Methane in the Atmosphere of Western Siberia: Results of Satellite Observations and Simulations

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Abstract. In this paper we study the behavior of total methane content in the atmosphere of Western Siberia using satellite observations and simulations. The AIRS/AQUA data show the increase of the total methane content at rate ~3.3±0.2 ppbv/year for 2003–2018. Using the global chemical transport model MOZART4, we analyzed the contributions of remote sources to the total methane content in the region's atmosphere. According to climatic models, the average value of methane emissions from bog complexes in Western Siberia was established for the period 2000–2013, and projected estimates of emissions up to 2050 are obtained.

Keywords: atmospheric methane, Western Siberia, AIRS/AQUA, remote sources, wetland complex.

1 Introduction

Atmospheric methane is one of the most important greenhouse gases making a significant contribution to climate change on the Earth. The Intergovernmental Panel on Climate Change 2013 reports that its contribution to radiation forcing is about 17% [1]. Over the past 270 years, the ratio of methane mixture in the surface layer of the background atmosphere has increased by about 257% and was about 1860 ppb at the beginning of 2018 [2]. The methane content increased particularly rapidly in 2014–2017 [3].

In this regard, the problem of the atmospheric methane monitoring, as well as the implementation of projected estimates of methane emission are the most important problems.

The aim of this work is to study the behavior of the total methane content in the atmosphere of Western Siberia according to satellite observations, as well as to establish methane emission trends up to 2050 using the results of climate models.

2 Methane content in the atmosphere of Western Siberia

The total methane content [CH_4] in the atmosphere of Western Siberia was estimated using the level 2 research product of the AIRS/AQUA, as well as the regression method developed by the authors earlier [4]. To optimize the statistical treatment, we use our "Methane content in the free troposphere of Western Siberia" database [5]. The analysis of the results was carried out in two zones of the study region: 1 - (65–55ºN, 60–90ºE), 2 - (55–45ºN, 60–90ºE). The northern zone contains the main natural source of methane in the region - the Great Vasyugan Mire.

Figure 1 shows the behavior of the total methane content in these two zones obtained using the regression model for the entire study period of 2003–2018. Dots on the figure refer to the daily mean of methane content averaged over the zone, and the line refers to moving average for 30 days. It is seen that in the annual cycle of [CH_4] in the atmosphere of Western Siberia there are two maxima: winter (January-February) and summer (July-September) ones.

The analysis of the total methane content anomalies obtained using the approach [6] and shown in figure 2 allows us to establish that the increase of [CH_4] in 2003–2018 has a trend of ~3.3±0.2 ppb/year.

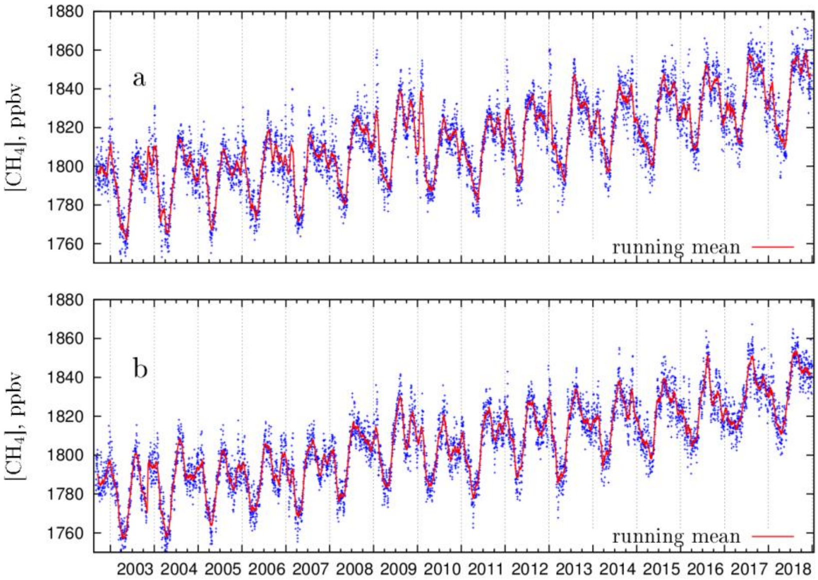

Figure 1. Annual cycle and interannual variability of total methane content in the atmosphere of Western Siberia for zones 1 (a) and 2 (b).

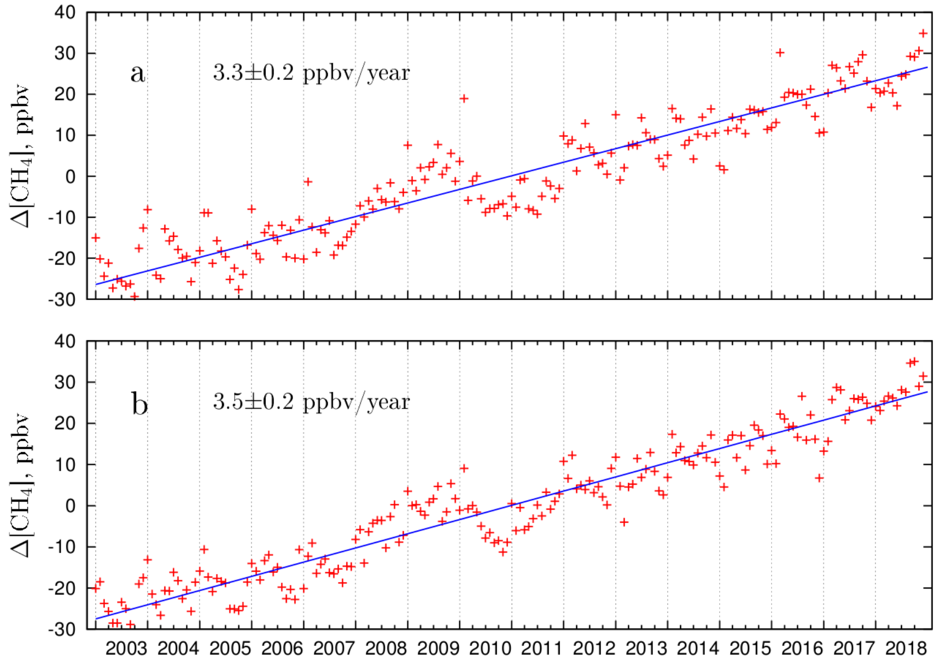

Figure 2. Anomalies of total methane content in the atmosphere of Western Siberia for zones 1 (a) and 2 (b).

3 The influence of remote sources

The sensitivity of the total methane content in the atmosphere of Western Siberia to remote sources was estimated using the MOZART-4 chemical transport model [7]. In the zone of the proposed source, the surface concentration of methane was increased artificially by 10 times. The MOZART-4 model run was carried out for a simulation period of 3 months, the duration of the emission was one month. The term sensitivity in this study refers to the ratio of the simulation results within the included remote source and without it. As the remote sources' zones we selected the regions in the Western Europe, the South-East Asia, the Eastern coast of North America, the Arabian Peninsula and the North of South America. Analysis of methane content in the case of spreading out from the remote sources was performed at atmospheric levels of 300, 500 and 700 hPa.

Figure 3 shows the sensitivity of total methane content [CH_4] in the atmosphere of Western Siberia during the summer months obtained from MOZART-4 results for the sources located in Europe, North America and Asia. It is seen that in the study period the main contribution to [CH_4] in the atmosphere of Western Siberia may be due to sources located primarily in Europe and North America. The maximum sensitivity for these sources is observed on the 15th and 25th day after the start of emission. Figure 4 shows the area of methane spread from the source in Western Europe to Western Siberia at the level of 300 hPa.

Analysis of similar results for other sources showed that methane emissions from Asia and the Arabian Peninsula could have an impact on the methane content in the upper troposphere of Western Siberia. Such events could occur in the case of the subtropical and mid-latitude air masses exchange. The sources located in the North of South America have almost no effect on [CH_4] in Western Siberia atmosphere.

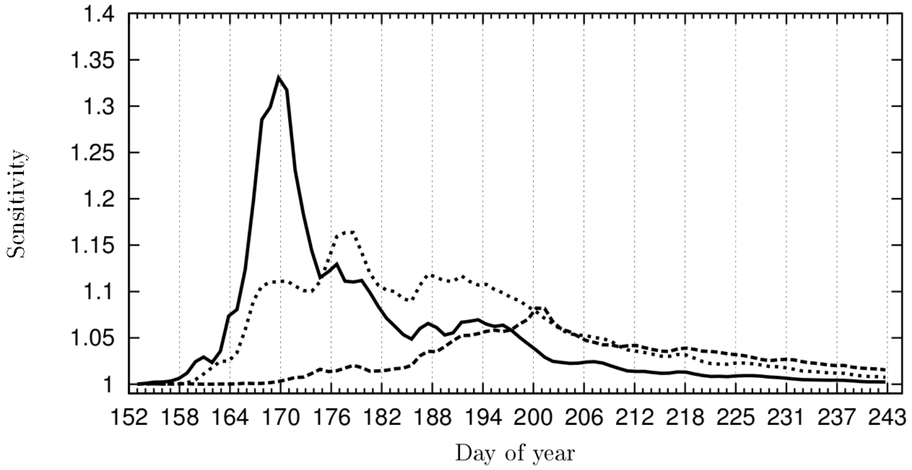

Figure 3. The sensitivity of total methane content [CH_4] in the atmosphere of Western Siberia during the summer months obtained from MOZART-4 results for the sources located in Europe (solid line), North America (point line) and Asia (dashed line).

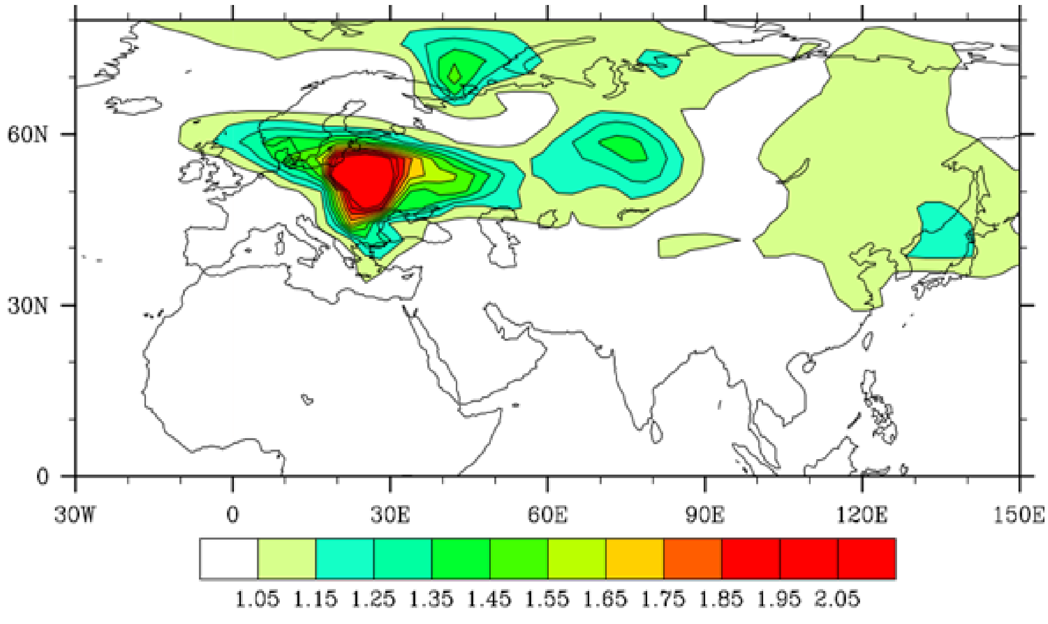

Figure 4. The sensitivity of the methane content at the level of 300 hPa to the Europe source in June 2007.

4 Methane emissions by wetland complexes

The modeling of methane emission by wetland complexes in Western Siberia was carried out using the approach described in [8]. As input data we used the results of the regional climate model RegCM4 [9], the model of heat and moisture transfer in the soil CLM4.5 [10], and the data from the database [11] containing information on the wetland ecosystems of Western Siberia. The model was driven by the data of NCEP-DOE Atmospheric Model Intercomparison Project reanalysis (NCEP-DOE AMIP-II (R-2)) and Hadley Global Environment Model 2 - Earth System (HadGEM2-ES) within the Representative Concentration Pathway 4.5 (RCP 4.5) and RCP 8.5 radiative forcing scenarios as initial and lateral boundary conditions.

Figure 5 shows the results of methane emission simulation for the period 2000–2050. The projected values for the period 2013–2050 were normalized taking into account the data for the contemporary period 2010–2013.

As a result of the analysis of the obtained data it was found that the mean value of methane emission by Western Siberia's wetland complexes in period 2000–2013 is ~4.34 Tg/year. Methane emission rate of change is almost zero in this period. The increase of CH_4 emissions was found only in the tundra and forest tundra zones. The projected increase of the methane emissions in 2041–2050 relative to the period 2001–2010 is 0.58 Tg/year with a trend of 0.18±0.06 Tg/10 years for the RCP 8.5 scenario. For the RCP 4.5 scenario the neutral trend of methane emissions was established. This is due to the fact that the increase of temperature is compensated by a decrease of soil moisture content.

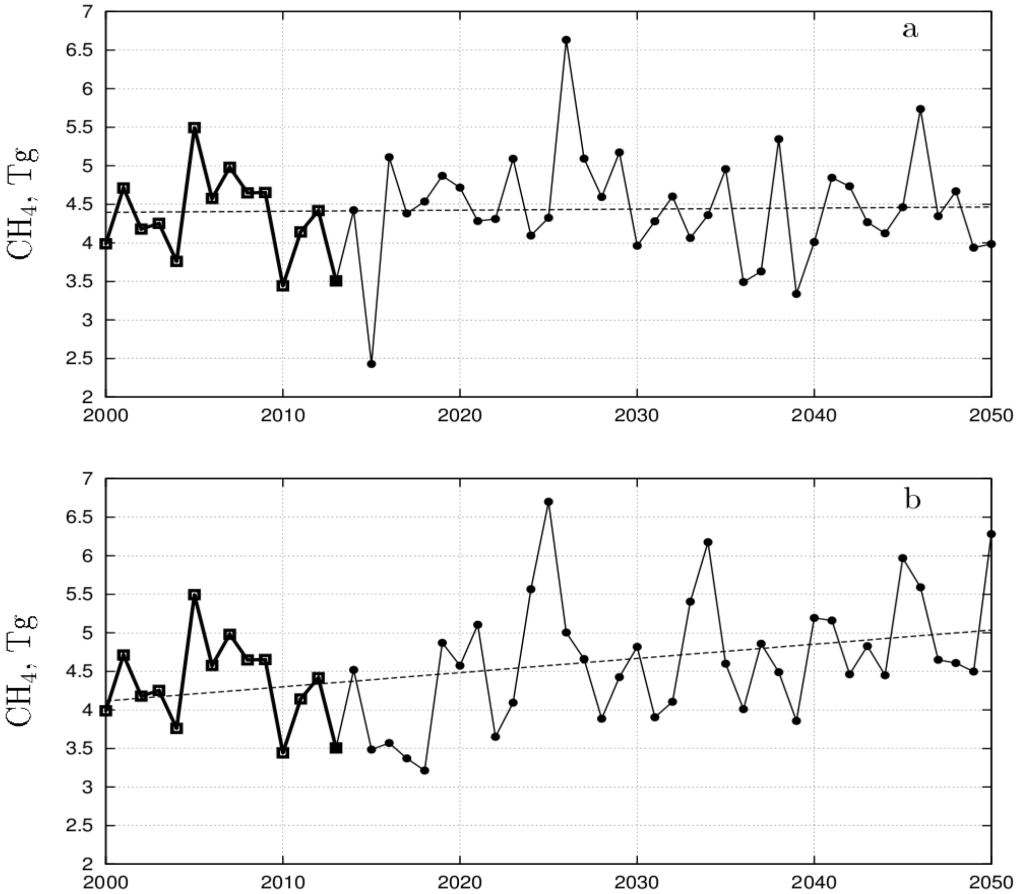

Figure 5. Methane emission by wetland complexes of Western Siberia for the period 2000–2050. Bold lines are data for the modern period; boundary conditions are from NCEP-DOE AMIP-II (R-2) reanalysis. Thin lines - projected estimates normalized to the data for contemporary period; boundary conditions according to the global model HadGEM2-ES in the framework of two scenarios: a) RCP 4.5; b) RCP 8.5.

5 Results and conclusions

The behavior of the total methane content in the atmosphere of Western Siberia was studied. The main results are as follows.

1. As a result of the analysis of the AIRS/AQUA data, the trend of total methane content in the atmosphere of Western Siberia for 2003–2018 ~3.3±0.2 ppb/year was established.
2. It is shown that the total methane content can be contributed to remote sources located primarily in Europe and North America.
3. Using the data of regional climate model it was found that in Western Siberia for the period 2000–2013 the mean value of methane emission by wetland complexes is ~4.34 Tg/year. The projected increase of methane emission in 2041–2050 relative to the period 2001–2010 is 0.58 Tg/year with a trend of 0.18±0.06 Tg/10 years for the RCP 8.5 scenario. For the RCP 4.5 scenario, the increase of emissions is negligible.

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