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# Impact of biomass fires on tropospheric nitrogen dioxide in South and Southeast Asia for the years from 2005 to 2014

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ABSTRACT

Nitrogen dioxide is a prominent air pollutant effecting public health, mainly formed by anthropogenic activities and biomass fires. To assess the impact of biomass fires on nitrogen dioxide, recent studies have analyzed the relationship between nitrogen dioxide and fires in relatively sparsely populated areas, avoiding the uncertainty of assessment caused by human activities. However, it is necessary to further investigate the relationship between nitrogen dioxide and fires in densely populated areas, which requires considering an appropriate way to distinguish between nitrogen dioxide from biomass fires and nitrogen dioxide from anthropogenic activities (e.g., industry). In this study, a new approach is proposed and applied to estimate the impact of biomass fires on tropospheric nitrogen dioxide in South and Southeast Asia, which has a high population density and is undergoing through the process of industrialization. We conducted ten year analysis of correlation (from 2005 to 2014) between nitrogen dioxide and fires, and further estimated the impacts of winter and summer monsoon on the correlation. The analysis indicates a high efficiency and reliability of this approach in presenting correlation between nitrogen dioxide and fire and demonstrates a strong monsoon impact on the correlation. Moreover, we concluded that the correlation is influenced by land use and local industrialization level as well.



## 1. Introduction

Biomass burning is playing a dominant role in influencing global climate system and biogeochemical cycles (Tanimoto, Ikeda, Boersma, & Garivait, 2015). There has been much research in exploring the behavior of biomass fires and their intensity variations spatially throughout a time series (Chen, Pereira, Masiero, & Pirotti, 2017; Kc & Corcoran, 2017). As a significant source of trace gases and aerosols, the influence of biomass fire on the column of ozone (Jena et al., 2015), carbon dioxide and nitrogen dioxide (Bucsela et al., 2013; Galanter, Levy, & Carmichael, 2000; Gaveau et al., 2014; Schreier, Richter, Kaiser, & Burrows, 2014; Tanimoto et al., 2015) has drawn much attention among the global researchers in geology.

In the troposphere, Nitrogen dioxide ($NO_2$) is one of the most prominent pollutant gases. It synthesizes industrial nitrous acid and nitric acid, which has the most deleterious consequences on human health and ecological environment in forms of acid rain, mist, ground-level ozone and photochemical smog (Agency May 1, 2012). $NO_2$ principally comes from power plants, industrial boilers, motor vehicles, large forest and peat land fires burning at high temperatures (Agency October 5, 2012; Gaveau et al., 2014; Lee et al., 1997). In developing areas, such as most countries in South Asia and Southeast Asia, the concentration of $NO_2$ is strongly influenced by both biomass burning and anthropogenic activities. Many countries (i.e. India, Indonesia, Malaysia, Thailand and the Philippines) are transforming economies from agricultural towards industrial development (Gans, King, Stonecash, & Mankiw, 2011). Furthermore, it has been demonstrated that biomass burning in South Asia and Southeast Asia emits large amounts of pollutant gases locally (Galanter et al., 2000). Exploring the relationship between $NO_2$ and biomass fires is essential to dive into the potential impact factors that may influence $NO_2$ emissions from biomass fires and come up with reasonable political suggestions to decrease $NO_2$

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pollutant.

The launch of Ozone Monitoring Instrument (OMI) on NASA'S Aura satellite (Levelt et al., 2006) and Global Ozone Monitoring Experiment (GOME) on European Space Agency (ESA)'s European Remote Sensing (ERS)-2 satellite (Burrows et al., 1999) has made it easier for researchers to retrieve $NO_2$'s total columns and tropospheric vertical columns. Fire radiative power (FRP) is a measurement of the radiant energy released from fire (Kaufman et al., 1998). In scientific researches, FRP is often used as a measurement of biomass fires (Tanimoto et al., 2015), because the study areas are selected from rural areas, where there is little anthropogenic impact. Since FRP can be accessed from the MODerate resolution Imaging Spectroradiometers (MODIS) on NASA's Terra and Aura satellites, it has been widely used to represent fire to study its relationship with emission gases (Boschetti & Roy, 2009; Freeborn, Wooster, & Roberts, 2011; Vermote et al., 2009; Wooster, 2002).

Recently, many studies have focused on exploring the relationship between tropospheric $NO_2$ and biomass fires by measuring long time-series biomass fire emissions, both globally and locally (Mebust & Cohen, 2014; Schreier et al., 2014; Tanimoto et al., 2015). Seiler and Crutzen (Seiler & Crutzen, 1980) were the first to estimate biomass burning emissions at a global scale. An empirical relationship between tropospheric $NO_2$ vertical column and FRP has been found, which demonstrates that the temporal relationship between tropospheric $NO_2$ and FRP can be used to distinguish source of $NO_X$ emission as from fire or other sources (Schreier et al., 2014). There are also studies on inter-annual variability of $NO_x$ emissions from boreal wildfires, indicating reasonably strong correlations (Tanimoto et al., 2015).

It has been noted that different land use and land cover can affect relationship between FRP and $NO_2$ differently. Mebust and Cohen identified biomes and ecosystems to analyze the global relationship between FRP from MODIS and $NO_2$ from OMI using emission coefficients (Mebust & Cohen, 2014). Monsoon is another factor influencing the concentration of fire emissions, because of precipitation variation (Kripalani, Oh, Kulkarni, Sabade, & Chaudhari, 2007) among summer monsoon, winter monsoon and their transition periods. Several studies have been conducted to estimate monsoon impact on $NO_2$ concentration (Majumder, Murthy, Khanal, & Giri, 2008), black carbon deposition (Yasunari et al., 2010) and other fire emissions (Joshi, 2003) in the context of climate change.

Most studies prefer to select areas with more fire events and less anthropogenic activities as study areas. This owes to the reason that the concentration of tropospheric $NO_2$ is strongly influenced by anthropogenic emissions, which will increase uncertainty in estimating the relationship between fire and $NO_2$ (Levelt et al., 2006). More frequent anthropogenic activities will lead to anthropogenic noise in the background column of tropospheric $NO_2$ and diminish the relationship between fire and $NO_2$. Therefore to study the relationship between fire and $NO_2$ in populated areas, a correlation method sensitive to population is required. In this study, we adopted population density to explore the 10-year correlation coefficient between tropospheric $NO_2$ and FRP in South Asia and Southeast Asia (North 37°, South 0°, East 60°, West 140°) from 2005 to 2014. We found that this new method describes a more reasonable and reliable changing trend for the study period as compared to previous research that did not consider population density. General correlation of our study area was also analyzed with monsoon impact and land use product. The impact of monsoon on the concentration of $NO_2$ is described in terms of monsoon wind blowing and $NO_2$ deposition by monsoon rains. Land cover products were used to further analyze the impact that different kind of land cover or land uses have on the fire emissions.

## 2. Experimental data

### 2.1. MODIS product

The MODerate resolution Imaging Spectroradiometers (MODIS) operate on National Aeronautics and Space Administration (NASA)'s Terra and Aqua satellite, which were launched in December 1999 and May 2002 respectively. Correspondingly, their equatorial overpass times are 10:30 local time and 13:30 local time (Mebust & Cohen, 2014). We used FRP calculated from NASA's Aqua satellite data to match the near-coincident daytime measurement of $NO_2$. The MODIS data covers 36 bands, from visible wavelength to IR wavelength. Fires with bigger size than 100 $m^2$ can be detected based on bands of 4 μm and 11 μm wavelength, even with the spatial resolution of MODIS data being $1 \times 1$ $km^2$. FRP is retrieved by the Stefan-Boltzmann law, according to the 4 μm temperature band (Giglio, Descloitres, Justice, & Kaufman, 2003; Justice et al., 2002; Kaufman et al., 1998). Qualification assessment of FRP concludes that the uncertainties of FRP can be decreased in a coarser spatial study area with a large temporal gap (Freeborn, Wooster, Roy, & Cochrane, 2014), which is suitable for our case. The monthly mean FRP product in our study is binned to a horizontal resolution of $1° \times 1°$, obtained from NASA database.[1]

Land cover product was used to further analyze the influence of different sorts of biomass burning on $NO_2$ emissions, which are classified using International Geosphere-Biosphere Program (IGBP) (Friedl et al., 2010) with an overall accuracy of 75%. Since the land cover product is available from year 2005–2012, our detailed discussion for specific land cover types is based on the most recent product in 2012.

### 2.2. OMI product

Monthly mean tropospheric $NO_2$ Level 2 (L2) (0–30% Cloud) product from Ozone Monitoring Instrument (OMI) was used in our study. OMI was launched on July 15, 2004 on the NASA's Earth Observing System (EOS) Aura satellite (Levelt et al., 2006), with its equatorial overpass time being 13:30 locally. Each pixel of OMI product represents $13 \times 24$ $km^2$ at nadir (Schreier et al., 2014). OMI offers everyday measurements globally. The measurements are done in the wavelength from 270 nm to 500 nm with a spectral resolution of 0.63 nm (Levelt et al., 2006; Schreier et al., 2014). It records ozone and some other atmospheric parameters which are relative to ozone precursors. The detailed process is described in paper (Bucsela et al., 2013). The retrieved $NO_2$ column has a good agreement with ground-based and in-situ $NO_2$ measurements and bottom-up emission inventories (Celarier et al., 2011). In our study, all the monthly mean $NO_2$ products are binned to a horizontal resolution of $1° \times 1°$.

### 2.3. Population density product

Since anthropogenic emissions are one of the main contributing sources of $NO_2$ (Castellanos & Boersma, 2012; Ghude, Fadnavis, Beig, Polade, & Van der, 2008; Miyazaki, Eskes, & Sudo, 2012) and our study area covers almost 60% of Asian population and over 33% of world's population (Affairs 2015; Desai, 2002), population density is a major factor that we have to consider. In this study, we use the Gridded Population of the World Version 3 (GPWv3) product, which is produced by the Columbia University Center for International Earth Science Information Network (CIESIN) in collaboration with Centro International de Agriculture Tropical (CIAT). The

[1] http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=neespi.