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Air quality in Singapore during the 2013 smoke-haze episode over the Strait of Malacca: Lessons learned

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ABSTRACT

The widespread wildfires that raged across Indonesia's island of Sumatra in June 2013 triggered the worst air pollution episode ever recorded in Singapore. The highest 24-h moving average $PM_{2.5}$ concentration reported by the authorities reached a whopping 310 $\mu g\,m^{-3}$ on June 20, 2013. However, a top 3-h moving average Pollutant Standard Index (PSI) of 401 (index ceiling is 500) based only in PM_{10} concentration data occurred the following day, and a maximum 24-h moving average PSI of 246 with an associated 24-h PM_{10} concentration of 382 $\mu g\,m^{-3}$ was reported on June 22, 2013. The decoupling between these air quality health advisories evidences the flaw in informing to the public on the hour when the air quality was at its worst. Up until now, despite the positive changes on the public dissemination of air quality information, the real hourly pollution levels experienced in Singapore during the 2013 smoke-haze episode are still unknown. To unveil the hourly $PM_{2.5}$ concentrations this work applies a set of statistical models to the available air quality data during the episode and the lately 1-h $PM_{2.5}$ concentration records published since April 2014 on a day-by-day bases. Results suggest maximum likelihood hourly $PM_{2.5}$ concentrations over 600 $\mu g\,m^{-3}$, twice the maximum 24-h moving average reported by the authorities.

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1. Introduction

Smoke-haze is a term used in Southeast Asia for large-scale plumes of airborne pollutants associated with wildfires. In the past these fires were created by the own nature as a cyclical response to rejuvenate and strengthen its different ecosystems. The Strait of Malacca is prone to natural fires on years affected by climate anomalies. Anomalous dry years occur when cold sea surface temperature in surrounding seas suppress local convection. Moisture becomes transported westward to the Indian Ocean as a consequence of the warm waters in the eastern Pacific Ocean and western Indian Ocean under the climate anomalies of El Niño Southern Oscillation and Indian Ocean Dipole (Field, van der Werf, & Shen, 2009).

Historically, severe biomass burning episodes have occurred in the islands of Sumatra and Borneo in Indonesia at least since the 1960s with pronounced regional impacts on air quality (Field et al., 2009). Their frequency and intensity has unfortunately increased during the last three decades, becoming almost an annual occurrence as a consequence of aggressive deforestation and agricultural expansion. In addition to the wildfires, anthropogenic forces such as the growing urbanization and economic activities (i.e., agribusinesses, refineries, energy production, shipping and industry) have also been responsible in the degradation of the air quality of the region and add to the intensity of the smoke-haze events.

Despite 2013 being a year with limited climate anomalies, the combination of a two-month dry weather in the region along with widespread anthropogenic land-clearing fires in central Sumatra shaded off the visibility and air quality of Singapore and peninsular Malaysia to unprecedented levels during the last two weeks of June of that year (Fig. 1). The concentrations of airborne particles, PM_{10} and $PM_{2.5}$ (particles with aerodynamic diameters $\leq$10 and 2.5 μm) recorded their highest levels. The 24-h moving average concentrations of the smaller particles reported by the National Environmental Agency (NEA) of Singapore were alarming given that they can be inhaled and retained into the respiratory system becoming a major health risk. Scientific evidence has shown associations between exposure to those particles and health symptoms such as premature mortality, cardiovascular and respiratory diseases, and lung cancer (Davidson, Phalen, & Solomon, 2005; Heal, Kumar, & Harrison, 2012).

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Fig. 1. Sky view of a neighbourhood in Singapore. (a) The peak of the smoke-haze episode in June 21, 2013. (b) A normal day after the smoke-haze episode.

On June 20, 2013, Singapore had its highest ever recorded 24-h moving average $PM_{2.5}$ concentration. Compared to the World Health Organization (WHO) guideline of 25 $\mu g\,m^{-3}$ (WHO, 2006), $PM_{2.5}$ concentration reached a whopping 310 $\mu g\,m^{-3}$ with a corresponding 3-h moving average Pollutants Standard Index (PSI) of 231 (index ceiling is 500). On the following day, the highest 3-h moving average PSI was recorded at 401 and the 24-h moving average $PM_{2.5}$ concentration was at 302 $\mu g\,m^{-3}$. Due to the decoupling of these two air quality indicators and the restrictions imposed by the authorities on reporting the 1-h $PM_{2.5}$ concentrations at the time, the citizens of Singapore started to question the authorities on the relevance, timelines and transparency of the city's air quality health advisory indicators. Ten months after (April 2014), the authorities started to publish the 1-h $PM_{2.5}$ concentration data, on a day-by-day bases but without the ability for the public to retrieve previous day records, let alone the 2013 record high concentrations.

With the aim of providing scientific support to the public demand for access to disaggregated and timely air quality data, this work makes use of the hourly 24-h moving average concentrations reported at the time of the smoke-haze episode of June 2013 and the lately published 1-h $PM_{2.5}$ concentration data and relevant statistical methods to impute the maximum likelihood hourly $PM_{2.5}$ concentration in Singapore during such episode that blanketed the whole island and triggered air pollution levels to record highs. The article expects to shed light on the importance of transparency and reporting short term hourly air quality records along with their moving average estimates, especially for $PM_{2.5}$ that has severe public health impacts.

Before introducing the methodology used to estimate the 1-h $PM_{2.5}$ likelihood concentrations, the article reviews briefly the underlying economic causes of the fires and some of the positive responses by the regional and Singapore authorities during and after the smoke-haze episode of 2013. A detailed description of the public access to air quality data before, during and after the episode in Singapore is also presented. The information from the 24-h moving average concentration data and PSI records reported by the authorities at the time of the episode are analysed pointing out their decoupling. Then, the set of numerical, stochastic and statistical models applied to the air quality data collected by the authors day after day from NEA's website is introduced. The obtained minimum and maximum likelihoods of the 1-h $PM_{2.5}$ concentrations are presented and analysed along the reported 24-h moving average $PM_{2.5}$ concentrations during the peak of the smoke-haze episode. The article closes with some lessons learned to be better prepared for when the smoke-haze returns.

2. Clearing land by burning: The cause of the wildfires

Logging and burning land for plantation, legally and illegally, creates employment for most of the less fortunate population of the region. The oil palm and pulpwood industries have largely flourished due to the limited employment in other sectors of the regional economy. These agribusinesses have growth at the expense of losing forests in peatlands. Peatlands are swamplands with carbon-rich soil (Page et al., 2009). Although peat forests are resilient to fires, once cleared and drained to make room for plantation they become fire-prone (Page et al., 2009). Fires in deforested peatlands tend to smoulder underground for weeks even after surface fires are fully extinguished (Usup, Hashimoto, Takahashi, & Hayasaka, 2004).

Based on a study by Gaveau et al. (2014), during the peak of the 2013 smoke-haze episode (June 18–24, 2013), satellite data and land ownership maps showed over 160,000 ha of burned land in Sumatra with over 80% being deforested peatlands. Of the total burned area at least 50% was located in lands under concession to private companies or local communities for plantation development. Although both, companies and communities claim to follow strict non-burning policies, the fact remains that clearing land by burning is yet common and largely applied since it is the most economical method (Gaveau & Mohammad, 2013). It may be of interest to note that the headquarters of many of these plantations are located in the more affluent neighbouring countries of the region, hence ironically contributing to the import of air pollutants to own local environments.

3. The regional response to the smoke-haze

Although the people of Sumatra are cyclically exposed to episodes of poor air quality as consequence of the wildfires, the high levels of air pollution recorded by their neighbours in Singapore and Malaysia in June 2013 raised the attention of the authorities over regional transboundary air pollution. In response, only a month after the record-high episode five countries of the Association of Southeast Asian Nations (ASEAN) namely Singapore, Malaysia, Brunei, Indonesia and Thailand, proposed a new regional fire monitoring and information system in which each member government needs to share data on plantation activities, including the name of companies and their concession boundaries. The objective of this new system would be to overlay concession maps with satellite images of ground fires (hotspots) to provide evidence for enforcement if needed (ASEAN, 2013).

The transboundary air pollution, natural and anthropogenic, has been in the ASEAN agenda since the eighties (Qadri, 2001). In 2002 the ASEAN Agreement on Transboundary Haze Pollution was signed (ASEAN, 2002). The agreement assigns, among other measures, Malaysia to oversee preventative measures, Indonesia to fire-fighting resources and Singapore to regional monitoring. It was not until September 2014 that Indonesia agreed to ratify the agreement (KLH-RI, 2014). The timing of such a positive response by Indonesia was due to the smoke-haze episode of 2013.

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