

## TEMPORAL VARIATION OF TROPOSPHERIC NO<sub>2</sub> COLUMNS IN VIETNAM DURING 2015–2020

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### ABSTRACT

Nitrogen dioxide (NO<sub>2</sub>) in the atmosphere can be measured using the tropospheric NO<sub>2</sub> columns, indicating the number of molecules of NO<sub>2</sub> in an atmospheric column from the ground surface to the top of the atmosphere above a square centimeter of the surface. In this study, the temporal variations of tropospheric NO<sub>2</sub> columns in Vietnam during 2015–2020 were investigated. To do this, data on the columnar NO<sub>2</sub> obtained from the Ozone monitoring instrument (OMI) onboard the NASA's Earth orbiting satellite Aura were used. Consequently, northeastern Vietnam showed the highest values of the tropospheric NO<sub>2</sub> columns over the whole study period (2015–2020), suggesting that this area would be a hot spot of NO<sub>2</sub> pollution in Vietnam. In addition, the lowest and highest mean levels of columnar NO<sub>2</sub> were found in 2020 and 2016, respectively. However, there is no statistical significance among the columnar NO<sub>2</sub> in 2015–2020. Regarding the monthly variation, March and April exhibited the highest levels of tropospheric NO<sub>2</sub> columns, which would be affected by frequent combustion activities (e.g., post-harvesting combustion) and meteorological conditions, such as lower air temperature. Results of this study can contribute to an understanding of NO<sub>2</sub> pollution in Vietnam over long period.

**Keywords:** Vietnam; tropospheric; NO<sub>2</sub>; OMI, Aura.

### 1. INTRODUCTION

Nitrogen dioxide (NO<sub>2</sub>), an indicator of poor air quality, is mainly emitted from fossil fuel combustion (e.g., emission from vehicles and power plants) and biomass burning (Carslaw, 2005). The quantity of NO<sub>2</sub> in the atmosphere can be measured using ground-based measurement or satellite observation. Regarding the latter, a product named tropospheric NO<sub>2</sub> column can be used. Particularly, the columnar NO<sub>2</sub> indicates the number of molecules of NO<sub>2</sub> in an atmospheric column from the ground surface to the top of the atmosphere (i.e., the tropopause), above a square centimeter of the surface (Stavrakou et al., 2008).

The tropospheric NO<sub>2</sub> columns from satellite sensors, such as the Ozone Monitoring Instrument (OMI), have been widely used to infer NO<sub>2</sub> concentration as well as NO<sub>2</sub> emissions on regional and local scales. Moreover, the tropospheric NO<sub>2</sub>

columns have also been used to investigate the temporal variation of NO<sub>2</sub>, such as yearly and monthly variation.

This study aims to understand the yearly variations of tropospheric NO<sub>2</sub> columns in Vietnam from 2015 to 2020. Additionally, the monthly variations of the columnar NO<sub>2</sub> in each year are also reflected. The results of this study can contribute to an understanding of NO<sub>2</sub> pollution in Vietnam over a long period.

### 2. METHODS AND MATERIALS

#### 2.1 Tropospheric NO<sub>2</sub> columns

The data used in this study are the tropospheric NO<sub>2</sub> column data obtained from the Ozone monitoring instrument (OMI) onboard NASA's Earth-orbiting satellite Aura. Additionally, the OMI-observed NO<sub>2</sub> columns were retrieved in the 405–465 nm spectral (NASA, 2012). The Level-3 daily products (OMNO2d v003), gridded at 0.25°

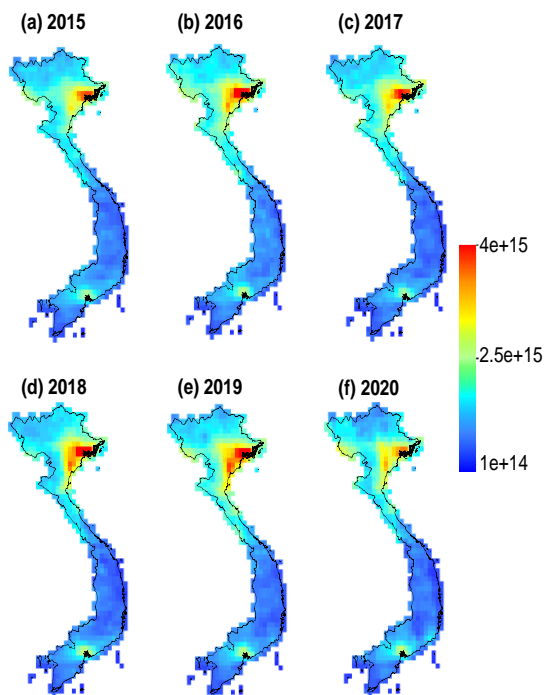
$\times 0.25^\circ$ , were selected for further data interpretation and downloaded from the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC). Moreover, the yearly and monthly mean values of the tropospheric  $\text{NO}_2$  columns were calculated as the average of the daily values in order to investigate the temporal variation of the tropospheric  $\text{NO}_2$  columns in Vietnam.

## 2.2 Data visualization and statistical analysis

The spatial distribution of tropospheric  $\text{NO}_2$  columns in Vietnam for several years was illustrated using ArcGIS (ESRI, USA). Moreover, OriginPro 2020 (Origin, USA) was used to plot the monthly and yearly variations of the columnar  $\text{NO}_2$  and perform statistical analysis of the data.

## 3. RESULTS AND DISCUSSION

### 3.1 Spatial distribution of tropospheric $\text{NO}_2$ columns in Vietnam



**Figure 1.** The yearly mean of the tropospheric  $\text{NO}_2$  columns in Vietnam from 2015 to 2020. (Unit: molecules/cm<sup>2</sup>)

The spatial distribution of tropospheric  $\text{NO}_2$  columns in Vietnam from 2015 to 2020 is shown in **Figure 1**. In general, the

northeastern area of Vietnam exhibited the highest values of the columnar  $\text{NO}_2$  over the whole study period (2015–2020), suggesting that this area would be a hot spot for  $\text{NO}_2$  pollution in Vietnam. In fact, the northern Vietnam key economic region, encompassing Ha Noi capital and covering several provinces (i.e., Hai Phong, Quang Ninh, Vinh Phuc, Bac Ninh, Hai Duong, and Hung Yen), is in this area. Therefore, air pollutants emitted from industrial activities as well as residential areas in the key economic region could contribute to the high levels of  $\text{NO}_2$  in northern Vietnam.

Additionally, northern Vietnam showed high values of the tropospheric  $\text{NO}_2$  compared to the other areas (e.g., southern and eastern Vietnam). The higher columnar  $\text{NO}_2$  in northern and northeastern Vietnam would be contributed by the characteristically meteorological conditions of these areas. For instance, the low ambient air temperature reduced the atmospheric mixing height and resulted in the lower dispersion of air pollutants. Added to this, the lower wind speed could also decline the dispersion of air pollutants and elevated the pollutant levels in the atmosphere.

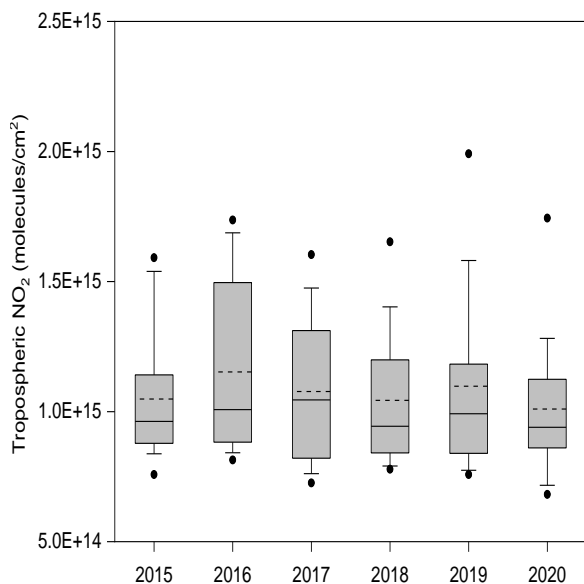
Moreover, the higher levels of tropospheric  $\text{NO}_2$  columns in northeastern Vietnam could also be stemmed from emissions from surrounding industrial areas, i.e., power plants and other industrial complexes located approximately 100 km to the east of Ha Noi city, the capital of Vietnam (Alliance, 2017). In particular, as reported by Alliance (2017), air mass containing  $\text{NO}_2$  emitted from the industrial cluster in Quang Ninh, a northeastern city of Vietnam, would be possibly transported to the inner areas, such as Ha Noi.

### 3.2 Yearly and monthly variation of tropospheric $\text{NO}_2$ columns in Vietnam in 2015–2020

The yearly variations of tropospheric  $\text{NO}_2$  columns in Vietnam from 2015 to 2020 are illustrated in **Figure 2**. Generally, the lowest and highest mean levels of columnar

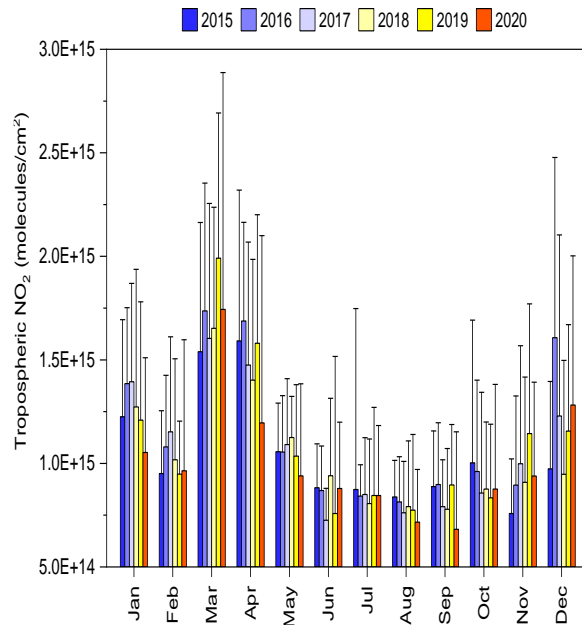
NO<sub>2</sub> were observed in 2020 and 2016, respectively. However, no statistically significant difference is found among the columnar NO<sub>2</sub> in 2015–2020 (ANOVA on ranks,  $p = 0.948$ ). The lowest levels of tropospheric NO<sub>2</sub> columns in 2020 would be contributed by a decline of transport activities, resulting in the lower NO<sub>2</sub> emission, derived from the lockdown or social distance because of the coronavirus pandemic (Acharya et al., 2021; Metya et al., 2020; Roy et al., 2021).

The other contribution could be meteorological conditions, such as the higher rainfall levels leading to the wet deposition of atmospheric NO<sub>2</sub>. This issue should be more investigated in further studies.



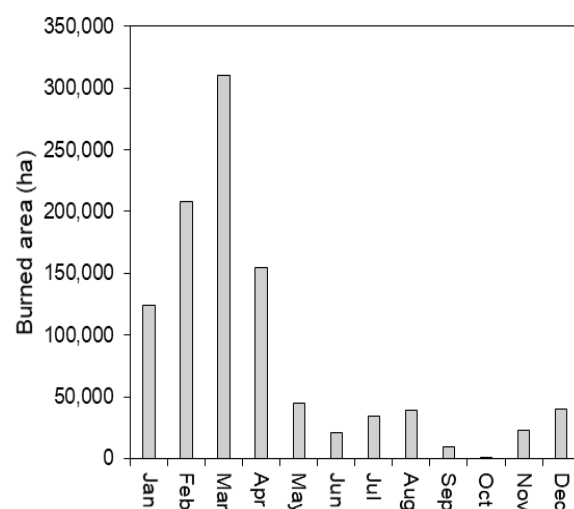
**Figure 2.** The yearly mean of the tropospheric NO<sub>2</sub> columns in Vietnam. Dots represent outliers. Solid and dash lines are median and mean, respectively.

The monthly mean levels of the tropospheric NO<sub>2</sub> column in Vietnam are displayed in **Figure 3**. As can be shown, March and April tend to exhibit the highest levels of columnar NO<sub>2</sub>, followed by December, January, February, and November. There are also statistically significant differences between the columnar NO<sub>2</sub> levels in such months and those in the others (i.e., May to October) (ANOVA Tukey’s test,  $p < 0.05$ ).



**Figure 3.** Monthly mean of the tropospheric NO<sub>2</sub> columns in Vietnam from 2015 to 2020.

The highest levels of tropospheric NO<sub>2</sub> columns in March and April would be affected by frequent combustion activities (e.g., post-harvesting combustion), especially in northern Vietnam (Itahashi et al., 2018; Lasko et al., 2018). This suggestion would be supported by the higher burned area in March and April (**Figure 4**). However, the opposite trend between burned area and tropospheric NO<sub>2</sub> in February should be more studied in further research.



**Figure 4.** Averaged burned area in Vietnam from 2015 to 2020. Data were obtained from the Global Wildfire Information System.

Moreover, the lower trend of ambient air temperature in November-December and January-February would also decline the dispersion of air pollutants, resulting in the high levels of columnar  $\text{NO}_2$  in these months (Acharya et al., 2021).

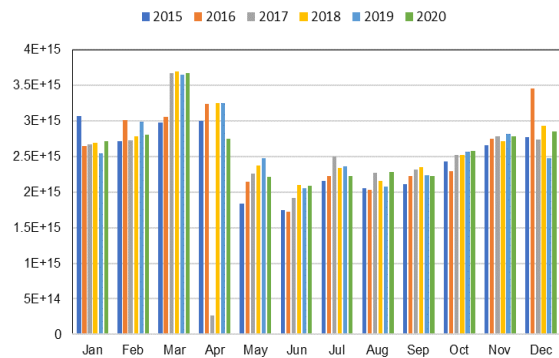
In addition, levels of columnar  $\text{NO}_2$  declined from May to October. In fact, rain tends to increase its levels and frequency during this period in Vietnam. Wet deposition during rain could lead to lower levels of atmospheric pollutants, i.e.,  $\text{NO}_2$ . This would be an explanation for the declining trend of the tropospheric  $\text{NO}_2$  columns from May each year.

### 3.3 Variation of tropospheric $\text{NO}_2$ in some major cities of Vietnam

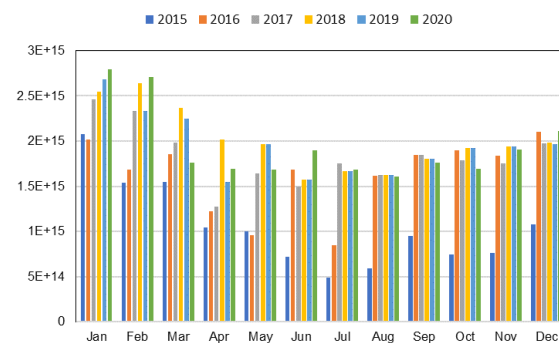
Hanoi and Ho Chi Minh, two biggest cities in Vietnam, generally have some common features in which the tropospheric  $\text{NO}_2$  was relatively high from December to April.

The mean of  $\text{NO}_2$  level in Hanoi was consistently higher than that of in Ho Chi Minh, mainly ranged from around  $1.5\text{E}+15$  to over  $3.5\text{E}+15$  molecules/ $\text{cm}^2$ . In the first 4 months from January to April, Hanoi saw an extremely high average  $\text{NO}_2$  columnar which surpassed  $2.5\text{E}+15$  molecules/ $\text{cm}^2$  and peaked at over  $3.5\text{E}+15$  molecules/ $\text{cm}^2$ . From June to September, the level of tropospheric  $\text{NO}_2$  increased by  $0.25\text{E}+15$  molecules/ $\text{cm}^2$ . For the next 3 months, this upward trend was still dominant to reach approximately  $2.5\text{E}+15$  molecules/ $\text{cm}^2$  in December.

Ho Chi Minh city had the same pattern as the columnar  $\text{NO}_2$  was highest from January to March and lowest from June to August. In particular, the mean level of  $\text{NO}_2$  ranged from  $5\text{E}+14$  to over  $2.5\text{E}+15$  molecules/ $\text{cm}^2$ , which was far lower than that of in Hanoi. However, there was a significant increase during the 5-year-period in Ho Chi Minh city when 2019 and 2020 were recorded at the highest figures, compared to Hanoi.



(a) Hanoi



(b) Hochiminh

**Figure 5.** Monthly mean of the tropospheric  $\text{NO}_2$  columns in two major cities in Vietnam from 2015 to 2020.

In 2020, the COVID-19 infection effected the change in activities on air pollution in Vietnam. Although there were decreases in tropospheric  $\text{NO}_2$  in Hanoi and Hochiminh during the lockdown time (in April 2020), the observed  $\text{NO}_2$  columns in two cities were generally higher than the average of 2015-2020 (Table 1). That could be construed in either of two ways: industrial manufacturing and transportation. The Prime Minister's Directive No. 16/CT-TTg dated on March 31, 2020 required shutdown of public transportation; movement restriction from one area to another. However, industrial factories in Vietnam were still allowed to operate under the restrictive prevention. Due to limitation of the tropospheric  $\text{NO}_2$  (i.e., a column  $\text{NO}_2$  from the ground to the tropospheric layer), further studies using data from ground-based measurement should be considered to more understand the effect of lockdown on air quality in major cities of Vietnam.

**Table 1.** Variations of tropospheric NO<sub>2</sub> columns during the lockdown period in two major cities in 2020.

| Month                             | Ha Noi   | Ho Chi Minh |
|-----------------------------------|----------|-------------|
| Jan                               | 2.72E+15 | 2.80E+15    |
| Feb                               | 2.81E+15 | 2.71E+15    |
| Mar                               | 3.67E+15 | 1.76E+15    |
| Apr                               | 2.75E+15 | 1.69E+15    |
| May                               | 2.21E+15 | 1.68E+15    |
| Jun                               | 2.09E+15 | 1.90E+15    |
| Jul                               | 2.22E+15 | 1.68E+15    |
| Aug                               | 2.28E+15 | 1.61E+15    |
| Sep                               | 2.22E+15 | 1.76E+15    |
| Oct                               | 2.58E+15 | 1.7E+15     |
| Nov                               | 2.78E+15 | 1.91E+15    |
| Dec                               | 2.85E+15 | 2.11E+15    |
| Mean of the period (2015 to 2020) | 2.60E+15 | 1.93E+15    |

#### 4. CONCLUSION

In summary, the highest values of the tropospheric NO<sub>2</sub> columns in Vietnam during 2015–2020 were found to be in northern and

northeastern regions. The NO<sub>2</sub> emission from industrial and residential activities, especially in the northern Vietnam key economic region, might contribute to the high levels of columnar NO<sub>2</sub> in the north and northeastern Vietnam.

Additionally, the lowest and highest mean levels of columnar NO<sub>2</sub> were observed in 2020 and 2016, respectively. Regarding the monthly variation, March and April exhibited the highest levels of tropospheric NO<sub>2</sub> columns, which would be affected by frequent combustion activities and meteorological conditions (e.g., the lower ambient air temperature).

Further studies should more focus on columnar NO<sub>2</sub> in the individual key economic region to more understand the NO<sub>2</sub> pollution in Vietnam. Moreover, the influence of meteorological conditions on NO<sub>2</sub> pollution should also be studied more to understand their effect on air pollution.

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