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Seasonal and long term variations of surface ozone concentrations in Malaysian Borneo

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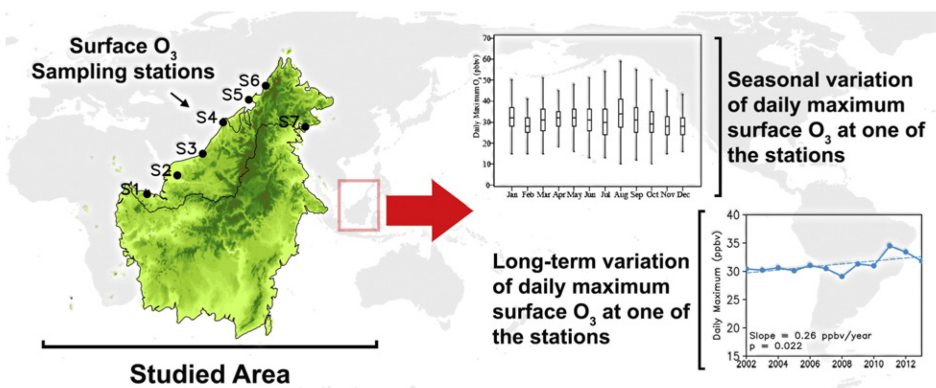
HIGHLIGHTS

- We determined the variation of surface O_3 concentration in Malaysian Borneo.
- Hourly surface O_3 data covering the period 2002 to 2013 were analysed.
- High surface O_3 recorded at station located near petrochemical industries.
- Seasonal wind influence origin of O_3 precursors and hence O_3 concentration.

GRAPHICAL ABSTRACT



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ABSTRACT

Malaysian Borneo has a lower population density and is an area known for its lush rainforests. However, changes in pollutant profiles are expected due to increasing urbanisation and commercial-industrial activities. This study aims to determine the variation of surface O_3 concentration recorded at seven selected stations in Malaysian Borneo. Hourly surface O_3 data covering the period 2002 to 2013, obtained from the Malaysian Department of Environment (DOE), were analysed using statistical methods. The results show that the concentrations of O_3 recorded in Malaysian Borneo during the study period were below the maximum Malaysian Air Quality Standard of 100 ppbv. The hourly average and maximum O_3 concentrations of 31 and 92 ppbv reported at Bintulu (S3) respectively were the highest among the O_3 concentrations recorded at the sampling stations. Further investigation on O_3 precursors show that sampling sites located near to local petrochemical industrial activities, such as Bintulu (S3) and Miri (S4), have higher NO_2/NO ratios (between 3.21 and 5.67) compared to other stations. The normalised O_3 values recorded at all stations were higher during the weekend compared to weekdays (unlike its precursors) which suggests the influence of O_3 titration by NO during weekdays. The results also show that there are

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distinct seasonal variations in O_3 across Borneo. High surface O_3 concentrations were usually observed between August and September at all stations with the exception of station S7 on the east coast. Majority of the stations (except S1 and S6) have recorded increasing averaged maximum concentrations of surface O_3 over the analysed years. Increasing trends of NO_2 and decreasing trends of NO influence the yearly averaged maximum of O_3 especially at S3. This study also shows that variations of meteorological factors such as wind speed and direction, humidity and temperature influence the concentration of surface O_3.

1. Introduction

Surface ozone (O_3) is a major air pollutant that impacts human health, materials and vegetation (Anenberg et al., 2009; Ishii et al., 2007; Lee et al., 1996). Studies by Levy et al. (2005) and Bell et al. (2014) have shown that O_3 can contribute to higher mortality, especially for elderly people. Several studies, such as West et al. (2006); Jerrett et al. (2009); Guo et al. (2014) and Yang et al. (2014) have indicated that high concentrations of surface O_3 can cause cardiovascular and respiratory dysfunction. The impact of O_3 on human health was found to be further influenced by increasing temperature (Ren et al., 2008). High concentrations of O_3 also damage materials, such as surface coatings and rubber goods, and plants, via membrane damage on leaves therefore affecting the photosynthesis processes (Chaudhary and Agrawal, 2015; Lee et al., 1996). Studies have also shown that surface O_3 can reduce the yield of certain food crops such as paddy-grown rice and grain (Amin, 2014; Debaje, 2014; Ghude et al., 2014; Van Dingenen et al., 2009; Wang and Mauzerall, 2004).

The change of land use from forest to agricultural, residential and urban use has created a change in the O_3 precursor environment, which can be seen clearly between urban and rural areas (Kulkarni et al., 2016; Tu et al., 2007; Xie et al., 2016). This phenomenon usually leads to the formation of high concentrations of O_3 downwind and in suburban areas due to increased concentrations of O_3 precursors generating high concentrations of O_3 (An et al., 2015; Latif et al., 2012). The high intensity of sunlight in tropical regions are conducive for O_3 formation (Ahamad et al., 2014; Awang et al., 2016a; Banan et al., 2013; Latif et al., 2012). Motor vehicles and industrial activities are the main sources of O_3 precursors such as NOx and CO (Vingarzan, 2004; Xie et al., 2016). Areas with high volumes of vehicles have increased NO levels, which can then produce high concentrations of NO_2. The transport of NO_2 downwind will release O radicals which will then interact with O_2 to form O_3. At the same time, high concentrations of NO will effectively titrate O_3 in urban areas. Volatile organic compounds (VOCs) are other precursors of O_3 that can be emitted from anthropogenic as well as natural sources (Shao et al., 2016; Tie et al., 2006). Forest areas have been found to contribute to the high levels of VOCs; an example is isoprene which can transform to other organic peroxides and then contribute to enhanced concentrations of the O radical (Stavrakou et al., 2014; Taraborrelli et al., 2012). The combination of anthropogenic and biogenic O_3 precursor species usually leads to high concentrations of O_3 in the areas between highly populated urban centres and more forested or rural areas.

The island of Borneo is internationally recognised for its extensive, diverse and relatively untouched environment. The expansion of urban areas due to increasing population has changed the landscape of this island. However, agricultural activities are still the main economic generators for this area. Information on O_3 and precursor trends could indicate the potential need for mitigation measures. Studies by Sicard et al. (2013) and Sicard et al. (2016) for example, have analysed pollutant trends to evaluate effectiveness of O_3 control measures and determine more suitable standards for human health and environmental protection. This study aims to determine the variations, particularly seasonal cycles and long term changes of surface O_3 in Borneo based on long term observational data provided by the Malaysian Department of Environment (DOE). The concentration of surface O_3 in relation to concentrations of O_3 precursors such as NO_x, CO and VOCs as well as other meteorological factors, such as wind speed and direction, UV radiation, humidity and temperature were analysed.

2. Methodology

2.1. Study area

Borneo is the largest island in Asia and home to one of the oldest rainforests in the world. The island is divided among three countries, Malaysia and Brunei in the north and Indonesia to the south. In the north, the East Malaysian states of Sabah, Sarawak and the federal territory of Labuan make up about 26% of the island. Kalimantan is located in the southern part of Borneo and belongs to Indonesia. Most major towns in Borneo are located in coastal areas due to the mountainous setting in the middle of the island. During the dry season, especially between January and March, and between July and September every year, biomass burning from peat swamp areas usually affects the air quality over Borneo.

This study analysed the variation of O_3 concentrations recorded at stations managed by Alam Sekitar Sdn Bhd (ASMA), a company which measures the air quality status on behalf of the Malaysian DOE in the Malaysian Borneo. Seven air quality stations in different areas around North Borneo had been chosen based on the availability of the O_3 air quality data during the study time period (Fig. 1). Kuching station (S1) is located at a medical store in Pending Industrial Estate, Kuching, Sarawak. This area is located on the outskirts of Kuching city. Sibu station (S2) is located at the Sibu Police Headquarters, close to the roadside in the city centre of Sibu. Both Kuching and Sibu stations are in busy areas with high volume of motor vehicles going in and out of the industrial areas, particularly during the rush hour. Bintulu station (S3) is located at the Bintulu Police Headquarters, on the outskirts of Bintulu city centre. The station is close to a less busy road next to a river, while to the north is an industrial area dominated by petrochemical industries (Liquid Natural Gas). Miri station (S4) is located in a school compound in the city centre of Miri near to a busy road. Miri is also located near to the border of Brunei. Both Miri and Brunei have extensive petroleum-related industries in the area. Labuan station (S5) is located in a housing area in centre of the Labuan Island. The station is located in the north of Labuan city. This station is expected to have less influence from motor vehicles compared to other stations. Kota Kinabalu station (S6) is located in a school compound in Putatan, a small town to the south of Kota Kinabalu city centre. The air quality is expected to be affected by the expansion of Kota Kinabalu city towards the south, including Putatan town. The number of motor vehicles during rush hour may influence the level of air pollutants at the station. Tawau station (S7) is located in a residential area of Tawau on the east coast of Sabah. The station located to the east of Tawau city centre which is one of the main towns on the east coast of Sabah. Detailed locations of the sampling points are presented in Supplementary 1.

2.2. Ozone and other parameter data collection

The air pollution data recorded at the ASMA stations between January 2002 and December 2013 includes the hourly average of surface O_3 concentrations, oxides of nitrogen (NO and NO_2), and carbon monoxide