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A PERSPECTIVE VIEW OF O_3 AND NO_2 EVOLUTION ABOVE SEVERAL IMPORTANT CITIES DURING 2005-2016 USING UV-VIS OBSERVATIONS FROM SPACE

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Abstract. In this work, we present the evolution of the atmospheric ozone (O_3) and nitrogen dioxide (NO_2) over the worldwide during 2005 - 2016. For this purpose, nine important locations over the globe were selected: Bucharest (44.43°N, 26.10°E), Bremen (53.08°N, 8.8°E), Athena (23.73°E, 37.98°N), Toronto (79.39°W, 43.66°N), St. Petersburg (30.702°E, 59.953°N), Cairo (31.28°E, 30.08°N), Mexico City (99.18°W, 19.33°N), Nairobi (36.81°E, 1.28°S), and New Delhi (77.21°E, 28.65°N). The O_3 and NO_2 remote sensing observations were provided by the space UV-VIs instrument OMI (Ozone Monitoring Instrument) onboard the AURA satellite. Data regarding O_3 and NO_2 were obtained from the Tropospheric Emission Monitoring Internet Service (TEMIS) database. Also, correlations between NO_2 and O_3 columns are presented in this work.

***Key words**: Atmospheric ozone, nitrogen dioxide, satellite observations*

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1. Introduction

The effects of urbanization raise concern on air pollution and health [1, 2]. Despite important improvements, the worldwide citizens still face high levels of air pollutants that pose major risks to humans and the environment. A serious environmental issue is generated by the air pollution due to the industrial facilities or different urban agglomerations over the globe. Different sources emit various and different quantities of air pollutants. Industry and transports are the main sources of air pollution.

Nitrogen dioxide (NO_2) is one of the most important atmospheric trace gases. It is released in the atmosphere by natural or anthropogenic sources. Ozone (O_3) is a trace gas which can be found in the stratosphere and troposphere. Ozone (O_3) is a toxic, unstable, trace gas which is known for protecting the life on Earth from the UV radiation when located in the stratosphere or ozonosphere. On the other hand, when O_3 at high concentration is located close to the ground it is harmful to both human health and vegetation. The ozone depletion and ozone interactions with other trace gases are the subject of many scientific works [3-5]. Air pollutants like NO_2 are released mainly as a result of combustion processes, such as the road traffic and energy production. Atmospheric NO_2 is a short-lived atmospheric pollutant that serves as an air-quality indicator and is a health concerning factor for WHO (World Health Organization) and EC (European Commission) [6]. The latest WHO and EC directives and guidelines stipulate that NO_2 concentrations have a negative influence on the urban population health. Toxicological studies have showed that population exposed to pollutant concentration levels above the limit experienced significant health problems. As one of the most harmful air pollutants, NO_2 is partially responsible for some respiratory system health problems [7, 8].

The NO_2 and O_3 atmospheric content can be measured with in-situ instruments or remote sensing sensors. Usually, the in-situ sensors are used in different ground locations to monitor the level of air pollution. On the other hand, the instruments onboard satellites can be used to determine the content of NO_2, O_3 and other trace gases in troposphere or stratosphere. The Differential Optical Absorption Spectroscopy (DOAS) technique [9, 10] is a method used to measure the NO_2 and O_3 concentrations in atmospheric layers. DOAS technique is a method which is used by several sensors onboard the space satellite. The measurements from space using DOAS systems show the atmosphere pollution at a low resolution scale [11]. Tropospheric global NO_2 columns values are retrieved from different satellite instruments as Global Ozone Monitoring Experiment (GOME), the Scanning Imaging Absorption Cartography (SCIAMACHY) and the Ozone Monitoring Experiment (OMI). The data sets provided by these instruments spread on more than 20 years (1996–2016) and have been used in a series of emissions trends studies [11]. Satellite instruments provide measurements for different trace gases (NO_2, O_3, SO_2, HCHO, etc.) with a global coverage and a fixed spatial and temporal resolution. Table 1 presents the space DOAS instruments used for NO_2 and O_3 monitoring.

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Table 1. The space DOAS instruments used for NO_2 and O_3 monitoring

Instrument	Start date	Horizontal resolution	Global coverage
GOME-1	Apr-1996	320 x 40 km²	3 Days
SCIAMACHY	Jul-2002	60 x 30 km²	6 Days
OMI	Oct-2004	13 x 24 km²	1 Day
GOME-2	Apr-2007	80 x 40 km²	1 Day

2. Method and data used

In the present work, data sets for NO_2 and O_3 atmospheric content retrieved from satellite instruments such as OMI were used for investigations. The used database is available online at www.temis.nl. The NO_2 and O_3 evolution, at the global level, is performed using the data sets provided by the OMI space instrument onboard the AURA satellite. The OMI NO_2 retrieval algorithm is based on Dutch OMI NO_2 algorithm (DOMINO) version 2.0. Nine cities were selected to show the evolution of NO_2 and O_3 content at the global level (Figure 1). These cities are Bucharest (44.43°N, 26.10°E), Bremen (53.08°N, 8.8°E), Athens (23.73°E, 37.98°N), Toronto (79.39°W, 43.66°N), St. Petersburg (30.702°E, 59.953°N), Cairo (31.28°E, 30.08°N), Mexico City (99.18°W, 19.33°N) and New Delhi (77.21°E, 28.65°N). From the OMI existing measurement data, the annual mean of tropospheric NO_2 VCD (Vertical Column Density), total Vertical Column (TVCD) of NO_2, and the total VCD for O_3 loading were extracted. The OMI data presented in this work are provided by TEMIS as daily observations. OMI data are provided as pixels which can be located at max 50 km from the station (city) center. The daily observations were averaged in a yearly mean. The data were filtered using a cloud fraction of <50%. For the current work, only the positive VCDs were selected. The time period covered by our study is from 2005 to 2016. The global evolution of the tropospheric NO_2 concentration is visualized, in a comparative approach, by using the ArcGIS software.

Figure 1. The map of the cities covered by this analysis

3. Results and discussion

The annual mean value of the TVCD and tropospheric NO_2 VCD for the cities mentioned in the Section 1 are shown in the Figure 2 and Figure 3, respectively. Figure 2 presents the total vertical column of NO_2 for the nine cities covered by this work. It can be observed that a slightly downward trend in NO_2 concentration is visible for all the presented cities. However, the TVCD contain both stratospheric and tropospheric NO_2 content and, from the human perspective, the tropospheric NO_2 VCD is more interesting since the tropospheric NO_2 directly influences the quality of life. Furthermore, TVCD is correlated to the ozone layer evolution. Figure 3 shows that the most polluted cities are Bremen (Germany), Toronto (Canada), and Mexico City (México). The tropospheric NO_2 VCD concentrations over these large urban areas range from $9x10^{15}$ molecules/cm² to $12x10^{15}$ molecules/cm2. Conversely, the cities having the lowest tropospheric NO_2 content are Bucharest (Romania), Athens (Greece), and St. Petersburg (Russia). The tropospheric NO_2 VCD concentrations over these locations range from $5x10^{15}$ molecules/cm² to $7x10^{15}$ molecules/cm². Nearly all cities had an average slowly decreasing trend of the annual mean, and only Toronto, Mexico City and New Delhi had an average increasing trend during 2011.

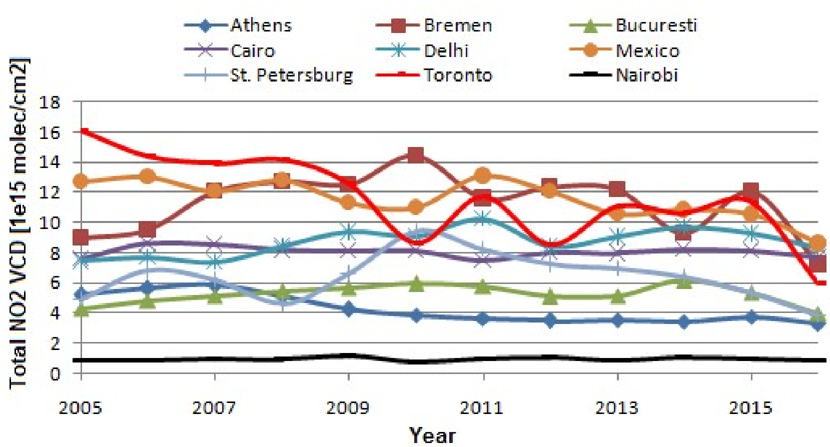

Figure 2. Mean annual values of Total Vertical Column (VCD) of NO_2 from OMI dataset for all 9 cities around the world, from 2005 to 2016

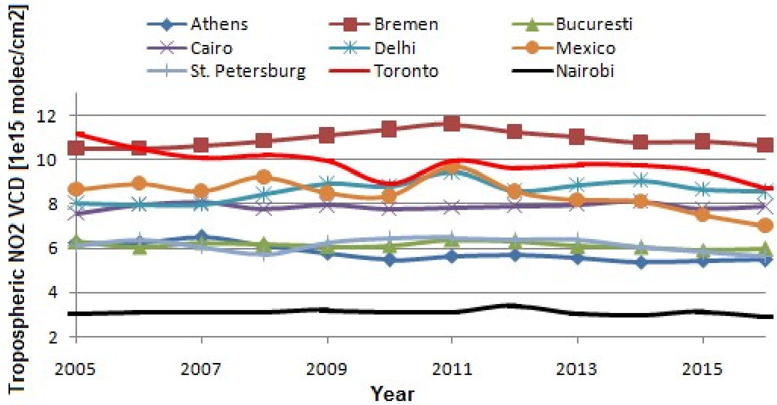

Figure 3. Mean annual values of tropospheric NO2 VCD from OMI dataset for all 9 cities around the world, from 2005 to 2016

Figure 4 shows the annual mean value of the total VCD O_3 concentrations expressed in DU (Dobson Units). One DU is 2.69×10^{16} ozone molecules/cm^2. Differences in the distribution and magnitude of O_3 are related to the thickness of the ozone layers. The lowest thicknesses of ozone layers are detected by OMI over Bremen (Germany) and St. Petersburg (Russia). In these locations, the ozone layer thicknessess are lower than 5×10^2DU. Mexico City (México) and Cairo (Egypt) show the highest thickness of ozone layer, around ~5.5×10^2DU. The general trend shown in Figure 4 indicates a small ascendant trend between 2004 and 2010 and a small downward trend between 2011 and 2014 for all considered locations.

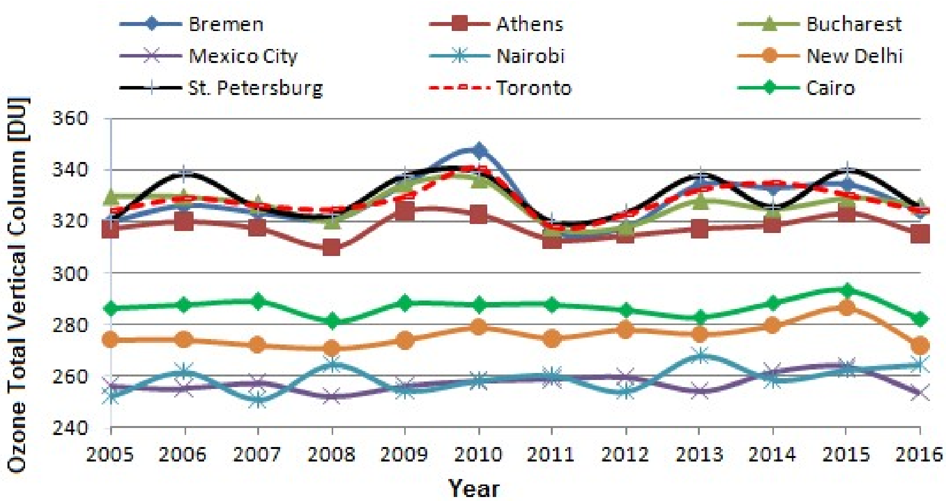

Figure 4. Mean annual values of O_3 VCDs from OMI dataset for all 9 cities around the world, from 2005 to 2016

The general annual variation of the tropospheric NO_2 content shows a small downward trend. It is a direct consequence of the policies and measures to minimize air pollution impacts such as Directive 2008/50/EC or WHO Air quality guidelines relating to ozone, nitrogen dioxide and sulfur dioxide in ambient air. High values of the mean annual NO_2 molecule densities are found above the big industrialized cities like Bremen (Germany) and Mexico City (Mexico). Low values of the mean annual tropospheric NO_2 are found above cities from the east region of Europe like Bucharest (Romania), Athens (Greece) and St. Petersburg (Russia) where air pollution is lower due to a low industrial development.

Table 2 presents the correlation factor (R^2) between the total NO_2 VCD and total O_3 VCD content for the analyzed locations. The highest correlation coefficient of 0.42 has been calculated for the city of New Delhi. Close correlations are found for Bremen, St. Petersburg and Nairobi (~0.35). The obtained values of the correlation coefficient somehow confirm the chemical relation between NO_2 and O_3; however, this subject needs further investigations. Usually, close to the ground, O_3 is depleted by the deposition on the surfaces and through the titration reaction of the NO to form NO_2. In the stratosphere, ozone depletion is due to the solar radiation and several trace gases including N_2O. However, the process of formation/destruction of the NO_2 or O_3 is quite complicated and cannot be explained without sound knowledge on the quantity of NO_2, UV radiation, and other trace gases which lead to ozone or NO_2 formation and destruction. Also, at a given location, a possible O_3/NO_2–independent contribution could exist and it can be viewed as a regional contribution. Moreover, a possible O_3/NO_2–dependent contribution could exist and it can be considered as a local contribution being strongly associated to the level of primary pollution. The atmospheric ozone content decreases with latitude. The highest ozone content was determined for the cities located at the highest latitude (e.g. Bremen, St. Petersburg).

Table 2. Correlation between Total VCDs of NO_2 and O_3

Location	Correlation factor R^2 [Total VC NO_2 *vs.* VCD O_3]
Bucharest	-0.01
Bremen	0.38
Athens	-0.07
Cairo	0.26
Mexico City	-0.04
New Delhi	0.42
Toronto	-0.16
Nairobi	-0.37
St. Petersburg	0.32

4. Conclusions

This paper presents the evolution of the NO_2 and ozone columns for several cities worldwide. Also, the existing correlations between the NO_2 total vertical column and O_3 total vertical column using the data sets collected from the space instrument Ozone Monitoring Instrument over the 2005–2016 time period are discussed. The study covered nine locations in different places around the Earth. They are Bucharest (Romania), Bremen (Germany), Athens (Greece), Cairo (Egypt), Mexico City (Mexico), New Delhi (India), Toronto (Canada), Nairobi (Kenya), and St. Petersburg (Russia). Our study also reveals that the ozone layer has a small thickness over the cities at lower latitudes compared to the other cities located at higher latitudes. Also, the correlation analysis does not indicate any important correlations between the two trace gases used as the total column. The highest correlation was identified for city of New Delhi, R^2=0.42. However, this project needs further investigations based on a large number of parameters to be able to provide accurate analysis of the ozone and NO_2 evolution.

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