Cl), methyl bromide (CH_3Br) and methyl iodide (Scholes *et al*., 2003) are not evaluated here for these gases and aerosols exhibit the risk of large scale burning of vegetation that may harm the health of people in the neighbouring countries and pollute the atmosphere of the region through the transboundary haze.

Table 4. The estimated emission of pollutants detected from satellites from February to March 2002

States	Particulate (tons)	Carbon monoxide (tons)	Non-methane hydrocarbons (tons)	Nitrogen oxides (tons)	Sulphur dioxides (tons)	PM (<2.5 μm) (tons)
Johor	55.2	688.7	54.6	9.7	3.7	59.1
Kedah	40.7	507.5	40.2	7.2	2.7	43.6
Kelantan	5.4	67.9	5.4	1.0	0.4	5.8
Melaka	4.1	50.9	4.0	0.7	0.3	4.4
N Sembilan	32.8	409.4	32.4	5.8	2.2	35.1
Pahang	90.9	1134.0	89.9	16.0	6.1	97.3
Perak	21.8	271.7	21.5	3.8	1.5	23.3
Selangor	15.6	194.3	15.4	2.8	1.0	16.7
Terengganu	38.4	479.2	38.0	6.8	2.6	41.1
Perlis	5.0	62.3	4.9	0.9	0.3	5.3
Penang	3.2	39.6	3.1	0.6	0.2	3.4
Total	313.2	3905.7	309.5	55.3	21.0	335.3
%	6.8	84.8	6.7	1.2	0.46	

The total estimated amount of carbon dioxide of 58216 tons from this country alone, alongside the higher amount released from the burning activities in Sumatra and Kalimantan during the same period, may cause a local climatic impact that is not assessed in this paper. Carbon dioxide was one of the major pollutants released during burning, representing 84% of the selected major pollutants. This was followed by particulates and nonmethane hydrocarbons. Emissions of nitrogen dioxide and sulphur dioxide were lower than carbon monoxide or particulates, representing only 1.2% and 0.5%, respectively.

Table 5. The estimated greenhouse gases and carbon during February to March 2002

States	CO_2 (tons)	CH_4 (tons)	N_2O (tons)	C from CO_2 (tons)	C from CO (tons)
Johor	10265.3	44.8	4.6	33423.7	160.7
Kedah	7565.4	33.0	3.4	24632.8	118.4
Kelantan	1012.5	4.4	0.5	3296.6	15.8
Melaka	759.3	3.3	0.3	2472.4	11.9
N Sembilan	6102.9	26.7	2.7	19871.1	95.5
Pahang	16902.5	73.8	7.5	55034.6	264.6
Perak	4049.9	17.7	1.8	13186.3	63.4
Selangor	2896.8	12.7	1.3	9431.9	45.3
Terengganu	7143.5	31.2	3.2	23259.2	111.8
Perlis	928.1	4.1	0.4	3021.9	14.5
Penang	590.6	2.6	0.3	1923.0	9.2
Total	58216.7	254.2	25.9	189553.5	911.3

The above results illustrate that biomass burning released pollutants which tantamount to the degradation of the local air quality and increase of greenhouse gases. One of the mitigating measures of reducing these pollutants and greenhouse gases is to ban open burning for agricultural purposes or solid wastes. This can act as a control strategy which reduces emissions into to the atmosphere and enhances the quality of the ambient air.

The health impacts of some of the regulated air pollutants are well known. For example, the primary health concerns of CO exposure pertain to its effects on the cardiovascular system and neurobehaviour. Other symptoms include headache, dizziness, irritability and malaise in children and adults (Godish, 2004). CO oxidation in the troposphere is an important source of ozone.

Oxidation products produced in nonmethane hydrocarbon sink processes serve as major reactants in the production of photochemical smog and tropospheric levels of ozone (Godish, 2004). Particulate matter can cause toxic effects when exposed to humans, may reduce visibility, and may also potentially cause local, regional and global climate change due to the scattering effect of light (Godish, 2004).

c. Dispersion analysis

Dispersion analysis was performed to analyze the impact of the air quality due to the burning over the peninsula. Many different species of pollutants are produced when tropical forests and agriculture residue are burned. The species of pollutants analyzed in this study were limited to pollutants such as carbon monoxide, nonmethane hydrocarbons, nitrogen oxides, sulphur dioxide, particulate matter of size 2.5 micrometer ($PM_{2.5}$) and total particulate matter (TPM). These pollutants were selected as they have been identified as potentially unfavorable to human health and the environment.

The forward trajectory analysis from the burnt clusters showed advections of pollutants from the burning areas in the Malaysian peninsula to Sumatra in the time frame of 48 hours from the release of the pollutants brought by the prevailing northeasterlies during this period. For most of the days investigated in February and March 2002, the trajectories displayed a more southwestward flow to the south of 5^0N. On three occasions, it was found that the wind flow to the north of 5^0N had a more easterly flow; where pollutants from the northern peninsula were carried over to the South Indian Ocean rather than directly towards Sumatra. The polluted sources were advected at the low level of less than 950 hPa (Figure 2).

Several dispersion runs were conducted in March 2002 to investigate the patterns of dispersed pollutants that originated from the fire clusters in the Malaysian peninsula. The simulation illustrated those individual clusters of puffs from the sources combined into a single larger puff after 48 hours. Some of the results of the concentrations of pollutants from the dispersion analysis that began on 6^{th} March are summarized in Figure 3. Comparatively, CO revealed the highest magnitudes of pollutants, followed by particulates, $PM_{2.5}$, NOx and SOx for the three consecutive days of the 6^{th} to 8^{th} March. Dispersion was performed for a duration of 2 days from the start of the source emission.

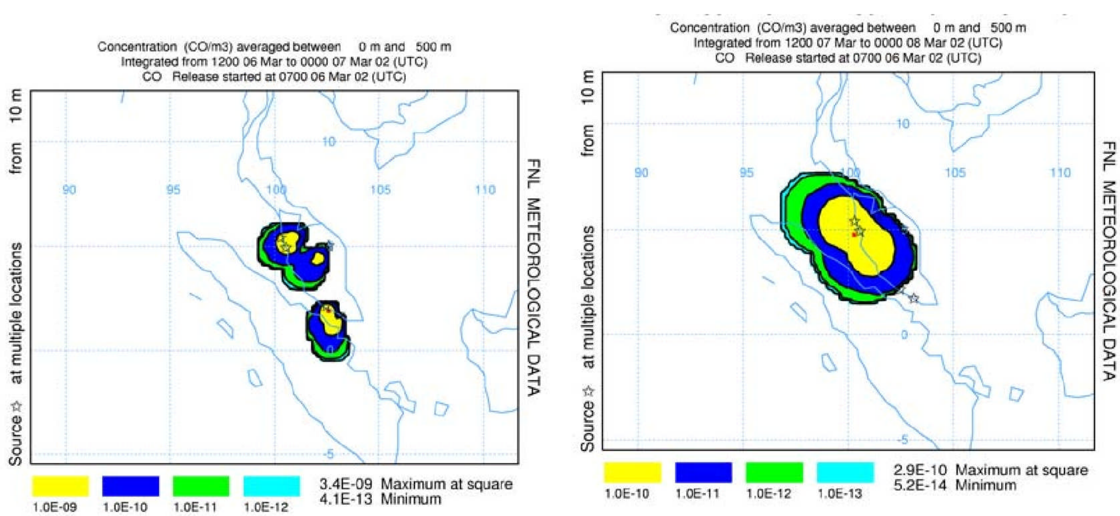
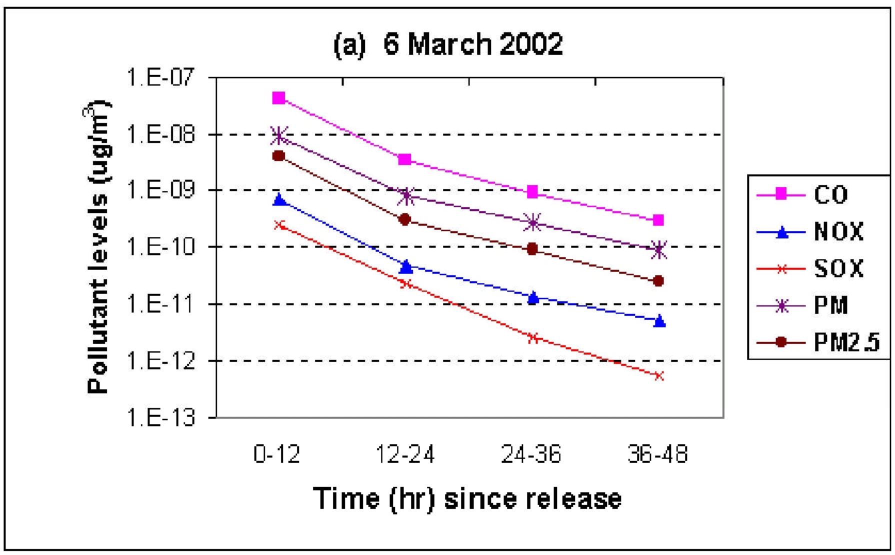
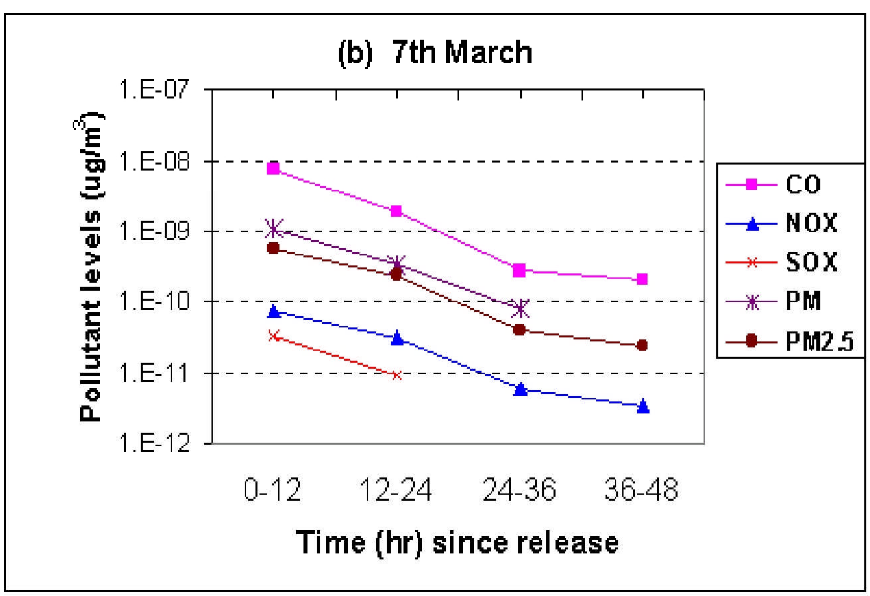


Figure 2. *The dispersion analysis showing the merging of several puffs after a period of 48 hours from integration*

Simulation of dispersion of pollutants from the Malaysian peninsula which began on 11th March 2002 showed that the smoke parcel had pooled and advected towards Sumatra by the end of the two days. Basically, the shapes of the clouds of pollutants were similar for each individual pollutant. The plume predicted was chosen for a depth of 500m from the surface. Smoke plumes within 24 hours were generally local phenomena when the plumes were confined near the locations of burning over the Malaysian Peninsula. This is due to the weak strength of the low level prevailing winds. Within 48 hours, the diluted and dispersed plumes were generally found over Sumatra. The resulting concentrations do not represent the actual condition as only the incremental predictions were calculated, and no new input on the subsequent day was generated during the interval of 24 to 48 hours. Realistically, the above prediction did not characterize the real situation due to the exclusion of the cumulative effect of the additional loading of the fresh burning on the successive day. Nevertheless, as a preliminary exercise, the calculation of the predicted concentrations of pollutants offered a fair representation of individual burning activities of a single day.





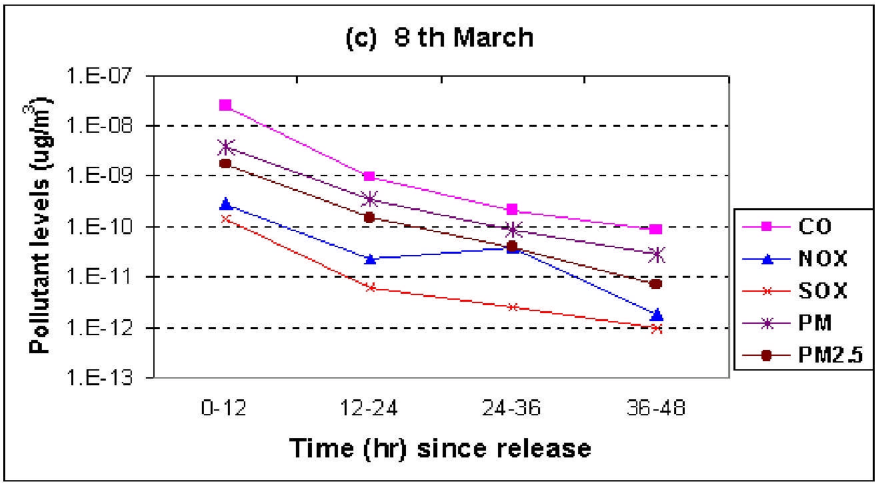


Figure 3. *The concentrations of the maximum levels of the pollutants within a puff for three simulations from (a) 6th (b) 7th and (c) 8th March 2002. Generally, the maximum levels of pollutants decreased gradually with time for all the pollutants investigated. The pollutants generally declined by a factor of 3 by the end of the 48 hours*

The study has highlighted the magnitude of the estimated emissions to the atmosphere over the Malaysian airspace from the burning activities through the dispersion and trajectory analyses. The overall impact from the burning in Indonesia was not included in this study but its effect is larger due to the cumulative loading of pollutants released to the atmosphere. Uncontrolled burning may be one of the causes of long-term damage to the climate. As signalled by the World Meteorological Organization (*UK Independent*, 2003), global warning and extreme weather conditions are fast becoming a reality.

Conclusion

The spatial distributions of active fires displayed a tendency of clustering of burning patterns which coincide with the paddy and sugarcane vegetation burning, particularly over the states of Perlis, Kedah and Pahang during early February as in contrast to March. The day-to-day burning patterns in several case studies featured a moderate index of dissimilarity, ranging from 30 to 50% for most of the cases.

One of the factors hampering continuous monitoring over our equatorial region is the presence of clouds. The NOAA satellite only obtained partial coverage of the peninsula for ten days within February and March 2002. Other uncertainties include the errors associated with the locations of fires. The estimated pollutants emitted vary during different combustion stages. Emissions of gases such as CO and CH_4 are higher in the smouldering stages compared to the earlier, flaring stage (Scholes *et al*., 1996). Errors may also be found in the fuel loading consumed, emission factors and yield for pollutant. However, despite these strictures, this estimate does give an indication of the quantity of pollutants released.

This study has shown the estimation of pollutants released to the atmosphere due to vegetation burning in Peninsular Malaysia alone. Biomass burning is a significant source of greenhouse gas such as methane, carbon dioxide and nitrous oxide. Ozone precursors such as nonmethane hydrocarbons and nitrogen dioxides are important in atmospheric chemistry and affect the radiative characteristics of the atmosphere. These aerosols also exert their own impact on the climate by scattering and absorbing solar radiation and changing the properties of clouds (Scholes *et al*., 2003).

This paper has considered the total emissions of methane, CO, CO_2, NOx and particulate matters from biomass burning that includes forest fires and agriculture waste burning. Further efforts are needed to refine or validate both the hotspots and emissions from the data. This would be useful as inputs to atmospheric and regional climate models requiring estimates of gases requiring and particulates (Scholes *at al*., 1996).

Projections of air pollution in Asia are expected to increase in the next twenty to fifty years if current development trends continue. Rapid urbanization, with associated growth in industry and transportation and changes in the land cover and land use activities are some of the causes of the increase in emissions into the atmosphere. Transboundary haze from biomass burning during the dry months and the Asian brown haze phenomenon are some of the current problems that have existed over the region (Lelieveld *et al*., 2001). Thus, regional intergovernmental cooperation is imperative to control the emissions of pollutants. For obvious reasons, Asian countries must take the initiative to prove that they can manage the situation better at regional and sub-regional levels than their European and North American counterparts.

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