Variability of PM10 in a Global Atmosphere Watch Station near the equator

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Abstract. Particulate Matter or aerosol is associated with climate change and global warming through the effect called radiative forcing. Biomass burning aerosol consists of Black Carbon, which has a positive radiative forcing that warms the atmosphere. The goal of this study is to ascertain biomass burning in Sumatera Island’s effect on aerosol concentration. We used Particulate Matter with diameter less than 10 µm (PM10) concentration in the near equator Global Atmosphere Watch Bukit Kototabang (GAW-BKT) and biomass burning in Sumatera Island from Visible Infrared Imaging Radiometer Suite (VIIRS) hotspot count. The statistical and spatial analysis was done for 2014-2018, which include the severe 2015 biomass-burning season. From the analysis of PM10 concentration and hotspot ($R^2=0.85$) and air mass trajectories, biomass burning in Sumatera is the source of PM10 in GAW-BKT. Statistical analysis showed that hotspot in Sumatera, as well as PM10 concentration, follows a monsoonal pattern where the 90th percentile of the hotspot and PM10 concentration fell on dry season. The seasonal variabilities of particulates suggest the strong contribution of biomass open burning which occurred annually with different intensities.

1. Introduction
Aerosol from biomass burning in Indonesia always gives problems to Indonesia as well as to neighboring countries (e.g. [1]). Aerosol in the form of particulate matter (PM) with an aerodynamic diameter of 10 micrometers called PM10. PM10 concentration of transboundary haze during biomass burning period can reach 48% and be mixed with PM10 from urban emission [2]. One important constituent of PM10 is Black Carbon. Not only Black Carbon has health impacts but also climate impacts [3][4].

The most severe biomass burning events in Indonesia was in 1997 and 2015 when strong El Nino hit (e.g. [5][6]). Biomass burning in Indonesia is almost all man-made and the burning activities depend on the atmospheric condition [7]. Fire can be used for forest management when applied properly [8].

Southeast Asia is a major aerosol source from the biomass burning activities [7][9], anthropogenic sources [10], and industry [11]. The study area is in the Asian monsoon region with strong convection...
that can distribute particles to the tropopause [12]. According to Persad et al. [13], the area near the equator with its high insolation is a good site to study the effect of aerosol.

Ambient aerosol in Indonesia near the equator is observed in the Global Atmospheric Watch Bukit Kototabang station (GAW-BKT) operated by the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG). The station is located in West Sumatera Province, 0°12'07" S - 100°19’05” E, 864.5 m a.s.l. and surrounded by tropical rain forest (gawbkt.id). Ground stations located in the high mountain are good in representing atmospheric chemistry for climate and environmental purposes [14]. There is an important publication by [15] for the aerosol optical properties in GAW-BKT. However, the study was done before the severe fire season in 2015.

This study aims to get the correlation between PM$_{10}$ and Black Carbon concentration and the variability of PM$_{10}$ concentration in ambient air in GAW-BKT affected by air mass and the biomass burning area in Sumatera.

2. Method

Monthly PM$_{10}$ and Black Carbon concentration data are from GAW-BKT. PM$_{10}$ concentration instrument is MetOne’s Automatic SPM analyzer (type BAM1020). The black carbon concentration instrument is Magee Scientific’s Aethalometer. The data are available hourly. Black carbon data is available since 2014 so we also explore PM$_{10}$ data from 2014. GAW-BKT instruments are audited by Swiss Federal Laboratories for Material Science and Technology (Empa) and BMKG headquarter calibration laboratory.

Biomass burning considered in this research is burning on Sumatera island only (6.2° S – 5.7° N and 94.9° E – 106.3° E). Even though biomass burning also occurred in other islands, the aerosol is aged more easily when it is above the sea [16]. Biomass burning data is taken from the monthly amount of hotspot from satellite data. The hotspot data used is Visible Infrared Imaging Radiometer Suite (VIIRS) of Suomi National Polar Orbiting Partnership (Suomi NPP). It is downloaded from Fire Information for Resource Management System (FIRMS). VIIRS resolution is 750 m x 750 m. Fires are detected using Fire Radiative Power (FRP) and it has better capture of small fires [17]. The hotspots counted from FIRMS are those with high confidence only.

Monthly rainfall data used is from The Climate Hazard group Infrared Precipitation with Stations (CHIRPS). CHIRPS combines ground station data with Cold Cloud Duration (CCD) from satellite and suitable for the region with complex topography such as Sumatera [18]. Monthly rainfall is classified to Class 1 (0.0 mm -100.0 mm), Class 2 (100.1 mm-200.0 mm), Class 3 (200.1 mm-300.0 mm), Class 4 (300.1 mm-400.0 mm), and Class 4 (> 400.1 mm), based on [19]. Minimum monthly rainfall is written in each hotspot and rainfall map. The monthly rainfall map shows the seasonal pattern of hotspots. Hotspots and rainfall spatial data are processed with ArcMap 10.7 software.

The source of PM$_{10}$ detected in GAW-BKT is obtained from backward air mass trajectories. Backward trajectories are performed with HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) model [20]. The model consists of meteorological assimilation data to calculate trajectory in a Lagrangian framework. HYSPLIT can calculate both forward as well as backward trajectories. HYSPLIT version used is the online version from NOAA’s READY (Real-Time Environmental Applications and Display sYstem) website [21]. This study uses the monthly trajectory frequency of backward trajectories from the GAW-BKT location. The “number of days” option for each month running is based on the month’s number of days. The dominant air mass source can be known from the trajectory frequency. The meteorological data chosen is the Global Data Assimilation System (GDAS) 0.5 degrees. The maximum total “run time” for backward frequency trajectory is 120 hours (5 days). Aerosol can stay in the atmosphere for one day to two weeks [22], so the total run time is set to Hysplit’s 120 hours. The sources are spatially collocated with the hotspots to give information on whether the PM$_{10}$ detected comes from biomass burning areas in Sumatera or not.
3. Result and Discussion
During the study period, Black Carbon is 3% of PM$_{10}$ and Black Carbon and PM$_{10}$ concentrations have a high correlation as seen in Figure 1. For Southeast Asia, [7] have reported high Black Carbon content in aerosol (10-25%). For the urban area in Indonesia, [23] have reported Black Carbon content in PM$_{10}$ is 7.8 to 18%. The percentage of the Black Carbon fraction in PM$_{10}$ from this research is lower than those reports. However, some of the references use laboratory analysis and according to Bond et al [24] the condition is better controlled.

![Figure 1. PM$_{10}$ and black carbon concentration (in µg m$^{-3}$).](image1)

It can be inferred from Figure 2 that the peak and fall of PM concentration were mostly matched with the peak and fall of a hotspot in the study period. It is also explicitly known from the linear regression graph and R-squared value in Figure 3 that the PM concentration in ambient GAW-BKT atmosphere is correlated to hotspot count in Sumatera.

![Figure 2. PM$_{10}$ concentration (in µg m$^{-3}$) and hotspot time series](image2)

The 90th percentile of PM$_{10}$ concentration was on months of the dry season and the year of 2014 and 2015. There was a strong El Nino in 2015 coincide with severe biomass burning (e.g. [1][6]). In Borneo, [25] reported that PM$_{10}$ concentration maximum was also in September and October, in the period of the dry season and the peak of forest fires. In November when the rainfall starts to increase there are
usually minimum hotspots like occurred in 2016 and 2018. For a month without a hotspot in November 2016, the PM$_{10}$ concentrations fell in the 10$^{th}$ percentile. Previously [26] found the minimum biomass burning aerosol in GAW-BKT was between November and January.

Figure 4 shows all hotspot count during the research period followed a seasonal pattern. The hotspot 90$^{th}$ percentile was on the months of the dry season. Based on [19] northern Sumatera has minimum rainfall in February and southern Sumatera has minimum rainfall in August-September-October. Hotspots likewise followed the pattern, where it had two peaks. The main peak was on September-October and the second peak was on February-March. [27] also found that the distribution of PM$_{10}$ from biomass burning sources is affected by the monsoonal flow. Monthly hotspots and air mass backward trajectories show that for months with 90$^{th}$ percentile of the hotspot and 90$^{th}$ percentile of PM$_{10}$ (February 2014, March 2014, August 2015, September 2015, and October 2015) the air mass sources were area with high hotspot. Therefore, the PM$_{10}$ observed in GAW-BKT was from the biomass burning area.

![Figure 3. PM$_{10}$ and hotspot concentration (µg m$^{-3}$).](image1)

![Figure 4. Monthly all hotspot data.](image2)

Interesting features were found in February 2015 and July 2014. In February 2015, the hotspot was relatively low (70$^{th}$ percentile) and mostly located in Riau Province while the PM$_{10}$ concentration was high (90$^{th}$ percentile). The aerosol probably came from other sources [10][11]. The comparison of February 2014 and February 2015 hotspot spatial distribution are in figure 5 a) and figure 5 b) and air mass trajectory are in figure 6 a) and figure 6 b). The figures show similar locations of most hotspots and directions of backward trajectories maps of the two periods. The sources of air mass were from the
northeast. However, in February 2015 more trajectories came from Riau Province and further, Peninsular Malaysia.

In July 2014 hotspot count was high (90th percentile) but it was not parallel to its PM$_{10}$ concentration (60th percentile). Figure 5 c) shows most hotspots laid on southern Sumatera whereas back trajectories in figure 6 c) show the air mass came mostly from the Indian Ocean. This explains the low PM$_{10}$ concentration because air mass from the ocean has a low concentration of anthropogenic aerosol [16].

![Figure 5](image_url)

**Figure 5.** Hotspot location and rainfall class for a) February 2014, b) February 2015, c) July 2014, d) September 2015, e) October 2015
Figure 6. NOAA HYSPLIT model backward trajectories frequencies for a) February 2014, b) February 2015, c) July 2014, d) September 2015, e) October 2015.

Figures 5 d) - e) and 6 d) - e) shows the condition in September and October 2015, the peak of severe biomass burning in Sumatera. The hotspot count, as well as PM10 concentration of October 2015, are the highest in the study period. PM$_{10}$ concentration in the study period correlates well but does not always represent hotspot count since atmospheric circulation also has a major role in PM$_{10}$ transported from the source to GAW-BKT. There are also other Black Carbon sources and atmospheric processes [4] beyond the scope of this study. According to Adhikary et al [28] concentration of PM$_{10}$ in the receptor area may be in a different extent with aerosol emission in the biomass burning source.

4. Conclusion
GAW-BKT PM$_{10}$ concentration in 2014-2018 is highly correlated with Black Carbon concentration ($R^2=0.93$) and hotspot count in Sumatera ($R^2=0.85$). Hotspot count and hotspot spatial distribution follow the rainfall pattern. The origin of air mass also affects the PM$_{10}$ concentration whether it is from biomass burning areas, places with other sources of PM$_{10}$, or the ocean.
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