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The influence of meteorological factors and biomass burning on surface ozone concentrations at Tanah Rata, Malaysia

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HIGHLIGHTS

► Overall ozone mixing ratios are low, with seasonal averages of 14.2–19.1 ppb.
► High temperature, low RH and minimum rainfall favour the formation of high O_3 levels.
► Diurnal variation is characterized by an afternoon maximum and a night time minimum.
► High O_3 on 07 August 2006 is mainly due to regional transport from biomass burning.
► Meteorological conditions and long range transport have elevated O_3 on 24 Feb 2008.

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ABSTRACT

The surface ozone concentrations at the Tanah Rata regional Global Atmosphere Watch (GAW) station, Malaysia (4°28′N, 101°23′E, 1545 m above Mean Sea Level (MSL)) from June 2006 to August 2008 were analyzed in this study. Overall the ozone mixing ratios are very low; the seasonal variations show the highest mixing ratios during the Southwest monsoon (average 19.1 ppb) and lowest mixing ratios during the spring intermonsoon (average 14.2 ppb). The diurnal variation of ozone is characterised by an afternoon maximum and night time minimum. The meteorological conditions that favour the formation of high ozone levels at this site are low relative humidity, high temperature and minimum rainfall. The average ozone concentration is lower during precipitation days compared to non-precipitation days. The hourly averaged ozone concentrations show significant correlations with temperature and relative humidity during the Northeast monsoon and spring intermonsoon. The highest concentrations are observed when the wind is blowing from the west. We found an anticorrelation between the atmospheric pressure tide and ozone concentrations. The ozone mixing ratios do not exceed the recommended Malaysia Air Quality Guidelines for 1-h and 8-h averages. Five day backward trajectories on two high ozone episodes in 07 August 2006 (40.0 ppb) and 24 February 2008 (45.7 ppb) are computed using the HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model to investigate the origin of the pollutants and influence of regional transport. The high ozone episode during 07 August 2006 (burning season during southwest monsoon) is mainly attributed to regional transport from biomass burning in Sumatra, whereas favourable meteorological conditions (i.e. low relative humidity, high temperature and solar radiation, zero rainfall) and long range transport from Indo-China have elevated the ozone concentrations during 24 February 2008.

1. Introduction

Although present only in trace amounts, ozone (O_3) is an important atmospheric constituent because it plays a key role as both an oxidant and a greenhouse gas. The Intergovernmental Panel on Climate Change (IPCC, 2001) has reported that tropospheric ozone is the third most important greenhouse gas after carbon dioxide and methane. At ground level, ozone is a harmful

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secondary pollutant and has adverse impacts to human health and ecosystem.

The sources of tropospheric ozone are photochemical production by the interaction of sunlight with nitrogen oxides (NO_x), carbon monoxide (CO) and volatile organic compounds (VOCs); and the transport of ozone from the stratosphere to troposphere (Duenas et al., 2004; Cristofanelli and Bonasoni, 2009).

Ozone is also a main ingredient of urban smog. Hence, the surface ozone conditions over urban areas are a primary focus of most research in Asia (e.g., Deng et al., 2008; Shan et al., 2008; Ahammed et al., 2006; Pulikesi et al., 2006). The diurnal variations in ozone show a typical pattern for polluted urban areas in Nanjing and Jinan, China characterized by high concentrations during daytime and low concentrations during late night and early morning (Tu et al., 2007; Shan et al., 2008). In New Delhi, India, the seasonal variation shows maximum ozone in summer and autumn months and minimum ozone in the wet seasons (Jain et al., 2005). Whereas in Nanjing, China, Tu et al. (2007) found that maximum ozone is observed in late spring and early summer; and an ozone minimum is observed in late autumn and winter.

Although urban and suburban areas have high levels of surface ozone, many rural areas are also exposed to high ozone levels as pollutants are transported away from their original sources (Wang et al., 2006; Kalabokas et al., 2008).

Ozone, a secondary pollutant, forms as a result of biomass burning because combustion products are ozone precursors in the atmosphere and biomass burning also leads to the formation of aerosol particles. Previous studies have shown that biomass burning emissions can contribute to elevated ozone concentrations at regions away from the origin of the sources (e.g., Jaffe et al., 2004; Boian and Kirchhoff, 2005; Shan et al., 2009). Surface ozone enhancements were observed over a non-source region of biomass burning in the state of Parana, Brazil when the anticyclonic circulation was well defined and the air masses came from significant source regions of biomass burning (Boian and Kirchhoff, 2005).

Meteorology plays an important role in the formation, dilution, dispersion and transport of air pollutants. The relationship between meteorology and air pollution has gained a lot of attention from the scientific community and extensive studies are carried out around the world on the effects of meteorological conditions on the trends and variations of ozone concentrations in Europe (e.g., Kalabokas et al., 2008; Cristofanelli and Bonasoni, 2009), North America (e.g., Vukovicha and Sherwell, 2003; Camaliera et al., 2007) and Asia (e.g., Debaje et al., 2003; Shan et al., 2008). Most studies show that the ozone concentration has a positive correlation with temperature and a negative correlation with relative humidity (e.g., Shan et al., 2008; Tu et al., 2007). High ozone levels are often associated with intense solar radiation, high temperature, less or minimum rainfall, low wind speed and low relative humidity (e.g., Pulikesi et al., 2006; Cheung and Wang, 2001; Jain et al., 2005).

The tropic is a crucial region for tropospheric chemistry; about 80% of the oxidation of the greenhouse gas methane (CH_4) occurs in the tropics (e.g., Bloss et al., 2005). However, there are only a few studies on seasonal and temporal variations of surface ozone and related meteorological factors in Southeast Asia and the tropical region. Sandroni and Anfossi (1994) found that during the 19th century, the ozone levels at tropical latitudes measured using the Schönbein method were distinctly lower than at mid latitudes in both the Northern and Southern Hemispheres. The conclusion was made after taking into account the limitation of the Schönbein method and the accuracy of the procedure used to convert the historical data. The Schönbein method is based on the oxidation of potassium iodide on a test paper, see Sandroni and Anfossi (1994) for details. Bennet and Engardt (2008) simulated surface ozone for Southeast Asia. The model produced higher surface ozone concentrations than observed at all the non-remote stations studied but underestimated ozone concentrations during the dry season at remote locations. Ilyas (1987) presented the surface ozone concentrations in the island of Penang (5.5°N, 100°E) from 1980 to 1984 which is located in the northwestern state of Peninsular Malaysia. The study identifies significant variations to the typical diurnal behaviour depending upon weather conditions which undergo rapid changes over the period of a day.

The National Aeronautics and Space Administration (NASA) has conducted the East Asia/North Pacific Regional Study (APARE) Global Tropospheric Experiment (GTE) Pacific Exploratory Mission (PEM) – West in the western Pacific. The airborne measurements in October 1991 showed low ozone mixing ratios in the remote marine boundary layer of the tropical and equatorial Pacific Ocean with average ozone mixing ratios as low as 8–9 ppb at altitudes of 0.3–0.5 km in the boundary layer (Singh et al., 1996).

The "Oxidant and particle photochemical processes above a South-East Asian tropical rainforest" (OP3) project was carried out in Sabah, Malaysia where intensive measurements of atmospheric composition and chemistry were made in April–July 2008 (Hewitt et al., 2010). The ground based and airborne measurements showed that ozone values are relatively low (8–25 ppb) at the ground sites, boundary layer and free troposphere.

The Southeast Asia haze pollution is not only a local air pollution problem but also extends to a regional and global scale. Biomass burning in Indonesia is mainly due to the large amount of forest being converted to other uses such as plantation, transmigration programmes and agriculture has resulted in the release of massive amounts of thick and dense smoke that blanket the entire region including neighbouring countries such as Singapore, Malaysia, Brunei and Thailand in haze. Page et al. (2002) estimated that the 1997/1998 fires in Indonesia generated the equivalent of about 13–40% of the annual global average greenhouse gas emissions from land use change, calculated over the period 1989–1995. Indonesia has emerged as the world's third highest emitter of greenhouse gas emissions, behind the US and China.

Yonemura et al. (2002) concluded that the enhancement of tropospheric ozone over Singapore and Malaysia in 1997 was associated with the large scale burning in Southeast Asia combined with the effects of the El Niño event. Hyer and Chew (2010) used the Fire Locating and Monitoring of Burning Emissions (FLAMBE) smoke flux model and Navy Aerosol and Analysis System (NAAPS) model simulations. Their results indicated that biomass burning smoke contributed to nearly all of the extreme PM10 observations over Singapore and Malaysia during September–November 2006. Kita et al. (2000) suggested that the total column ozone increase over Indonesia during 1982–1983, 1987, 1991, 1994 and 1997 are associated with the forest fires during the dry season of the El Niño periods.

Several studies on air quality over Malaysia have been published but these are mainly focused on atmospheric acidity (Ayers et al., 2000), particles (Juneng et al., 2009) and total column ozone (Yonemura et al., 2002). This study analyses the meteorological effects on diurnal, monthly and seasonal variations of surface ozone concentrations using ozone, meteorological parameters and particulate matter (PM10) data measured at the Tanah Rata regional Global Atmosphere Watch (GAW) Station from June 2006 to August 2008. This study complements the currently available studies on surface ozone concentrations and contributes to a better understanding of the effects of meteorological conditions on the trends of surface ozone concentration in the Southeast Asia tropical region which are strongly associated with the monsoons.