AIR POLLUTION MAPPING WITH NITROGEN AND SULFUR DIOXIDES IN THE SOUTH-EASTERN PART OF UKRAINE USING SATELLITE DATA

Sergey STANKEVICH[1], Olga TITARENKO[1], Mykhailo SVIDENIUK[1],
Mykola KHARYTONOV[2], Aissa BENSELHOUB[2,4*], Valentine KHLOPOVA[3]

[1] Scientific Centre for Aerospace Research of the Earth, Kiev, Ukraine
[2] Dnipropetrovsk State Agro-Economic University, Dnepropetrovsk, Ukraine
[3] Dnipropetrovsk Center of Hydrometeorology, Dnipropetrovsk, 49600, Ukraine
[4] Laboratory of Mining Resources Valorization and Environment, Mining Department, Badji Mokhtar University, Annaba, Algeria

Abstract: Atmospheric pollution in Ukraine has become a significant environmental problem, especially in the eastern part where heavy industries are located, and it is particularly severe in industrial centers such as; Zaporizhia, Kryvyi Rih, Dnipropetrovs'k and Dniprodzerzhyns'k. The main emission sources are ferrous metallurgical plants and the coal industry. The purpose of this project is to estimate the degree of pollution from dioxides of nitrogen and sulfur in the south-eastern part of Ukraine using satellite data. An assessment of atmospheric pollution by NO_2 is carried out using the data from satellite spectrometer EOS/OMI, and information products Level 3 from Goddard Earth Sciences Data, (GES DISC) NASA for 2009-2014. According to the results study, the largest area of propagation of SO_2 aerosol was observed in the industrial agglomerations of Kryvyi Rih, Dnipropetrovs'k and Vilnohirs'k.However, a somewhat smaller content of NO_2 in the air recorded near the town of Kryvyi Rih and the cities of Vilnohirs'k and Zaporizhia.The results obtained from this research will aid the creation of awareness among Ukraine's policy makers about the need for air pollution abatement, and also serve as a stepping stone towards addressing the negative impacts of acid rains.

Keywords: air pollution, industry, acid rains, spatial distribution, remote sensing

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* **Corresponding authors**: benselhoub@yahoo.fr (A. Benselhoub)

INTRODUCTION

Air pollution comes from both natural and man-made sources. The Blacksmith Institute issues annually a list of the world's worst polluted places. According to 2007 issues the ten top nominees are located in Azerbaijan, China, India, Peru, Russia and Ukraine (ORG/WWPP, 2007). Atmospheric pollution in Ukraine becomes a significant environmental problem especially in south-eastern part, where are located heavy industries. It is particularly severe in industrial centres such as Donets'k, Zaporizhia, Kryvyi Rih, Dniprodzerzhyns'k and Dnipropetrovs'k. However, the level of pollution in the air exceeds the maximum allowable concentration of 10 mg/m^3 in some Ukrainian cities (Babiy et al., 2003).Moreover, MPC (maximum permissible concentration) for nitrogen oxides have been exceeded in 1.25–2.25 times (Kharytonov et al., 2015) .The main emission sources are ferrous metallurgical plants and the coal industry. Industrial emissions consist of 21.4% particulate pollution, 33.5% CO_2, 30.2% SO_2, 8.0% NO and NO_2 (Buksha et al., 1998).

The degree of atmosphere pollution from anthropogenic sources depends on a combination of meteorological factors. At constant parameters of the emission level ,air pollution is characterized by direction overlooking transport and dispersion of impurities in the air, the intensity of solar radiation, which causes photochemical reactions to toxic substances, the appearance of secondary products of contamination, increase in the number and duration of precipitation promoting "washing out" of impurities from the atmosphere. Dissipating capacity of the atmosphere depends on the vertical distribution of temperature and wind speed conditions, the intensity of turbulent exchange of air layers (Kokhanovsky et al., 2013). Eventually, in one case, one substance will be placed at large distances from contamination source and in the other concentrated in the area of their place of release. During last decade, due to the resumption of the pace of industrialization and urbanization, air pollution has become a major environmental problem in the industrial cities of the south-east of Ukraine (Shupranova et al., 2014). The constant excess of MPC in terms of man-made dust, nitrogen dioxide, formaldehyde, phenol, ammonia and certain other pollutants in the atmosphere of urban agglomerations leads to the formation of acid rain, photochemical smog, increase the number of diseases among the local population and, in particular, children (Vasilyeva et al., 2006).

The risk of acid rain is that they may fall far from the source of primary substances emission. Sulphur dioxide emitted into the atmosphere from fossil fuel burning, and the nitrogen dioxide formed by oxidation of air nitrogen at high temperatures, as well as from the decomposition and oxidation of the nitrogen compounds present in the fuel. In the atmosphere nitrogen dioxide is supplied in the form of warm emission of big industrial enterprises and heat power stations, and as "low" cold emissions of transport. Acid born aerosols spreading monitoring is carried out using various weather data: wind direction and speed, the nature and pH of the precipitation. The rain

precipitation pH in the Dnipropetrovsk industrial region showed the range 3.75-5.6 (Kopach et al., 2006). The purpose of our research was to conduct an analysis to produce a time series data by comparing stationary ground-based measurements and satellite observations of atmospheric pollution in south-eastern part of Ukraine connected with nitrogen and sulfur dioxides emissions for 2009-2014.

SATELLITE REMOTE SENSING SYSTEMS

The basic principle of remote sensing of the atmosphere is measuring the spectral intensity of electromagnetic radiation in certain spectral bands to determine the physical parameters of the environment. This is possible due to the presence of the spectral absorption bands and their own infrared or microwave radiation, in accordance with Kirchhoff's law. Hence, the spectral intensity of radiation passing through the atmosphere is a function of gas composition and temperature (Buksha et al., 1998).

Table 1. Earth's atmosphere operational satellite systems

Satellite system	Equipment	Spectral bands, µm	Spectral resolution, µm	Swath,km	Spatial resolution, km	Atmospheric products
Envisat	GOMOS	0.25–0.95	0.17–0.20	120	15–40	O_3, NO_2, NO_3, O_2, H_2O, aerosols
	MIPAS	4.15–14.6	1.6–2.0	150	3×30	O_3, NO, NO_2, HNO_3, N_2O_5, $ClONO_2$, CH_4CH_4
	SCIAMA-CHY	0.24–2.40	$(0.2–0.5) \cdot 10^{-3}$	960	32×215	O_3, NO_2, BrO, SO_2, HCHO, H_2O, CH_4, CO, CO_2, aerosols
MetOp	IASI	3.62–15.5	$1.4 \cdot 10^{-3}$	1066	12–18	O_3, aerosols
	GOME-2	0.24–0.79	$0.135 \cdot 10^{-3}$	960	80×40	O_3, NO_2, BrO, SO_2, HCHO
	HIRS/4	3.8–15.0	0.5–0.7	2160	10–16	CO_2, O_3, N_2O
EOS	MOPITT	2.2–4.7	0.22–0.55	650	22	CO, CH_4
	AIRS	3.74–15.4	$4.9 \cdot 10^{-3}$	1650	13.5–19.5	CO_2, CO, CH_4, O_3, SO_2, aerosols
	OMI	0.27–0.5	$(0.45–1.0) \cdot 10^{-3}$	2600	13×24	O_3, NO_2, SO_2, HCHO, BrO, OClO, aerosols
	TES	3.2–15.4	$(29–85) \cdot 10^{-3}$	5.3×8.5	0.53×5.3	H_2O, O_3, CH_4, CO, HNO_3
	HIRDLS	6–18 мм	$(0.4–0.8) \cdot 10^{-3}$	500	10×300	O_3, HNO_3, NO_2, N_2O_5, $CHClF_2$, CCl_2F_2
	MLS	118–2250 GHz	400–510 MHz	300	1.5×3	H_2O, HNO_3, HCN, ClO, N_2O, O_3, SO_2, CH_3CN, CO, HCl, HOCl, BrO, CH_3CN
NPOESS	OMPS	0.25–0.38	10^{-3}	2800	50–250	O_3, BrO, HCHO, NO_2, OClO, SO_2
GOSAT	TANSO	5.5–14.3	$(0.6–0.8) \cdot 10^{-3}$	790	1.5–10.5	CO_2, CH_4, aerosols, clouds

To measure the parameters of the Earth's atmosphere, specialized optical or microwave sensors mount on the remote sensing satellite systems. From operating now satellite-based remote sensing of the atmosphere the most famous European Envisat (GOMOS, MIPAS and SCIAMACHY spectrometers) and MetOp (IASI, GOME-2 and HIRS/4 spectrometers), American EOS (MOPITT, AIRS, OMI, TES infrared spectrometers, HIRDLS and MLS microwave radiometers) and NPOESS (OMPS ultraviolet/visible band spectrometer) (Stankevich et al., 2015). The main technical specifications of the onboard equipment to measure the parameters of the Earth's atmosphere operational satellite systems are shown in Table 1.

MATERIALS AND METHODS

2.1. METHODS OF GROUND-BASED OBSERVATIONS

Extraction and processing of iron, manganese, uranium and polymetallic ores are associated with urban agglomerations such as Dnipropetrovs'k, Dniprodzerzhyns'k, Kryvyi Rih, Nikopol, Zhovti Vody and Vilnohirsk.All of them are located in the central and western part of Dnipropetrovs'k region (Fig. 1).
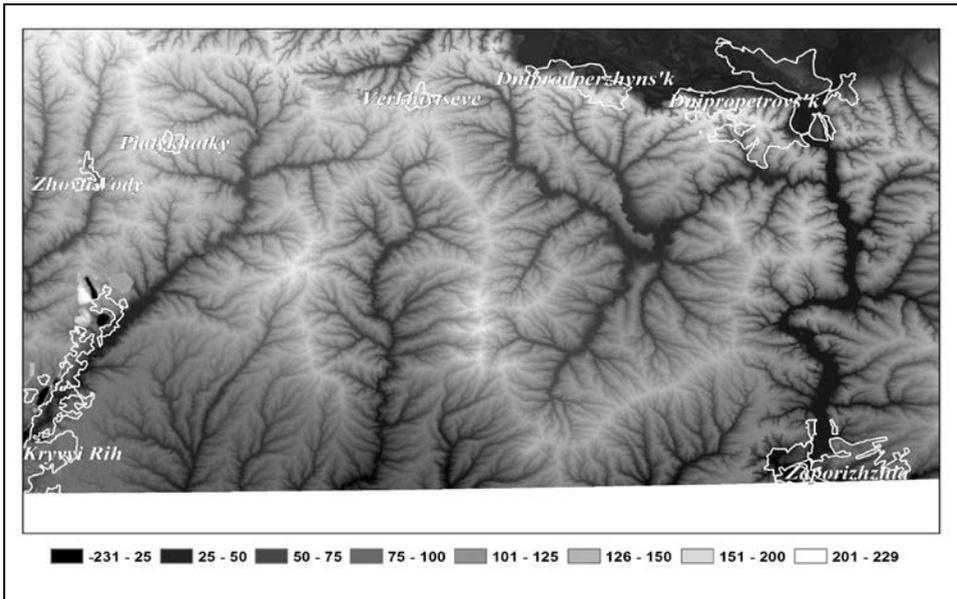

Fig. 1. Relief map of right side of Dnipropetrovs'k oblast

The landscape of the Dnipropetrovs'k region is a rolling plain altitude of 100-200 m. Local middle size rivers occur in the western part of the region occupied by the

Dnieper upland. The northwestern part of the area gradually decreases in a south-easterly direction, and terminates the Dnieper steep ledge.

<div align="center">DATA PROCESSING</div>

Evaluation of air pollution in Pridneprovs'k industrial area by NO_2 and SO_2 was performed by measurements of satellite spectrometer EOS/OMI with the certification of ground data. The initial data used information products Level 3 Goddard Earth Sciences Data and Information Services Center (GES DISC) NASA for 2009-2014: tropospheric NO_2 molecules/cm^2 (disc.sci.gsfc.nasa.gov/Aura/data-holdings/OMI/omno2e_v003.shtml) and ground-level of SO_2 in Dobson units (disc.sci.gsfc.nasa.gov/Aura/data-holdings/OMI/omso2e_v003.shtml), accessible through a search subsystem Mirador (mirador.gsfc.nasa.gov/). Tenderloin territorial segments, selection of the layers of data and monthly average values were made using the web-service Giovanni (disc.sci.gsfc.nasa.gov/giovanni/). The result was obtained by measuring 36 segments on a regular grid (Fig. 2) for each information product EOS/OMI.
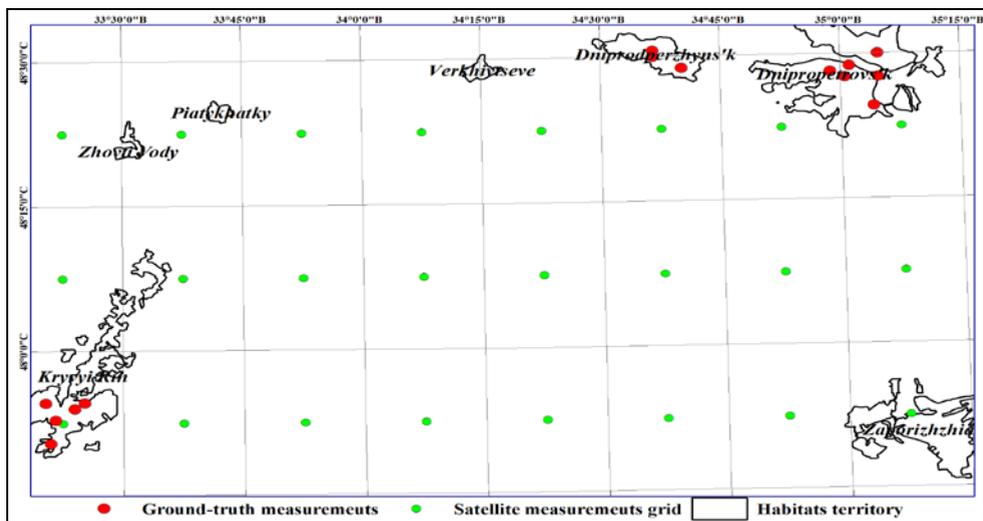

Fig. 2. Grid satellite atmospheric measurements of Dnipropetrovs'k province

Ground-based measurements of air ground layer state conducted in three laboratories of Dnipropetrovs'k city, Dniprodzerzhyns'k, Kryvyi Rih, are subordinate to the Dnipropetrovs'k Regional Center of Hydrometeorology. The semantic information on the content of toxicants in the weather going through the organization of a network of stationary posts: 6 in Dnipropetrovs'k and 5 in Dniprodzerzhyns'k and Kryvyi Rih. Air pollution evaluation was established using laboratory expressways and automatic control methods. Obtained average daily, monthly and annual data of

background monitoring of tested substances in the atmospheric air compared to the maximum permissible concentration (MPC). For ground-truthing satellite data used monthly averages concentrations of NO_2 and SO_2 in mg/m^3 for 2009-2014. The values of satellite measurements on a regular grid interpolated by the method of inverse squares in terrestrial point of measurements and these data was based on linear regression. Average grade of regression reliability on 36 measurements at each point using the Fisher's *F*-statistic was 0.62 (George et al., 1997). Further satellite measurements on a regular grid were translated at the obtained regression equation for the entire study area. The 48 datasets for monthly concentrations of NO_2 and SO_2 were acquired. The trend and periodic components of given observations were extracted by time-series analysis. Finally, the time-series parameters were mapped: the monthly concentration averages for whole period of observation, (mg/m^3); the average annual concentration increments, (mg/m^3); concentrations annual periodic component, (unit less). The resulting maps of these variables distribution are shown in Fig. 2 and Fig. 3.
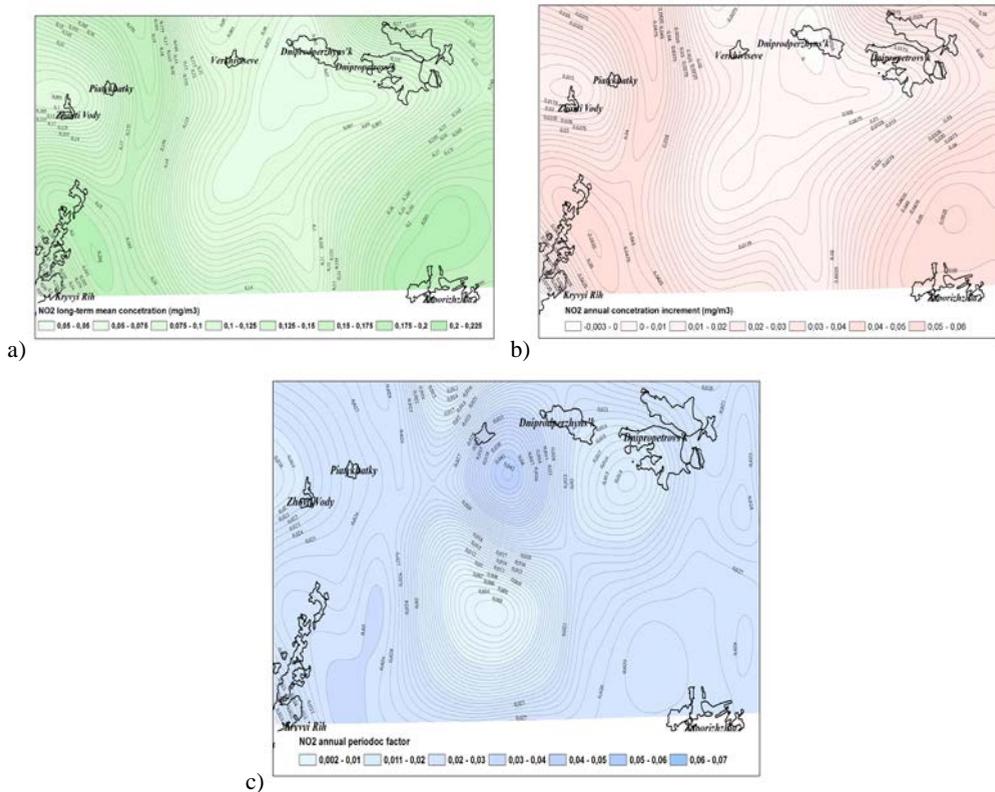

Fig. 3. Spatial distribution of time-series parameters of NO_2 content in atmosphere of Dnipropetrovs'k region for 2009–2014: a – average value of concentration (mg/m^3), b – average annual increment of concentration (mg/m^3), c – concentration annual periodic component
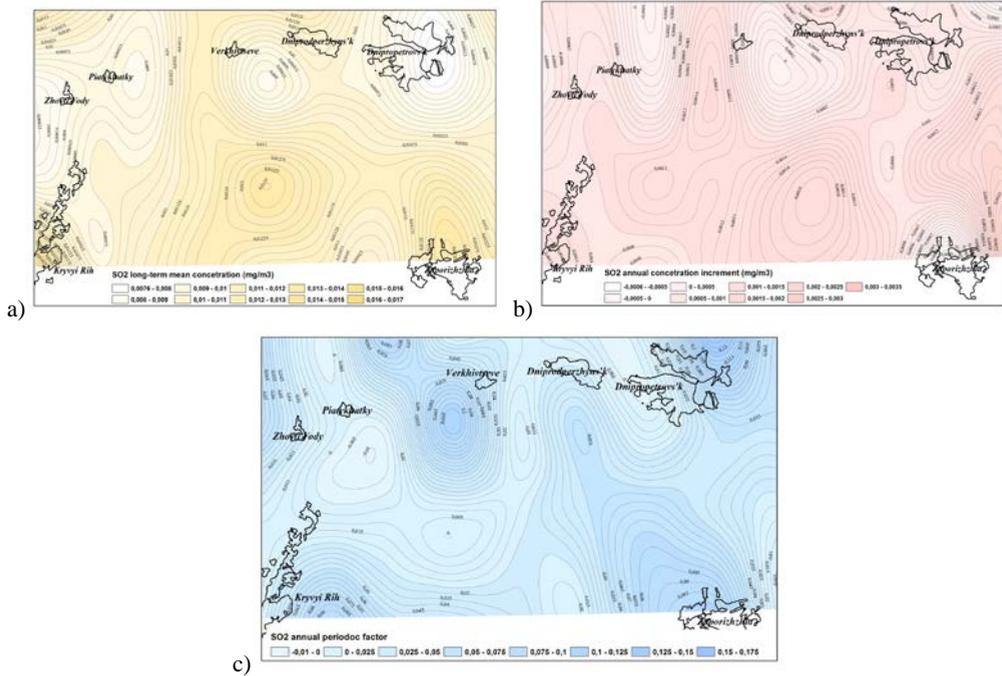
Fig. 4. Spatial distribution of time-series parameters of SO$_2$ content in the atmosphere of Dnipropetrovs'k region for 2009 – 2014; a – average value of concentration (mg/m^3), b – average annual increment of concentration (mg/m^3), c – concentration annual periodic component

RESULTS AND DISCUSSION

The analysis of pollution maps with NO$_2$ and SO$_2$ concentrations distribution in the atmosphere of Dnipropetrovs'k province indicates the formation of certain aerosol flow patterns. It is evident that their formation depends on the power sources. There is no doubt that the nature of propagation of the torches on the territory of the region associated with the photochemical properties of toxicants, features megarelefa areas, including riverbeds. It was recorded the offset of finding the halo of maximum concentrations of nitrogen and sulfur dioxides over some cities. The monitoring of wind rose shows that for the period 2009-2014, on the territory of Dnipropetrovs'k and Kryvyi Rih prevailing northeasterly wind direction and near Dniprodzerzhyns'k – southern direction. Two reasons can be highlighted to explain this: the rose of the winds and thermal convection of the atmospheric masses. It is apparent that during the cooling of the layers previously heated contaminated air down, including down rivers.

Investigations of the acid rain spatial distribution in the western part of the region suggest the leading role of wind rose.

Based on data from the map 3a, the concentration of nitrogen dioxide in the air of cities Dnipropetrovs'k and Dniprodzerzhyns'k exceed twice the value of the maximum allowable concentration (Shupranova et al., 2014). A somewhat smaller content of NO_2 in the air recorded near the town of Kryvyi Rih and the cities of Vilnohirs'k and Zaporizhia. Comparison of the data analysis of time series related to the assessment of the average annual growth of NO_2 concentrations in the atmosphere according to the map 3b also demonstrates an increased risk of accumulation of nitrogen dioxide on the above urban agglomerations.

According to the data of the map 4a, the largest area of propagation of SO_2 aerosol was observed in the industrial agglomerations of Kryvyi Rih, Dnipropetrovs'k and Vilnohirs'k. However, to date any of the industrial centers have been recorded cases of MPC.

A study of average annual growth rate of SO_2 concentrations in the atmosphere according to the map 4b shows the trend of accumulation of SO_2 not only on industrial centers, but also on the promotion of the torches over the countryside. Considering that in the overwhelming number of urban thermal power plants fueled by coal should be presented for the control of sulfur content in the fuel. It should also take into account that NO_2 and SO_2 have the effect of summation. By entering into a chemical reaction with each other and with some other chemical compounds, they form a highly toxic substance .Therefore, ignoring the trends of accumulation of NO_2 and SO_2 can lead to an increase in the frequency of acid rain, cases of damage to state of agricultural crops, the increasing number of diseases among the population, etc. Spatial distribution of annual periodic components of atmospheric pollutants is not in relation with the location of industrial centers. It can be attributed to the influence of the remaining natural plant ecosystems affected by seasonal activity cycles of atmospheric absorption.

CONCLUSION

Analysis of distribution maps of the torches NO_2 and SO_2 showed some differences in the dispersion of toxicants. It is obvious that the formation of certain flow patterns of aerosols of nitrogen dioxide and sulfur is associated to the photochemical properties of toxicants, the climate and terrain mega relief. The results can be taken into account in the short-term forecasts of acid rain in the countryside. Using maps of average annual growth of concentration of toxicants is promising for quantitative and qualitative evaluation of photochemical smog, the increasing number of airborn diseases among the population of industrial cities. The data overlay maps studied by two indicators

can help to develop preventive measures reducing the risk of the combined effect associated with the formation of highly toxic substances.

ACKNOWLEDGEMENTS

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