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Long-Term Assessment of Daily Atmospheric Nitrogen Dioxide in Thailand Using Satellite Observed Data

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Abstract

Nitrogen dioxide (NO_2) is one of the major air pollutants playing a key role in tropospheric chemistry and climate change. This study analyzed the long-term trend of daily tropospheric NO_2 columns in Thailand from 2007 to 2017 (11 years) retrieved from the SCIAMACHY, GOME-2A, GOME-2B and OMI satellites. The consistency between the satellites (GOME-2A vs. SCIAMACHY, GOME-2A vs. GOME-2B and GOME-2A vs. OMI) were investigated during the overlapped time period. Overall, the results showed a good agreement in seasonal variation. The satellite NO_2 data were also compared with ground data including NO_2 concentrations from ground monitoring stations and meteorological data (temperature, relative humidity and wind speed) over 6 regions of Thailand (North, Northeast, Central, East, Southwest and Southeast). The comparative analysis between satellites NO_2 columns and ground NO_2 concentrations presented well correlated results. NO_2 data from both satellite and ground measurements had maximum levels in the dry season (November-April) with the peak in March while the minimum levels were mostly observed in the wet season (May-October). Moreover, NO_2 generally presents at high levels when relative humidity (RH) levels are low.

Keywords: GOME; NO_2; OMI; SCIAMACHY; Thailand

1. Introduction

In the past decades, increasing human activities have changed the tropospheric chemistry and the Earth's climate. Nitrogen dioxide (NO_2) is one of the major air pollutants (David and Nair, 2012; Cheng, *et al*., 2012) released by anthropogenic sources, including industrial burning of fossil fuels (coal, oil and gas), transportation, biomass burning, and electricity generation (Melkonyan and Kuttler, 2012). NO_2 from natural sources, including forest fires, emits from soils through the decomposition process and lightning (Vinken, *et al*., 2014). Tropospheric NO_2 is a major source of photochemical ozone (O_3). During daytime, NO_2 may react with hydroxyl radicals (OH) and become nitric acid (HNO_3) (Solomon, *et al*., 1999; Valks, *et al*., 2011).

The monitoring of ground-level NO_2 is conducted through ground measurements with in-situ data. The development of satellites remote sensing observation of tropospheric NO_2 columns had starts since mid-1990s, including Global Ozone Monitoring Experiment (GOME) in 1995. It continued with the Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY (SCIAMACHY) in 2002, followed by the Ozone Monitoring Instrument (OMI) in 2004, and new version of GOME-2A in 2006 and GOME-2B in 2012 (Duncan, *et al*., 2014; Wang, *et al*., 2013; Callie, *et al*., 2000; Richter, *et al*., 2011).

Comparisons between ground measurements and tropospheric NO_2 columns from satellites observations were done from in many researches. Zheng, *et al*., 2018 compared data from OMI satellite with the ground station observation in Inner Mongolia urban agglomerations. The result showed that NO_2 increased in 2005-2011 (14.3% per year) and decreased in 2011-2016 (-8.1% per year). Zhang, *et al*., 2016 also reported long-term trend (2005-2014) of OMI retrieved NO_2 concentrations in Henan province, China. The result showed the highest level in winter with the lower level in summer and spring. NO_2 continuously increased from 2005-2011 (6.4% per year), and thereafter decreased in 2012-2014 (10.6% per year). Jin, *et al*., 2016 compared data from MAX-DOAS measurement to OMI satellite in a rural site of North China. The result showed the maximum level in winter and minimum level in summer.

The data from tropospheric NO_2 satellites revealed long-term trends NO_2 concentration in China from 1997-2016, comparing between GOME vs. SCIAMACHY and SCIAMACHY vs. GOME-2A. The results indicated that correlation coefficient (R2) in four seasons were within 0.85-0.93 and 0.85-0.95, respectively (Zhang, *et al*., 2018).

This study focuses on the long-term trend of temporal variability of NO_2 columns retrieved from satellites (SCIAMACHY, GOME-2A, GOME-2B, and OMI) over six regions of Thailand during 2007-2017 (11 years). The relationship between NO_2 columns derived from satellites and meteorological data of the east of Thailand is focused because it is where most industrial estates located and anthropogenic NO_x emissions caused by human activities is also high in this area.

2. Materials and Methods

2.1. Satellites data

Satellites-based tropospheric NO_2 columns (unit: 1015molecules/cm2) used in this study were daily retrieved from SCIAMACHY (2007-2011), GOME-2A (2007-2017), GOME-2B (2013-2017) and OMI (2007-2017) over six regions of Thailand: north, northeast, central, east, southeast and southwest based on meteorology. Satellite data were published through the website of the Tropospheric Emission Monitoring Internet Service. More details of the satellites were presented in Table 1.

2.2. Ground monitoring data

Hourly data of NO_2 concentrations (ppb), temperature (°C), wind speed ($m.s^{-1}$) and relative humidity (%) during 2007-2016 were obtained from the Pollution Control Department (PCD), Thailand. The data were obtained during 2007-2017 over six regions of Thailand, including north (N) (12 stations), northeast (NE) (2 stations), central (C) (31 stations), east (E) (10 stations), southeast (SE) (4 stations) and southwest (SW) (2 stations); 61 stations of the PCD in total. Three-hour

Table 1. Characteristics of Satellites

Sensor	SCIAMACHY	OMI	GOME-2A	GOME-2B
Platform	ENVISAT	Aura	MetOp-A	MetOp-B
Spectral range (μm)	0.23-2.38	0.27-0.50	0.24-0.79	0.24-0.79
Ground pixel res. (km)	60×30	24×13	80×40	40×40
Overpass local time	10.00	13.45	09.30	09.30
Operating time	2002-2012	2004-present	2006-present	2012-present

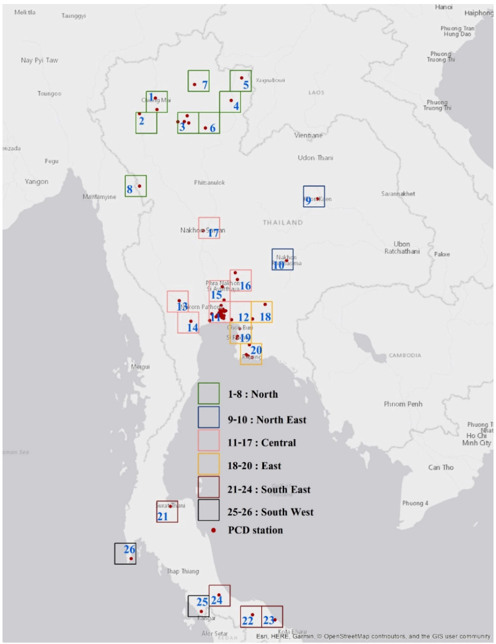

Figure 1. Locations of grid boxes over Thailand

Table 2. Locations of ground monitoring stations and considered grid boxes over six regions of Thailand

Region	Box ID	0.5×0.5° Box (Lat, Lon)	Number of station/ Province
North	1	18.50-19.00°N, 98.75-99.25°E	2 stations in 2 provinces (Chiangmai and Lamphun)
	2	18.00-18.50°N, 98.50-99.00°E	1 station in Chiangmai
	3	18.00-18.50°N, 99.50-100.00°E	4 stations in Lampang
	4	18.50-19.00°N, 100.50-101.00°E	1 station in Nan
	5	19.00-19.50°N, 100.75-101.25°E	1 station in Nan
	6	18.00-18.50°N, 100.00-100.50°E	1 station in Phrae
	7	19.00-19.50°N, 99.75-100.25°E	1 station in Payao
	8	16.50-17.00°N, 98.25-98.75°E	1 station in Tak
Northeast	9	16.25-16.75°N, 102.50-103.00°E	1 station in Khon Kaen
	10	14.75-15.25°N, 101.75-102.25°E	1 station in Nakhon Ratchasima
Central	11	13.50-14.00°N, 100.25-100.75°E	23 stations in 3 provinces (Bangkok, Samut Prakan and Samut Sakhon)
	12	13.50-14.00°N, 100.75-101.25°E	1 station in Samut Prakan
	13	13.75-14.25°N, 99.25-99.75°E	1 station in Kanchanaburi
	14	13.25-13.75°N, 99.50-100.00°E	1 station in Ratchaburi
	15	14.00-14.50°N, 100.25-100.75°E	2 stations in 2 provinces (Pathum Thani and Ayutthaya)
	16	14.25-14.75°N, 100.75-101.25°E	2 stations in Saraburi
	17	15.50-16.00°N, 100.00-100.50°E	1 station in Nakhon Sawan
East	18	13.50-14.00°N, 101.25-101.75°E	2 stations in 2 provinces (Chachoengsao and Prachinburi)
	19	13.00-13.50°N, 100.75-101.25°E	3 stations in Chonburi
	20	12.50-13.00°N, 101.00-101.50°E	5 stations in Rayong
Southeast	21	8.75-9.25°N, 99.00-99.50°E	1 station in Surat Thani
	22	6.25-6.75°N, 101.00-101.50°E	1 station in Yala
	23	6.25-6.75°N, 101.50-102.00°E	1 station in Narathiwat
	24	6.75-7.25°N, 100.25-100.75°E	1 station in Songkhla
Southwest	25	6.50-7.00°N, 99.75-100.25°E	1 station in Satun
	26	7.75-8.25°N, 98.00-98.50°E	1 station in Phuket

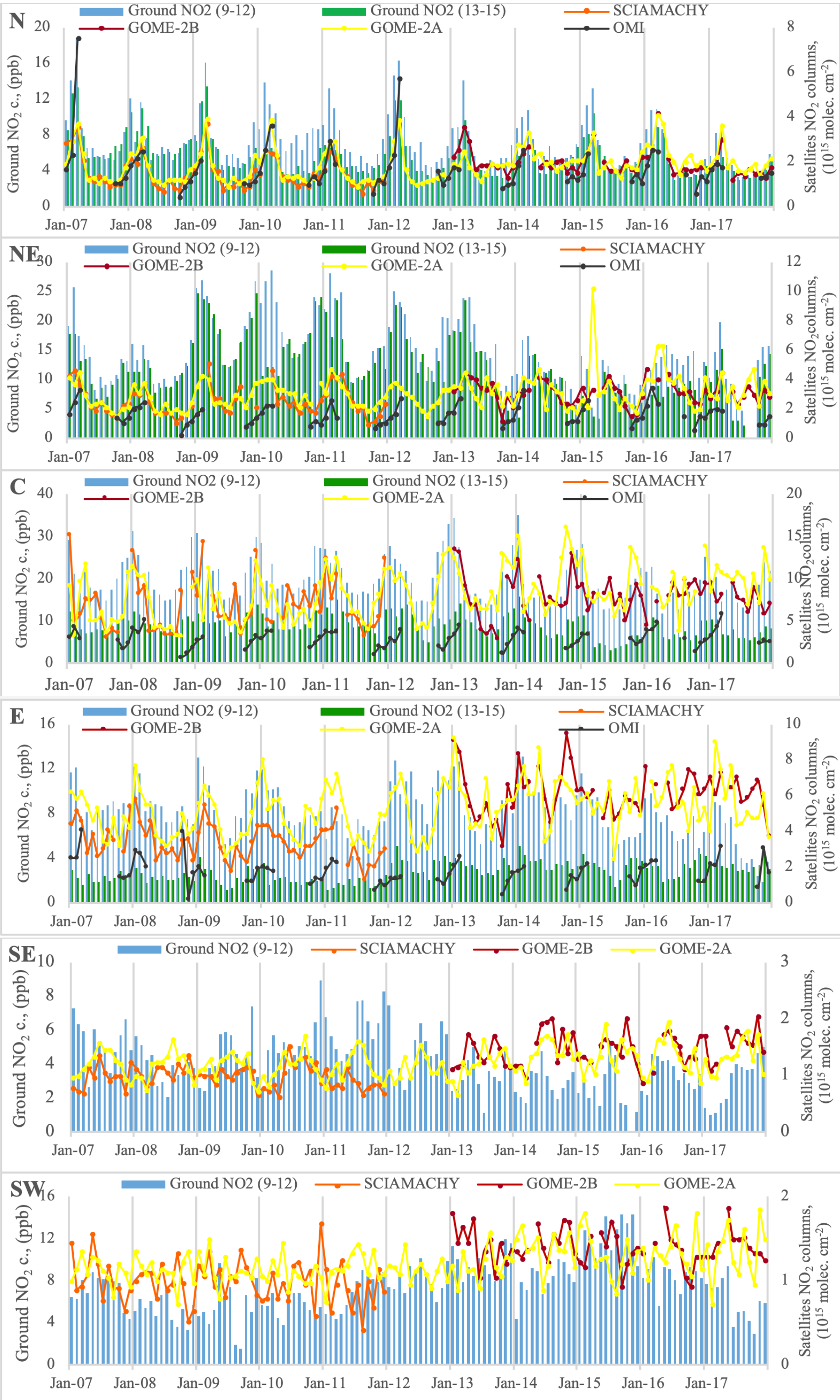

Figure 2. Long-term Satellites NO_2 columns and ground NO_2 concentrations over Thailand

ground NO_2 concentrations data from 9.00-12.00 were compared with data from three morning satellites (SCIAMACHY, GOME-2A and GOME-2B) and data from 13.00-15.00 were compared with data from OMI afternoon satellite. Twenty-six of 0.5°×0.5° grid boxes were set around the 61 PCD stations over six regions. The details and illustration of the locations were presented in Fig.1 and Table 2.

3. Results and Discussion

The results are presented in three parts. The first part is long-term trend observation of NO_2 columns retrieved from satellites and ground NO_2 concentrations over six regions of Thailand. The second and third parts, focusing on the east, present the comparison between NO_2 columns derived from satellites and ground data NO_2 concentrations and meteorology. The east is chosen as main focus of this study because several industrial estates are located in this region.

3.1 Time series of satellites and ground NO_2 data

Fig. 2 shows the comparison of monthly average of satellites and ground data of NO_2 over Thailand. In this study data from satellites retrieved from SCIAMACHY, GOME-2A, GOME-2B and OMI were compared with ground NO_2 concentrations over six regions of Thailand during 2007-2017 (11 years). The satellites capture the same trend of NO_2 concentration in this area. Observation of the north (N) area shows that maximum levels of ground NO_2 concentrations and NO_2 columns from satellites, caused by forest fires, are shown in January - March of every year. Observation of the northeast (NE) area indicates that biomass burning is the main cause of maximum levels

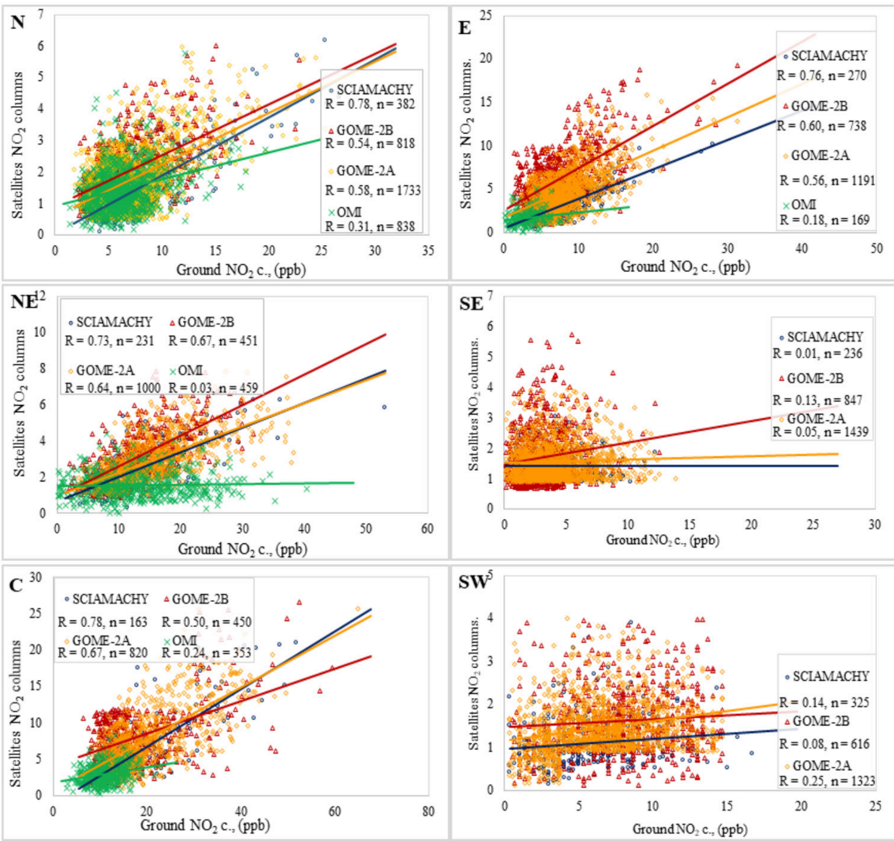

Figure 3. The scatter plots of ground NO_2 concentrations and satellite NO_2 columns (unit: 10^{15} molec.cm^{-2})

shown in January - April. The result were the similar to the form of biomass which increased during February - April and the highest level in March, Chiang Mai of Thailand from 2010-2014 (Punsompong and Chantrara, 2015). The central (C) and east (E) observation reveals that concentrations measured in both regions are in the same trend and the maximum levels in November – February. Moreover, in these areas, ground NO_2 concentrations are at high levels because of a lot of traffic and industrial estates (Mavroidis and Chaloulakou, 2010). The possible causes of this trend are due to the amount of direct NO_2 traffic emissions. As for the observation in the southeast and the southwest, it is shown that data from satellites and ground measurements are not related. There is only one ground station compared with the whole satellite grid box.

In the same way, the study of Lalitaporn, 2017, analyzing NO_2 columns observed from satellites and ground NO_2 concentrations over six regions of Thailand during 2008-2015 showed that the maximum levels of NO_2 columns were reported during the winter months (November - February). The previous studies in Turkey (Oner, *et al.*, 2016), China (Cui, *et al.*, 2016) and India (Ghude, *et al.*, 2008) also showed that the maximum levels of NO_2 columns derived from satellites were generally observed during summer, winter and dry season while the minimum levels were observed during fall, winter, summer and wet season.

Fig. 3 showed the scatter plots of ground NO_2 concentrations over six regions of Thailand and tropospheric NO_2 columns from SCAIAMCHY, GOME-2A, GOME-2B and OMI. Fig. 3 (N, NE, C and E) are NO_2 data from satellites of north, northeast, central and east of Thailand that show correlation coefficients (R) between 0.54-0.78, 0.64-0.73, 0.50-0.78 and 0.56-0.76 respectively. R-value greater than 0.5 indicates the consistency of data in the same direction. However, R-value from OMI observed were 0.31, 0.03, 0.24 and 0.18 respectively. This shows that NO_2 data were not

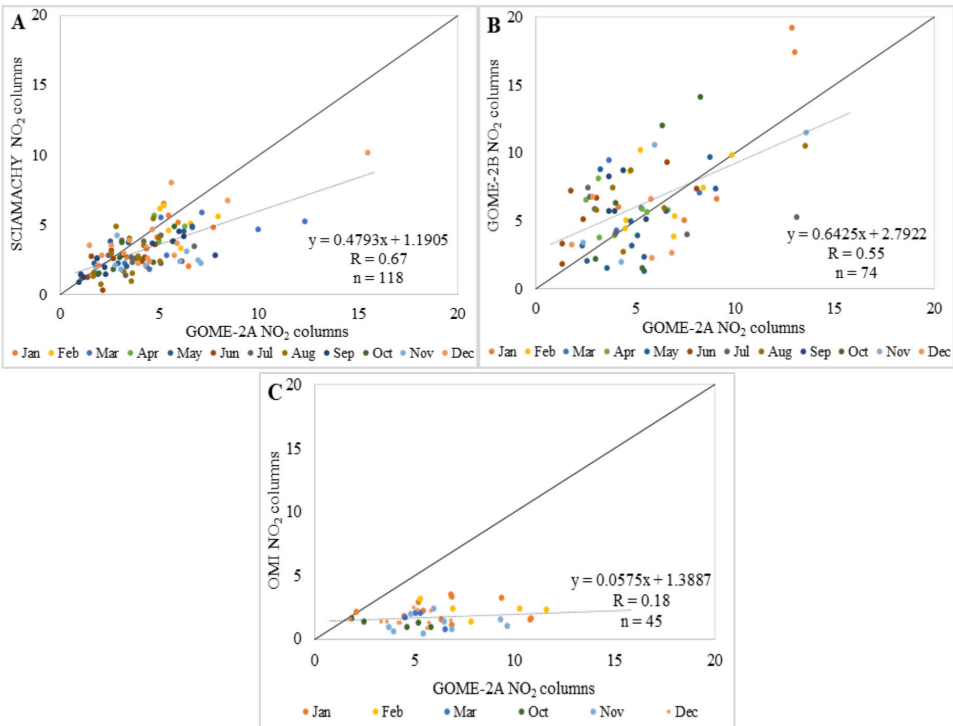

Figure 4. Consistency between (A) GOME-2A vs. SCIAMACHY (2007-2012), (B) GOME-2A vs GOME-2B (2013-2017) and (C) GOME2A vs. OMI (2007-2017), (units: 10^{15} molec.cm^{-2})

relevant. This can be explained by missing data of OMI during April – September of every year.

In Fig.3 (SE-SW) R-values of southeast and southwest were at 0.01-0.13 and 0.08-0.14 respectively and OMI data are not available. The low R-values is due to the low amount of ground data and probably due to variation of the meteorology.

3.2 The relationship between satellite data

The scatter plots between daily tropospheric NO_2 columns in the east shown in Fig. 4.

Fig. 4 (A, B) are the relationship between the NO_2 data retrieved from satellites with the local time in the morning which show that data characteristics tend to be in the same direction. R-values were 0.67 and 0.55 respectively; this represents the consistency of the data. In Fig. 4 (C), R-value was 0.18 representing inconsistency of the data because OMI retrieved in afternoon and GOME-2A retrieved in morning, the data was inconsistency and low number of OMI data (missing data in April – September).

3.3 Comparison of satellites data and meteorology

Tropospheric NO_2 columns in the East from SCIAMACHY, GOME-2B and GOME-2A were compared with monthly averages of meteorological factors including; temperature (° C), wind speed (m.s-1) and relative humidity (%) during 2007-2016 were presented in Fig. 5. The results show that temperature and wind speed are not the main causes of NO_2 level. Relative humidity is low when NO_2 is high. In wet season, when exposed to the sunlight, water vapor reacts with oxygen atoms (caused by photolysis of O_3) to form these OH radicals. They react with NO_2 to form HNO_3 ($NO_2 + OH \rightarrow HNO_3$) (Stavrakou, *et al*., 2013).

4. Conclusion

Long-term trend and seasonal variation of NO2 over six regions of Thailand during 2007-2017 retrieved from satellites: SCIAMACHY, GOME-2A, GOME-2B and OMI, were compared with ground NO_2 concentrations. The maximum levels occur during the dry season (November - April). The correlation coefficients (R) of NO_2 retried from satellites and ground measurements reveals that R of satellites data retrieved in morning, are greater than 0.5; this means both datasets, regarding to north, northeast, central and east are consistent. R of OMI in four regions are inconsistent because this satellite cannot detect NO_2 all year round. R of southeast and southwest are inconsistent. This I due to the lack of OMI data during April – September.

The relationship of NO_2 columns retrieved from satellites of the east was focused. The results show that the R of satellites retrieved in each morning are consistent because data were collected during the same period.

Comparison of data retrieved from satellites and meteorology focused on the east. The results show that temperature and wind speed are not the main causes of NO_2 level and NO_2 is high when relative humidity is low.

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