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Original article

Evaluation of NO_x emissions for Turkey using satellite and ground-based observations

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ABSTRACT

The aim of this study was to evaluate NO_x emissions from available inventories using satellite NO_2 retrievals for Turkey. NO_x emissions from two available inventories (EMEP and TNO) were compared with each other, differences and similarities were determined. NO_x emission inventories were also compared with OMI NO_2 satellite retrievals. Correlation coefficients (R^2) between parameters and emissions were found in the range of 0.29–0.69 for selected high populated cities. OMI NO_2 satellite retrievals overpass NO_2 ground observation stations were also processed and the correlation between these observations for selected cities were found highest in summer and lowest in fall and winter. According to the comparison for individual cities, good correlations were observed for Ankara (R^2 = 0.62), Izmir (R^2 = 0.59) and Istanbul (R^2 = 0.90). Weekly profiles and weekend/weekday ratios for ground-based and OMI NO_2 observations were calculated and weekly profiles used for EMEP were also compared with observed weekly profiles. Findings showed that OMI is able to detect polluted regions in Turkey, but there are discrepancies between OMI and ground-based NO_2 observations. Results also indicated issues on NO_x emissions of large scale power plants in EMEP emission inventory for Turkey.

1. Introduction

Air pollution has been a great problem during the history of mankind with its effects on human health and the environment. Among the major criteria air pollutants, Nitrogen oxides (NO_x) are still an issue with increasing emissions and their contribution to secondary particulate matter and especially tropospheric ozone (O_3) formation. Currently, particle matter and ozone are the major pollutants showing exceedances worldwide, thus have most widespread health threats. NO_x are emitted from both anthropogenic sources (e.g., fossil-fuel combustion and human-induced biomass burning) and natural sources (e.g., wildfires, soil release, lightning, ammonia oxidation) (Lu and Streets, 2012). NO_x emissions are mainly located in populated areas, where NO_2 exposure can affect lung function and increase the risk of respiratory symptoms (Panella et al., 2000).

Major advances have been observed in the detection of atmospheric pollution from space in the recent years. Satellite retrievals have been used for monitoring air pollutants such as carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), O_3 and particulate matter and supply information on the global spatial distribution of these pollutants. Satellite retrievals supply column totals, and require processing for the separation of the tropospheric contribution which is usually the focus of air pollution. The short lifetime of NO_2 is an advantage for the use of satellite retrievals for evaluating NO_x emissions. The relationship between NO_x emissions and satellite retrievals of tropospheric NO_2 columns were investigated previously (Leue et al., 2001; Martin et al., 2003; Jaegle et al., 2005; Toenges-Schuller et al., 2006; Kaynak et al., 2009).

Changes in tropospheric NO_2 concentrations over Europe were observed using OMI retrievals during 2004–2010 and 20% reductions were observed in NO_2 concentrations in 2010 because of the 2008–2009 global economic recession (Castellanos and Boersma, 2012). Similarly, NO_2 columns from three instruments (SCIAMACHY, GOME-2, and OMI) observed over Athens indicated significant reductions in the range of 30–40% from 2008

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(Vrekoussis et al., 2013). OMI NO_2 vertical tropospheric columns observed over Europe during 2004–2009 indicated significant negative changes in areas with large anthropogenic sources over Western Europe (mostly from −4 to −8% $year^{-1}$) (Zhou et al., 2012). The overall negative changes are consistent with European Monitoring and Evaluation Programme (EMEP) Centre on Emission Inventories and Projections (CEIP) emission estimations. However, large spatial variations in NO_2 column observed within individual regions such as Spanish power plants (from −10 to approx. −20% $year^{-1}$) and over the center of England (up to approx. −12% $year^{-1}$). NO_2 tropospheric columns over south Eastern Europe was studied to determine characteristics of spatial and temporal variability using GOME, SCIAMACHY, OMI and GOME-2 (Zyrichidou et al., 2009). Tropospheric NO_2 amounts were simulated with CAMx, and comparison with satellite retrievals showed that in most of the cases the model revealed similar spatial patterns with satellite observations, while at certain areas such as Istanbul, large discrepancies were observed. Over the polluted sites, there was a relative offset between SCIAMACHY and OMI measurements.

In order to evaluate NO_x emissions, EMEParea, HERMES-DIS (High-Elective Resolution Modelling Emissions System e DISaggregation module) and TNO inventories were compared (Ferreira et al., 2013). A predefined common spatial resolution was selected as 12 × 12 km^2, and significant differences were found for residential/commercial combustion (S2), solvent use (S6) and road transport (S7) sectors. TNO emissions were more concentrated in large urban areas, where HERMES-DIS emissions were more dispersed. According to regression analysis, the greatest correlation was observed between EMEParea and HERMES-DIS. This study indicates the spatial discrepancies in emission inventories are really important in modeling applications and air quality modelling requires appropriate temporally and spatially resolved emission inventories.

The monitoring of ambient NO_2 is performed through various platforms. Ground-based platforms are the most common; however, observations from satellite-based and aircraft platforms can also be used (Bechle et al., 2013; Mendolia et al., 2013; Wang and Chen, 2013). NO_2 concentrations derived from OMI NO_2 retrievals using scale factors (surface to column ratios) were compared with observations from 25 US EPA ambient monitoring stations for 2005. It was found that OMI provides good spatial density in the study region and demonstrated that OMI satellite observations provide a reliable measure of spatial variability in ground level NO_2 exposure for a large urban area (Bechle et al., 2013). NO_2 vertical column densities retrieved from optical absorption spectroscopy, satellite remote sensing with in situ vertical column densities estimated using a pair of chemiluminescence monitors with different spatial scales was compared in Toronto, Canada. Good correlation was observed between the remotely sensed and in situ NO_2 vertical column densities (R^2 = 0.72–0.81), but in situ vertical column densities were 52–58% greater than remotely sensed columns. These results indicate that horizontal heterogeneity of NO_2 strongly impacted the magnitude of the remotely sensed columns (Mendolia et al., 2013). OMI-derived ground-level NO_2 concentrations were compared with concentrations predicted by a GIS-Based Multi-Source and Multi-Box model (GMSMB) and in-situ measurements, resulting correlation coefficients between three sets of data were all above 0.84 for California in 2008 (Wang and Chen, 2013).

NO_x emissions from large, anthropogenic point sources are clearly one of the major targets for remote sensing measurement from space (Ghude et al., 2008; Zhang et al., 2009; Lu and Streets, 2012; Russell et al., 2012). They represent a strong signal that is usually within the detection limits of available instruments, and also command the attention of environmental regulatory bodies because of their pollution potential.

OMI NO_2 tropospheric columns obtained using BEHR retrieval algorithm showed an average decrease of 26 ± 12% in NO_x emission from 23 large power plants throughout the U.S. from 2005 to 2011 (Russell et al., 2012). NO_x emissions from new power plants built away from large urban areas were studied in Inner Mongolia, China during 2005–2007 and the summertime OMI NO_2 tropospheric columns were found to be correlated with the emissions from new power plants (Zhang et al., 2009). Power plant NO_x emissions were investigated using satellite retrievals in India, and major hotspots because of power plant NO_x emissions were demonstrated using GOME and SCIAMACHY for 1996–2006 (Ghude et al., 2008), and using OMI for 2005–2007 (Prasad et al., 2012). In addition, GOME, SCIAMACHY, OMI, and GOME-2 retrievals were combined to quantify increase of NO_x emissions from Indian power plants (Lu and Streets, 2012).

There are various studies some of which are summarized here using NO_2 satellite retrievals; however this retrievals were not previously used for Turkey. In our study, EMEP and TNO NO_x emission inventories, selected emission parameters such as road transportation (S7), residential heating (S2) and energy (S1), and NO_2 ground based observations were compared with OMI NO_2 retrievals for Turkey. The aim is to identify the similarities and differences between these datasets and demonstrate the applicability of OMI NO_2 retrievals for emission evaluation in Turkey where the number of ground-based observation stations is limited.

2. Methodology

2.1. NO_2 satellite retrievals

OMI instrument is on NASA's EOS Aura satellite which was launched on July 2004 on a sun-synchronous orbit. It has an equator crossing time around 13:40 local time and provides a complete global coverage daily. OMI NO_2 columns have pixel sizes in the swath direction ranges from 13 × 24 (exact nadir position) to 13 × ~128 km^2 (most outer swath angle (57°)) (Boersma et al., 2007). Therefore, it has much finer spatial resolution than GOME (320 × 40 km^2) (Damiani et al., 2012) and better spatial and temporal resolutions than SCIAMACHY (60 × 30 km^2 and global coverage within six days).

OMI retrieval errors can come from instrument itself and retrieval algorithms. The retrieval uncertainties are coming mainly from the uncertainty in the estimate of the tropospheric air mass factor, which can be significantly affected by the cloud fraction, surface albedo and a priori NO_2 profile shape (Boersma et al., 2011). The uncertainty in the individual OMI NO_2 slant column dominates the overall retrieval error over the oceans and remote areas (~0.75 × 10^{15} molecules/cm^2) (Boersma et al., 2004, 2011; Bucsela et al., 2013) and. AMF uncertainties dominate overall retrieval errors over continental polluted regions (~20% in clear-sky and 30–80% under cloudy conditions) (Lamsal et al., 2014).

OMI NO_2 satellite retrievals used in this study were obtained from NASA (2015). The Level-2 NO_2 tropospheric column data product was used instead of the gridded products (Level-3) in order to have high spatial resolution. The satellite NO_2 retrievals were filtered with respect to parameters suggested by the guidelines, and columns with cloud fraction less than 30% (near clear sky conditions) were used. The average tropospheric NO_2 columns were calculated for the EMEP grids with area weighted averaging. The uncertainties given for the tropospheric NO_2 columns in the data product were also propagated. EMEP grids were selected as the common spatial resolution for the comparison of NO_x emissions with NO_2 retrievals. However, when ground observations and