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An intercomparison of satellite-derived ground-level NO_2 concentrations with GMSMB modeling results and in-situ measurements – A North American study

Baozhen Wang, Zhi Chen*

Department of Building, Civil and Environmental Engineering, Concordia University, Montreal, Quebec H3G 1M8, Canada

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ABSTRACT

This paper investigates the biases associated with the ground-level nitrogen dioxide (NO_2) concentrations derived from the satellite Ozone Monitoring Instrument (OMI) NO_2 data through comparisons with the modeling and the monitoring results for the state of California in 2008. The seasonal and annual average ground-level NO_2 concentrations are both analyzed from the OMI using the local NO_2 profile obtained from the GEOS-Chem simulation. The OMI-derived ground-level NO_2 concentrations are then compared with the NO_2 concentrations predicted by a GIS-Based Multi-Source and Multi-Box model (GMSMB) and the in-situ measurements, correlation coefficients among the three sets of results are all above 0.84 with an average slope of 0.81 ± 0.04. Particularly, various biases associated with the three data sets have been analyzed, and the OMI-derived NO_2 concentrations and the GMSMB modeling results have been proven to be essential for assessing regional air pollutant exposure risks with the aid of the extensive remote sensing database.

1. Introduction

Nitrogen dioxide (NO_2) is one of the most important air pollutants that directly affects human health and plays a major role in the formation of ground-level ozone (Seinfeld and Pandis, 2006). NO_2 is also one of the key greenhouse gases (GHGs) that is responsible for global warming (Solomon et al., 1999). Therefore, it is desirable to have a state-of-the-art monitoring and dynamic assessment of NO_2 concentrations in the atmosphere, especially at the ground level.

The current monitoring of ground-level NO_2 is typically conducted through ground surface measurements with in-situ data. The exposure assessments of NO_2 are impaired by the sparse and unevenly located monitoring network (Lamsal et al., 2008). Recent advances in satellite remote sensing technology make remote air pollution measurements available. Compared to surface and aircraft measurements, satellite remote sensing data provide two important information sources: more complete spatial coverage and a vertically integrated measure of atmospheric components (Engel-Cox et al., 2004).

Satellite observation of tropospheric NO_2 columns started in the mid-1990s with the Global Ozone Monitoring Experiment (GOME-1) (Burrows et al., 1999) and was continued with the Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY) (Burrows et al., 1995, 1999). Recent developments include the Ozone Monitoring Instrument (OMI) (Levelt et al., 2006) and GOME-2 (Callies et al., 2000). Among these instruments, OMI has a better spatial resolution (13 km × 24 km at nadir, larger at non-nadir viewing) than the earlier GOME (320 km × 40 km) and SCIAMACHY (60 km × 30 km). It can also achieve the global coverage observations in a day compared to three and six days for GOME and SCIAMACHY, respectively (Boersma et al., 2007).

An increasing number of studies have reported the applications of satellite remote sensing for air quality management in the past two decades (Schaub et al., 2006; Sheel et al., 2010; Uno et al., 2007). Most previous studies focused on the retrieval of the tropospheric NO_2 density from GOME and SCIAMACHY (Ghude et al., 2009). Recently, a few studies have explored tropospheric NO_2 retrieval from OMI (e.g. Boersma et al., 2007; Bucsela et al., 2006, 2008; Hains et al., 2010; Halla et al., 2011; Lee et al., 2011). These studies have demonstrated the enormous potential of using OMI-derived data to support other air pollution management efforts, including air quality modeling and emission examining. However, only few studies have determined ground-level NO_2

* Corresponding author.
E-mail address: zhichen@alcor.concordia.ca (Z. Chen).

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concentrations from the analysis of OMI data, especially at finer spatial resolutions (Lamsal et al., 2008; Lee et al., 2011).

In this study, we present the results of the ground-level NO_2 concentrations derived from the analysis of the OMI tropospheric NO_2 column retrievals using the global three-dimensional chemical transport model GEOS-Chem for North America in 2008. Then the OMI-derived ground-level NO_2 concentrations are compared with the modeling results of the NO_2 spatial concentration distribution predicted by a GIS-Based Multi-Source and Multi-Box (GMSMB) modeling approach (Wang and Chen, 2013) and in-situ NO_2 surface measurements for the state of California. The three independent results of the ground-level NO_2 concentrations from OMI-derived, GMSMB modeling and in-situ surface measurement are cross-verified through regression analysis.

2. Method and data

2.1. OMI tropospheric NO_2 retrievals

The Ozone Monitoring Instrument (OMI) was launched onboard NASA's Earth Observing System (EOS) Aura satellite in 2004 (Schoeberl et al., 2006). The Aura satellite passes over the North America around 13:00 local time. OMI measures the upwelling radiance in the ultraviolet and visible wavelength range between 270 nm and 500 nm, and continuously provides a 2600 km wide spatial swath on the Earth's surface (Levelt et al., 2006). The nadir spatial resolution of 13 km × 24 km allows finer details to be observed and higher detection sensitivity for NO_2 compared to other available satellite instruments (Boersma et al., 2007; Hains et al., 2010).

The regional monthly mean OMI tropospheric NO_2 column retrievals from DOMINO (Dutch OMI NO_2) (version 2.0) for North America in 2008 are obtained from the European Space Agency (ESA)'s Tropospheric Emission Monitoring Internet Service (TEMIS) project website (http://www.temis.nl). Detailed descriptions of the algorithm for the DOMINO product are given in Boersma et al. (2007, 2011) and Dirksen et al. (2011). The presence of clouds can increase the instrument's sensitivity to monitor gases above the clouds because of light scattering and/or decrease its sensitivity to trace gases below the clouds due to shielding (Stammes et al., 2008). Therefore, the tropospheric NO_2 columns (i.e. NO_2 vertical column density (VCD)) have been retrieved and averaged monthly in situations with a cloud radiance fraction <50%, corresponding to cloud fractions approximately <20% (Boersma et al., 2011). This study focuses on the state of California region (32° 32′ N–42° 00′ N, 114° 08′ W–124° 26′ W), which is divided into 15 air basins by the California Air Resources Board (CARB) based on similar meteorological and geographic conditions and state political boundaries (CARB, 2009), as shown in Fig. 1.

2.2. Derivation of the ground-level NO_2 concentrations based on the GEOS-Chem model

The OMI tropospheric NO_2 VCD retrievals are applied to derive the ground-level NO_2 concentrations, which require local tropospheric NO_2 profile information. For this purpose, we use the global three-dimensional model GEOS-Chem (version 9-01-02) to simulate atmospheric composition. The GEOS-Chem model is a chemical fate and transport model driven by assimilated meteorological observation data available from the Goddard Earth Observing System (GEOS) of the NASA Global Modeling and Assimilation Office (GMAO) (Yantosca et al., 2011). The model includes a detailed simulation of the tropospheric ozone-NO_x-hydrocarbon chemistry including aerosols and their precursors. We use the GEOS-5 meteorological field to implement the simulation at 0.5° × 0.667° horizontal resolution for North America. The data for profiles at 47 vertical levels are established starting from the ground surface to a height of 0.01 hPa (approximately 80 km). Among the 47 vertical levels, 35 are in the troposphere, including 14 levels below 2 km. The OMI-derived surface NO_2 concentration represents the mixing ratio (refers to the mole fraction of NO_2 to the total amount of air species in a unit of ppb) at the lowest vertical layer (100 m) (Lamsal et al., 2008). The boundary conditions are created at a coarse resolution, i.e., to run a 2° × 2.5° global simulation first, and then recompile the GEOS-Chem model for the 0.5° × 0.667° nested simulation. The U.S. EPA/NEI2005 emission inventory is used for this simulation (US EPA, 2010a).

The ground-level NO_2 concentrations are obtained from the GEOS-Chem simulation and OMI column retrievals (Lamsal et al., 2008):

Fig. 1. The study area (32° 32′ N–42° 00′ N, 114° 08′ W–124° 26′ W) with the air basins and the main cities.