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Inference of surface concentrations of nitrogen dioxide (NO_2) in Colombia from tropospheric columns of the ozone measurement instrument (OMI)

JOHN FREDDY GRAJALES and ASTRID BAQUERO-BERNAL
Grupo de Simulación del Sistema Climático Terrestre, Departamento de Física, Universidad Nacional de Colombia, Cra. 30 45-03, Bogotá, Colombia
Corresponding author: A. Baquero-Bernal; e-mail: abaquerobe@unal.edu.co

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RESUMEN

Por primera vez se presentan mapas de concentración superficial de dióxido de nitrógeno (NO_2) para el territorio colombiano. Se infirieron concentraciones superficiales de NO_2 para 2007 a partir de dos fuentes de datos de densidad de columna troposférica: 1) una simulación que utiliza el modelo global tridimensional GEOS-Chem y 2) mediciones realizadas por el instrumento de monitoreo del ozono (OMI, por sus siglas en inglés) instalado a bordo del satélite Aura de la NASA. Los resultados muestran valores mensuales promedio de 0.1 a 6 ppbv. Se compararon las concentraciones superficiales de NO_2 inferidas con mediciones in situ corregidas y se encontraron coeficientes de correlación de hasta 0.91. Una fuente importante de NO_2 es la quema de biomasa, la cual puede ser diagnosticada a partir de los datos de potencia radiativa de los fuegos provenientes del reanálisis para el monitoreo de la composición atmosférica y el clima (MACC, por sus siglas en ingés). Se encontró una fuerte relación entre altas concentraciones de NO_2 inferidas y quema de biomasa para un área extensa que comprende los departamentos de Caquetá, Meta, Guaviare, Vichada y Putumayo.

ABSTRACT

For the first time, maps of surface concentration of nitrogen dioxide (NO_2) are presented for the Colombian territory. NO_2 surface concentrations for the year 2007 are inferred based on two sources of tropospheric NO_2 column data: (1) a simulation using a three-dimensional global model (GEOS-Chem) and (2) measurements made by the ozone monitoring instrument (OMI) onboard the NASA Aura satellite. Results show monthly averages between 0.1 and 6 ppbv. We compare these inferred values to corrected ground measurements of NO_2. We find correlation coefficients of up to 0.91 between the inferred data and the corrected observational data. A significant source of NO_2 is biomass burning, which can be diagnosed by data of fire radiative power (FRP) from the Monitoring of Atmospheric Composition and Climate (MACC) reanalysis. We find a close relationship between high values of inferred NO_2 surface concentrations and biomass burning for a large area which encompasses the departments of Caquetá, Meta, Guaviare, Vichada, and Putumayo.

Keywords: Inference of nitrogen dioxide surface concentration, density of tropospheric columns, OMI, GEOS-Chem, fire radiative power, chemiluminescence interference, overestimation, Colombia.

1. Introduction

NO_2 is both an important contributor to ozone (O_3) decomposition in the stratosphere and a major precursor in the chain of chemical reactions that produces O_3 in the troposphere. Both O_3 and NO_2 are toxic to biota. Long-term exposure to NO_2 is significantly associated with decreased lung function and is a risk factor for respiratory diseases (Ackermann-Liebrich, 1997; Schindler *et al.*, 1998; Gauderman, 2000, 2002; Panella *et al.*, 2000; Smith *et al.*, 2000). The measurement of pollutants not only allows the tracking of anthropogenic activity, but also improves our understanding of the relationships between pollution and natural phenomena. In this study, we focus on

NO_2. Nitrogen oxide (NO) and NO_2 species are produced from lightning, biomass burning, fossil fuel combustion, and soils (Sauvage *et al.*, 2007). The high temperatures of combustion break down molecular oxygen (O_2) from the air, which subsequently enters an important chemical reaction that produces NO and NO_2 (Jacob, 1999). Their production in combustion makes NO_x a marker of industrial activity (including fossil fuel-based power generation, transportation, and concrete manufacture) as well as other human activities, such as agricultural biomass burning. Therefore, NO_2 serves as an indicator of air quality and anthropogenic activity. Researchers have made significant efforts to analyze pollutant emission and overall air quality in Colombia, but none were focused specifically on NO_2 (Lacouture, 1979; Bedoya, 1981; Ruiz, 2002; Benavides, 2003; Barreto, 2004; Jiménez, 2004; Oviedo, 2009).

Our primary interest in this study is the inference of surface NO_2 concentrations in Colombia. To infer these concentrations, we use the GEOS-Chem tropospheric chemistry model along with tropospheric column data from the ozone-measuring instrument (OMI) onboard the NASA Aura satellite. The first step of the inference process was the acquisition of NO_2 tropospheric column data from the OMI. We use the OMNO2e product (Kempler, 2010). There are other OMI products that report NO_2 density of tropospheric columns, such as the different products of the Royal Netherlands Meteorological Institute (KNMI) (Boersma *et al.*, 2007, 2011). However, the analysis of these products and their intercomparison are beyond the scope of this study.

Aerial measurements reveal that the concentration of NO_2 in the tropospheric column is determined primarily by NO_2 in the mixed layer, as well as by that in the boundary layer (Martin *et al.*, 2004, 2006; Boersma *et al.*, 2008; Bucsela *et al.*, 2008). However, the proportion of NO_2 in these two layers varies in space and time. Lamsal *et al.* (2008) proposed a method that uses the local NO_2 profiles obtained from the GEOS-Chem model to capture this variation in space and time. The GEOS-Chem model is a global three-dimensional model of tropospheric chemistry driven by assimilated meteorological observations from the Goddard Earth Observing System (GEOS) of the NASA Data Assimilation Office (Bey *et al.*, 2001; Gass, 2012; Rienecker *et al.*, 2008). This model provides a comprehensive description of atmospheric composition and allows us to obtain tropospheric column densities and profiles up to 0.01 hPa. These profiles are used together with the tropospheric column data from OMI (see details in section 4.5) to infer quasi-observed concentrations of NO_2 at the surface.

Celarier *et al.* (2008) validated the tropospheric, stratospheric and total NO_2 columns from the OMI with respect to surface measurements from multiple sources. This validation is difficult for many reasons, perhaps the most important of which is that each OMI column corresponds to the average over a large area (at least 340 km^2), whereas surface measurements are site-specific. In addition, surface measurement instruments are often placed at points of maximum emission and, therefore, do not measure background concentrations. Another difficulty is that the length of each time data series for validation is short, and the number of series is small, which makes statistical analysis difficult. Despite these and other difficulties, OMI measurements and surface measurements yield correlations in the data that are generally above 0.6. Another way to validate the tropospheric columns is through air campaigns or in situ experiments, which provide vertical profile data. Boersma *et al.* (2008) reported a high similarity between OMI data and in situ profile data.

For the first time, maps of surface concentration of NO_2 are presented for the Colombian territory for a whole year, 2007. Additionally, in order to assess the contribution of the biomass burning to the NO_2 concentrations in the country, the inferred surface NO_2 concentrations are compared with fire radiative power data, which is used to monitor biomass burning. A brief summary of all the datasets used is given in section 2. Section 3 describes the methods used to infer the surface concentrations of NO_2 and to calculate the correction factors to NO_2 concentrations measured at surface stations. The results and conclusions are presented in sections 4 and 5.

2. Data

2.1 NO_2 tropospheric column from OMI

We used data from the OMNO2e product, which is a daily, global, gridded data product, where each file is produced from one day's worth of NO_2 measurements made by the ozone monitoring instrument onboard the EOS-Aura spacecraft (OMI Team, 2009). The data are filled into a grid with horizontal resolution of 0.25×0.25^{o} in latitude and longitude. The data fields included in the product are two: (a) total column NO_2