Algorithms for using the database of OMI and OMPS spectrometers for estimating sulfur dioxide emissions

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Abstract. The paper is devoted to investigation of SO₂ emissions in atmospheric air using the OMI space monitoring database for the northern territories of the Krasnoyarsk region in Russia. The highest concentration of SO₂ emissions was recorded in April 2019 - 41.2 DU, and the smallest in July 2019 - 0.5 DU. Actual air pollution in populated areas for the northern territories of the Krasnoyarsk Territory corresponds to a high degree of pollution, except for 2013 and 2014 when it was a moderate degree of pollution.

1. Introduction

The degradation and destruction of forests near industrial enterprises located near resource companies in the northern latitudes of the Krasnoyarsk Territory is due to high concentrations of sulfur dioxide in the air (SO₂). This negatively affects people's health. This leads to the need to monitor the environmental situation, in particular, monitoring the emission of SO₂ - the main element of pollution in this region.

A number of methods for controlling the atmospheric gas composition are known: satellite, aviation, and ground. The control of SO₂ emissions from enterprises located in the northern territories of the Krasnoyarsk Territory is based on the ground based method [1]. It is proposed to use a control method based on satellite data, since it has a number of advantages: wide coverage of the Earth’s surface, the ability to assess the level of pollutants at various altitude levels, and the ability to monitor the further direction of emission propagation.

2. Development of criteria and algorithms for using the database of OMI and OMPS spectrometers

For this, 4 OMI and OMPS space monitoring databases are used for atmospheric SO₂ emissions for the northern territories. Two databases OMI and OMPS have the form of a text table with a description (table 1) [2]. This table displays the date, time of measurement, cloud cover and coordinates of the measurement site. The four columns of the table show the SO₂ content for four altitudes.

Table 1. OMI text database fragment.

| Date          | c. (UTC) | Longitude, deg. | Latitude, deg. | SO₂_0.9km E.D. | SO₂_2.5km E.D. | SO₂_7.5km E.D. | SO₂_17km E.D. |
|---------------|----------|-----------------|----------------|----------------|----------------|----------------|---------------|
| 01.10.2007    | 10468    | 88.93           | 68.98          | 4.2            | 0.3            | 3.8            | 0.0           |
| 01.10.2007    | 10470    | 88.61           | 69.01          | 5.0            | 7.5            | 1.4            | 0.76          |
SO\textsubscript{2}_0.9 km - concentration of SO\textsubscript{2} at an altitude of 0.9 km in E.D., SO\textsubscript{2}_2.5 km - concentration of SO\textsubscript{2} at an altitude of 2.5 km in E.D., SO\textsubscript{2}_7.5 km - concentration of SO\textsubscript{2} at an altitude of 7.5 km in E.D., SO\textsubscript{2}_17 km - concentration of SO\textsubscript{2} at an altitude of 17 km in E.D.

To control SO\textsubscript{2} emissions, it takes place by reading the total array of SO\textsubscript{2} emissions data for the study area from 2 sources of information OMI and OMPS (text database) based on satellite data [3]. Then the processing of this data array is carried out in accordance with the algorithm presented in figure 1, since it contains partially false data.

![Image 1](image1.png)

**Figure 1.** OMI and OMPS numeric database processing algorithm.

A feature of this algorithm is that sulfur dioxides concentration data for two OMI and OMPS devices obtained during the period when the cloud coefficient exceeds 30% are excluded. Negative values of SO\textsubscript{2} emission concentration are also excluded, as they do not make sense [3].

Using the algorithm depicted in figure 2, a graphic database for assessing the state of the environment by mass and area of distribution of sulfur dioxide emissions is processed [4].

![Image 2](image2.png)

**Figure 2.** NASA SO\textsubscript{2} emissions graphic database processing algorithm.

A distinctive feature of this algorithm is that for two OMI and OMPS instruments obtained during the period of increased cloudiness above 30%, data on the area of distribution and mass of SO\textsubscript{2} emissions are excluded [5]. Also, data obtained not on two measuring systems OMI and OMPS at the same time
for a specific day are not used. A database of SO$_2$ emissions for the study area is being formed in accordance with these parameters.

However, NASA databases are not processed and partially contain false values. Therefore, it is impossible to apply them to assess the state of atmospheric air.

3. Development of an information application for processing OMI and OMPS databases

The analysis of SO$_2$ emissions is based on the data obtained as a result of processing the database of SO$_2$ emissions for the northern territories of the Krasnoyarsk Territory with an information application developed in the MATLAB shell. The application interface is mapped to figure 3.

![Figure 3](image3.png)

**Figure 3.** Text database processing application information interface SO2 emissions for the northern territories of the Krasnoyarsk Territory.

The method of estimating SO$_2$ emissions is used to assess the state of atmospheric air for the northern territories of the Krasnoyarsk Territory. Estimation of SO$_2$ emissions is carried out according to 3 main parameters: by mass, concentration and distribution area. For this, the numeric and graphical databases of the OMI spectrometer from 2007 to 2019 are used. The average daily concentration of sulfur dioxide emissions for the northern territories for 2007 was analyzed from March 28, 2007 to October 11, 2007 and amounted to 197 days (figure 4).

![Figure 4](image4.png)

**Figure 4.** The average daily concentration of SO$_2$ emissions for 2007.

In 2007, due to adverse weather conditions and the occurrence of the polar night, data on the concentration of sulfur dioxide emissions are not available in January, February, from November to
December. The highest concentration of sulfur dioxide emissions falls on the interval from April 10 to June 10 (100-160 days). The maximum concentration of SO\textsubscript{2} emissions in 2007 was recorded on April 30. On this day, she reached a value of 33.3 E.D. Also, emission peaks were recorded on April 29 -23.6 E.D., on May 2 - 19.8 E.D., on May 7 - 27.4 E.D., on May 14 - 25.5 E.D., 23 May - 23.2 E.D.

From April 16 to May 28, the concentration of SO\textsubscript{2} did not fall below 6 fU, with the exception of a few days. From April 16, the concentration of SO\textsubscript{2} emissions is significantly reduced to a level of no higher than 1.3 e. and remains until October 1, with the exception of certain days: from June 14 to 17 - 7 E.D., on August 16 - 5.3 E.D., on September 26 - 4.6 E. In October, the concentration of sulfur dioxide emissions increases to values of 3 E.D.-6 E.D. For 53 days a year, the concentration of SO\textsubscript{2} emissions does not exceed a value of 1 E.D., on other days of observation it has an increased level.

Figure 5 shows a graph of mean monthly SO\textsubscript{2} concentrations. The highest value of SO\textsubscript{2} concentration was recorded in April - 9.5 E. and May - 11.3 E.D. In June, the concentration of SO\textsubscript{2} decreases to the level of 3.27 E.D., in July to 2.42 E.D., and in August - September to 1.4 E.D. In October, increases 3 E.D.

![Figure 5. Monthly average SO2 emissions.](image)

The average annual value of the concentration of sulfur dioxide for the northern territories for 2007 exceeds MPC\textsubscript{s.g.} 6.9 times. The actual atmospheric air pollution of populated areas for oil refineries, in accordance with the value of indicator P (on a five-point scale), corresponds to the maximum IV - severe degree of pollution.

In 2019 (figure 6), measurements of SO\textsubscript{2} emissions by the OMI instrument were carried out from March 17 to October 7 (76-280 days). The maximum value of SO\textsubscript{2} was recorded on April 20 - 41.2 E. From April to May, the concentration of SO\textsubscript{2} did not exceed 6 e. With peaks of concentration of May 2 - 26 DU, May 8 - 30.1 DU and May 11 - 30.2 E.D. Since June, the concentration of SO\textsubscript{2} mainly ranges from 0.5 e. up to 2 E.D., at peaks reaching values of 3-8 E.D. In 2018, the concentration of SO\textsubscript{2} does not exceed MPC\textsubscript{s.s.} within 78 days.

![Figure 6. 2019 daily average SO\textsubscript{2} emission concentration.](image)
In 2019 (figure 7), a high value of SO$_2$ concentration is recorded in April - 8.9 E.D., in May - 9.7 E.D. Since June, the concentration of SO$_2$ is reduced to 1.7 e. and persists until September. In October, it jumps up to 4.3 d.u.

Figure 7. The average monthly concentration of SO$_2$ emissions in 2019.

The average annual value of SO$_2$ concentration near resource companies in the northern latitudes of the Krasnoyarsk Territory in 2019 exceeds the MPC$_{s,s}$ 5.4 times. Actual air pollution on in accordance with the value of the indicator P corresponds to the maximum IV - severe pollution [6].

Table 2 presents the main indicators for analyzing the concentration of SO$_2$ emissions for the northern territories of the Krasnoyarsk Territory for 2007-2019.

| Year | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| The average annual concentration of SO$_2$, E.D. | 4.4 | 4.6 | 3.9 | 4.1 | 4.5 | 3.48 | 2.29 | 2.52 | 2.67 | 3.28 | 3.51 | 3.13 | 3.46 |
| The number of days in a year when the concentration of SO$_2$ is higher than MPC$_{s,s}$, 5*MPC$_{s,s}$, 10*MPC$_{s,s}$ | 176 | 173 | 180 | 179 | 170 | 161 | 181 | 157 | 154 | 182 | 161 | 148 | 164 |
| Power pollution atmosphere | IV | IV | IV | IV | IV | IV | III | III | IV | IV | IV | IV | IV |

The average annual concentration of SO$_2$ exceeds MPC$_{s,s}$, the entire observation period. The excess is in the range from fourfold in 2014 to sevenfold in 2011. The number of days when the concentration of sulfur dioxide exceeds MPC$_{s,s}$ is in the range of 148 ... 182 days a year. 5-fold excess of MPC$_{s,s}$ - 35 ... 71 days a year. 10-fold excess of MPC$_{s,s}$ - from 9 to 43 days a year. Actual air pollution in accordance with indicator P corresponds to a high degree of pollution, except for 2013 and 2014 - a moderate degree of pollution.

4. Conclusion
The analysis of the state of atmospheric air near resource companies in the northern latitudes of the Krasnoyarsk Territory was carried out and the following results were obtained based on the developed method for monitoring sulfur dioxide emissions from satellite data. The average annual concentration of sulfur dioxide in the atmosphere near resource companies in 2007-2019 on an area of 19384 km$^2$ is about 0.11 mg/m$^3$, which exceeds the limit norm by 2.2 times.

The number of days in a year when the concentration of sulfur dioxide exceeds MPC$_{s,s}$ in the atmosphere near resource companies. annually lies in the range from 148 to 182 days for 2007-2019.
The number of days in a year when the concentration of sulfur dioxide is 5 times higher than MPC.s. in the atmosphere near resource companies annually lies in the range from 35 to 71 days for 2007-2019.

References

[1] Fioletov V E, McLinden C A, Krotkov N, Li C, Joiner J, Theys N, Carn S and Moran M D 2016 A global catalogue of large SO$_2$ sources and emissions derived from the Ozone Monitoring Instrument Atmos Chem. Phys. pp 497-519

[2] Fioletov V E, McLinden C A, Krotkov N and Li C 2015 Lifetimes and emissions of SO$_2$ from point sources estimated from OMI Geophys. Res. Lett pp 1969-76

[3] Li C, Joiner J, Krotkov N A and Bhartia P K 2013 A fast and sensitive new satellite SO$_2$ retrieval algorithm based on principal component analysis: Application to the ozone monitoring instrument Geophys. Res. pp 1548-55

[4] Li C, Krotkov N, Carn S, Zhang Y, Spurr R J and Joiner J 2017 New-generation NASA Aura Ozone Monitoring Instrument (OMI) volcanic SO$_2$ dataset: algorithm description, initial results, and continuation with the Suomi-NPP Ozone Mapping and Profiler Suite (OMPS) Atmos. Meas. Tech pp 445–58

[5] Flynn, L, Long C, Wu X, Evans, Beck C T, Petropavlovskikh I, McConville, Yu W, Zhang Z, Niu J and Beach E 2014 Performance of the Ozone Mapping and Profiler Suite (OMPS) products Geophys. Res.

[6] Krotkov N A, Carn S A, Krueger A J, Bhartia P K and Yang K 2006 Band residual difference algorithm for retrieval of SO2 from the Aura Ozone Monitoring Instrument (OMI) IEEE Transactions on Geoscience and Remote Sensing 44(5) 1259-66

[7] Kashkin V B and Sukhinin A I 2001 Remote sensing of the Earth from space. Digital image processing (Moscow: Logos) p 33