Monitoring of NO_2 emission at Russian cities scale using TROPOMI (Sentinel-5P) data

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Abstract

The paper presents products on gas components, created in the archives of the Center for Collective Use "IKI-Monitoring" and available in information services, developed at the IKI RAS. The features of constructing composite images of different time duty cycle with average, minimum and maximum values of the products are described. Approaches to the analysis of nitrogen dioxide concentration in Russian cities based on the data of the TROPOMI Sentinel-5P device are presented, seasonal and interannual trends in concentration are revealed.

Keywords

Remote sensing, data processing, satellite data, environment, gas components, air pollution, nitrogen dioxide, "IKI-Monitoring" Center for Collective Use.

1. Introduction

Air pollution is one of the main factors that have a negative impact on public health and the environment. An increase in the concentration of various substances in the atmosphere destroys the ozone layer of the Earth, leads to acid rain, to a decrease in soil fertility, affects the respiratory tract and lungs of a person, and causes changes in the composition of the blood. Therefore, a comprehensive monitoring of the state of the atmosphere is required, including an assessment of the concentration of a certain substance in the atmosphere.

For monitoring the air condition in the information system (IS) Vega-Science (http://sci-vega.ru, the Constellation-Vega family), operating on the basis of the IKI-Monitoring Center for Collective Use (http://ckp.geosmis.ru) [1] provides access to information products of the concentration of gaseous substances according to data from the Sentinel-5P (TROPOMI), AURA (OMI) satellites. Data on sulfur dioxide, nitrogen dioxide, ozone, methane, carbon monoxide are available. In turn, on the basis of these products, arriving daily in the form of sessions, composite images are automatically created, which are uploaded to the archives of the IKI-Monitoring Center for Collective Use and are also available in the ISs developed at the IKI RAS.

It should be noted that nitrogen dioxide (NO_2) is one of the first in terms of emissions into the atmosphere as a result of anthropogenic activities and is of particular relevance for research in the field of environmental protection. It is a dangerous toxic gas that causes lung disease and increases the risk of chronic disease in the population, thereby directly affecting the life expectancy of citizens. It is formed as a result of the combustion of fuels and biomass, as well as

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natural processes such as forest fires, lightning, etc. In large cities, the main source of nitrogen dioxide is combustion products from vehicles and thermal power plants, and nitrogen dioxide is a good indicator for assessing the state of urban air quality. At the same time, the lifetime of this gas is relatively short, on the order of several hours, which, in a first approximation, makes it possible to use satellite data to obtain actual values of its concentrations in the tropospheric column and to monitor air pollution without access to the territory, and to form an independent global picture.

With the help of the automated tool for monitoring the state of objects ObjectsSurveysSMIS [2], developed at the IKI RAS, and based on the created composite images, the average values of the concentration of this gas within large cities of Russia were calculated, including within the sectors of circles with a large radius of influence of these cities. The following chapters are devoted to the peculiarities of the construction of information products on gas components and the analysis of the obtained results of the analysis of nitrogen dioxide on the scale of large cities.

2. Available satellite data

In April 2018, as part of the Copernicus program, the European space agency ESA launched the Sentinel-5P satellite. The satellite is equipped with a TOPOMI instrument with a spatial resolution of 3.5 by 7 km. (Tropospheric Monitoring Instrument), which measures the concentration of gas components in the atmosphere. The purpose of the TROPOMI instrument is to provide accurate and timely observations of the key elements of the atmospheric composition for monitoring air quality, climate and ozone layer. TROPOMI data is provided by the ESA Copernicus Open Access Hub [3]. In 2004, NASA launched the AURA research satellite, designed to study the Earth's atmosphere. The satellite has an OMI device with a spatial resolution of 13 by 24 km, the main task of which is to control climate change on Earth, air pollution, and the state of the Earth's ozone layer. OMI data is provided by the NASA Level-1 and Atmosphere Archive and Distribution System Distributed Active Archive Center (LAADS DAAC) [4].

Figure 1 shows the data coverage area by TROPOMI and OMI for one day. To monitor and analyze the dynamics of the state of the atmosphere based on the daily incoming data on the

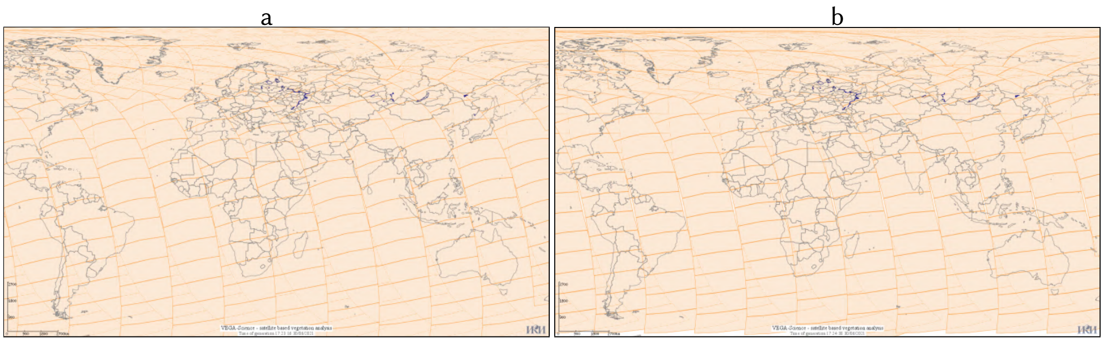

Figure 1: Coverage by TROPOMI (a) and OMI (b) data for one day in the archives IKI-Monitoring Center for Collective Use.

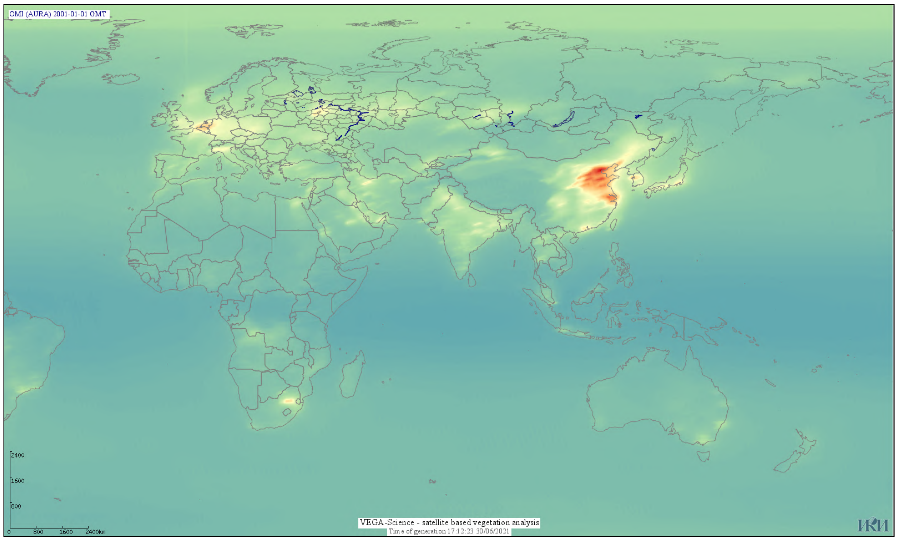

Figure 2: Long-term composite image with average NO_2 concentration according to OMI for 2016–2021.

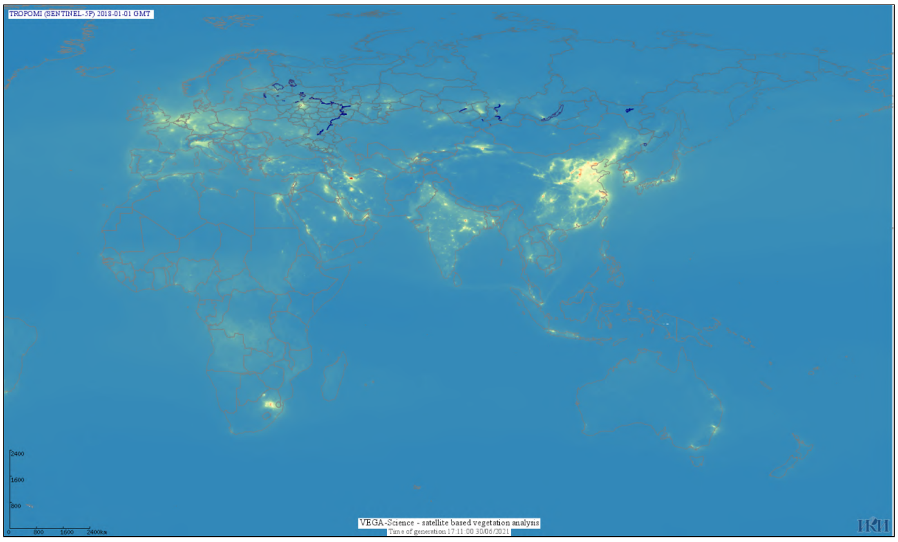

Figure 3: Long-term composite image with average NO_2 concentration according to TROPOMI for 2018–2021.

concentration of gases in the atmosphere, composite images of various temporal resolutions are automatically created: daily, weekly, monthly, annual and long-term. Users of the Vega-Science IS have access to the averaged, maximum and minimum concentration data for each type of gas available in the archives of the IKI-Monitoring Center for Collective Use. Figures 2 and 3 show examples of calculated information products.

3. Instrument

At IKI RAS, an automated tool for monitoring the state of objects ObjectsSurveysSMIS was developed, which allows calculating the averaged values of various indicators (thematic products, spectral indices, channel data) along the contours of arbitrary polygons of the objects under study based on the satellite data scenes available in the archives of the IKI-Monitoring Center for Collective Use, historical and operational. With the help of this tool, integrated into the Vega-Science information system, the concentrations of nitrogen dioxide over the territory of large cities of Russia were calculated. Figure 4 shows a specialized section for working with objects (cities) and indicators calculated for them in the Vega-Science IS, an example of establishing a zone of influence of a pollution source (city) with an indication of the radius of influence and subsequent division of the zone into sectors and moving away from the center of the ring is given.

After automated calculations, it is possible to visualize the values of indicators on the map, including by sectors and rings. For greater contrast, you can "renormalize" the values of the indicator within the area of influence, that is, apply the original palette of the thematic product relative to the local minimum and maximum (Figure 4). To identify seasonal and interannual trends in the values of indicators, as well as for the joint analysis of several objects (cities), a module for analyzing the time series of objects and uploading the calculated values to tabular interfaces is available.

As a result of the study, 15 cities of Russia, located in different federal districts, were delineated. The cities were selected visually from the constructed annual composite image with the average concentration of nitrogen dioxide of the TROPOMI device (Sentinel-5P). Within the framework of this experiment, cities with the maximum average annual emissions of nitrogen dioxide were taken. To assess the air quality, a polygon was set up directly above the city's territory, corresponding to the city's territory according to MSI high-resolution data (Sentinel-2A, B). To analyze the distribution of gas around cities and identify the most polluted areas, zones of influence with a radius of 100 km were set up, the concentration of nitrogen dioxide was calculated for a fixed number of sectors (45 degrees each).

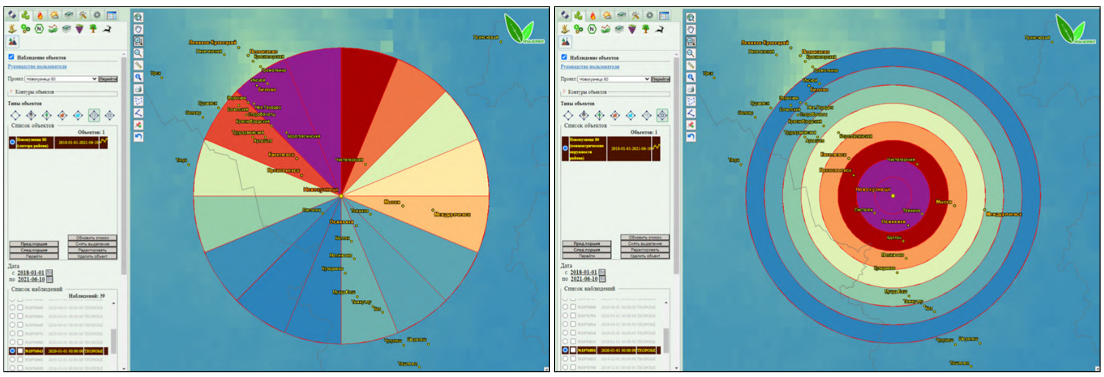

Figure 4: Distribution of the annual concentration of nitrogen dioxide by sector and rings (after "renormalization") of Novokuznetsk 2020.

4. Examples

This section provides examples of approaches to monitoring nitrogen dioxide in selected cities of Russia. First of all, on the basis of the created composite images, the average annual concentrations of nitrogen dioxide over the territories of cities were calculated since the launch of TROPOMI (Sentinel-5P) to the present. Table 1 presents the calculation results, cities are sorted in descending order of nitrogen dioxide emissions, taking into account the entire observation period.

The table clearly shows that the same trends are observed for some cities. For large cities located in the European part of Russia, there is a predominantly decrease in the concentration of nitrogen dioxide from 2018 to 2020, while almost all cities located in Siberia are growing. The study of the reasons for the obtained trends requires a more detailed analysis and research with the connection of climatic indicators and is not considered in this work.

Since the cities in the Siberian part of Russia have a similar distribution of nitrogen dioxide concentration, they were combined into a group for analyzing the concentration on a monthly basis. The graphs in Figure 5 show the intra-annual course of nitrogen dioxide concentration for 2019 and 2020. In almost all cities, a seasonal change in concentration is observed: a decline in the summer months and an increase in the autumn-winter period, which is presumably related to the heating season and also requires a separate study. To confirm this assumption, small areas of sparsely populated and unpopulated areas were delineated.

In Figure 6 shows a comparison of monthly concentrations of nitrogen dioxide for 2020 over the territories of Moscow and Novokuznetsk with the concentrations of sparsely populated areas near these cities. It is clearly seen from the graphs that the gas concentration outside urban areas remains practically unchanged throughout the year.

Table 1
Average annual concentration of nitrogen dioxide by TROPOMI for 2018, 2019, 2020.

Cities	Average NO_2, micromol/m^2		
	2018	2019	2020
Moscow	139.31	136.34	125.82
Novokuznetsk	87.29	103.52	100.47
St. Petersburg	95.04	92.57	70.47
Irkutsk	72.33	81.83	82.83
Krasnoyarsk	65.29	66.82	72.23
Kemerovo	59.37	72.25	68.50
Chelyabinsk	60.20	68.40	67.59
Novosibirsk	57.84	64.84	70.69
Yekaterinburg	52.66	54.22	61.77
Nizhny Novgorod	58.92	52.15	48.00
Rostov-on-Don	48.00	57.45	50.90
Voronezh	46.53	45.33	48.66
Kazan	45.29	46.23	42.00
Omsk	39.04	41.65	45.39
Cherepovets	39.40	44.40	35.00

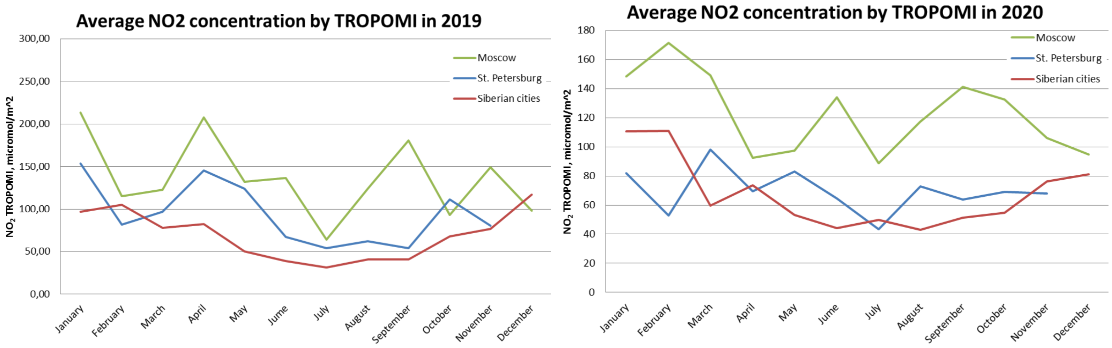

Figure 5: Average season NO_2 concentration by TROPOMI in 2019 and 2020 for Russian cities.

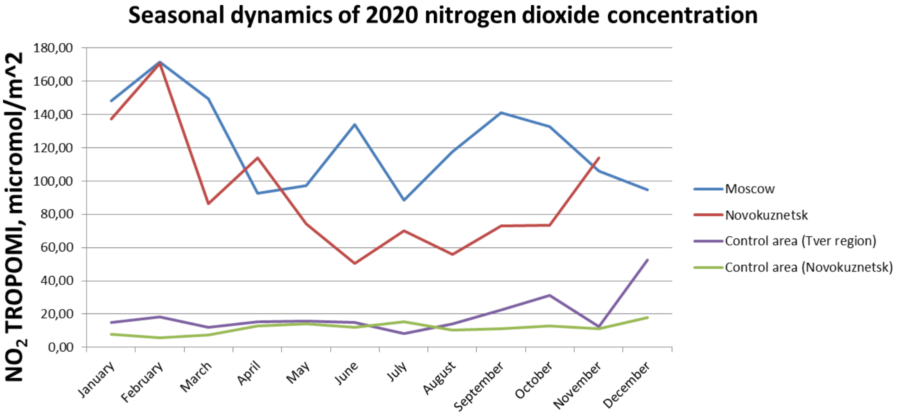

Figure 6: Comparison season dynamics of nitrogen dioxide concentrations between urban and sparsely populated areas.

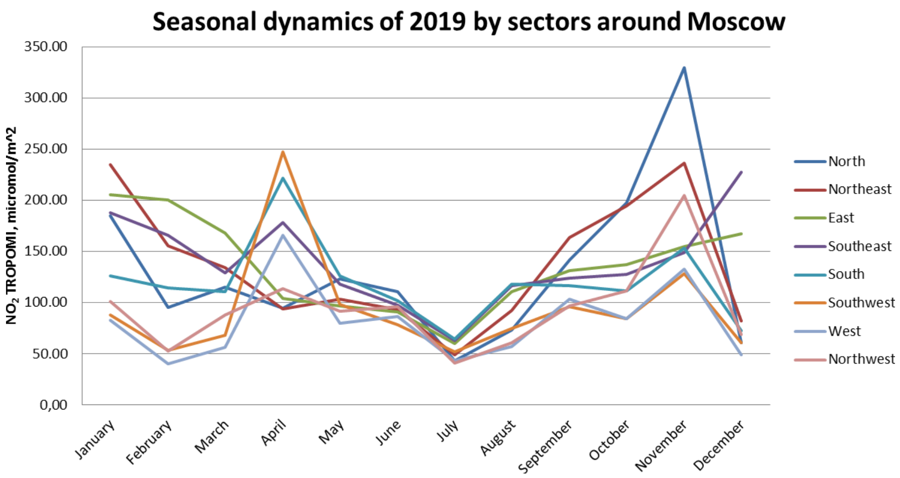

Figure 7: Seasonal dynamics of 2019 by sectors around Moscow.

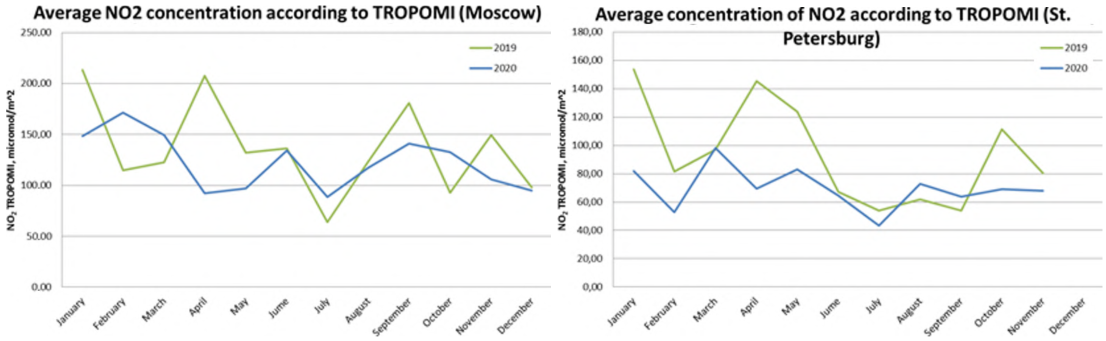

Figure 8: Decrease in nitrogen dioxide emissions during the period of restrictive measures for Moscow and St. Petersburg.

To analyze the distribution of emissions from large cities, the concentrations of nitrogen dioxide were calculated by sectors within the 100-kilometer zone. Figure 7 shows the average monthly concentration of dioxide for the 2019 season by sector around Moscow. From the presented graph it can be seen that in the summer months in all directions from the city center, the concentrations are approximately equal, while in winter, in some directions, there is a decrease in concentration (mainly in the West and South-West), and in some — an increase in concentrations (East and Northeast), which also indicates the presence of a seasonal trend and significant wind drift of nitrogen dioxide emissions.

Also, based on monthly data, studies were conducted on how restrictive measures on movement and anthropogenic activities during the spread of Covid-19 affected nitrogen dioxide emissions in large cities. In some cities, there is a significant drop in nitrogen dioxide concentration in April-May 2020, apparently related to the restrictive measures for Covid-19. For example, in Moscow, the official lockdown lasted from March 30, and on June 9, digital passes were canceled. Figure 8 shows graphs of nitrogen dioxide emissions for several representative cities for 2019 and 2020.

5. Conclusions

Thus, we can say that the presence in the archives of the IKI-Monitoring Center for Collective Use of data on the concentration of the main gases in various layers of the atmosphere using the TROPOMI (Sentinel-5P) and OMI (AURA) instruments allows solving quite a variety of tasks related to monitoring the state of the atmosphere.

Using nitrogen dioxide as an example, we see that the created TROPOMI data information products (Sentinel-5P) and a set of tools for observing objects in a first approximation can become the basis for monitoring atmospheric pollution with this gas within large cities. The results obtained clearly show seasonal trends and a decrease in nitrogen dioxide emissions during the period of restrictive measures is observed. For a more detailed analysis, it is necessary to take into account the meteorological conditions, the relief, the wind rose in the entire tropospheric column, and the presence of local sources of nitrogen dioxide emissions.

Acknowledgments

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