DISPERSION MODELING OF PM_{10} AND NO_X EMISSIONS FROM THE KLIAS-BINSULOK PEAT FOREST FIRES

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ABSTRACT

Every year, forest fires occur in the Klias – Binsulok peat swamp forest. These peat forest fires release large amounts of carbon, PM_{10}, NO_x, and SO_x into the atmosphere. This study was done to model the dispersion of these particle when they are emitted into the atmosphere. The main objectives for this study is to model the dispersion of PM_{10} and NO_x, analyse the dispersion pattern in regards to the meteorological conditions of that time and also to determine the exposure concentrations of PM_{10} and NO_x along the simulation period. In this study, the HYSPLIT_4 (Hybrid Single Particle Lagrangian Integrated Trajectory Version 4) is used to model the dispersion of PM_{10} and NO_x towards the surrounding area. Throughout the whole study, a total of 6 models were run. This includes 2 trajectory models and 4 concentration models. All models were displayed in two formats, one a 2-D map and the other a GIS map provided by Google Earth. Modelling was done at 2 periods, March and August 1998. Meteorological data used were from the NOAA Reanalysis data. Overall, the study revealed dispersion patterns that were expected. The monsoon winds showed a direct effect on the direction of dispersion, thus confirming that the meteorological condition can directly effect the dispersion pattern. Exposure concentrations were also determined for PM_{10} and NO_x along the simulation period.

ABSTRAK

Setiap tahun, kebakaran hutan berlaku di kawasan hutan paya gambut Klias - Binsulok. Kebakaran hutan paya gambut menghasilkan dan melepaskan banyak karbon, PM_{10}, NO_x, dan SO_x kedalam atmosfera.kajian ini dilakukan untuk menentukan corak penyerakan partikel-partikel ini apabila ia dilepaskan kedalam atmosfera. Objektif kajian ini dilakukan adalah untuk membuat simulasi penyerakan PM10 dan NOx dan juga menentukan kepekatan PM_{10} dan NO_x sepanjang tempoh simulasi. Perisian HYSPLIT_4 (Hybrid Single Particle Lagrangian Integrated Trajectory Version) digunakan bagi tujuan simulasi corak penyerakan PM_{10} dan NO_x. Dalam kajian ini, 6 simulasi telah dijalankan, iaitu, 2 simulasi trajektori dan 4 simulasi kepekatan. Kesemua simulasi dipaparkan dalam 2 format, satu format peta 2-D dan satu lagi menggunakan peta GIS daripada Google Earth. Simulasi dijalankan dalam 2 tempoh masa iaitu Mac dan Ogos 1998. Data cuaca menggunakan data NOAA Reanalysis. Keselruhannya, kajian ini memberikan corak penyerakan yang dijangkakan. Angin monsun, seperti yang dijangka telah mempunyai kesan langsung terhadap corak penyerakan PM_{10} dan NO_x. kepekatan PM10 dan NOx juga telah ditentukan disepanjang tempoh kajian.

LIST OF CONTENTS

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Among the most recent climatic phenomenon affecting today's global community is the "El Nino" phenomenon. This term became all familiar with the meteorological events of 1997-1998. This was when "El Nino" was blamed for every weather phenomenon from tornados and thunderstorms in Florida to the widespread forest fires in Indonesia (Botkin et al., 2003). Speaking of forest fires, the island of Borneo was not spared. Fires were raging in the forest of Klias, Binsulok, Mengalong, Tawai and several other areas in Sabah. To understand the problems of that year, there is a need to know the climatic changes that are happening at that moment, which is the "El Nino" phenomenon. "El Nino" means little boy in Spanish. This is a specific referral to the Child of Christ, reasons which states that this phenomenon begins off the coast of South America around Christmas time. The *El Nino* phenomenon affects the oceanic and atmospheric system in the Pacific. Basically, *El Nino* weakens the east to west trade winds and warms the waters of the eastern Pacific Ocean. This results in a shift of tropical rainfall from the South East Asia region, from countries such as Indonesia, towards South America.

This is because tropical rainfall follows the warm water of the Pacific Ocean. With the heavier than usual rainfall in South America, countries such as Peru experience flooding while countries such as Indonesia experience droughts. It is then not uncommon for forest fires to be raging through Australia, Indonesia and Malaysia (Borneo). Furthermore, because warm ocean water serves as an atmospheric heat source, the effects of *El Nino* does not only encompass the regions surrounding the Pacific Ocean but has other far reaching consequences, far from the tropics of the Pacific. For an example, North America experiences warmer winters than usual during the *El Nino* phenomenon.

Having an understanding of the *El Nino* phenomenon will now help to explain the raging wildfires in Indonesia, and to a certain extent, Borneo. With the slash and burn practices in Indonesia, which has been the norm of farming in the tropics, forest fires are common. Communities or families will burn a few hectares of land, plant, harvest and then move on. Burning is the preferred method for land clearing since alternatives such as bulldozing are just too expensive. It has to be stated here that generally, slash and burn practices has not been thought to be of dire consequences to the ecology of tropical rain forest, because the fires are not widespread and controlled.

However, we have to now take into account the *El Nino* phenomenon to explain the catastrophic forest fires that ravaged the tropical forests of Indonesia and Borneo. With the monsoon rains that were late that year in 1998, the farmers took the dry weather to burn more hectares of forest. There were more than 20,000 hectares burned in the 1997-1998 period alone. Furthermore, the dry weather and drought lowered the water table and further propagated the peat fires.

Needless to say, tonnes of particulate matter and smoke were released into the atmosphere. Emissions from forest fires include NO_x, SO_x, carbon emissions and particulate matter. This caused a severe pollution problem in the South East Asia region. During the 1997-98 forest fires in Borneo, there was a regional impact which was felt as far as Peninsular Malaysia. The air pollution phenomenon known as haze was reported in Kuala Lumpur (Peninsular Malaysia), Kota Kinabalu (Borneo, Sabah) and even in Brunei. Particulate matter was found to be the major contributor to the haze episode. Studies done in Bandar Seri Begawan (Borneo, Brunei) determined that during the whole haze episode, which lasted from 1 February – 30 April 1998, the WHO guideline for PM_{10} (70μm m^{-3}, 24hr average) was exceeded on 54 days. On the contrary, NO_2 and O_3 were below the same WHO guidelines, and the level of CO (8hr average) was only exceeded 7 times (Radojevic et al., 1999). This clearly indicates that the major cause of the haze was due to the high concentration of particulate matter in the air caused by Long Range Transboundary Air Pollution from the forest fires.

Another pollutant produced during the occurrence of forest fires is the release of NO_x. NO_x includes the gases NO_2 and NO. Compared to particulate matter, this NO_x does not present the problem of haze. However, they create an environmental problem on their own as well, which is known as acid deposition, or in layman's term, acid rain. In contrast to particulate matter, NO_x is a gaseous molecule. Basically, its dispersion in the atmosphere compared to particulate matter is bound to be different. Therefore, this study will be able to determine the difference in the dispersion of particulate matter and NO_x.

Through determining the dispersion of particulate matter during a forest fire, we will be able to determine the occurrence of haze in these local communities. With the dispersion study of NO_x, the threat of acid deposition to the local communities can be determined. This is seeing as how air pollution in a region is usually not originally from that region, but it is rather generated elsewhere and then transported to that region. The location where the pollution is generated is known as the source. The area that is affected by the pollution is known as the receptor. Source-receptor mechanics is based on the fact that air pollution happens in a medium which is spatially dynamic, that is the atmosphere. Long range transport of the pollutants (LRTAP) is based on several factors including wind and weather. Dynamic meteorological conditions such as temperature, wind direction, wind speed, and humidity, can change and alter the way pollutants are mixed, deposited, dispersed, and transported transboundary across the region.

In this study, the primary areas which will be researched are the Klias and Binsulok peat swamp forests. After the 1998 forest fires, preliminary damage assessment indicated that approximately 500 ha of the Binsulok peat swamp forest was affected (Lagan et al., 1999). According to the Sabah Forestry Department (SFD), the Klias - Binsulok areas are still high risk areas for a forest fire (Figure 1.1). This means that there is a chance that fires will occur in that area again. Local villages in that area include Kampung Klias Baharu, Kampung Sungai Klias and Kampung Rompang among others. Urban areas in the area include Beaufort and Labuan (Figure1.2).

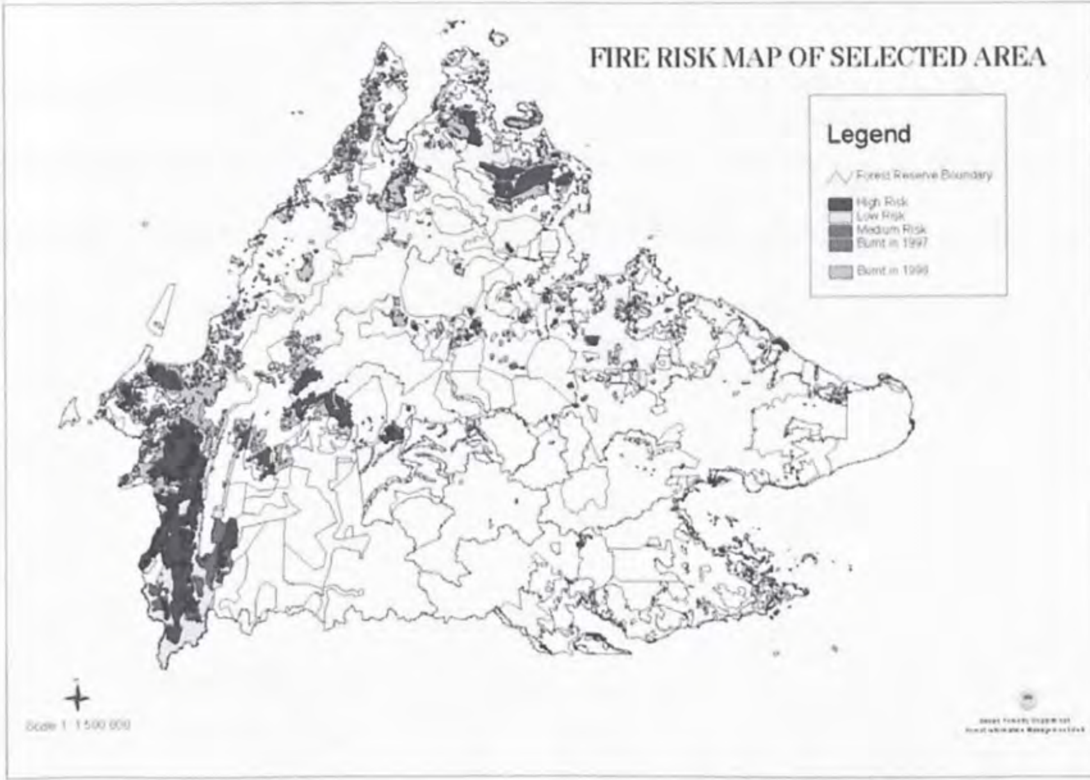

Figure 1.1 Fire Risk Map of Sabah (Sabah Forestry Department)

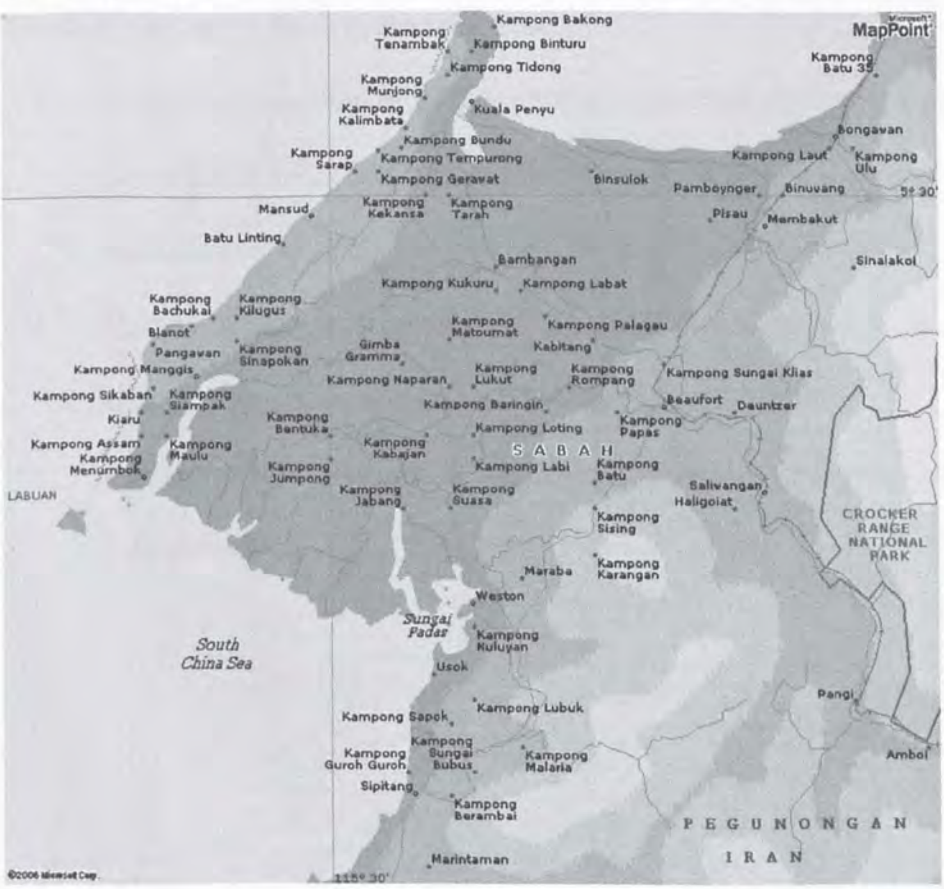

Figure 1.2 Local communities (receptors) in the Klias – Binsulok area (MSN Encarta)

Significantly, *El Nino* happens at intervals of 2 to 7 years. This means that throughout the years, these fires will recur. As was in 1994, 1997, 1998, these forest fires have a high possibility of occurring in the future. Therefore, it is important that this study be carried out. The dispersion of particulate matter and NO_x from the source to the receptor presents a problem to the receptors, which are the local communities. The study being done will be able to assess the exposure of the receptors to particulate matter and NO_x.

1.2 OBJECTIVE

The study is done to reach these objectives:-

i. Model the dispersion of PM_{10} and NO_x concentrations from the peat forest fire in the Klias and Binsulok peat forest using NOAA's Hysplit_4 atmospheric modelling software.

ii. Study the dispersion patterns of PM_{10} and NO_x concentrations, and analyse the different dispersion pattern from both pollutants.

iii. Determine the exposure concentrations of PM_{10} and NO_x 24 hours from emission site.

CHAPTER 2

LITERATURE REVIEW

2.1 PEAT FOREST FIRE

Modelling emissions from a peat forest fire requires an understanding of the chemistry and fundamentals of the forest fire itself. Peat forest fires have certain unique characteristic that makes it different from any other forest fires. In a peat forest fire, it must be understood that not only are the trees and vegetation on fire, but the peat is also smouldering. The fact that peat can form layers of up to 5-7 m overlying mineral soil makes it vulnerable to smouldering subterranean fires. These subterranean fires continue to propagate even after the ground fire has been suppressed. Especially during times of drought, where the water table recedes, peat then becomes combustible and the peat forest is then even more susceptible to subterranean fires (Lagan et al., 1998). Another problem with peat fires is that while fire needs a constant supply of air, under certain conditions, the combustion wave propagates along the peat bed even in the absence of an influx of air from the outer medium (Subbotin, 2003).

The forest fire goes through several stages as follows:-

Ignition

↓

Flaming

↓

Smouldering

↓

Extinction

Figure 2.1 Four stages of a peat forest fire (Radojevic, 2003)

The peat forest fires actually have a longer smouldering stage as compared to rain forest fires or any other fire. This is because that, as mentioned earlier, there is an accumulation of peat, or biomass at the forest floor. Substances emitted during the smouldering stage are large amounts of incompletely oxidized compounds (VOCs, PAHs) which have the potential to do more harm than the substances emitted during the high temperature flaming stage of the fire (Muraleedharan et al., 2000).

Emissions factors for the smouldering of peat were done by Muraleedharan et. al., (2000). In that study, peat was combusted in the lab at different temperatures which are similar to the temperature of smouldering peat, 500-600°C. From this study, the emissions of CH_4, C_2H_6, C_3H_8, C_4H_{10}, C_2H_4, CO, and CO_2 were detected and emission factors determined. These emissions factors will later come in handy when it comes to running the model as emissions rates have to be input into the modelling software.

2.2 AIR POLLUTION

Air pollution is the presence of undesirable substances in the air (solids, liquids or gases), in concentrations high enough to produce harmful effects (de Nevers, 1995). This definition of air pollution is by no means limited or linked only to anthropogenic threats but also encompasses the threat to animals and vegetation. These undesirable substances cause damage to human health, vegetation, human property, the global climate system as well as create unwanted aesthetics insults in the form of haze and other air pollutant phenomenon. Air pollution is a major problem, especially in the rapidly developing Third World countries such as Malaysia, Thailand and Indonesia where industrialization is taking place. Countries such as this which put precedence towards development rather than environmental preservation tend to suffer the most from air pollution. There is a lack of mitigating legislature and even with environmental laws; enforcement is lacking (Kolstad, 2000).

Humans can survive 6 days without water, but will barely last 60 seconds without air. Importance of air to the human being cannot be stressed enough. However, it must be taken into consideration that air pollution can also happen of natural causes. A volcanic eruption belching tonnes of ash and dust into the atmosphere, winds picking up dust and soot along the way and also natural forest fires producing vast quantities of drifting smoke. As we know it, in the 1997-98 forest fire events, the problem was exacerbated by the El Nino phenomenon causing dry weather and drought.

2.2.1 Particulate Matter, PM_{10}

Particulate matter or PM_{10} refers to a class of pollutants made up of particles with a diameter size of less than 10μm. These particles are not uniform chemically, for example, how a CO molecule is identical to another CO molecule (de Nevers, 1995). The term is used for a varying mixture of particles (solids or liquid) suspended in the air. There are always particles in the air we breathe. However, certain particles are known to cause health complications, such as asbestos and heavy metal particles, such as arsenic. Smaller particles under $PM_{2.5}$ (diameter smaller than 2.5μm) are even more hazardous as they can enter the bloodstream directly via the respiratory system. For a comparison, human hair diameter is in the 60μm to 150μm range. Imagine how the particles can actually be inhaled and either end up in the bloodstream or remain embedded in the lungs. According to (Botkin et al., 2003) health effects associated with particulate matter exposure includes 1) increased chronic and acute respiratory diseases and 2) irritate tissue of throat, nose, lungs and eyes.

There are two main emission sources for particulate matter, anthropogenic and natural sources. Anthropogenic sources include industries, incinerators and practically anything that involves combustion. Natural sources are from events such as volcanic eruptions and ironically naturally occurring forest fires. Especially in urban areas, anthropogenic particulate matter pollution happens frequently. It should be noted that particulate matter pollution is the most noticeable because it causes haze which reduces visibility (Ahrens, 2005).

2.2.2 Nitrogen Oxides, NO_x

Nitrogen oxides, or NO_x occur in many forms in the atmosphere, but they are largely emitted in 2 forms, nitrogen dioxide (NO_2) and nitric oxide (NO). Under the Air Quality Guidelines, only these 2 forms are subjected to emission controls. Of these 2 forms, nitrogen dioxide (NO_2) usually takes precedence. This yellow-brown to reddish gas can undergo complex photochemical reactions within small water particulates to form NO_3^{2-}, and impairing visibility. NO_2 and NO both play major roles in the occurrence of smog. Another problem associated with NO_x is acid rain, or acid deposition, where the main culprit is again NO_2. Nitric acid is formed when NO_2 reacts within precipitation droplets, which is precipitated as rain (Chang, 2005). The threat to health posed by NO_x includes 1) irritation to eyes, nose, throat, and lungs and 2) increased susceptibility to viral infections, including influenza (which can cause pneumonia and bronchitis) (Botkin et al., 2003).

Anthropogenic sources of emissions of NO_x contribute a large part to the amount of NO_x being released into the atmosphere. Natural sources such as biomass burning, bacterial action and lightning release as much as 20 million metric tons/year. On the other hand, anthropogenic sources produce as much as 100 million tons/year. The biggest contributor, more than 20% are from the combustion of fossil fuels, from both stationary (power plants, waste disposal systems) and mobile sources (vehicles) (Manahan, 2005).

2.3 ATMOSPHERIC MODELLING

The approach to solving and determining the movement of particulate matter in the atmosphere is through atmospheric pollution modelling. This approach is now commonly employed by environmental scientist worldwide in an attempt to understand how the environment changes and also to make predictions how it can potentially evolve in the future (Deaton et al., 1999). These models are not borne out of mere academic curiosities but are used as a tool, which is used to shape public policy. This in turn has significant impacts on the society as well as the environment.

Modelling the environment requires a lot of assumptions. This happens because of what modelling is all about, the simplification of a complex process, making it easier to understand, comprehend and predict the outcome of changes in the system. (Mullingan et al., 2004). Through these simplifications, the major components of the system can be analysed thoroughly, giving a better understanding of the system as a whole. In atmospheric chemistry and pollution dispersion modelling, common assumptions are 1) the receptor is downwind of the source site, 2) constant wind direction and wind velocity during the modelling period, 3) emission rate of pollutants are constant, 4) constant rate of chemical transformation and deposition, and 5) there are natural sources for pollutant gasses due to natural processes, and these add into the reservoir i.e. SO_2 (Deaton et al., 1999).

Therefore, it can be safe to say that although models try to mimic as close as possible to real life systems, there are invariably differences between the modelling results and the actual results. Therefore, after a simulation, there is a dire need for a validation to be done. This can then determine how far off the simulated results is compared the observed results. There are many programs available for atmospheric modelling, including US EPA's AERMOD and NOAA's HYSPLIT_4 (HYbrid Single-Particle Lagrangian Integrated Trajectory Version 4). Even spreadsheet processing programs such as MS Excel can be used for modelling the environment (Mullingan et al., 2004).

The program being used is the HYSPLIT_4 program which is able to simulate complex dispersion and depositions scenarios from area source pollution, such as a peat forest fire. The NOAA HYSPLIT_4 program was chosen primarily because of its ability and flexibility to ingest multiple types of meteorological model output fields. All meteorological data has to be interpolated to a variety of different vertical coordinate systems prior to output. Besides that, forest fires are basically area source, which can be dealt with the HYSPLIT_4 model (Draxler et al., 2004). Meteorological datasets which can be used by the HYSPLIT_4 system includes all under the gridded NWP (Numerical Weather Prediction) model output, which is:-

1. GFS (Global Forecast System)
2. ETA-12 (NCEP's Limited Area Step Mountain Coordinate Model)
3. WRF (Weather Research and Forecasting)
4. 4km NMM (4km Nested Mesh Model)

These meteorological datasets can be obtained through the NCEP (National Centres for Environmental Protection) website: http://www.ncep.noaa.gov.

CHAPTER 3

METHODOLOGY

3.1 REVIEW

Below is just a succinct review on what comprises the 5 stages of this study.

Stage 1: Program Acquisition

HYSPLIT_4 requires registration so that it can be used in conjunction with forecast data. Registration form has been acquired.

Stage 2: Data Acquisition

i. Combustion and biomass data needed to determine the amount of particulate matter and NO_x released during the forest fire.
ii. Meteorology data needed to input the weather factor into the simulation.
iii. Archive air quality index (AQI) at the receptors for a comparison and validation of the simulation.

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