

Observed atmospheric total column ozone distribution from SCIAMACHY over Peninsular Malaysia

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Abstract. The increase in atmospheric ozone has received great attention because it degrades air quality and brings hazard to human health and ecosystems. The aim of this study was to assess the seasonal variations of ozone concentrations in Peninsular Malaysia from January 2003 to December 2009 using Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY). Level-2 data of total column ozone WFMD version 1.0 with spatial resolution $1^\circ \times 1.25^\circ$ were acquired through SCIAMACHY. Analysis for trend of five selected sites exhibit strong seasonal variation in atmospheric ozone concentrations, where there is a significant difference between northeast monsoon and southwest monsoon. The highest ozone values occurred over industrial and congested urban zones (280.97 DU) on August at Bayan Lepas. The lowest ozone values were observed during northeast monsoon on December at Subang (233.08 DU). In addition, the local meteorological factors also bring an impact on the atmospheric ozone. During northeast monsoon, with the higher rate of precipitation, higher relative humidity, low temperature, and less sunlight hours let to the lowest ozone concentrations. Inversely, the highest ozone concentrations observed during southwest monsoon, with the low precipitation rate, lower relative humidity, higher temperature, and more sunlight hours. Back trajectories analysis is carried out, in order to trace the path of the air parcels with high ozone concentration event, suggesting cluster of trajectory (from southwest of the study area) caused by the anthropogenic sources associated with biogenic emissions from large tropical forests, which can make important contribution to regional and global pollution.

1. Introduction

Ozone is considered to be secondary pollutant and plays an important role in atmosphere heating rates due to its good capability to absorb harmful ultraviolet (UV) radiation from the sun. Most ozone resides in the upper part of the atmosphere, which called the stratosphere, situated more than 10 km above Earth's surface. In stratosphere, about 90% of atmosphere ozone is contained in the "ozone layer". The remaining of about 10% for the atmospheric ozone exists in the troposphere. The troposphere extends from the Earth's surface to the tropopause at 10-18 km, in which human live and emit chemicals compound due to anthropogenic activity of human [1]. In the troposphere, the major sources and sinks are the surface dry deposition, photochemical interaction (production or destruction), and the air mass exchange between troposphere and stratosphere [2, 3].

Recently, climate change becomes a hot issue to be discussed vastly whole the world. The abrupt change in global greenhouse gases in the atmosphere can bring the impacts on climate change. Due to the absorption by ozone on the infrared radiation, it can significant enhance the greenhouse effect with the relatively small change of ozone concentrations in the atmosphere [4]. In the atmosphere, solar irradiance, aerosols, and greenhouse gases are the important variables that control the climate [5]. Greenhouse gases include water vapor, carbon dioxide (CO₂), methane (CH₄), O₃, and nitric acid

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(N₂O). Ozone in the Earth's atmosphere is the major absorbent for infrared radiation and contributes for 3-7 % of greenhouse effect.

From many researches and investigations done for the ozone concentrations in the atmosphere, the results showed that the concentration of ozone in the Earth's atmosphere is altering. Over the past century, there is a good agreement based on the rise in background levels. However, in recent decades, the observations showed that there was a divergent trend in tropospheric ozone over the globe, especially in the north hemisphere [6]. Satellite remote sensing is one of the most effective approaches to monitor the distributions of greenhouse gases in global scale with very high spatial temporal resolution [7]. It provides an alternative way, in order to evaluate the influence of human anthropogenic activity on the climate change. The free download satellite scanning imaging absorption spectrometer for atmospheric chartography (SCIAMACHY) onboard the ENVISAT data makes it as useful space instrument for observing the Earth's greenhouse gases concentrations.

2. Study area and methods

The study area of Peninsular Malaysia is located within latitudes 1° to 7° north and longitudes 99° to 105° east, where located in South-East Asia (south of Thailand, north of Singapore and east of the Indonesian island of Sumatra). Area of Peninsular Malaysia is approximately 131587 km², with an estimated population of 21 million [8] (Fig. 1). There were totally five sites have been selected and presented in Table 1.

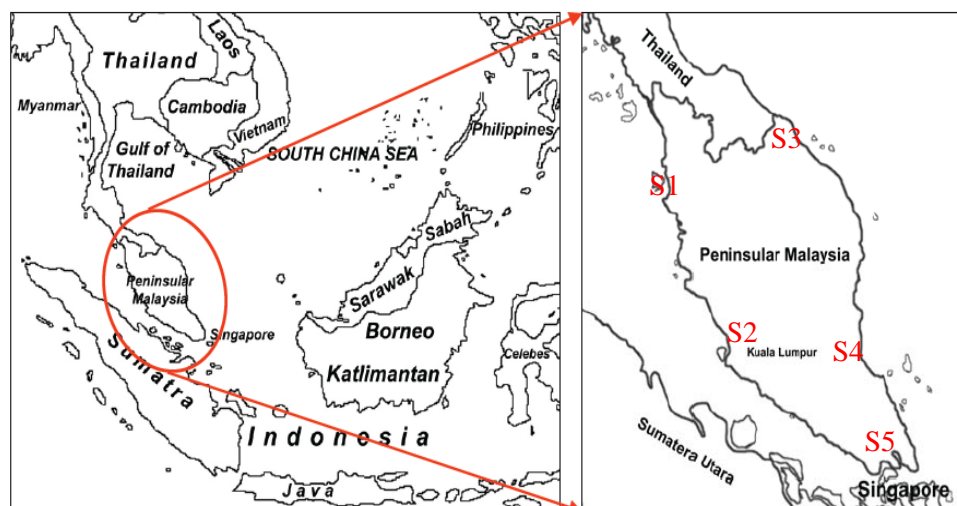


Figure 1. The geographical features of the study area.

Table 1. Location and description of selected sites in Peninsular Malaysia.

Selected site	Location	Longitude
S1	Bayan Lepas, Penang	100°17'24.39" E
S2	Subang, Selangor	101°33'6.71" E
S3	Kota Bharu, Kelantan	102°15'08.16" E
S4	Kuantan, Pahang	103°19'26.53" E
S5	Johor Bahru, Johor	103°45'15.93" E

Peninsular Malaysia enjoys a humid tropical climate throughout the entire year; the weather is warm and humid and the temperature ranging from 20°C to 32°C [9]. It is much influenced by the mountainous topography and complex land-sea interactions. Intraseasonal and interdecadal fluctuations such as the El Niño-Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), and Madden Julian Oscillation (MJO) are known to significantly influence the interannual climate variability of Malaysia. For the monthly average temperature, from April to May and July to August will be the month with the highest average temperature and it's occur in most place. While the lowest average monthly temperatures occur from November-January.

In Peninsular Malaysia, the mean monthly humidity falls within a range 70% to 90%, varying due to the different locations and different months [10]. Peninsular Malaysia experiences two rainy seasons throughout the year, due to the effect of Northeast Monsoon (NEM) from November to February and the Southwest Monsoon (SWM) from May to August [11]. Normally, near the end of the year during the early NEM, maximum rainfall occurs in most of the areas. The lowest monthly rainfall occurs in February, and the highest monthly rainfall occurs in December [12].

For the purpose of investigate and analysis the ozone distribution over Peninsular Malaysia region, daily retrieved ozone data from SCIAMACHY for seven years period were chosen. This research has been carried out for seven years from 2003 to 2009 with the average monthly ozone results in Peninsular Malaysia. The data (SCIAMACHY WFMD version 1 Level-2 products) acquired from WFMD, was developed by Institute of Environmental Physics (IUP), University of Bremen [13]. The SCIAMACHY WFMD version 1 Level-2 product contains the gridded data at daily with the resolution of $1^\circ \times 1.25^\circ$.

The atmospheric ozone coupled with backward trajectory simulations from Hybrid Single-particle Lagrangian Integrated Trajectory (HYSPLIT) model is useful to study and analyze the air mass arriving the study site. The HYSPLIT 4.9 Model [14] developed by the National Oceanic and Atmospheric Administration (NOAA) Air Resource Laboratory (ARL) was used to identify the source regions for the days on which the transport is suspected. The trajectory ensemble model simulations on selected SWM and NEM were used to determine the origin of the air masses and pollutants that arrive at the sampling site. The meteorological input for the trajectory model was the National Weather Service's National Centers for Environmental Prediction (NCEP) GDAS (Global Data Assimilation System) dataset. The analysis was performed with the GDAS meteorological dataset and the starting time of 0000 UTC, with the total run time of 96 hrs.

3. Results and discussion

Fig. 2 (a), (b), (c), (d) and (e) show the average monthly of ozone from 2003-2009 for five locations: Bayan Lepas, Subang, Kota Bharu, Kuantan, and Johor Bahru, respectively. The ozone experienced various seasonal variations, which depends on weather conditions and topography, and shows maxima in 2004 and minima in 2009 for all the observed stations. Monthly mean baseline levels of ozone at Bayan Lepas reached a peak of 280.97 Dobson Unit (DU) in August 2004, 280.52 DU in July 2004 at Kota Bharu, 279.64 DU in August 2004 at Subang, 278.64 DU in July 2004 at Johor Bahru, and 278.40 DU in September 2004 at Kuantan. However, the month that shows the lowest range of ozone at every station in December 2009, with 241.21 DU at Kota Bharu, 237.95 DU at Bayan Lepas, 236.14 DU at Johor Bahru, 233.82 DU at Kuantan, and 233.08 DU at Subang, respectively. There was a strong variations of the ozone fluctuated between NEM and SWM caused by seasonal variations. For all the selected sites, the concentration of ozone is highest during summer monsoon or SWM, followed by inter-monsoon season (April and October) and observed the lowest concentration during winter monsoon or NEM.

Ozone has a positive relationship with temperature and wind speed and inverse relationship with precipitation and relative humidity [15]. Ozone shows maximum value during SWM because of Peninsular Malaysia experienced highest temperature at most of the area. In addition, during this season, there are an increasing number of sunny hours, where it reached the highest rates in May with 8.7 hours/day). In most of the areas in Peninsular Malaysia, maximum rainfall occurs near the end of the year. Nevertheless, there is a second maximum rainfall during the inter-monsoon months (April and October). The highest monthly rainfall occurs in December, and the lowest monthly rainfall occurs in February [12]. During raining day, the tropical regions have a thick cloud, which means little ultraviolet radiation. Therefore, there is less ozone formation during raining day [10].

In 2004, ozone concentrations exceeded 280 DU in Bayan Lepas and Kota Bharu, and reach 279.64 DU in Subang. Strong winds during monsoon season, ozone can be transported and propagated by the long distances to the monitoring stations [16]. There was a drastic increase of ozone values during SWM in 2006 due to air pollution emissions from anthropogenic sources associated with biogenic emissions from forest fires in Sumatra and Kalimantan, Indonesia [17].

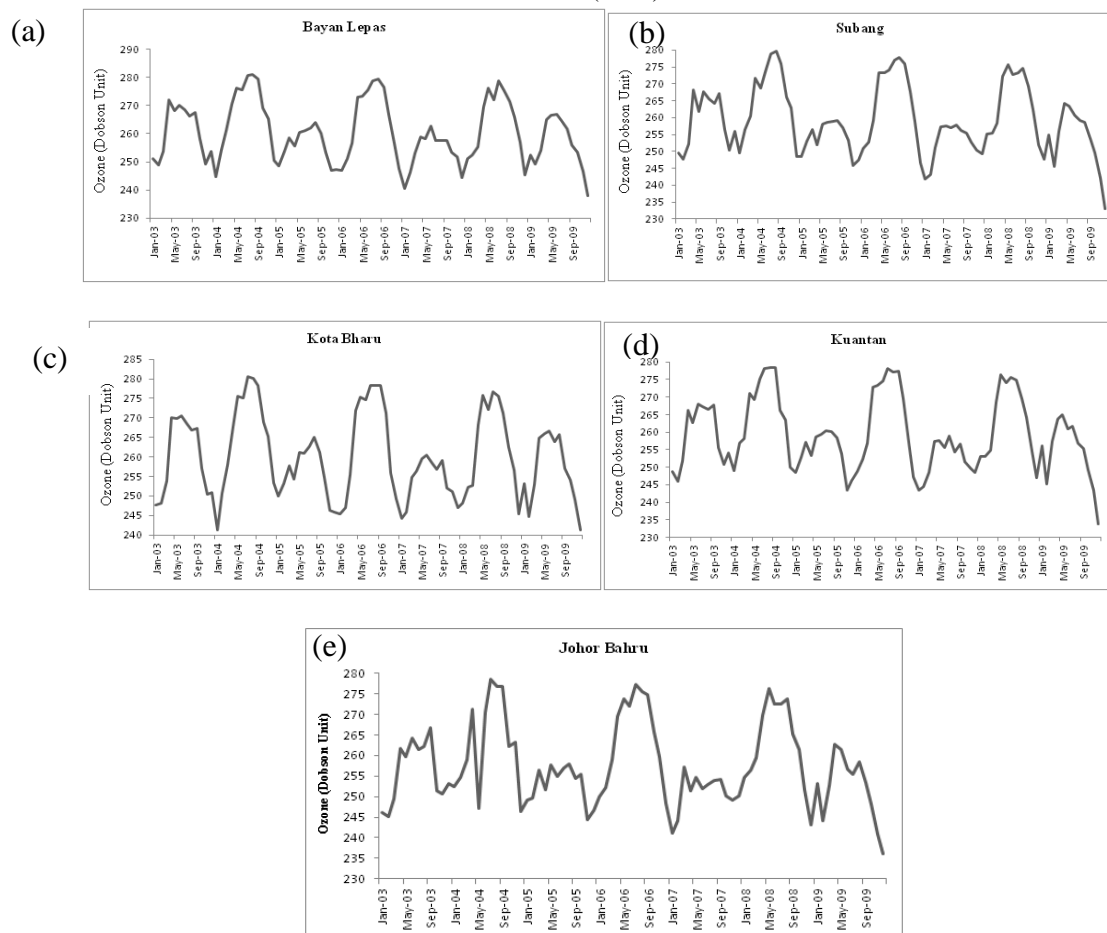


Figure 2. Monthly averaged ozone between 2003-2009 for (a) Bayan Lepas, (b) Subang, (c) Kota Bharu, (d) Kuantan, and (e) Johor Bahru.

The origin of air quality in Peninsular Malaysia is analyzed using HYSPLIT backward trajectories. The case studies are divided into two categories, namely the biomass burning period during the SWM and the NEM. Each HYSPLIT backward trajectory was calculated for 96 hours with the GDAS meteorological dataset and the starting time of 0000 UTC simulates multiple trajectories from the selected starting location. Fig. 3(a) and (b) demonstrate the typical trajectories of the background air masses of Peninsular Malaysia for cases of southwest and northeast monsoons, respectively. As the northeastern monsoon prevails, cold air outbreaks from Siberia high and spread to equatorial region in the form of northeasterly cold surge winds around the low-level anticyclones over South East Asia. Inversely, the air masses from southwesterly contribute for long range of air pollutant, including ozone due to transportation of pollutants by wind during SWM associated with biomass burning in Sumatra, Indonesia.

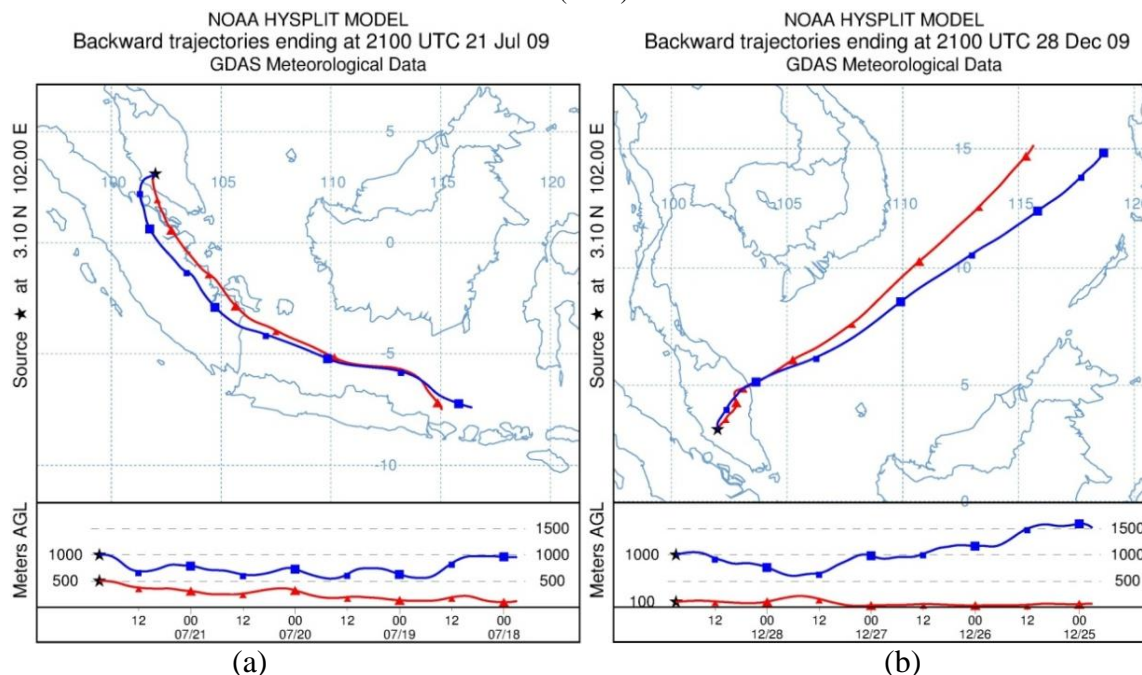


Figure 3. Typical trajectories of background air masses arriving in Peninsular Malaysia in case of (a) SWM, and (b) NEM.

4. Conclusion

This paper focuses on the study of monthly distribution of diurnal total column ozone in Peninsular Malaysia based on satellite (SCIAMACHY) data. As demonstrated here, SCIAMACHY monthly views of ozone through the study area successfully identify both the spatial and temporal variations, especially in the visualization of subsequent transport and emissions. The analysis of ozone above five selected sites in the study area show the seasonal variations in the ozone fluctuated considerably observed between NEM and SWM. The highest atmospheric ozone was observed during SWM. It was due to the increasing of temperature and number of sunshine hours over the study area. Furthermore, the impact of forest fires on ozone pollution enhance the concentrations of ozone in atmosphere. Inversely, the lowest ozone concentrations were observed during NEM because of highest raining month, low temperature, few sunshine hours, and high relative humidity.

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