Carpathian Journal of Earth and Environmental Sciences, August 2019, Vol. 14, No. 2, p. 423 - 430; DOI:10.26471/cjees/2019/014/091

OVERVIEW OF TROPOSPHERIC NO_2 USING THE OZONE MONITORING OBSERVATIONS INSTRUMENT AND HUMAN PERCEPTION ABOUT AIR QUALITY FOR THE MOST POLLUTING COUNTRIES ACCROSS THE WORLD

Adrian ROȘU*, Bogdan ROȘU[1], Daniel-Eduard CONSTANTIN[1], Maxim ARSENI[1], Mirela VOICULESCU[1], Lucian Puiu GEORGESCU[1], Gabriel MURARIU[1] & Ionel POPA[2]

[1]Faculty of Science and Environment, European Center of Excellence for the Environment, "Dunarea de Jos" University of Galati, 111, Domneasca Street, RO-800201, Galati, Romania

[2]National Institute of Research and Development in Forestry "Marin Drăcea" – Campulung Moldovenesc. Calea Bucovinei Street, no. 73 bis, 725100, Suceava, Romania

**Corresponding author: rosu_adrian_90@yahoo.ro*

Abstract: In this study, we present the assessment of air pollution for the period 2007 – 2017 for the first five most polluting countries from each continent according to World Health Organization (WHO) and NUMBEO databases. Spatial variation of NO_2 in each studied region is analyzed. Concurrent measurements of the NO_2 pollution come from long-term satellite observations using the spaceborne instrument Ozone Monitoring Instrument (OMI). The satellite OMI instrument performs daily global measurements of NO_2 using nadir Differential Optical Absorption Spectroscopy (DOAS) observations at a spatial resolution of 13x24 km^2. Nitrogen dioxide data was extracted from OMI observations using Geospatial Interactive Online Visualization and ANalysis Infrastructure (GIOVANNI v4.24). The space observations represent the 30% cloud screened tropospheric vertical column densities of NO_2 integrated over a surface of a binned pixel of 25x25 km^2.

Keywords: NO_2 satellite observations, OMI, perceived air pollution, tropospheric NO_2, GIOVANNI

1. INTRODUCTION

During the last thirty years, a large interest has been manifested to study atmospheric composition using the latest technologies. These may be used to create a global picture of air pollution especially in areas where the population, accompanied by industrial development, is steadily rising (Richter et al., 2005; van der A et al., 2006). The overall picture of air pollution can be obtained either by using remote sensing or in-situ observations by static or mobile observations (Noxon, 1975; Ma et al., 2013; Constantin et al., 2013; Constantin et al., 2017). The first experiment using remote sensing for detection of atmospheric trace gases was conducted in 1926 by Gordon Dobson and Douglas Harrison (Dobson & Harrison, 1926), where a spectrometer was used to study the total column density of ozone in the layers of the atmosphere. This technique is nowadays called DOAS (Differential Optical Absorption Spectroscopy) and it uses the signal gathered from the sunlight to measure the absorptions of numerous trace gases. The technique is based on the spectral footprint of different absorbers (Platt & Stutz, 2008). Nitrogen dioxide is one of the main trace gases detected by DOAS (Noxon, 1975). Nitrogen dioxide is a brownish - red gas with a pungent odor. The coloration of this compound is given by the ability to absorb solar radiation at wavelengths between 230 - 550 nm (UV-visible band) so it can be visually seen in industrial areas or inside large cities where its concentration exceeds 200 µg/m³ (Seinfeld & Padis, 2016). It is naturally formed due to the electrical discharge from the atmosphere (Beirle et al., 2004), the activities of solar energetic particles and volcanoes. At the same time, this nitrogen compound is emitted mainly through combustion processes.

The first UV-Vis DOAS space observations of atmospheric composition were performed by GOME-1 (Global Ozone Monitoring Experiment) instrument mounted on board of the ERS-2 satellite launched in 1995. The observations of this satellite instrument showed areas with a high level of NO_2 pollution (Leue et al., 2001; Martin et al., 2002). Also, studies involving this space instrument investigated long-distance transport episodes of NO_2 pollution from the natural biomass burnings (Spichtinger et al., 2001).

Ozone Monitoring Instrument (OMI) is mounted on the Aura satellite and is one of the most advanced DOAS instrument used to determine NO_2 and other trace gases densities, from space (Boersma et al., 2004; Krotkov et al., 2016). This space instrument has a temporal resolution of one day and a spatial resolution of 13x24 km^2.

The study aims to compare the NO_2 pollution over several countries in different zones of the globe as it is perceived by humans and as it results from space observations.

2. STUDY AREA

The research presented in this work is focused on the evolution of NO_2 over five important countries from each continent. The selection of the countries was based on one hand on the NO_2 tropospheric densities observed by OMI satellite instrument and on the other hand on the perception of the population about the level of air pollution, quantified by a air pollution index based on the statistical data presented on the NUMBEO website (https://www.numbeo.com/pollution/, accessed on 20.04.2018). The selected countries for our studies are presented in Figure 1 and Table 1.

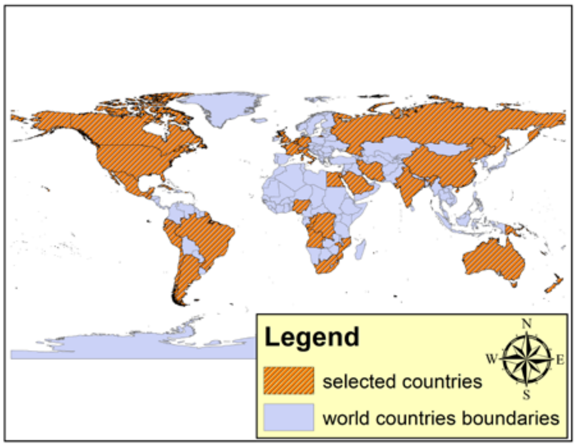

Figure 1. The countries selected for this study

3. METHODOLOGY

The first part of this study was to identify the main polluting country using the NUMBEO database. This database uses surveys from visitors of this website and World Health Organization (WHO) data to compare the real air pollution level with user opinion and to complete the database where users didn't have an opinion on air pollution level for certain areas (cities, regions, countries).

The NUMBEO air pollution index is given on a scale of [0, 100]. Studies including NUMBEO air pollution index showed that there is a link between development, road transport, air pollution perceived and climatic conditions for countries like Papua New Guinea (Borowski, 2017), Vietnam (Hoang et al., 2017) or Portugal (Begashvili, 2016). Other studies use this air pollution index to assess the quality of life or other environmental problems in cities like Teheran (Dehghani et al., 2017), Timisoara (Stancu et al., 2016) and other cities (Kaklauskas et al., 2018).

To generate an air pollution index, data up to 36 months old are used. The index is given for cities for which the air pollution is perceived by the visitors (residents or tourists) as high or low and it also includes the study areas (countries). The air pollution index of the envisaged countries is presented in Table 1. Air pollution index from NUMBEO is based mainly on human perception, the main air pollutant being the particulate matter. The gaseous pollution is rarely perceived since most gases, at atmospheric concentrations do not impact on human senses (smell, color, size).

Studies showed that the presence of high particulate matter concentrations ($PM_{2.5}$, PM_{10}) is linked to a high amount of gaseous pollutants (NO_2) as the main pollution sources are represented by industrial activity, road traffic or burnings of fossil fuels (Beckerman et al., 2008; Eeftens et al., 2012).

The amount of tropospheric NO_2 molecule densities is determined from measurements of the space-borne instrument OMI. The space sensor OMI is an UV/Vis spectrometer which is used to record the spectrum of solar light backscattered by the lower layers of the atmosphere. The recorded spectra are analyzed in the 405–465 nm spectral window and, with the help of TM4 model (Boersma et al., 2007), the tropospheric column densities are extracted from each spatial determination. The global results are available on NASA's OPeNDAP portal on two grid data formats L2 and L3. The L2 data is composed on a grid of 13x24 km^2 for each atmospheric product (trace gases), L3 data is composed on a uniform grid of 25x25 km^2 obtained through the spatial recombination of the L2 data products (pixels) and screened for bad data points. In our study, we used L3 data. Tropospheric vertical column densities (VCD) for NO_2 extracted from OMI observations after correction for spurious across-track variability show an uncertainty for each pixel of approximately 0.7×10^{15} molec./cm^2 (Boersma et al., 2007).

Table 1.The averaged last three years air pollution perceived and measured level for all study regions

Country	Population (millions)	Region	NUMBEO air pollution index	Mean VCD_{tropo} NO_2 last three years ($x10^{15}$ molec./cm^2)
Angola	31	Africa	92.5	1.06
Congo	5	Africa	91.67	1.05
Egypt	99	Africa	77.74	0.87
South Africa	57	Africa	68.97	1.00
Mozambique	31	Africa	62.18	1.05
China	1415	Asia	84.84	2.10
Russia	144	Asia	76.07	0.94
India	1354	Asia	68.75	1.71
Iran	82	Asia	68.19	1.41
Saudi Arabia	34	Asia	60.9	0.99
Italy	59	Europa	84.35	1.95
France	65	Europa	54.42	1.78
United Kingdom	67	Europa	53.75	2.28
Netherlands	17	Europa	50	5.35
Belgium	11	Europa	45.65	4.70
Cuba	11	North America	62.5	0.84
Mexico	131	North America	48.85	0.88
Guatemala	17	North America	24.34	0.83
USA	327	North America	22.03	1.25
Canada	37	North America	19.81	0.85
Papua New Guinea	8	Oceania	79.64	0.13
New Zealand	5	Oceania	47.5	0.41
Australia	25	Oceania	18.35	0.50
Chile	18	South America	72.3	0.43
Ecuador	17	South America	55.75	0.34
Peru	33	South America	50	0.28
Brazil	211	South America	48.65	0.54
Argentina	45	South America	44.55	0.59

Using an online tool called using Geospatial Interactive Online Visualization and ANalysis Infrastructure GIOVANNI developed by NASA (Acker & Leptoukh, 2007) the data extraction for the entire envisaged period and regions in a grid of 25x25 km^2/pixel was performed. GIOVANNI is an online tool which can be used for the display and analysis of geophysical parameters in which the provenance can easily be accessed (https://giovanni.gsfc.nasa.gov/giovanni/, accessed on 20.04.2018). The global average NO_2 pollution level, for the period 2007 – 2017, is shown in Figure 2.

4. RESULTS

The result of surface averaged NO_2 global emissions observed by the space instrument OMI are presented in Figure 2 as a map resulted from using a GIS (Geographic Information System). High tropospheric vertical column densities of NO_2 (2.89 – 2.15 x 10^{16} molec./cm^2) are identified in regions like North-Est of China, Japan, North Est of India, Est of South Africa, East and South of Europe (Po Valey), South - West, and Est of the United States of America, central Mexico. High values of NO_2 pollutions are caused by urban activities, biomass burnings, or industry. Localized high NO_2 values can be observed in zones like Rusia (Moscow), Iran (Teheran), Saudi Arabia (Riad, Bahrain, Qatar), Arab Emirates (Dubai), Ukraine (Luhansk), Uzbekistan (Tashkent), China (Ürümqi), Egypt (Cairo), Spain (Madrid), Brazil (Rio de Janeiro), Argentina (Buenos Aires), Chile (Santiago de Chile), Australia (Sidney, Melbourne).

Low NO_2 VCD_{tropo} can be observed in North and central Africa, North West part of South America, North and South regions of North America, Oceania, Siberia and above seas and oceans. We can also observe from Figure 2 that for areas where snow is present in all seasons (e.g. Antarctic and Greenland) there is no data available due to high albedo.

The NO_2 pollution level was compared with the perception of people on air quality in these countries. Comparison between measured air pollution with NO_2 and perceived air quality was performed for the period 2014 – 2017 and is expressed as normalized recorded values (N) to maximum for each continent.

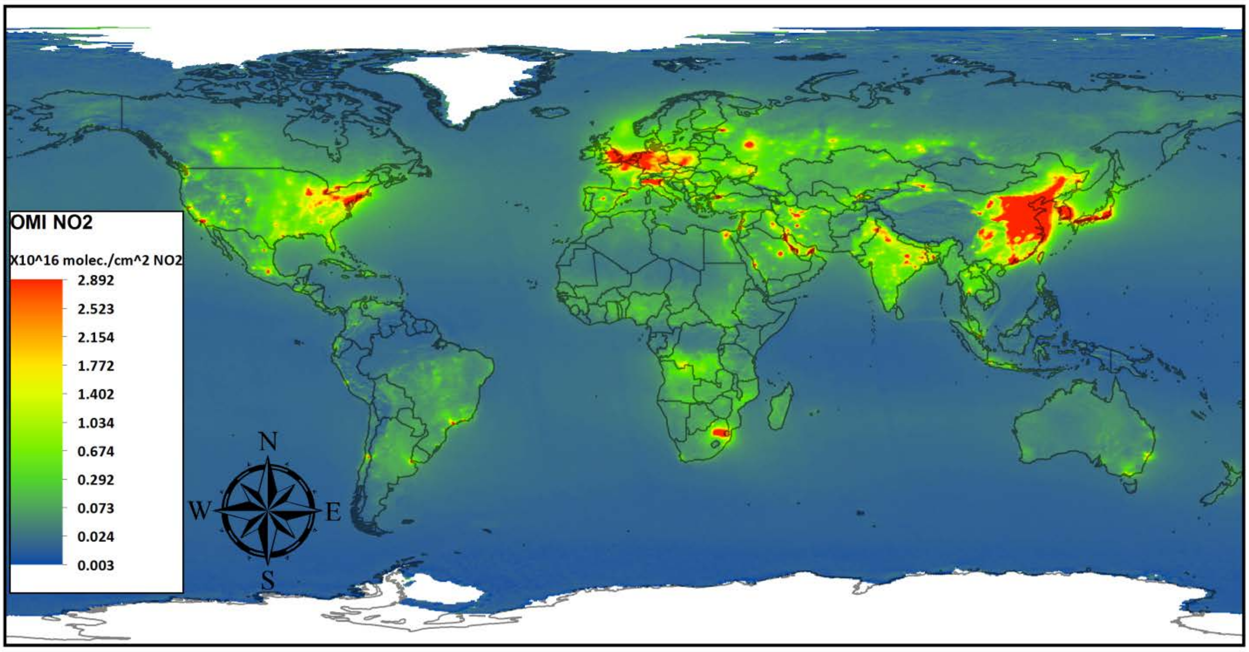

Figure 2. The global map of spatial and time-averaged NO_2 VCD_{tropo} observed by OMI satellite instrument at a resolution of 25x25 km^2 for the period 2007 – 2017

4.1. South America

Chile, Ecuador, Brazil, Peru, and Argentina were selected as the most polluted countries in South America, as perceived by NUMBEO. Figure 3 shows a decrease of NO_2 pollution detected by OMI in the period 2007 – 2017 for the selected countries. Highest averaged NO_2 VCD_{tropo} was detected in Argentina (6.82×10^{14} molec./cm^2) and Brazil (6.12×10^{14} molec./cm^2). For Chile, Peru, and Ecuador the annual averaged NO_2 VCD_{tropo} did not exceed 5.1 $\times10^{14}$ molec./cm^2.

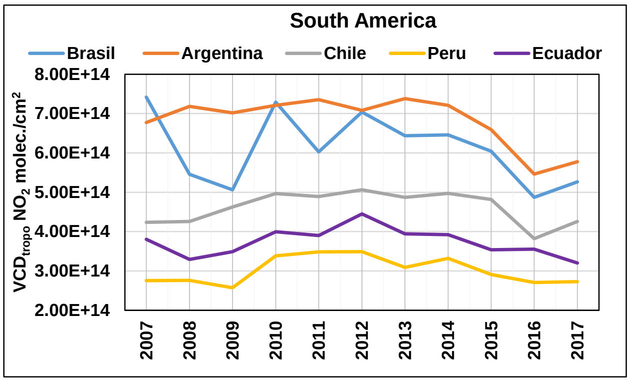

Figure 3. Evolution of annual average NO_2 VCD_{tropo} for 2007 – 2017 in the selected countries in South America

Figure 4 presents a comparison between normalized measured NO_2 pollution with the population opinion on air quality for the most NO_2 polluted countries from South America. For Chile, Ecuador and Peru we observed that the perceived air quality is high, which is correlated with the measured NO_2 pollution from space. The normalized values of the studied parameters are comparable and underline the idea that NO_2 pollution has an important role in how air quality is perceived. For Brazil and Argentina high values of NO_2 have a lower impact on people opinion possibly due to localized NO_2 pollution hot spots or due to the dispersion of NO_2 pollution on extended surfaces (large countries), the average value being low.

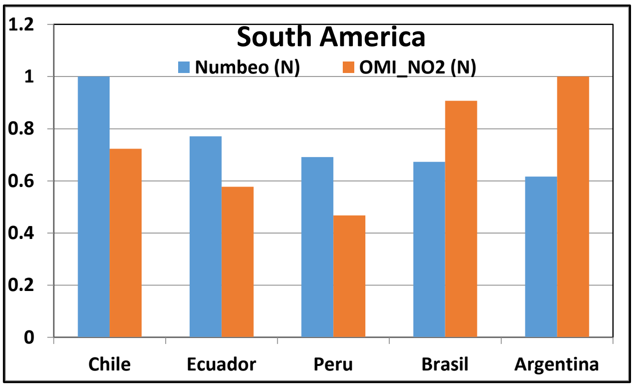

Figure 4. Comparison between normalized NO_2 pollution (OMI) level and normalized human perception (NUMBEO) for South America.

4.2. North America

Figure 5 presents the NO_2 VCD_{tropo} measured by OMI above North America. From this figure an increase for Mexico, Canada, Guatemala, Cuba and a decrease for the USA can be observed. Annual high values of NO_2VCD$_{tropo}$ for the USA between 1.5 – 1.25 ×10^{15} molec./cm^2 was observed in the period 2007 – 2017. Compared to USA Mexico, Canada, Guatemala, Cuba NO_2 pollution level show values lower than 0.91 ×10^{15} molec./cm^2.

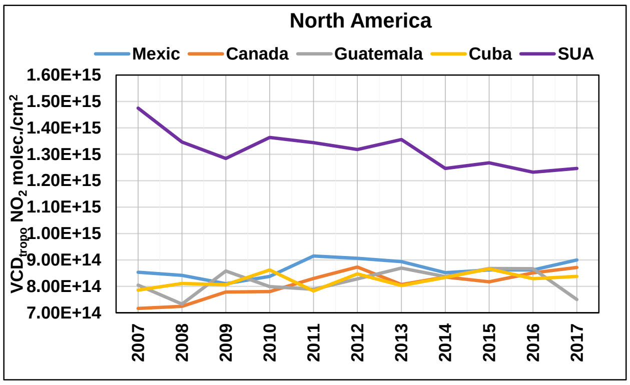

Figure 5. Evolution of annual country average NO_2 VCD$_{tropo}$ for 2007 – 2017 in North America

Comparison of population perception on air quality by NO_2 measured from space presented in Figure 6 shows that air pollution is perceived high in Cuba and Mexico being sustained by the values determined from space in the last three years. For Guatemala, Canada, and the USA the air quality is lower. This is in contrast with OMI measurements for NO_2. A possible explanation that high values of NO_2 are localized in small areas and so affecting just a small portion of the population from that country.

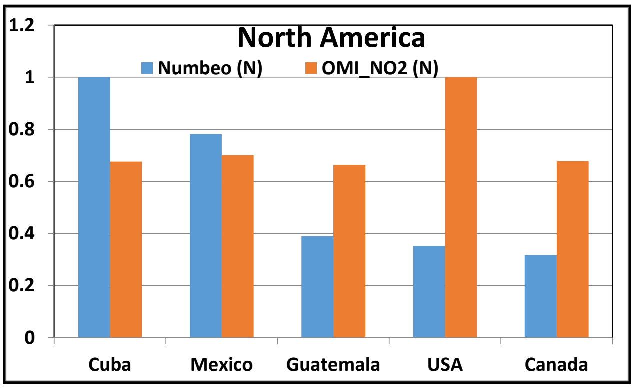

Figure 6. Comparison between normalized NO_2 pollution (OMI) level and normalized human perception (NUMBEO) for North America

4.3. Africa

Figure 7 shows the tropospheric NO_2 VCD for several countries from Africa including South Africa, Congo, Angola, Congo, Mozambique, and Egypt. The results obtained for the African countries show a decreasing trend for NO_2 observed from space for South Africa, Congo, Angola and an increase for Mozambique and Egypt. Averaged annual NO_2 column tropospheric densities show highest values for South Africa between 1.19 - 1.35 ×10^{15} molec./cm^2. In countries like Congo, Angola, Mozambique and Egypt OMI measured lower values between 0.74 - 1.14 10^{15} molec./cm^2.

Analyzing Figure 7 and Figure 8 we observed that the perceived air pollution level and measured NO_2 pollution from space show a similar ranking for the African countries. Also, we can observe that there are findings which underline the idea that NO_2 is a major pollutant that affects the human perception on air quality level.

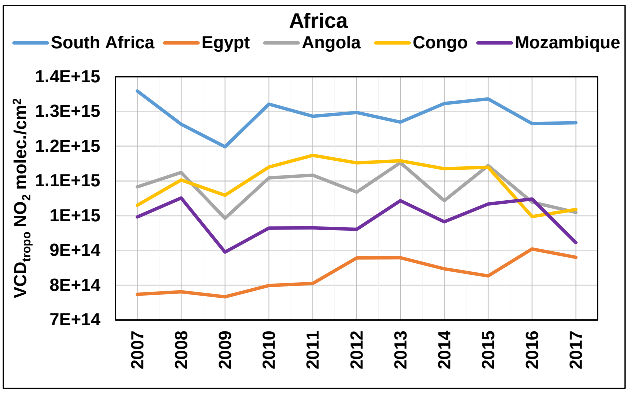

Figure 7. Evolution of annual country average NO_2 VCD$_{tropo}$ for 2007 – 2017 for several African countries

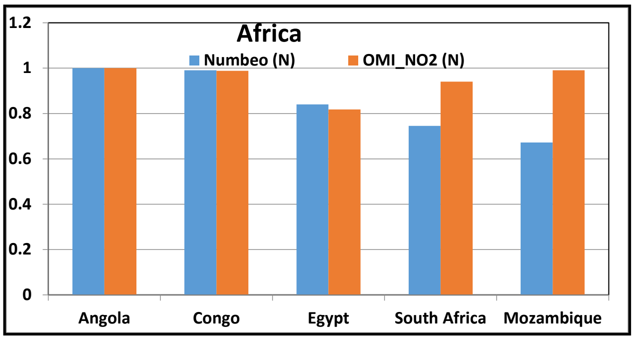

Figure 8. Comparison between normalized NO_2 pollution (OMI) level and normalized human perception (NUMBEO) for Africa

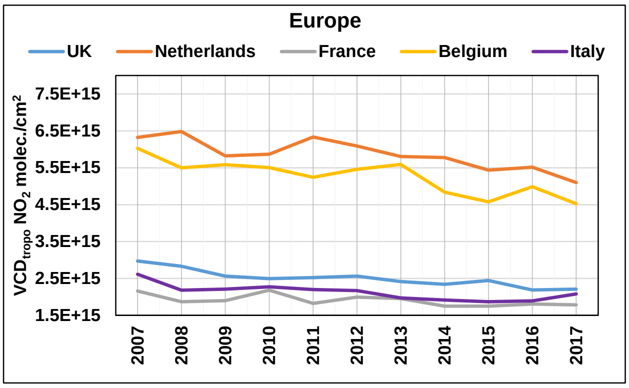

Figure 9. Evolution of annual country average NO_2 VCD$_{tropo}$ for 2007 – 2017 for several European countries

4.4. Europe

Figure 9 shows the NO_2 pollution observed by OMI above Europe's for the five most polluted countries. All countries present a decreasing trend in NO_2. Highest values were observed above the Netherlands ranging between 5-6.5 $\times 10^{15}$ molec./cm^2 followed by Belgium with values between 6 - 4.5 $\times 10^{15}$ molec./cm^2. For United Kindom (UK), Italy and France, the tropospheric NO_2 detected by the space sensor for the period 2007 – 2017 don't exceed 3$\times 10^{15}$ molec./cm^2, lowest values being recorded above France.

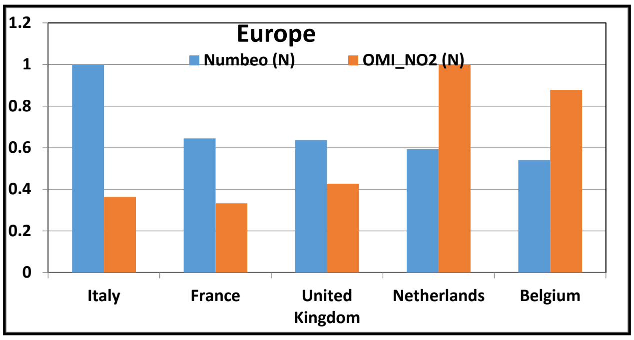

Figure 10. Comparison between normalized NO_2 pollution (OMI) level and normalized human perception (NUMBEO) for Europe.

Figure 10 shows that for Italy, France, and the UK the population perceives the highest level of pollution despite the lower NO_2 values measured by OMI. The results show that NO_2 pollution level doesn't have a major impact on the population opinion. This can be possibly because the bad air quality perceived is caused by the pollution with other pollutants or because of the NO_2 pollution is done across the entire surface of the country. The cases of Netherlands and Belgium show an opposite case. Here the NO_2 pollution is higher and the air pollution perceived is above medium average. This can sustain the idea that NO_2 has an important impact on how pollution is felt and that for the perceived air quality level an impact is caused by another pollutant as well.

4.5. Asia

Figure 11 present the NO_2 observed from space for the first five most polluted countries in Asia. The NO_2 VCD_{tropo} measured above China shows a decreasing trend and the highest values recorded in Asia. Figure 12 shows that China is the most polluted country in Asia. Also, the perception of the population about pollution is proportional to the level of pollution. Due to the averaging effect or pixel effect, the entire surface of the country shows 2.9 $\times 10^{15}$ molec./cm^2. For India, Iran, Saudi Arabia, and Russia an increase in NO_2 VCD_{tropo} can be noticed. The values recorded by OMI don't exceed 1.63 $\times 10^{15}$ molec./cm^2. The measured values above Asia, as we expected, are lower than Europe because of the averaging of NO_2 VCD_{tropo} over the surface of each country.

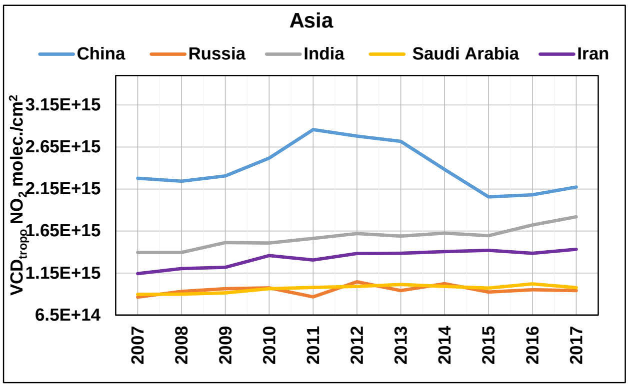

Figure 11. Evolution of annual country average NO_2 VCD_{tropo} for 2007 – 2017 in South America

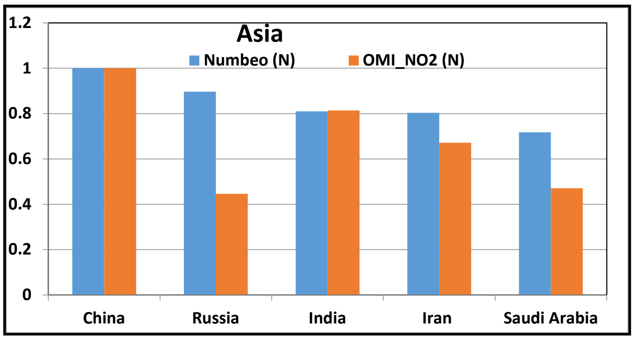

Figure 12. Comparisons of normalized NO_2 pollution (OMI) level and normalized human perception (NUMBEO) for South America

Figure 12 shows that, for the selected Asian countries, there is a good agreement between the perceived level of air pollution and measured NO_2 VCD_{tropo} from space. An exception is Russia, where the averaged NO_2 VCD_{tropo} on the entire surface of the country shows a lower value. Due to localized high population densities the air pollution is perceived high. Figure 2 shows that NO_2 VCD_{tropo} averaged for 2007 – 2017 show high values above urban agglomeration located in the South (Moscow) and West of Russia (Sankt Petersburg).

4.6. Oceania

In this study, we included also Oceania. Figure 13 introduces the level of NO_2 pollution observed from space for Australia, New Zeeland, and Papua New Guinea. The OMI satellite instrument measured a decreasing tropospheric NO_2 above Australia and an increasing one above Papua New Guinea and New Zeeland. The highest annual average values were determined above Australia, ranging from 0.56 – 0.5 $\times 10^{15}$ molec./cm^2, followed by New Zeeland with values between 0.35 – 0.43 $\times 10^{15}$ molec./cm^2 and Papua New Guinea, with lowest values between 0.11 - 0.16 $\times 10^{15}$ molec./cm^2.

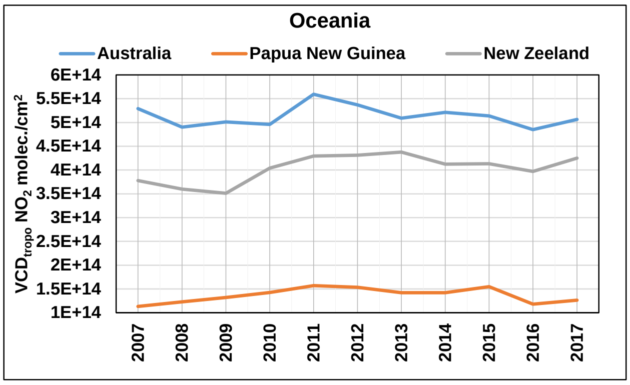

Figure 13. Evolution of annual country average NO_2 VCD_{tropo} for 2007 – 2017 over several countries from Oceania

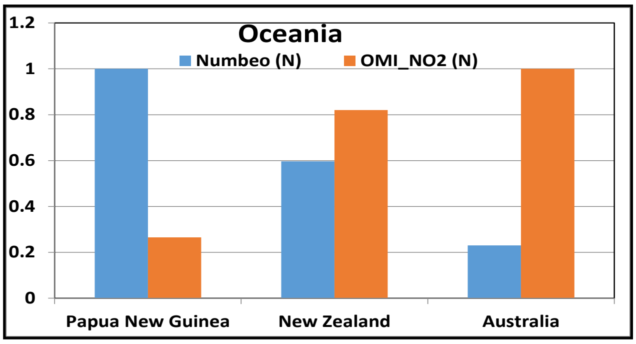

Figure 14. Comparisons of normalized NO_2 pollution (OMI) level with normalized human perception (NUMBEO) for Oceania

New Zeeland presents the best ratio between measured NO_2 pollution and perceived air pollution from Oceania (Figure 14). For Australia OMI recorded highest NO_2 pollution compared to population perception on air pollution. There is a high discrepancy that can be explained by the averaged NO_2 pollution on the entire surface of the country. For Papua New Guinea air pollution is high but a small portion is caused by NO_2 pollution from this country, the cause being probably other types of air pollutants.

5. CONCLUSIONS

The NO_2 emissions detected by OMI are mainly caused by anthropogenic activities which includes urban and industrial ones. The highest pollution level is observed over Europe, followed by Asia (China, India, Iran), North America (USA), Africa (South Africa, Egypt). The lowest values are associated to regions like Oceania and South America.

Results of this study show that the index of NO_2 pollution, which is an important indicator for urban and industrial development, for several cases (e.g. China, Ecuador, and Brazil) is close and very close to the index of population opinion about air pollution.

The air pollution usually is focused around urban and industrial areas. The population which lives in or around these zones can perceive the air pollution in a different way compared to the persons who live in rural or remote areas. Countries like China, New Zeeland, India, and Iran are characterized by large metropolises, with a high level of pollution, where the peoples feel the effects and are able to report these issues.

The obtained results underline the idea that space-borne measurements are a necessity for checking the time and space evolution of pollution levels for zones that are known as hot spots. Comparing global satellite observations to the perceived air pollution by human population we demonstrate the possibility to assess air quality from the human perspective.

Acknowledgments

The work of Adrian Roșu, Bogdan Roșu Ionel Popa and Gabriel Murariu was carried out in the framework of the Ministry of Research and Innovation project – 6PS /2017 – Researches for forest national monitoring system modernization using remote sensing techniques and UAV devices. The work of Daniel-Eduard Constantin and Mirela Voiculescu was supported by the project ASSESS no. 150/2017, a grant of the Romanian Space Agency (ROSA-STAR).

Data about NO_2 VCD_{tropo} used in this paper were produced with the GIOVANNI online data system, developed and maintained by the NASA GES DISC.

REFERENCES

Acker J. G. & Leptoukh G., 2007, *Online Analysis Enhances Use of NASA Earth Science Data*, Eos, Trans. AGU, Vol. 88, No. 2, pages 14 and 17.

Beckerman, B., Jerrett, M., Brook, J. R., Verma, D. K., Arain, M. A., & Finkelstein, M. M., 2008. *Correlation of nitrogen dioxide with other traffic pollutants near a major expressway.* Atmospheric Environment, 42(2), 275-290.

Begashvili, S., 2016. *Improving quality of life in urban areas: a decision support frame for air and noise pollution*, U. Portugal.

Beirle, S., Platt, U., Wenig, M. & Wagner, T., 2004. *NOx production by lightning estimated with GOME*, Adv. Space Res., 34, 793–797.

Boersma, K. F., Eskes, H. J., & Brinksma, E. J., 2004.

Error analysis for tropospheric NO_2 retrieval from space. Journal of Geophysical Research: Atmospheres, 109(D4).

Boersma, K. F., Eskes, H. J., Veefkind, J. P., Brinksma, E. J., Van Der A, R. J., Sneep, M., & Bucsela, E. J., 2007. *Near-real-time retrieval of tropospheric NO_2 from OMI.* Atmospheric Chemistry and Physics, 7(8), 2103-2118.

Borowski, P. F. 2017. *Environmental pollution as a threats to the ecology and development in Guinea Conakry.* Ochrona Srodowiska i Zasobów Naturalnych, 28(4), 27-32.

Constantin, D. E., Merlaud, A., Van Roozendael, M., Voiculescu, M., Fayt, C., Hendrick, F., Pinardi, G. & Georgescu, L., 2013. *Measurements of tropospheric NO_2 in Romania using a zenith-sky mobile DOAS system and comparisons with satellite observations.* Sensors, 13(3), 3922-3940.

Constantin, D. E., Merlaud, A., Voiculescu, M., Van Roozendael, M., Arseni, M., Rosu, A., & Georgescu, L., 2017. *NO_2 and SO_2 observations in Southeast Europe using mobile DOAS observations.* Carpathian Journal of Earth and Environmental Sciences, 12(2), 323-328.

Dehghani, M. H., Salari, M., Naddafi, K., Nazmara, S., Ahmadi, E., & Kumar, P., 2017. *Evaluation of ormaldehyde concentration in the ambient air of a most populated Iranian city, Tehran.* Air Quality, Atmosphere & Health, 10(6), 763-772.

Dobson, G.M. & Harrison, D.N., 1926, *Measurements of the amount of ozone in the earth's atmosphere and its relation to other geophysical conditions*. Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character, 110(756), 660-693,

Eeftens, M., Tsai, M., Ampe, C., Anwander, B., Beelen, R., Bellander, T., Cesaroni, G.,Cirach, M., Cyrys, J., de Hoogh, K., De Nazelle, A., de Vocht, F., Declercq, C., D_edel_e,A., Eriksen, K., Galassi, C., Grąulevičienė, R., Grivas, G., Heinrich, J., Hoffmann, B.,Iakovides, M., Ineichen, A., Katsouyanni, K., Korek, M., Krämer, U., Kuhlbusch, T.,Lanki, T., Madsen, C., Meliefste, K., Mölter, A., Mosler, G., Nieuwenhuijsen, M.,Oldenwening, M., Pennanen, A., Probst-Hensch, N., Quass, U., Raaschou-Nielsen,O., Ranzi, A., Stephanou, E., Sugiri, D., Udvardy, O., Vaskövi, É., Weinmayr, G.,Brunekreef, B., & Hoek, G., 2012. *Spatial variation of PM2. 5, PM10, PM2. 5 absorbance and PM coarse concentrations between and within 20 European study areas and the relationship with NO_2–Results of the ESCAPE project.* Atmospheric Environment, 62, 303-317.

Hoang, T. A., Chu, N. X., & Van Tran, T. (2017). *The Environmental Pollution In Vietnam: Source, Impact And Remedies.* Transportation, 495(112.856), 38-122.

Received at: 07. 11. 2018
Revised at: 07. 06. 2019
Accepted for publication at: 12. 06. 2019
Published online at: 17. 06. 2019

Kaklauskas, A., Zavadskas, E. K., Radzeviciene, A., Ubarte, I., Podviezko, A., Podvezko, V., Kuzminske, A., Banaitis A., Binkyte, A., & Bucinskas, V., 2018. *Quality of city life multiple criteria analysis.* Cities, 72, 82-93.

Krotkov, N. A., McLinden, C. A., Li, C., Lamsal, L. N., Celarier, E. A., Marchenko, S. V., Swartz, W. H., Bucsela, E. J., Joiner, J., Duncan, B. N., Boersma, K. F., Veefkind, J. P., Levelt, P. F., Fioletov, V. E., Dickerson, R. R., He, H., Lu, Z., & Boersma, K. F. (2016). *Aura OMI observations of regional SO_2 and NO_2 pollution changes from 2005 to 2015.* Atmospheric Chemistry and Physics, 16(7), 4605-4629.

Leue, C., Wenig, M., Wagner, T., Klimm, O., Platt, U., & Jähne, B., 2001. *Quantitative analysis of NOx emissions from Global Ozone Monitoring Experiment satellite image sequences*. Journal of Geophysical Research: Atmospheres, 106(D6), 5493-5505.

Ma, J. Z., Beirle, S., Jin, J. L., Shaiganfar, R., Yan, P., & Wagner, T., 2013. *Tropospheric NO_2 vertical column densities over Beijing: results of the first three years of ground-based MAX-DOAS measurements (2008–2011) and satellite validation*. Atmospheric Chemistry and Physics, 13(3), 1547-1567.

Martin, R. V., Chance, K., Jacob, D. J., Kurosu, T. P., Spurr, R. J., Bucsela, E., &Li, Q., 2002. *An improved retrieval of tropospheric nitrogen dioxide from GOME*. Journal of Geophysical Research: Atmospheres, 107(D20).

Noxon, J. F. (1975). *Nitrogen dioxide in the stratosphere and troposphere measured by ground-based absorption spectroscopy*. Science, 189(4202), 547-549.

Platt, U. & Stutz, J., 2008, *Differential absorption spectroscopy. Differential Optical Absorption Spectroscopy*. 135-174, ISBN 978-3-540-75776-4.

Richter, A., Burrows, J. P., Nüß, H., Granier, C., & Niemeier, U., 2005. *Increase in tropospheric nitrogen dioxide over China observed from space.* Nature, 437(7055), 129.

Seinfeld, J. H. & Pandis, S. N., 2016. *Atmospheric chemistry and physics: from air pollution to climate change*. John Wiley Sons.

Spichtinger, N., Wenig, M., James, P., Wagner, T., Platt, U., & Stohl, A., 2001. *Satellite detection of a continental scale plume of nitrogen oxides from boreal forest fires.* Geophysical Research Letters, 28(24), 4579-4582.

Stancu, A., Ilin, C., & Gruicin, A., 2016. *Perceived urban quality of life in Timişoara's districts.* Romanian Journal of Psychology, 18(1).

Van Der A, R. J., Peters, D. H. M. U., Eskes, H., Boersma, K. F., Van Roozendael, M., De Smedt, I., & Kelder, H. M., 2006. *Detection of the trend and seasonal variation in tropospheric NO_2 over China.* Journal of Geophysical Research: Atmospheres, 111(D12).