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Intercomparison of tropospheric nitrogen dioxide retrieved from Ozone Monitoring Instrument over China

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ABSTRACT

Tropospheric NO_2 columns observed from the Ozone Monitoring Instrument (OMI) were evaluated and the seasonal characteristics were analyzed at eastern China with surface measurements. A comparison between the DP (DOMINO) and SP (Standard Product) tropospheric NO_2 products from OMI different algorithms shows similar spatial and temporal variability, but DP is generally higher than SP by 13% in wintertime and lower 9% in summertime on average over East China. Larger differences occur on the significantly contaminated regions. The differences in seasonality are associated with emissions sources. In order to investigate and monitor the air pollution monitoring over east China, the relative contributions of the stratosphere–troposphere separation and air mass factors calculations to the observed difference between DP and SP tropospheric NO_2 columns were compared. The seasonal difference due to stratosphere–troposphere separation is opposite in sign to the tropospheric vertical columns. Air mass factors (AMFs) of DP are smaller than SP AMFs, leading to higher DP tropospheric columns. Impacts induced by different AMFs calculation are crucial. Then, the differences of four cities in significant polluted areas were compared. The results showed apparent discrepancies between two products in local region with irregular monthly variation, however the seasonal mean columns demonstrated that basically DP is larger than SP. Overall, this study analyses the discrepancies in DP and SP, as well as the seasonal variations over East China which is an important implication for the control of nitrogen oxides.

Keywords: *Nitrogen dioxides, retrieval algorithm, DOMINO, Standard Product, East China*

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1. Introduction

Nitrogen oxides (NO_x=NO+NO_2) are emitted from anthropogenic combustion sources as well as natural sources from lightning, soil and biomass burning in the troposphere. Nitrogen dioxide (NO_2) as an important trace gas plays an important role in the atmosphere by affecting the formation of tropospheric ozone, nitrate aerosol and the abundance of the hydroxyl radical (OH) with significant consequences on air quality, climate forcing and acid deposition. These secondary pollutants have highly uncertain effects on climate (IPCC, 2013), influence the oxidizing capacity of the troposphere, and affect human health. As an primary indicator of surface air quality standard, NO_2 is closely associated with mortality (Stieb et al., 2003; Burnett et al., 2004; Samoli et al., 2006) and respiratory morbidity (U.S. EPA, 2008) that should be proposed to strengthen the primary NO_2 national air quality standard (U.S. EPA, 2009; Ministry of Environmental Protection of the People's Republic of China, 2012). Understanding the sources and sinks is crucial both for estimating the effects of NO_2 on the environment and issuing appropriate emission control policies.

Several inversion studies show that satellite remote sensing can provide data for tropospheric NO_2 vertical column densities (VCDs), such as GOME (Global Ozone Monitoring Experiment) (Burrows et al., 1993; ESA, 1995; Burrows et al., 1998) and its successor GOME–2 (Callies et al., 2000; Munro et al., 2006), SCIAMACHY (Scanning Imaging Absorption SpectroMeter for Atmospheric CHartographY) (Bovensmann et al., 1999), and OMI (Ozone Monitoring Instrument) (Levelt et al., 2006a; Levelt et al., 2006b). Additionally, the OMI has better spatial and temporal resolution than the other sensors, so it was used widely in the current study. The validation of tropospheric NO_2 column retrieval from OMI has been examined with in–situ NO_2 measurements. Comparison of tropospheric NO_2 from in–situ aircraft measurements from the INTEX–A, PAVE and INTEX–B campaigns with near–real–time and standard product data from OMI were presented, but these campaign–based validations are limited by sparse spatial and temporal sampling and by the need to extrapolate below the lowest measurement altitude (Bucsela et al., 2008). Ground–based tropospheric NO_2 measurements from other novel techniques are yet to be thoroughly evaluated (Celarier et al., 2008). Validation with in–situ surface NO_2 measurements from dense networks [U.S. Environmental Protection Agency's Air Quality System (AQS) and Environment Canada's National Air Pollution Surveillance (NAPS) network for 2005] is complicated by interference in surface data (Lamsal et al., 2008). The NO_2 columns retrieved from satellite measurements have also been used to evaluate chemical transport models, and were affected by large discrepancies among contemporary tropospheric NO_2 retrievals (Boersma et al., 2008; Bucsela et al., 2008). However, two independent tropospheric NO_2 column data products from OMI observations are available. The OMI standard product (SP) available from the NASA Goddard Earth Sciences Data Active Center (http://disc.sci.gsfc.nasa.gov/Aura/data–holdings/OMI) and the Dutch OMI NO_2 (DOMINO) product (DP) available from Tropospheric Emission Monitoring Internet Service (TEMIS) (http://temis.nl/airpollution/no2.html). Several researches were developed based on the two products. The seasonal variation in lower tropospheric NO_2 at northern mid–latitudes were evaluated from OMI with surface SEARCH and AQS sites, and the comparison of the two OMI products over the

southeast United States indicated bias existing between the DP and SP (Lamsal et al., 2010). Stratospheric vertical columns comparison from OMI DOMINO and SP has indicated they agree with independent ground–based measurements taken from networks within 13% (Dirksen et al., 2011). Comparison of daily and monthly average global OMI NO_2 SP with DP indicated that tropospheric DP is slightly lower than SP in January and higher in July averaged over latitudes 35°N to 55°N (Bucsela et al., 2013). Since much attention has been paid to China due to its strong and rapidly increasing anthropogenic emissions caused by growing economy and rapid industrialization (Richter et al., 2005; van der A et al., 2006; Wang et al., 2007; Zhang et al., 2007; Stavrakou et al., 2008; Zhao and Wang, 2009; Lin et al., 2010a; Lin et al., 2010b; Lin and McElroy, 2010; Lin and McElroy, 2011; Wang et al., 2012). Both of the products were applied to quantitative air pollution monitoring, pollution trend studies, and budget calculations. And all focused on the densely populated and industrialized eastern part of China. In order to support the INTEX–B, Zhang et al. (2009) updated the inventory of air pollutant emissions in Asia for the year 2006. Verification of anthropogenic emissions of China by satellite and ground based observations show that correlation coefficients are 0.9 between modeled and OMI DP NO_2 column over East China (Wang et al., 2011). Satellite constraint for emissions was studied to estimate emissions of NO_X from anthropogenic, lightning and soil sources individually for 2006 over East China on a 0.25°longitude × 0.25°latitude grid, employing the DP data (Lin, 2012). The NO_2 column products retrieved from OMI SP were used to investigate the NO_2 tropospheric and total column global distribution and temporal and spatial variability (Xiao et al., 2013). All studies provide an important basis for understanding the changes of air pollution in China.

In this paper, the comparison of SP and DP was extended to the east China (10°–55°N, 90°–135°E). A detailed discussion of DP and SP retrieval algorithms is presented in Section 2. Then, the differences due to OMI NO_2 different algorithms in retrieval steps of DP and SP were compared over east China by analyzing the sources of seasonal variation and discrepancies according to inversion methods in Section 3. In addition, we evaluated the monthly and seasonal variation of major polluted cities in China based on OMI DP and SP tropospheric NO_2 columns using in–situ surface NO_2 measurements.

2. Data

We used the DP released by KNMI and SP released by NASA GSFC to compare the NO_2 VCD between the DP and SP algorithms (Boersma et al., 2004; Bucsela et al., 2006; Boersma et al., 2007; Bucsela et al., 2008; Boersma et al., 2011; Bucsela et al., 2013). In this study we focus on East China in 90°E–135°E, 10°N–55°N covering the mainly industrial areas (see Figure 1). The surface NO_2 concentration was derived from the daily air pollution index (API) released by Ministry of Environmental Protection of the People's Republic of China. (http://datacenter.mep.gov.cn/report/air_daily/). The API is the average of observed air pollutant concentrations from urban monitoring sites in each city (Jiang et al., 2004). The significant environmental monitoring centers are concentrated in Beijing, Shanghai, Guangzhou, and Chengdu. Daily averaged data were adopted for every city. Table 1 summarizes the observational data used in this study.

2.1. Ozone Monitoring Instrument (OMI)

The Dutch–Finnish Ozone Monitoring Instrument (OMI) is a nadir–viewing imaging spectrograph recording direct and atmosphere–backscattered sunlight in the ultraviolet–visible (UV–VIS) range from 264 nm to 504 nm aboard NASA's EOS Aura satellite (Levelt et al., 2006b). EOS Aura was launched on July 15, 2004 into a Sun–synchronous polar orbit at approximately 705 km altitude with a period of 100 min and a local equator crossing time between 13:40 and 13:50 local time (LT). OMI has three spectral channels; UV1 (264–310 nm) and UV2 (310–365 nm) are covered by CCD1. CCD2 covers the VIS–channel from 365–504 nm with a spectral sampling of 0.21 nm, and a spectral resolution of 0.63 nm. The spectral features of NO_2 in this channel are most prominent. The tropospheric NO_2 vertical columns that can be currently obtained from OMI are SP (version 2.1) and DP (version 2.0). The following is the detailed description of their algorithm.

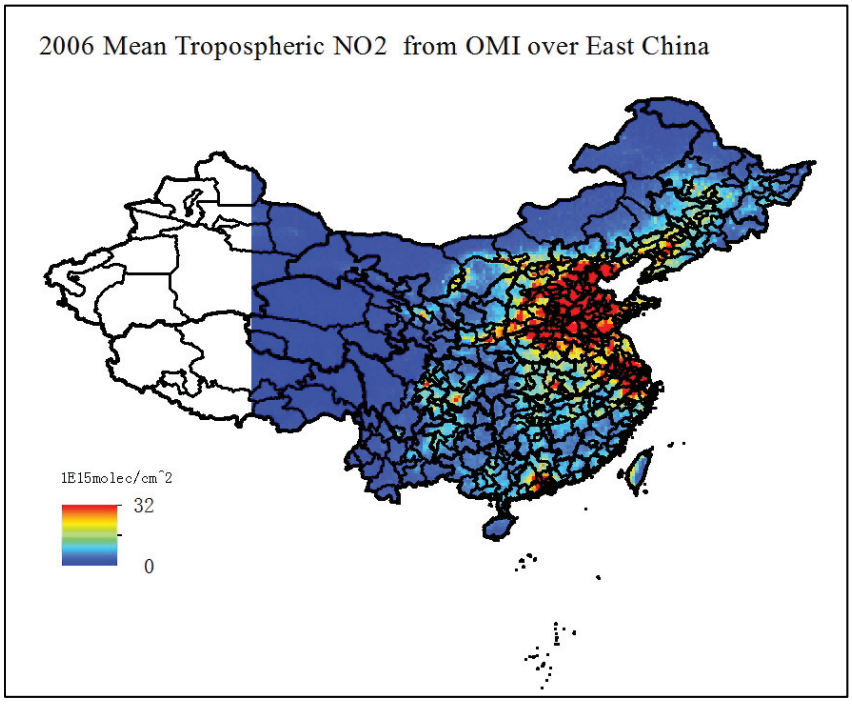

Figure 1. *Regional maps with provincial boundaries of yearly average tropospheric NO_2 columns over East China.*