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Atmospheric impacts of Indonesian fire emissions: Assessing remote sensing data and air quality during 2013 Malaysian haze

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Abstract

The 2013 Malaysian haze event coincided temporally with rising trends of hotspots detected in Sumatra, Indonesia. Based on satellite remote sensing, air quality data and wind vector maps, our study aims to provide a preliminary assessment on the remote effects of Indonesian forest fires on the Malaysian haze. In order to locate and detect the occurrence of active fires in Sumatra, MODIS Active Fire Data was retrieved from NASA/LANCE – FIRMS for satellite imagery and analysis. Air quality at Petaling Jaya was assessed based on PM_{10} concentration and meteorological data provided by the Malaysian Meteorological Department. Wind vector maps for the Indian Pacific region were constructed with the NCEP/NCAR Reanalysis Product developed by NOAA-ESRL. In June, southwesterlies prevailed in the region and brought substantial amounts of particulate matter from Sumatra to Peninsular Malaysia, with Petaling Jaya being one of the most severely inflicted cities.

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*Keywords:*Haze; PM10; Active Fire Data; hotspot; forest fires

1. Introduction

Haze events have been plaguing Peninsular Malaysia in the summer monsoon season almost every year since 1983, with the 1997 and 2005 cases being the most severe outbreaks[1,2]. The recent most Malaysian haze occurred in 2013 severely diminished nationwide horizontal visibility as thick smoke blanketed Peninsular Malaysia. On 23 June 2013, a state of emergency was declared in two southern districts on the Peninsular Malaysia as the air pollution worsened to extremely hazardous levels unprecedented in Malaysian history[3].

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Extensive areas of land and forest grounds are cleared for palm oil plantations, leading to the recurrent problem of uncontrolled wildfires in Sumatra, Indonesia over the past few decades[4,5]. The ongoing problem stems from the agricultural roots of the nation[6]. The purpose of our study is to provide a preliminary assessment on the remote effects of Indonesian forest fires on the Malaysian haze. Particular emphasis will be on assessing satellite remote sensing over Sumatra and air quality data at Petaling Jaya. Wind vector maps will be constructed for monthly analysis of wind vector variation over the Indian Pacific region.

2. Methodology

2.1. Air quality data

Assessment of air quality at Petaling Jaya was performed based on concentration of particulate matter, PM_{10} provided by the Malaysian Meteorological Department. Measurements for air quality data were collected daily over a sampling period of 1 April to 31 August 2013. Daily PM_{10} concentrations were recorded using β-ray attenuation mass monitor (BAM-1020) as described in relevant studies[2,7,8]. As southern districts were most affected by the 2013 Malaysian haze[3], our study area has focused on Petaling Jaya (3° 06' N, 101° 39' E). Situated in the southern districtof Peninsular Malaysia, Petaling Jaya is a city where the highest loadings are concentrated[8]. In addition, PM_{10} data of Petaling Jaya are easily accessible and relatively well documented compared to other cities.

2.2. Satellite remote sensing

In order to locate and detect the occurrence of active fires in Sumatra, satellite remote sensing was employed to retrieve active fire data for hotspots coverage over the Central Sumatra basin. Satellite remote sensing retrievals were obtained using the Moderate Resolution Imaging Spectroradiometer (MODIS) from the Terra and Aqua satellite. MODIS Active Fire Data was requested from the NASA/LANCE – FIRMS to study the distribution of hotspots occurring in the designated polygon area. A polygon area was delineated to include Riau (0° 32′ N, 101° 27′ E) and Jambi (1° 35′ S, 103° 36′ E) province in Sumatra. Fire pixels in the active fire shapefile mark the center point location in which there is at least one fire activity occurring within 1km radius from the flagged pixel. Only hotspot counts with confidence level higher than 30% were included in this study.

2.3. Wind vector maps

Daily mean composites of wind vector were computed at an upper air analysis level of 925mb in the Indian Pacific region. The Indian Pacific region has been selected as our base map to fully capture the monsoonal wind patterns on a regional scale. It strategically depicts tropospheric flow patterns in the region where Indonesia and Malaysia are situated. For monthly analysis of wind vector variation, the daily mean composites were averaged and plotted into monthly wind vector maps from April to August 2013. A Cylindrical Equidistant projection was used to construct a mapping domain of 20 °N to 20 °S latitudes and 60 °E to 180 °W longitudes for our intended area of study. The maps were constructed with the NCEP/NCAR Reanalysis Product developed by NOAA-ESRL[9].

3. Results and Discussion

3.1 PM_{10} concentration at Petaling Jaya

The plot of PM_{10} concentration (Fig.1) is characterized by a peak concentration on 23 June 2013 during the dry summer monsoon. The prominent peak represents PM_{10} concentration reaching a record high of 290 $\mu g/m^3$. The abrupt peak in PM_{10} concentration is likely due to stronger transport energy in the atmosphere during summer monsoon season. Packets of atmospheric pollutants are lifted, suspended and transported away from the fire emission sources in Sumatra with greater amount of energy available.

PM_{10} variations at Petaling Jaya were influenced by the direction and strength of wind transport, in addition to the proximity of emission sources to the target area. Principal component analysis by Juneng et al.[8] has shown that PM_{10} concentration fluctuates seasonally in two timescale bands, with the largest variance found in summer.

Seasonal fluctuations as such are only apparent in timescales longer than one year. They are thus not observed in this study, especially when there are stronger anthropogenic forcings at work (i.e. emission sources in Sumatra).

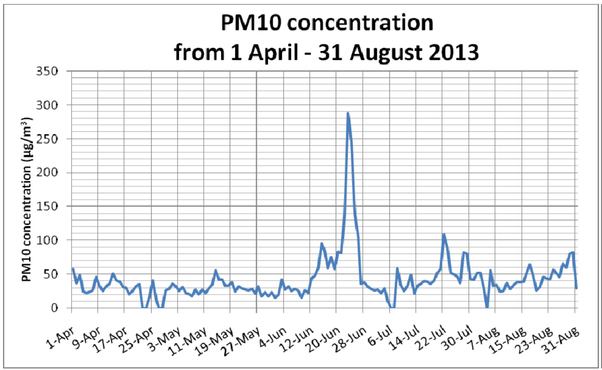


Fig. 1: PM_{10} concentration at Petaling Jaya.

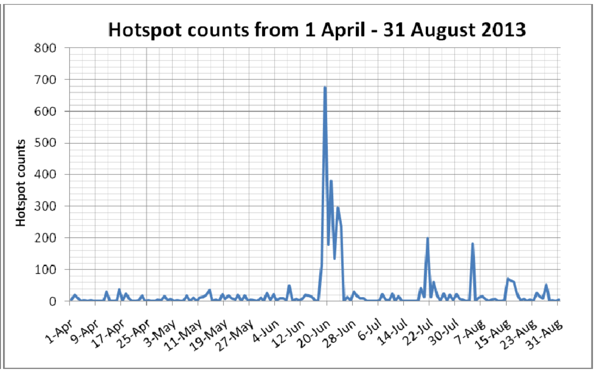


Fig. 2: Hotspot counts in Sumatra.

3.2 Hotspot counts in Sumatra

The hotspot counts (Fig. 2) show a prominent peak on 19 June 2013. As many as 676 fire activities were recorded in Sumatra on the same day. June 21 and June 23 had the second and third highest number of fire activity respectively. There is a time lag of 4 days between the highest peak on hotspot counts and the PM_{10} peak on 23 June 2013. The time lag could be related to the wind speed of southwesterlies in the region. Taking time lag into account, the peaking profile of hotspot counts seems to match well with that of PM_{10} concentration.

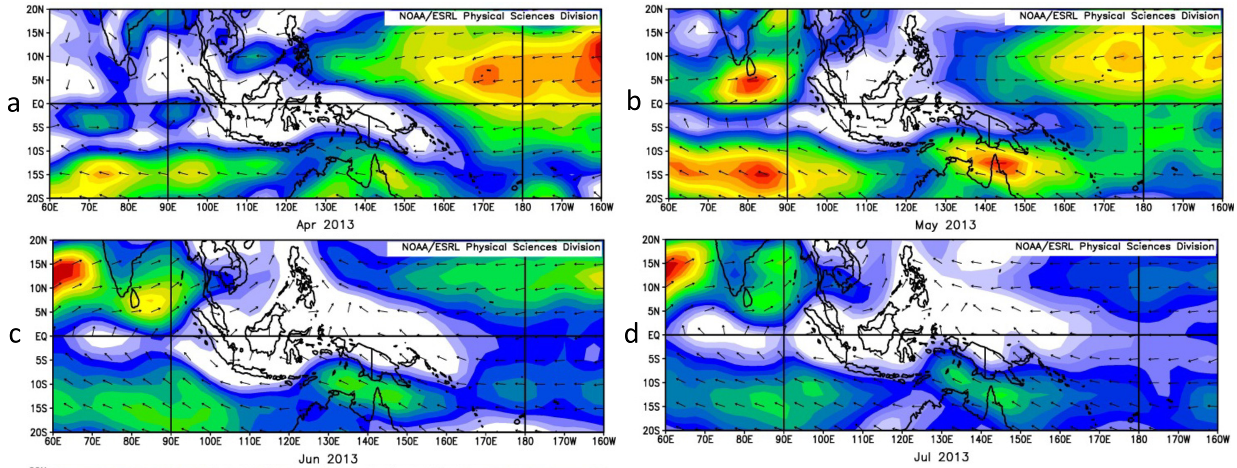
Fire activities in Sumatra were detected within 3 hours from their occurrence using MODIS. The resultant meteorological effects were, nonetheless not immediately felt on Peninsular Malaysia since particulates need time to travel from their emission sources in Sumatra. Long-range transport of particulates across the Straits of Melaka was further delayed by lower southwesterly wind speeds during the monsoon season. Previous studies on Malaysian haze episodes[2,10,11] have traced back sources of particulate matter to Sumatra using backward air mass trajectories. Our study presents new evidence for attributing PM_{10} variations at Petaling Jaya to foreign emission sources in Sumatra.

3.3 Wind vector maps in the Indian Pacific region

The wind vector maps (Fig. 3) show a weakening of the regional wind over the Indian Pacific region from April to May. This marks the arrival of inter-monsoon period at Peninsular Malaysia in late April and early May[7,8,10]. In June, southwesterlies trending in the northeast direction began to strengthen and gain intensity. The time when PM_{10} concentration peaked at Petaling Jaya matches well with the time when southwesterlies prevailed at Malaysia. The southwestern monsoon flow was strengthened by a south to north pressure gradient, with northern hemisphere having a lower surface pressure than southern hemisphere. The pressure gradient is a consequence of the temperature contrast between the northern and southern hemisphere due to seasonal variations.

In June, equatorial trade winds above the western Pacific weakened to a lesser extent. Since the effects of northeasterly trade winds were offset by the stronger southwesterly monsoonal flow, the northeasterly flow was essentially suppressed. The resulting southwesterly flow brought relatively less rainfall from the Straits of Melaka to the west coast of Peninsular Malaysia. In comparison, northeasterly trade winds across the South China Sea carried a lot more moisture into the east coast of Peninsular Malaysia. Less rainfall in the west coast resulted in surging PM_{10} concentrations at Petaling Jaya.

With respect to seasonal fluctuations of particulates, El Nino modulations might weaken aerosol dispersion and exacerbate haze pollution during summer monsoon season, as in the case of 1997 and 2006 Indonesian forest fires[2,12,13]. However, El Nino only adds minor modulations when we consider two major drivers of PM_{10} variations. Here we suggest two controls that led to the rise and drop of PM_{10} concentrations at Petaling Jaya: (1) foreign emission sources in Sumatra, and (2) a change of monsoonal wind directions over the Indian Pacific region.



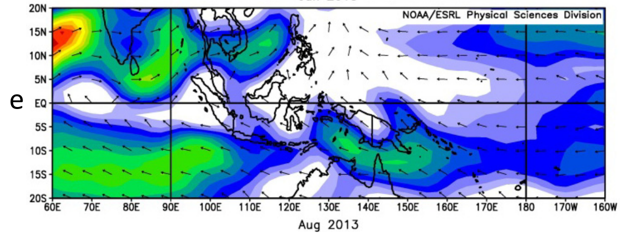


Fig. 3: Wind vector maps constructed with NCEP/NCAR Reanalysis Product[9] for (a) April, (b) May, (c) June, (d) July, (e) August 2013.

4. Conclusions

Air quality assessment has enabled a detailed analysis of PM_{10} temporal variations at Petaling Jaya, whereas remote sensing data has been useful for plotting hotspot counts in Sumatra. PM_{10} concentrations reached a record high of 290 $\mu g/m^3$ on 23 June 2013. Hotspot counts peaked on June 19, followed by the second highest counts on June 21, and the third highest on June 23. Wind vector maps show how airborne pollutants were transported from Indonesia to Peninsular Malaysia during the summer monsoon season in June. The monsoonal flow of southwesterlies was so strong that it outweighed the effect of northeasterly trades wind, resulting in reduced rainfall at Petaling Jaya. Consequently, PM_{10} concentrations soared markedly in response to dryer weather conditions.

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