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GREENHOUSE GAS EMISSIONS FROM A LAND USE CHANGE ACTIVITY DURING A HAZE EPISODE IN SOUTHEAST ASIA

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ABSTRACT

Carbon dioxide is by far the dominant greenhouse gas released from biomass burning activities for agricultural purposes, which can lead to a global warming potential if emissions to the atmosphere were left uncontrolled. The emissions of greenhouse gases from Sumatera, Indonesia during a major haze episode that occurred in August 2005 were investigated. The highest rate of burning occurred mainly in the province of Riau during the first two weeks of August. Total greenhouse gases emitted were estimated from the active fire counts derived from the NOAA satellite. During the haze episode that hit the western coast of Peninsular Malaysia, much green house gases such as carbon dioxide, carbon monoxide, nitrous oxide and methane were emitted to the atmosphere. The dispersion patterns of one the greenhouse gases during the height of the haze episode showed the path of transportation of the gas and the locations affected within the vicinity of the sources. The emission and transportation of the greenhouse gases, mainly carbon monoxide, from the biomass burnt in Sumatera also increased the local concentration in Peninsular Malaysia.

Keywords: greenhouse gases, Southeast Asia, biomass burning, land use, global warming

ABSTRAK

PENGELUARAN GAS RUMAH HIJAU DARIPADA AKTIVITI GUNA TANAH SEWAKTU PERISTIWA JEREBU DI ASIA TENGGARA

Gas karbon dioksida merupakan gas rumah hijau yang paling banyak dikeluarkan daripada pembakaran biomas yang disebabkan oleh aktiviti manusia saperti pembersihan tanah untuk tujuan pertanian. Gas ini boleh membawa kepada potensi pemanasan global jika pengeluarannya ke atmosfera tidak dikawal. Makalah ini bertumpu kepada pengeluaran gas rumah hijau yang berpunca dari Sumatera, Indonesia sewaktu satu peristiwa jerebu yang berlaku pada bulan Ogos 2005. Kadar pembakaran biomas berlaku sepanjang awal dua minggu bulan Ogos, terutama di provinsi Riau. Jumlah gas rumah hijau dianggarkan daripada jumlah titik panas yang dicerap daripada satelit NOAA. Sewaktu peristiwa jerebu melanda bahagian pantai barat Semenanjung Malaysia, kebanyakan gas rumah hijau saperti karbon dioksida, karbon monoksida, nitrous oksida dan metana dilepaskan ke atmosfera. Pola penyerakan gas rumah hijau sewaktu peristiwa jerebu menunjukkan bagaimana pengangkutan gas dan lokasi yang terjejas berhampiran sumber bahan pencemar. Pengeluaran dan pengangkutan gas rumah hijau, terutama karbon monoksida, daripada biomas yang terbakar di Sumatera telah meningkatkan kepekatan tempatan di Semenanjung Malaysia.

Kata kunci: gas rumah hijau, Asia Tenggara, pembakaran biomas, guna tanah pemanasan global

INTRODUCTION

Biomass burning of forests and excesses from agricultural land, undoubtedly one of the easiest and cheapest methods of eliminating biomass wastes, contributes to emissions of greenhouse gases (GHG) and chemically active gases that consequently changes the local atmospheric composition (Levine et al. 1999). Emissions of GHG from land-use land use change and forestry (LULUCF) effects (such as deforestation) are on the rise, particularly in some developing countries. This poses a difficult approach in addressing the climate change issue in terms of limiting the GHG emissions to the specified baseline emissions for the United Nations Framework Convention on Climate Change, UNFCCC (Parker & Blodgett 2005). Continuous GHG and unlimited emissions from fossil fuel combustion, industry and agriculture, and complex chemistry-aerosol processes can eventually cause a possible irreversible future climate feedback if left unchecked (Scholes et al. 2002). GHG emitted into the atmosphere during the burning season can perturb the local atmospheric concentration from its equilibrium state, where the overall effect of this periodic perturbation may be sensitive to regional climate change due to the lengthy residence time of carbon dioxide (CO_2) in the climate system of the order of a century compared to the non-CO_2 GHG such as methane and nitrous oxide that are easily destroyed by processes such as oxidation, decomposition or deposition.

In Southeast Asia, uncontrolled burning from large-scale land clearing processes produce transboundary haze, poor visibility and degrade the local air quality between neighbouring countries particularly during the burning season from June to October. The 1997 haze from the forest fires in Indonesia was one of the notable events that caught the world's attention due to its magnitude and its coincidence with the dry major El Nino event (Sari et al. 2007).

Indonesia is rated as the world's top three GHG emitters from land use change effects, significantly from the release of carbon dioxide from deforestation (Sari et al. 2007). Deforestation and land conversion are the largest sources of emissions of the GHG, with forest fires accounting for 57% of the contribution. Indonesia has maintained its position as one of the top twenty emitters of greenhouse gases from land-use, land use change and forestry since 2000 (Parker & Blodgett 2005). This is due to the very large stock of carbon stored in the vegetation and soil that amount to approximately 24 billion tons (Ministry of Environment 2004), and where deforestation accounts for 85% of the annual emissions of GHG in Indonesia (Sari et al. 2007).

One of the consequences of the vegetation burning activities in Sumatera, Indonesia was a major haze event that occurred in Peninsular Malaysia during August 2005. On 11 August 2005, a haze emergency was declared in the districts of Port Klang and Kuala Selangor in the state of Selangor after the Malaysian Air Pollutant Index (MAPI) reached dangerous levels (The New Straits Times 2005). Fortunately, the haze emergency was removed on 13 August when the MAPI dropped to an acceptable level due to the favorable atmospheric wind conditions compared to the previous days.

This study will quantify the emissions of the GHG emitted to the atmosphere as a result of large-scale burning from the island of Sumatera, Indonesia. The local GHG in the state of Selangor, the nearest neighbour to Sumatera are also explored. The mode of transportation of the GHG from the land use change activity was investigated through dispersion analysis.

METHODS AND MATERIALS

Pyrogenic emissions of GHG are estimated based on parameters such as the area burned, fuel load, completeness of combustion, and emission factors. Emissions are calculated from the equation by Seiler & Crutzen (1980):

$$E_x = \sum_{i,j} A_i F_{i,j} CC_{i,j} (EF_x)_{i,j}$$

where E_x = total pyrogenic emissions for pollutant x (g); $A_{i,j}$ = burned area (km^2); $F_{i,j}$ = fuel load ($kg\ km^{-2}$); $CC_{i,j}$ = completeness of combustion; $(EF_x)_{i,j}$ = emission factor for compound x ($g\ kg^{-1}$); i,j = spatial coordinates; and x = compound for which emissions are estimated (Korontzi et al. 2003).

The areas burned were approximated from the active fire counts obtained from the National Oceanic Atmospheric Administration (NOAA) Advanced Very High Radiation Radiometer (AVHRR) data. However, the accuracy of the area of an active fire count is limited by the coarse resolution within the spatial area of 1.1 km^2. Nevertheless, similar spatial accuracies were found between the hotspots from the Along Track Scanning Radiometer (ASTR) and NOAA AVHRR satellites in Kalimantan for 1997/98 with only a slight overestimation from the NOAA data (Siegert et al. 2001).

Another limitation of the number of hotspots derived from satellites is the uncertainty due to cloud cover. Apart from that, the timing and spatial extent of burning cannot be estimated reliably as the satellite may not overpass when burning occurs (Justice et al. 1993; 2002; Robinson 1991).

Emissions of major GHG in Sumatera were computed independently from different vegetation types that include peat land, paddy fields, forest vegetation and grassland. Different emission factors and combustion completeness estimates were utilized for the different vegetation types (Christian et al. 2003). An exercise was also performed to investigate if the local air quality at a station in Gombak, Selangor on the western coast of Peninsular Malaysia was affected by the transboundary haze.

A dispersion analysis was also performed for a selected day as a case study to illustrate one of the means of transportation of a selected GHG, carbon dioxide, into the atmosphere. The model utilized was the Hysplit (Hybrid Single particle Lagrangian Integrated Trajectory) model, which was a part of the Program to Access ASEAN Regional Transboundary Smoke (PARTS) programme (Elvidge et al. 2002). Hysplit computes air trajectories and dispersion of pollutants based on the dispersion rate of vertical diffusivity, wind shear and horizontal deformation of the wind field (Draxler 1998).

RESULTS

a. Types of Vegetation Burned

The spatial distribution of active fire counts during August in Sumatera is shown in Figure 1, which revealed that most of the vegetation fires occurred in Riau, followed by Sumatera Utara and Sumatera Selatan. The highest number of hotspots (1540) was identified in the peat areas of Riau, followed by Sumatera Utara (277) and Sumatera Selatan (194), respectively. Burning was also identified in the paddy fields, particularly in Riau, where 915 hotspots were detected (Figure 2). This study showed that 65% of the land burned in Riau originated from a combination of vegetation such as peat forest, paddy fields, and the evergreen forests. The next highest burning activities were found in Sumatera Utara (16%), followed by Sumatera Selatan (10%).

The rate of burning also differed from week to week. More than 500 hotspots were detected in the peat land areas in Riau, followed by the paddy field areas (471 hotspots), and forest areas (310 hotspots), which included the evergreen and degraded forests during the first week of August (Figure 3). Twenty nine percent of active fires were detected in the peat land areas, compared to 28% that occurred in the paddy fields, mainly in the provinces of Riau, Sumatera Utara, and Sumatera Selatan.

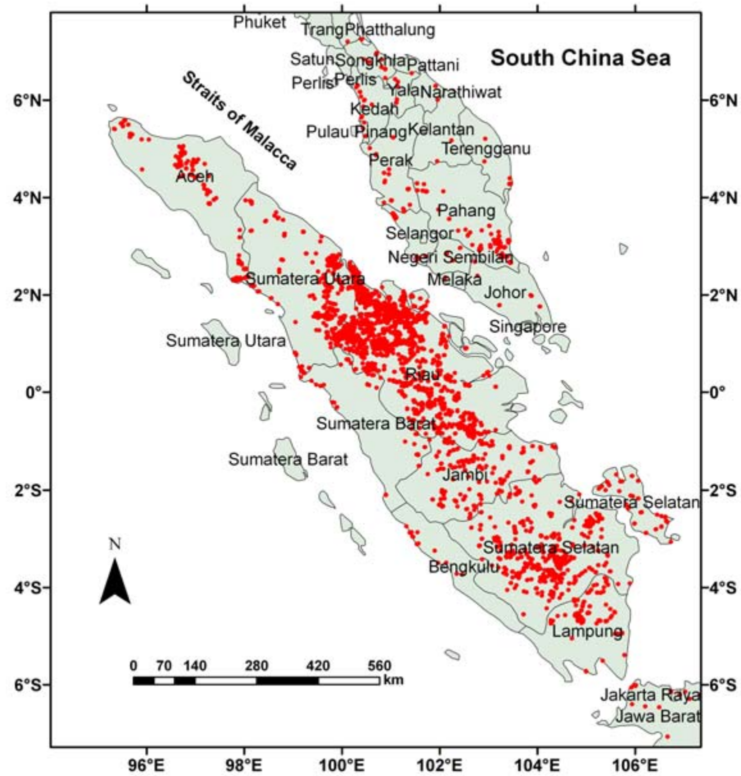

Figure 1. Distribution of the active fire counts in Sumatera during August 2005

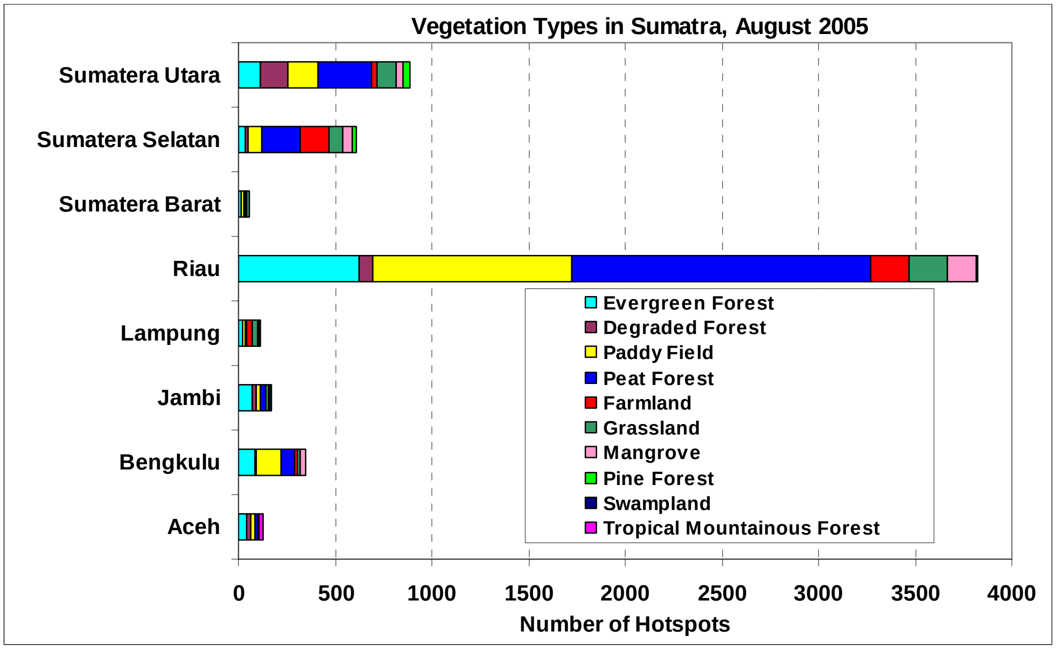

Figure 2. The total active fire counts on the types of vegetation during August 2005 in Sumatera.

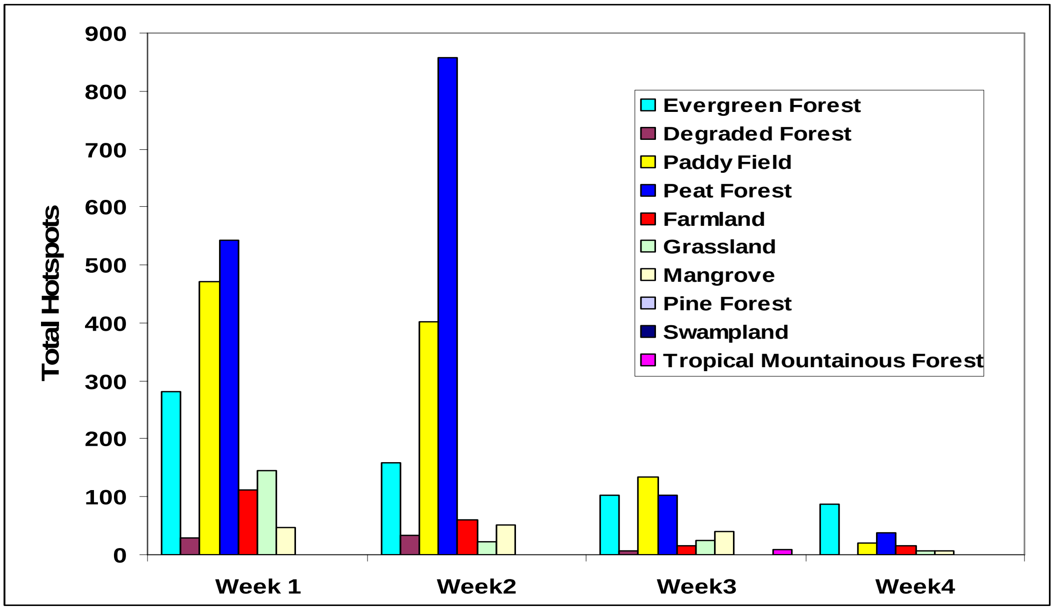

Figure 3. The weekly total number of hotspots detected over the different vegetation types in the province of Riau.

In the second week of August, peat land areas continued to record high values of hotspots (857 hotspots), followed by burning of paddy stalks, with a record of 403 hotspots. Forty five percent of burning was conducted in the peat land areas compared to 23% in paddy fields. The burning activities thereafter decreased during the third week of August, where in total, 107 hotspots were detected from the burning of various vegetation types in Riau. The level of burning activities in Riau further reduced during the last week of August, in contrast to the burning activities in the Sumatera Selatan province.

b. Emission Estimates

Emission estimates from biomass fires that occurred during August 2005 over the Sumatera Island were calculated based on the various vegetation types. Fuel loading was estimated for different tropical vegetation types that included emissions due to burning of agro-wastes and paddy fields, forest land, and peat land. The emission factor for a given compound is defined as the amount of compounds released per amount of fuel consumed

(Scholes et al. 2003) and from published information on the Indonesian fuels (Christian et al. 2003).

Table 1 shows the estimated emission of pollutants detected from satellites for the different provinces in Sumatera during August 2005. The largest area burnt in Riau emitted the highest amount of pollutants, followed by those in Sumatera Selatan. Clearly, burning activities contributed to a high magnitude of GHG emitted to the atmosphere during that period. A total emission of 163 Mt of CO_2 was released from the various provinces in Sumatera, with a high amount of 5.8 Mt of gaseous carbon monoxide (CO) emitted to the atmosphere. Seventy percent of CO_2 was emitted from Riau, which represents the province with the highest burning activity. Oxides of nitrogen (NOx) were also released in abundance, by as much as 116 Mt. In this study, NOx are selected as an indirect GHG that produce the tropospheric GHG 'ozone' during their breakdown in the atmosphere. NOx also affect the GHG budget through their effect on the atmospheric hydroxyl radicals (Reay 2006). Emissions of methane and non-methane hydrocarbons from burning of agricultural wastes and clearance of tropical forests were also estimated at 2.19 Mt, and 0.91 Mt respectively. The above results illustrate that biomass burning releases a large amount of GHG to the local environment.

Table 1. The estimated emission of GHG in Sumatera during August 2005.

Provinces	Carbon dioxide (Mt)	Carbon monoxide (Mt)	Non-methane hydrocarbons (Mt)	Methane (Mt)	Nitrogen oxides (Mt)
Aceh	1.284	0.046	0.007	0.017	0.916
Bengkulu	5.817	0.208	0.032	0.078	4.150
Jambi	2.190	0.078	0.012	0.029	1.563
Lampung	0.906	0.032	0.005	0.012	0.646
Riau	116.328	4.151	0.647	1.563	83.006
Sumatera Barat	0.906	0.032	0.005	0.012	0.647
Sumatera Selatan	14.654	0.522	0.081	0.197	10.457
Sumatera Utara	20.924	0.747	0.116	0.281	14.930
Total	163.011	5.817	0.907	2.191	116.315

The daily average GHG such as methane (CH_4), NOx, CO, and non-methane hydrocarbons (NmHC) at the Gombak air quality station in the state of Selangor, Peninsular Malaysia was investigated to find out if the GHG of local air in Peninsular Malaysia was affected by the transboundary haze caused by the biomass burning. The Gombak station was selected as it recorded one of the highest levels of MAPI compared to other stations during the haze situation (Figure 4a). Gombak is an urban station which is influenced by local pollution sources even during non-haze situation, as an example in the situation during August 2004 (Figure 4b). CO was the only GHG that exhibited elevated concentrations during the height of the haze emergency episode from 7 to 11 August, with a peak of 6.2 ppm on 11 August. This corresponded to the enhanced MAPI levels that exceeded the 200 mark from 10 to 12 August.

Other GHG such as NOx did not exhibit a marked increase in concentration except for a slight increase for CH_4 and NmHC from 9 to 11 August 2005. This is in contrast to the time series of the daily average concentration during the non-haze event in August 2004 that showed good the air quality levels where the daily average MAPI were below 80 (Figure 4b). Concentrations of NOx, NmHC and CH_4 were found to be consistently low throughout the month (Figure 4b) and also throughout the haze event in August 2005, implying these are the indicators of the air quality conditions from the local sources of urban pollution in Gombak that were not too affected by the transboundary haze.

The 8-hourly CO concentrations from 5 to 15 August 2005 is shown in Figure 5. The CO concentrations gradually increased from 9 to 11 August, peaking to a value of 7.9 ppm at 9 pm. This value is still beneath the Recommended Malaysian Air Quality Criteria ambient air levels of 9 ppm. Therefore, the ground level GHG appears to be transient in nature, corresponding to the elevated MAPI values that occurred for a few days.

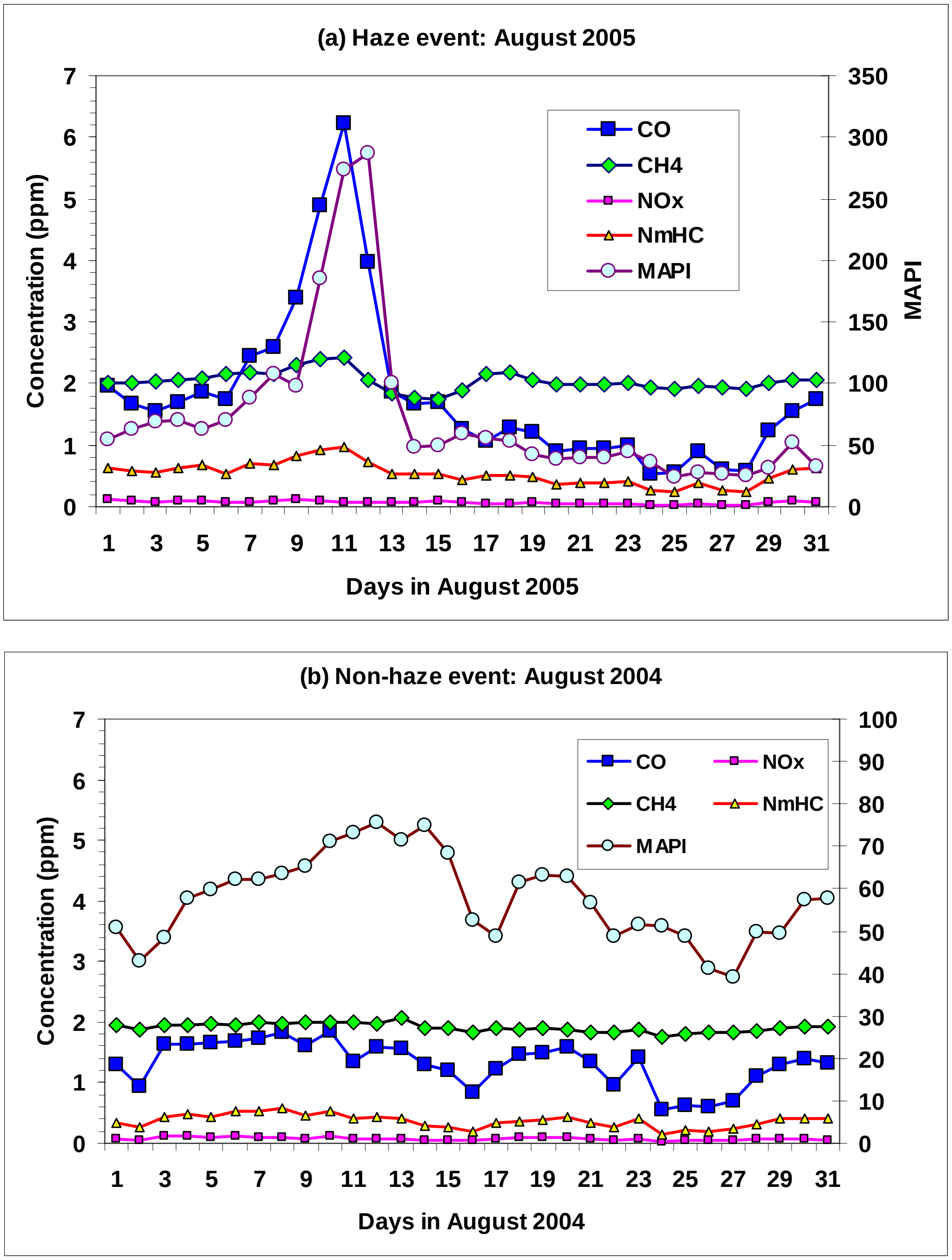

Figure 4. The GHG detected at the Gombak air quality station during a (a) haze episode in August 2005 and (b) a non-haze episode during August 2004.

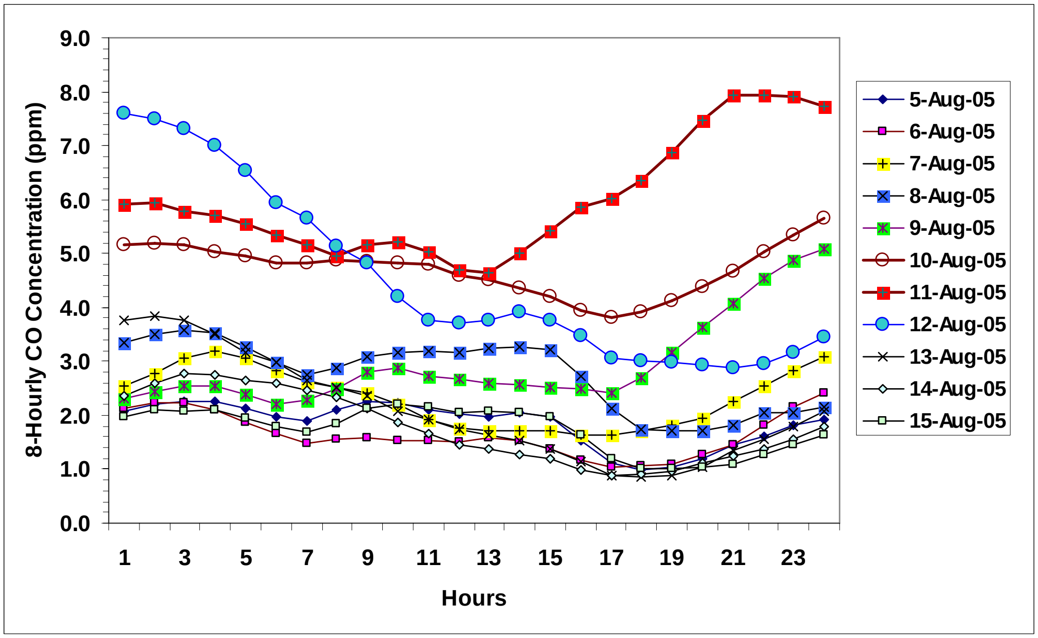

Figure 5. The hourly time series of the 8-hourly CO concentrations from 5 to 15 August 2005.

Comparatively, CO was the only GHG that displayed significantly enhanced levels during the haze emergency event in 2005. Other GHG such as CH_4, NOx and NmHC did not exhibit increased concentrations they are easily destroyed through the processes of oxidation, decomposition and deposition. So CO may be utilised as an indicator of increased GHG during a major large-scale biomass burning episode.

c. Dispersion

Dispersion analysis can assess the transport of a species of air pollutant emitted to the atmosphere. The Hysplit model is applied for the simulation of CO_2 dispersion during the height of the air pollution episode. Although CO_2 is not a pollutant, however, as a GHG, it is deemed important to investigate the mode of dispersion. The evaluation of the temporal and spatial evolution of the CO_2 can be investigated from the transportation and advection characteristics of the dispersion patterns. The analysis only selected the CO_2 gas as a showcase in this study since it was one of the main contributors of the GHG. Similar patterns of plumes were displayed for the other GHG were not shown for brevity.

Figure 6 shows the case study of the dispersion of CO_2 from the NOAA active fire counts. The case was selected for 10 August 2005 as the highest number of hotspots was detected on this day. Plumes were emitted from the active fire counts throughout the island of Sumatera six hours after emission, with the largest plume concentrated near the sources in Riau (Figure 6a).

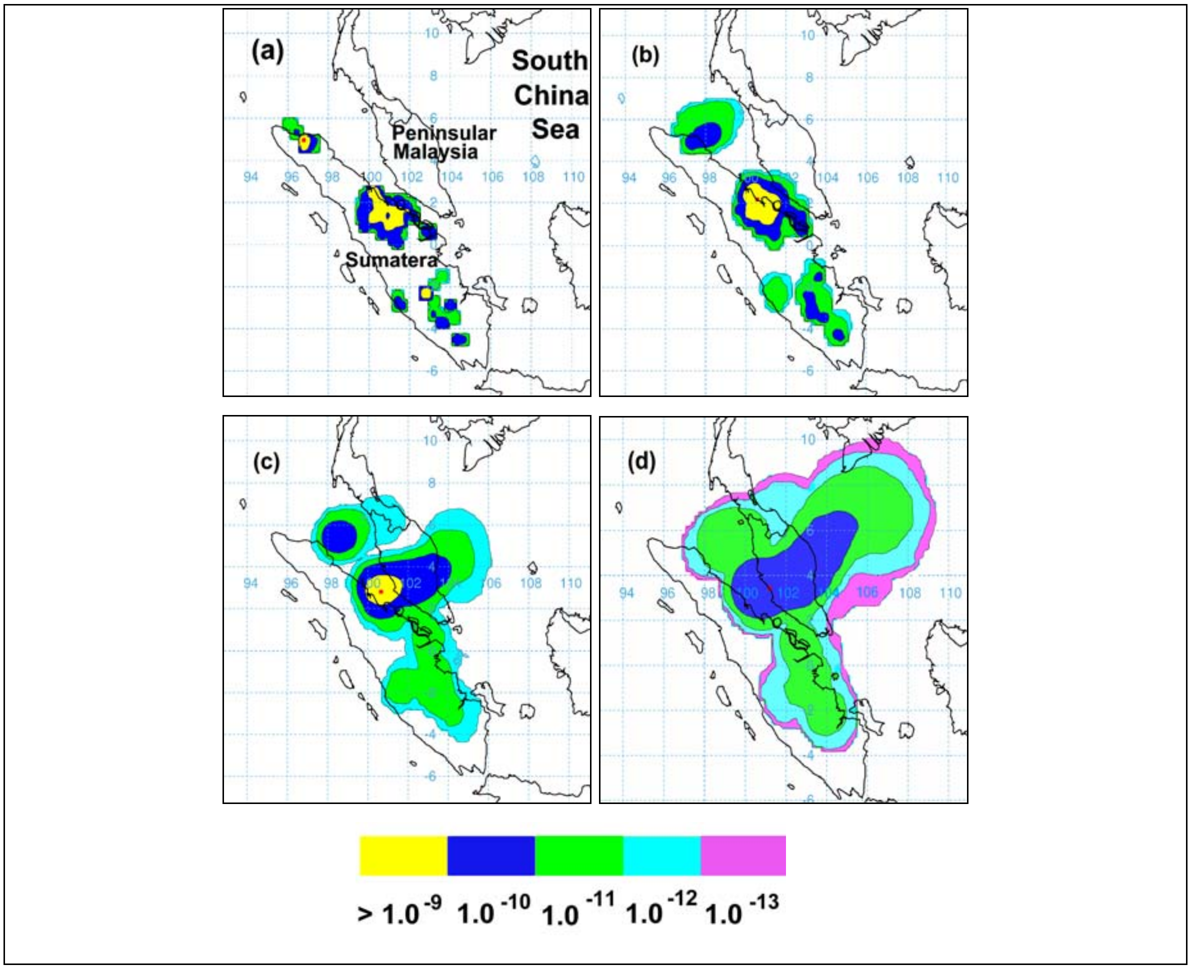

Figure 6. The estimated dispersion of CO_2 from the active fire counts in Sumatera on (a) 10 August, 1200 GMT, (b) 11 August 0000GMT, (c) 11 August 1200 GMT, and (d) 12 August 0000GMT. The units of the contours are in g/m^3.

Twelve hours later, the most concentrated plume that was located in Riau advected slowly towards the western coast of Peninsular Malaysia (Figure 6b). The other plumes within the other region of Sumatera expanded in size but were still located within

Sumatera. Thirty six hours later, the three main plumes that previously existed amalgamated and formed into a major plume, and reached the central region of Peninsular Malaysia (Figure 6c). Forty eight hours after the start of the simulation, the major plume expanded further in size and enclosed the whole of Peninsular Malaysia and part of the southern South China Sea.

The dispersion exercise has shown that, the CO_2 plume had spread and encompassed an area from the western coast of Sumatera towards the South China Sea forty eight hours after simulation.

CONCLUSION

Results from this study had shown that over the duration of one month, biomass burning concentrated mainly in the province of Riau (approximately 150 km from the state of Selangor in Peninsular Malaysia), was a significant source of greenhouse gases such as CO_2, CO and methane. Ozone precursors such as non-methane hydrocarbons and nitrogen dioxides were also produced in significant amounts.

This article only considered the estimated emissions of CH_4, CO, CO_2, and NOx, from biomass burning that included sources from forest, degraded forests, peat land areas and agricultural wastes. Changes in land use, and forest management practices alter the natural carbon flux between biomass soil and the atmosphere. The combination of greenhouse gases, smoke particulates and hazardous gases in the transboundary haze is of concern especially to the neighbouring countries that are directly affected due to their close proximity to the source of the burning.

Clearly land use change and forestry activity is identified as one of the largest emitters of GHG in developing countries with an estimated amount of 0.2 tonnes per capita compared to energy related emissions from fossil fuel combustion that are tied to industrialization (Parker & Blodgett, 2005). However, further economic development of agriculture and exploited resources in the land use land cover change in developing countries, such as Indonesia and Brazil can substantially increase the GHG emissions. However, these countries can utilize their abundance forests with improved and better forest management practices, regeneration of cleared forest and timber harvesting that may be a net carbon sink.

The lengthy residence times of some of the GHG in the atmosphere are of concern. The burning activity that took place during the dry season when precipitation was minimal would prevent efficient removal of the haze and prolong visibility reduction. For example, the residence time of CO in the atmosphere is approximately one month in the tropics, whilst methane is 21 times more effective in trapping heat in the atmosphere than CO_2.

As transboundary haze from biomass burning during the dry months becomes a recurring problem in the region, intergovernmental cooperation in controlling the emissions of pollutants is crucial. ASEAN countries must take the initiative to better manage not only GHG emission but also air pollution from biomass burning at regional and sub-regional levels. Amongst the benefits of controlled emissions of GHG are the slow progression of global warming besides the reduction in the acid rain and production of ground level ozone.

Sustainable development contribution to the land use land cover change activities can mitigate climate change such as the implementation of guidelines and procedures, participation of the local community in the development, distribution and transfer as well as adaptation of technology and best practices methods.

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