SEASONAL VARIATIONS AND POTENTIAL SOURCES OF PM_{10} IN MALAYSIA

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I affirm that this dissertation is of my own effort except the excerpt and summary which each of them has been referred to the sources mentioned in the reference section.

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VARIASI BERMUSIM DAN SUMBER BERPOTENSI PM10 DI MALAYSIA

ABSTRAK

Jerebu adalah kehadiran partikel halus dengan diameter 0.1 hingga 10 µm di udara dan menyebar dalam kepekatan yang tinggi dan majoritinya mengandungi PM10. Episod jerebu dan insiden serius ke atas Asia Tenggara termasuk Malaysia berlaku sejak akhir 1980-an. Kajian ini adalah untuk menganalisis kejadian jerebu di Malaysia dan mengesan punca pada tempoh yang disyaki tertentu. Hotspot pencemaran dan monsoon bermusim digunakan untuk menerangkan dan menjelaskan tempoh jerebu. Model HYSPIT telah digunakan sebagai perisian trajektori jerebu dan empat stesen yang berbeza dengan lokasi geografi telah dipilih iaitu Kuala Lumpur, Pahang, Kuching, dan Kota Kinabalu. Dalam kajian ini, jerebu didapati jarang berlaku di Kota Kinabalu tetapi ia sering dilihat di Semenanjung Malaysia. Tempoh Jerebu dan corak di Semenanjung Malaysia adalah sama dan biasanya berlaku semasa tempoh monsoon musim panas. Sumber-sumber PM10 Semenanjung biasanya dari Sumatra, Indonesia. Kuching telah diperhatikan dengan beberapa kejadian jerebu pada Januari kepada Mac (2008) dan bulan Julai hingga September (2009 & 2010). Untuk Kota Kinabalu, tempoh masa didapati dengan peningkatan kepekatan PM10 besar. Ia berlaku pada bulan Februari untuk bulan April 2010. Ia disumbangkan oleh El Nino dan kemarau yang berpanjangan dari tahun 2009 hingga 2010. Monsun dan El Nino adalah kedua-dua faktor penting dalam menentukan arah tuju jerebu dan intensiti sebagai monsun perubahan laluan perjalanan bahan pencemar dan El Nino meningkatkan kekerapan pembakaran biomass.

ABSTRACT

Haze is defined as the presence of fine particles with diameter of 0.1 to 10 μm in the air which dispersed at high concentration caused white or brown vision (Soleiman *et al.*, 2003) and majority containing particulate matter (Rahman, 2013). The haze episodes and incidents were severe over the Southeast Asia including Malaysia since the late 1980s. This research is to analyze occurrence of haze in Malaysia and backward tracking its sources at the specific suspected period. Pollution hotspot and seasonal monsoon were used to further explain and clarify the haze period. HYSPIT model was used as backward trajectory software and four different stations with geographical locations were selected which are Kuala Lumpur, Pahang, Kuching, and Kota Kinabalu. In my findings, haze seldom happened in Kota Kinabalu but it was frequently seen in Peninsular Malaysia. Haze period and pattern in Peninsular Malaysia was similar where it usually happened during period of summer monsoon. The sources of PM_{10} to Peninsular are usually from Sumatra, Indonesia. Kuching was observed with few haze outbreaks which is in January to March (2008) and July to September (2009 & 2010). For Kota Kinabalu, a period of time was found with tremendous increased PM_{10} concentration. It happened in February to April in 2010. It is contributed by occurrence of *El Nino* and prolonged dry spells from year 2009 to 2010. Monsoon and *El Nino* are both important factors in determining the direction of haze and its intensity as monsoon changes the travelling path of pollutants and *El Nino* increases frequency of forest burning.

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LIST OF SYMBOLS AND UNITS

^0C	Degree Celsius
%	Percentage
$\mu g/m^3$	Microgram per cubic metre
µm	Micrometer
hrs	Hours
km	Kilometre
m	Metre

LIST OF ABBREVIATIONS

AOD	Aerosol optical depth
API	Air Pollution Index
Apr	April
ARL's Ready	Real-time Environmental Applications and Display system
ASMA	Alam Sekitar Sdn. Bhd.
Aug	August
CO	Carbon monoxide
COADS	Comprehensive Ocean -Atmosphere Data Set
Dec	December
DJF	December-January-February
DOE	Department of Environmental
ENSO	*El Nino* Southern Oscillation
Feb	February
GUI	Graphical user interface
HYSPLIT	Hybrid Single-Particle Lagrangian Integrated Trajectory
IOD	Indian Ocean Dipole
ITCZ	Intertropical convergence zone
Jan	January
Jul	July
Jun	June
LAS	Live Access Sever
Mar	March

MC	Maritime Continent
MJO	Madden Julian Oscillation
MLD	Mixing level depth
NO_2	Nitrogen dioxide
NOAA	National Oceanic and Atmospheric Administration
Nov	November
Oct	October
PC	Personal Computer
PM	Particulate matter
PM_{10}	Particulate matter < 10 µg/m^3
$PM_{2.5}$	Particulate matter < 2.5 µg/m^3
PSD	Particle size distribution
RM	Ringgit Malaysia
SEA	South-east Asia
Sept	September
SON	September-October-November
SST	Sea surface temperature
USD	United States Dollar
UV	Ultraviolet
VOC	Volatile organic compounds
WWF	World Wildlife Fund for Nature

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CHAPTER 1

INTRODUCTION

1.1 Overview on Haze Pollution

Air pollution is the presence of chemicals in atmosphere in sufficient quantities and duration which cause harm to abiotic and biotic (Miller, 2004). These chemical gases or particles in air are called air pollutants (Kaufmann and Cleveland, 2008). It can be defined as primary pollutants which are emitted directly from combustion of fuels and industrial operations and secondary pollutants form where the primary pollutants react with one another or with basic components in atmosphere. Long-lived primary and secondary air pollutants might spread by prevailing winds from its origin areas to country-side and to downwind urban and rural areas. These pollutants are influenced not only by the rate of emission but also interference by wind speed, turbulence level, air temperature and precipitation (Dominick *et al.,* 2012). Man-made urban air pollution is a complex mixture with toxic compounds which are considered as particulate matter (PM) usually comes from combustion processes (Cohen *et al.*, 2004). Particulate matter with less than 10 μm of its diameter (PM_{10}) has been known as an important atmospheric pollutant and act as main contributor of haze. This particulate matter pollutant in air is the combination of solid and liquid particles. Majority sources of particulate matter were contributed by biomass burning.

Haze is air pollution which can be carried by wind from its origin and often to hundreds or thousands of miles (EPA, 1999). Haze is defined as the presence of fine particles with diameter of 0.1 to 1.0 μm in the air which dispersed at high concentration caused white or brown visible in view (Soleiman *et al.*, 2003). It contains dust and smoke particles together with air pollutants such as sulphur dioxide, nitrogen oxide, ozone, carbon monoxide and majority containing particulate matter (Rahman, 2013). It can be as fine as droplets of liquids in fogs and mists or as solid particles such as soot (Mahajan, 2003). Haze particles not only influence visibility of atmosphere, but also solar radiation and even can involve further chemical reactions in atmosphere to produce secondary pollutants (Roosli *et al.,* 2001). When sunlight (solar radiation) encounters tiny pollution particles in the air, some of the light is reflected, scattered, or absorbed by haze particles before it reaches an observer (EPA, 1999). Light absorption by particles which also called light absorbing particles is primary contains elemental carbon.

Particles of haze generally come from many sources, some from natural and some from anthropogenic. Anthropogenic activities especially biomass burning including forest fires, open burning and agricultural land clearings are the main causative factors for deteriorating of air quality and visibility (Rahman, 2002). Fire can influence air quality of both local and regional (McKenzie *et al.*, 2006). During the 20th century, biomass combustion due to man-kind activities has been more vigorous and fire activities have been annual phenomena over the last 30 years (Field *et al.*, 2009). Biomass burning releases more air pollutants compare to well control combustion sources on a mass of pollutants per mass of fuel basis (Lin *et al.*, 2007; Shih *et al.*, 2008). Beside, fires activities not only cause haze pollutions, but also release large amounts of carbon into the atmosphere (Page *et al.*, 2002). In western region of the United State, it was found that total carbon was the major contributor to $PM_{2.5}$ concentrations and elevated contributions at the upper extremes of aerosol fine mass probably correspond to biomass burning (Ames and Malm, 2001).

Therefore, biomass burning is known as the major source of global greenhouse gases and hazardous aerosols (Andreae and Merlet, 2001; Lee *et al.*, 2011).

Meteorological conditions are important role in transportation, diffusion and deposition the air pollutants (Chen *et al.,* 2007; Zhu *et al.,* 2010). The major weather system such as stable continental high-pressure and low-pressure systems will make favorable for meso-scale and large scale of heavy haze pollutions form. Beside, as haze concentration is high, it means that the particular area is with higher pollutants and humidity level. Relative humidity affect the light extinction effect, which either by hydration of dry particles when the humidity is high or by condensation of water vapor to droplets which often occur of fog (Elias *et al.*, 2009; Winkler, 1988).The aerosols component are hygroscopic especially sulfates and nitrate particles, usually grow in size as humidity increases by accumulating water from the atmosphere and cause further impairing visibility. Besides, several factors such as prolonged dry weather and stable atmosphere are the supreme ingredients for the haze formation (Rahman, 2013). Wind and weather are playing an important part on transporting the pollution from one place to another. A lower surface wind speed and stably stratified atmosphere can lead to accumulation of air pollutants. Somewhere, the most important reasons of long-lasting haze pollution process happen due to accumulation of air pollutants near the surface caused by low mixing level depth (MLD). However, usually, as a cold front passed through the region polluted place, the pollutants can be induced due to strong wind and precipitation (Kang *et al.,* 2013). Particles in haze are eliminated from atmosphere mainly due to the precipitation. The interaction between rainwater and haze caused chemical degradation and influences the pH values (Tanner *et al.*, 1997). Deposition of the particles to the soil and water were increase during the period of haze (Norela *et al.,* 2013).

Haze is an indicator of high concentration of particulate matter, therefore, it has potential to harm and cause impact to public health, ecological systems and climate (Tie *et al.*, 2009; Chameides *et al.,* 1999; Solomon *et al.,* 2007). The particles in haze can increase physical health problems, allergies, cancer as well as pre-term delivery. It can influence the health either local or systemic effect. Local effect can result in eye, nose and throat irritation while systemic effect can be range from respiratory conditions to worsening of heart diseases. Transportation accidents increase and lower vegetation productivity occur during haze periods (Radojevic and Hassan, 1999). Smoke aerosols are the particulate matter in air which is mainly released by biomass burning influence directly and indirectly to temperature, atmospheric circulation, clouds formation, precipitation and climate (Xian *et al.*, 2013).

The haze episodes and incidents were severe over the Southeast Asia including Malaysia since the late 1980s. Most of the air quality studies in Malaysia are related to the occurrence of haze episodes (Cheang, 1991; Awang *et al.*, 1997, Juneng *et al.*, 2011). Malaysia is one the world's twelve areas of mega-biodiversity and act as home to a number of species disproportionate to its geographical size (CIJ, 2007). Land use change in Malaysia from forest to plantations, mainly oil palm remains the major threat to biodiversity. Activities such as forest fires, industrial emissions and transport emissions worsen the quality of air. Occurrence of haze has threatened precious natural environment of Malaysia. Particulate matter is one of the major air pollutants and is conclusive in the computation of Air Pollution Index (API) (Afroz *et al.,* 2003). API is simple, generalized way and provides easily understandable information to describe the air quality used in Malaysia, Singapore and China (Hajah, 1997). API level less than 100 consider good and safe air while API level higher than 100 consider the haze pollution process (Kang *et al.*, 2013). API level in the range of 200 to 300 is consider very unhealthy air and API level higher than 300 is consider hazardous air.

According to Dominick (2012), Malaysia is known as a tropical climate country which experience constant temperatures and continuous high relative humidity. High humidity usually gives a result of high precipitation. Wind is generally light and flexible throughout the country as Malaysia located near the equator. The wind flow patterns change with four seasons which are the Northeast Monsoon from November to March, a transitional period from April and May, the Southwest Monsoon from June to September and a second transitional period from October to November. The air pollutants usually move with winds flow base on northeast monsoon and southwest monsoon. High amount of particulate matter from biomass burning in Sumatera and Kalimantan, Indonesia follow wind pattern of southwest monsoon to Malaysia while during northeast monsoon, wind bring particulate matter from Indochina region to Peninsular Malaysia (Juneng *et al.,* 2009).

Transportation of particulate matter can be calculated in various scales by using various trajectory models such as Ash3d, PUFF, ATHAM, and HYSPLIT. Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model is known as a complete system for computing both simple air parcel trajectories and complex dispersion and deposition simulations (NOAA, 2011). Through National Oceanic and Atmospheric Administration (NOAA) and Australia's Bureau of Meteorology cooperation, this model uses advection algorithms, updated stability and dispersion equations, a graphical user interface, and the option to include modules for chemical transformations. Air Resources Laboratory's HYSPLIT model is a tool that helps to explain how, where, and when chemicals and materials are atmospherically transported, dispersed, and deposited. It is designed to support a wide range of simulations which associated to the atmospheric transport and dispersion of pollutants and hazardous materials along with its deposition to the Earth's surface. Trajectory can show local emission and regional transport (Kang *et al.*, 2013). The transport pathway of air parcels pass through the region places can be detected by HYSPLIT model. Backwards trajectory analysis can use this model as well to estimate the central path from the original air mass to the receptor (Chang *et al.*, 2013).

1.2 Research Question

Haze episodes over the Southeast Asia region has been recurring in unprecedented scale. It happened in greater extent and intensity, longer duration and impacted larger community. Malaysia is one of the countries which experiencing the haze pollution disaster. Malaysia is made up of Peninsula, Sarawak and Sabah which characterized with different geographic locations. There are several questions to ponder in this research. Firstly, where is the haze pollution coming from? Is it originating from within Malaysia or neighboring countries for example Indonesia, Thailand and etc.? How do Peninsula and Borneo vary in timing during regional scale haze incident? Which places in Malaysia are considered the pollution hotspots? How is the transportation route of air pollutants differ in both dominant monsoons?

1.3 Objectives

In order to ponder and study the uncertainties stated in the research questions, this research is designed to achieve the following objectives:

- To develop backward trajectory of haze in Malaysia in different locations and during different monsoon seasons
- To determine potential sources of PM_{10}
- To determine the role of monsoon seasons to the haze coverage and transport over Malaysia region

1.4 Scope of Study

In this research, two locations in Peninsula Malaysia and two locations in East Malaysia are chosen. In Peninsula Malaysia, the selected locations were Kuala Lumpur (3.1357° N, 101.6880° E) and Pahang (3.7500° N, 102.5000°N). While in East Malaysia, Kuching (1.5600° N, 110.3450° E) and Kota Kinabalu (5.9714° N, 116.0953° E) were selected. In order to perform trajectory analysis, Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model will be employed to determine the long range transport of pollutants over Malaysia.

CHAPTER 2

LITERATURE REVIEW

2.1 Air Quality Status in Malaysia

In an undisturbed environment with no human interference, fire activity is a rare occurrence in humid tropical region of insular South-east Asia (SEA) (Goldammer, 2006). Fire can influence air quality of both local and regional (McKenzie *et al.*, 2006). Regional haze form as area burned and fire severity increase cause the increase of biomass consumption and smoke emissions which consequently release more atmospheric dispersion of particulates and aerosols (McKenzie *et al.*, 2006). The haze episode and incident is severe over the Southeast Asia including Malaysia since the late 1980s. Haze incident in the 1997 is the most extreme due to association of *El Nino* event. Most of the air quality studies in Malaysia are related to the occurrence of haze incident (Cheang, 1991; Awang *et al.*, 1997, Juneng *et al.*, 2011). The haze incident 1997 is enormous and its extent has influenced over the region. About 70% of total emissions are vehicular emission during the non-haze period. Awang *et al.* (2000) states that the smoke haze is mainly consist of abundant suspended microparticulate matter and also associated with other gaseous pollutant. During the haze occasion in 1997, study shows the PM_{10} concentration has increased four times higher in Klang and 20 times more in Kuching in comparable to the Malaysian Air Quality Guideline 1989 (Awang *et al.*, 2000).

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