Simulation of spread and transformation of emissions from Norilsk industrial zone with the WRF-CHEM model: comparison with experimental data of airborne sensing

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ABSTRACT

The verification of the results of numerical simulation of the distribution of anthropogenic emissions of the Norilsk industrial zone using the WRF-CHEM model using airborne sounding data carried out in 13 August 2004 was carried out. The results of numerical modelling of the distribution of the concentration of sulphur dioxide, ozone and mass concentration of aerosol reproduce qualitatively the distributions obtained during airborne sounding. Quantitative estimates showed that the root-mean-square error for sulphur dioxide, the mass concentration of aerosol PM2.5 and ozone, calculated for all three flights, was 36 ppb, 3.4 μg/m^3, 7.7 ppb, respectively.

Keywords: Airborne sensing, industrial emissions, simulation, WRF-CHEM

1. INTRODUCTION

The Norilsk industrial zone is one of the largest industrial areas north of the Arctic Circle. The main source of pollutant emission into the atmosphere is the Norilsk Nickel Mining and Smelting Enterprise. The total annual volume of its anthropogenic emissions exceeds 2 million ton [1]. Sulfur dioxide (SO2), carbon monoxide (CO), and nitrogen oxides (NO, NO2) are major contributors to these emissions. Sulfur dioxide is one of the most hazardous pollutants, because it rather easily reacts with atmospheric moisture, leading to formation of sulfuric acid and following acid fallout. As a result, vegetation undergoes degradation, inland fresh water bodies acidify, and soil acidity increases.

Sulfur dioxide is characterized by the highest solubility in tissue fluids in comparison with other emitted gases. Reaching the lungs, it fast diffuses to bronchi walls and penetrates inside to some depth. Thus it deteriorates

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mechanic functions of upper and lower airways, that is, increases the resistance to airflow because of bronchi contraction under the effect of the gas. In addition, entering the lungs, sulfur dioxide quickly spreads by the blood circulatory system, causing changes in cellular structures. The long-term action of sulfur dioxide can lead to development of cancer.

All the aforesaid indicate the necessity of studies aimed at the estimation of technogenic impact of anthropogenic emissions from the Norilsk industrial zone on the environment of the region.

In this paper, we have simulated the spread of pollutants from the Norilsk industrial zone with the use of the WRF-CHEM v.3.5.1 model. The obtained model results were compared with the results of airborne sensing [2-3], which has allowed us to estimate the quality of the calculations and to reveal some peculiarities of global databases of emission sources, which should be taken into account in studies of this kind.

2. MEASUREMENT DATA AND CALCULATION METHODS

For this study, we used the data of airborne sensing of the An-30 OPTIK-E flying laboratory. The equipment installed onboard the An-30 aircraft is listed in Table 1. The WRF version 3.5.1 [4] hydrodynamic model for numerical weather forecast complemented with the chemical prediction unit (RACM - Regional Atmospheric Chemistry Mechanism) [5] was used for calculations. This model was used in articles [6-8]. The calculations were carried out for the region of the most probable spread of SO2 emissions (60x70 nodes with a center in the city of Norilsk) with a spatial step of 5 km. For preparation of initial and boundary conditions for the chemical unit, we used the RETRO/EDGAR set of statistically plane emissions. The calculations corresponded to the case of airborne sensing of 13.08.2004.

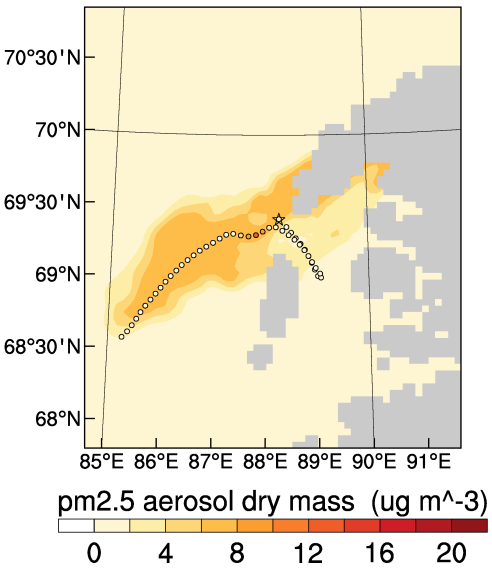
Table 1. Instrumentation used onboard the An-30 Optik-E flying laboratory

Device	Parameter	Range	Error
TEI 43	SO_2, ppm	0...100	20%
3.02P-A	O_3, $\mu g/m^3$	0...500	20%
K100	CO, mg/m^3	0...50	20%
AZ-5	N, cm^{-3}	100...510^5	20%

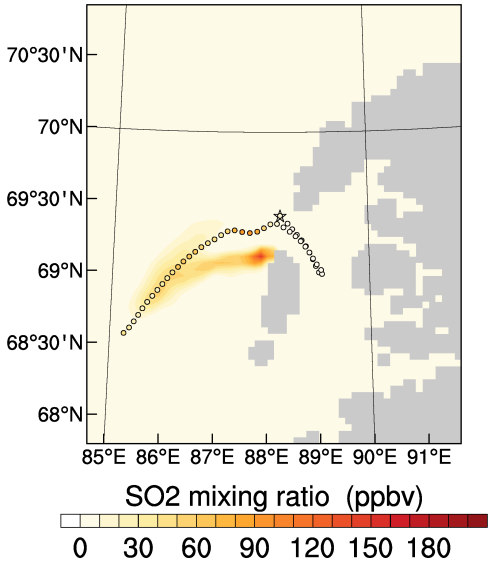
3. RESULTS

Figures 1a and 1b compare the area distributions of PM2.5 and SO2 concentration obtained in the airborne sensing and numerical simulation by the WRF-CHEM model (airborne measurements (dots) and model fields are given for a height of 400 m). Figure 2 shows the comparison of the concentrations obtained during the flight and the results of numerical simulation.

The results of numerical simulation of the distributions of sulfur dioxide and ozone concentrations and the ma aerosol concentration are in a good agreement with the results of airborne sensing. Exclusion was the distribution of carbon monoxide concentration, whose model values were underestimated by two orders of magnitude. However, this may be a consequence of the fact that the used database of pollutant emission sources had incorrect data concerning the carbon monoxide emission for the region under study. This situation calls for further examination.



a)



b)

Figure 1. Comparison of measured data and results of simulation by WRF-Chem v3.5.1: (a) PM2.5 (g/m3), (b) SO2 (ppb)

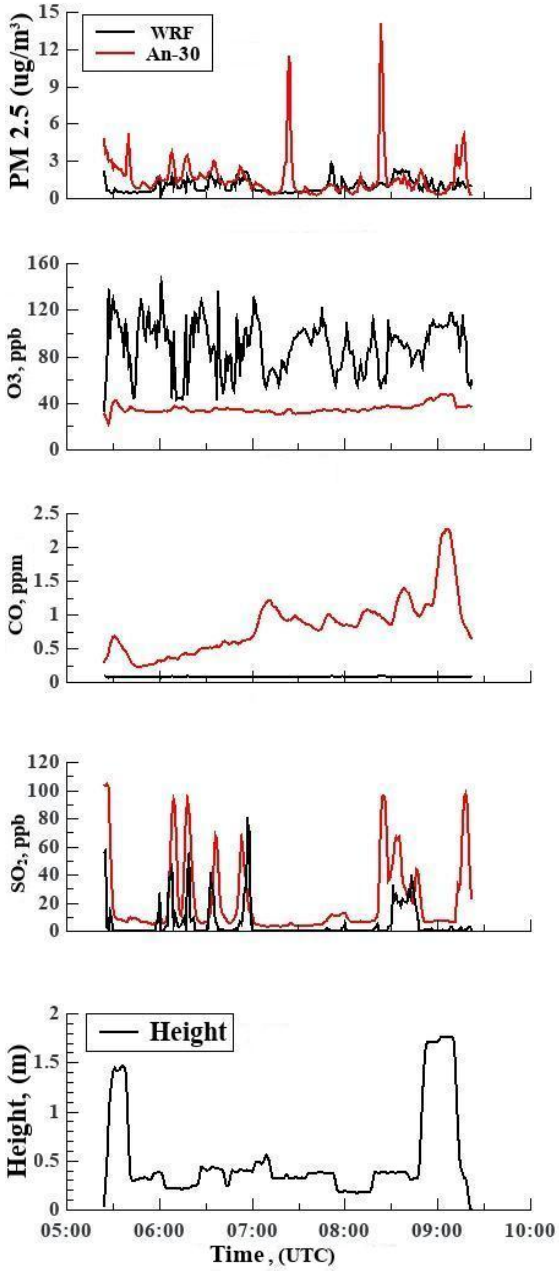


Figure 2. Comparison of measured data and results of simulation by WRF-Chem v3.5.1

4. CONCLUSION

As a result of this study, we can conclude that the WRF-CHEM v3.5.1 model adequately reconstructs meteorological parameters obtained during the measurement campaign of 2004. The results of numerical modeling of the distribution of sulfur dioxide, ozone concentration and mass concentration of aerosol have a high degree of

agreement with the results of aircraft sounding. The exception was the distribution of carbon monoxide, the model estimates of which were understated by 2 orders of magnitude, but this may be due to the fact that emission of carbon monoxide for the region of investigation was incorrectly reflected in the base of sources of impurity emissions, which requires additional studies.

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