Large Increase in Atmospheric Methane over West Siberian Wetlands during Summer Detected from Space

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Abstract

Although wetlands are the largest natural source of atmospheric methane, the amount and variability of methane emissions from wetlands still have large uncertainty. We investigated the local growth rate of the column-averaged methane dry air mole fraction (XCH4) in Siberia where wetlands are widely abundant using 11-year (2009−2019) Greenhouse gases Observing SATellite (GOSAT) data. While the mean growth rate during the summer from the GOSAT observations is 7.2 ppb yr−1 globally, that in West Siberia is 8.4 ppb yr−1. In particular, the growth rates in West Siberia after 2013 is much larger in July and August than in the other months. Moreover, the growth of XCH4 in West Siberia appears to larger than in the other boreal areas. These results imply that methane emissions from wetlands in West Siberia increased during the summer in recent several years.

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1. Introduction

Methane (CH4) is the second most important anthropogenic greenhouse gas. Its present concentration is more than double its level in the pre-industrial era. In the 21st century, the growth rate of global CH4 increased by 0.71 ppb yr−1 from 1999 to 2006, 3.68 ppb yr−1 from 2007 to 2013, and 9.05 ppb yr−1 from 2014 to 2018 (https://www.esrl.noaa.gov/gmd/ccgg/trends_ch4/). Wetlands are the single largest source of CH4 and have a large impact on the global CH4 budget (Saunois et al. 2016). Natural sources of CH4 account for 35−50% of the global emissions (Intergovernmental Panel on Climate Change 2014), and wetlands are the most dominant natural source. It is reported that the CH4 emission is largely affected by soil temperature and moisture (Saarnio et al. 1997; Friberg et al. 2003; Christensen et al. 2003; Moore et al. 2011; Glagolev et al. 2011; Sabrekov et al. 2014). This fact indicates that emissions from wetlands act as a positive feedback to global warming (Gedney et al. 2004; Ellisoev et al. 2008; Ringeval et al. 2011), particularly in high latitudes because these regions have extensive wetlands and warming has progressed rapidly here (Intergovernmental Panel on Climate Change 2014). However, CH4 emission from wetlands still has a large uncertainty (Intergovernmental Panel on Climate Change 2014) because of its large spatial and temporal variations.

Siberia, with extensive wetlands, is one of the large source areas of CH4. In west, Y. Siberia, where wetlands account for about 27% of the total area, has the largest wetland area in Siberia (Peregon et al. 2009). Moreover, permafrost is a very large reservoir of organic carbon in the Arctic and sub-Arctic region, and it contains ~1700 Pg of organic carbon, which accounts for approximately 50% of the underground carbon pool (Zimov et al. 2006; Tarnocai et al. 2009; Hugelius et al. 2014). An increase in CH4 emission in this area is believed to accelerate global warming via positive feedback (Schunk et al. 2015; Zhang et al. 2017; Knoblauch et al. 2018; Walter Anthony et al. 2018). Therefore, extensive monitoring of CH4 emission in Siberia is extremely important for global climate research. However, there are only a few sites for monitoring greenhouse gases in Siberia (Sasakawa et al. 2010).

Satellite observation is an effective tool for monitoring atmospheric environment globally. Greenhouse gases Observing SATellite (GOSAT) is the first satellite dedicated to monitor CO2 and CH4 concentrations from space. GOSAT data are used for global and regional scale trend analysis of CH4. Turner et al. (2016) detected a large increase in CH4 emission in the U.S. from the GOSAT data. Sheng et al. (2018) also detected CH4 trend in North America using GOSAT measurements. Parker et al. (2018) estimated the interannual variations of CH4 emissions in North America using the GOSAT measurements and found those to be consistent with the changes in the extent of wetlands. Maasakkers et al. (2019) also estimated the global CH4 emission trend from 2010 to 2015 via an inversion analysis from the GOSAT data and attributed increases in CH4 emissions from some areas. In this study, we investigated the local CH4 growth rates in Siberia from 11-year GOSAT data for the period 2009−2019. Since the lifetime of CH4 in the atmosphere is about 12.4 years (Intergovernmental Panel on Climate Change 2014), the locally emitted CH4 is well mixed and spread globally. Therefore, if the emissions are temporally constant, the local growth rate should be approximately equal to the global growth rate. A significant difference between the local growth rate and the global average implies that the emissions in the area have changed. Local growth rates of CH4 in the grid cells were estimated and compared with the global average to extract the local CH4 emission signals.

2. Data and method

GOSAT is a sun-synchronous polar orbit satellite launched on 23 January 2009, with a revisit cycle of three days and an equator-crossing time of 13:00 LT. It is equipped with an instrument called Thermal And Near−Infrared Sensor for carbon Observation (TANSO), which has two sensors, namely, Fourier Transform Spectrometer (FTS) and Cloud and Aerosol Imager. The main sensor, TANSO-FTS has four bands—three in the short-wave infrared (SWIR) region and one in the thermal infrared region. The full width at half maximum of the instrument line shape function and sampling interval of TANSO-FTS are about 0.275 cm−1 and 0.2 cm−1, respectively. In this work, we used the TANSO L2 products column-averaged CH4 molar fraction (XCH4) estimated from the SWIR bands (Yoshida et al. 2011; Yoshida et al. 2013) provided by National Institute for Environmental Studies. The retrieval algorithm is based on the maximum a posteriori solution (Rodgers 2000). The greenhouse gas concentrations and the other parameters (e.g., surface pressure, atmospheric temperature, water vapor, surface albedo, and aerosols concentration) were retrieved simultaneously (Yoshida et al. 2013). The product version of V02.81 from April 2009 to August 2019 was used in this study. GOSAT data are continuously available from April 2009, except for a few periods because of the problems related to the instruments. GOSAT XCH4 was validated by comparing it with data from the Total Carbon Column Observing Network (TCCON; Wunch et al. 2011), and the bias and standard deviation were ~1.9 ppb and 13.4 ppb, respectively (NIES GOSAT project...
2019). In this study, we used only data over land. Since the GOSAT SWIR band utilizes reflected solar radiation, the amount of data depends on the interval of the daytime. In high latitudes, little data are available in the fall and winter seasons (see Figs. S1 and S2).

We estimated the XCH₄ growth rate from the 11-year data observed by GOSAT. The growth rates with a unit of ppb yr⁻¹ were estimated as the slope of the regression line using the data in the focused period (see Fig. S5). The horizontal distributions of the growth rates were described using the 4° × 4° grid cells.

3. Results and discussion

Figure 1 shows the growth rates of XCH₄ for annual and June-July-August (JJA) means and the anomaly from the global average around Siberia. The top panel of Fig. 1 shows large XCH₄ growth rates of more than 8 ppb yr⁻¹ in western Siberia; these values are approximately 1 ppb yr⁻¹ higher than the global mean. In JJA, significantly higher values are seen in West Siberia in the bottom panel of Fig. 1. This area corresponds to wetlands (Lehner and Döll 2004). In particular, the growth rate and its anomaly reach approximately 8.5 ppb yr⁻¹ and 1.0–1.5 ppb yr⁻¹ within the area enclosed by the box, and these values are significantly higher than those of the other areas in the figure.

Figure 2a shows the time series of monthly XCH₄ averaged for the world and West Siberia (boxed area in the bottom panel of Fig. 1). Both the plots show increases with time with seasonal variations. In West Siberia, CH₄ emissions from wetlands depend on the microbial activities and microbial activation because the temperature increase leads to methane emission increase. Therefore, the peak of the CH₄ concentration is the summer season. The values for West Siberia from 2009 to 2013 are approximately at the same level as the global mean, while those for the peak season are different. However, the values for West Siberia from 2014 to 2019 are higher than the global mean, especially in July and August. Figure 2b shows the growth rates obtained using JJA data for West Siberia and the world, and their differences. While the growth rate for the world over land from GOSAT is 7.15 ± 0.01 ppb yr⁻¹, that for West Siberia is 8.39 ± 0.09 ppb yr⁻¹. The uncertainty is 1σ. The difference between these values is much larger than 1σ and statistically significant. The growth rates were estimated by linear regression as mentioned in Section 2. The GOSAT data is not temporally uniform; therefore, the estimated growth rates are potentially biased. We estimated the growth rates by correcting the biases in the amount of data using the annual mean XCH₄. Consequently, we obtained the growth rates of 7.11 ppb yr⁻¹ globally and 8.18 ppb yr⁻¹ in West Siberia. Even when using the annual mean to correct the biases in the amount of data, the growth rate in West Siberia is much larger than the global value.

To examine the seasonality minutely, the growth rates for each month for West Siberia are shown in Fig. 2c. The regression lines are separated between 2009–2013 and 2013–2019. From 2009 to 2013, the growth rates for each month are relatively small (~7.10 ppb yr⁻¹). After 2013, these rates are increased in all the months. In May, June, and September, the growth rates are similar at 7.93 ± 0.26, 7.87 ± 0.34, and 7.55 ± 0.36 ppb yr⁻¹, respectively. However, those in July and August are 9.07 ± 0.28 and 9.03 ± 0.27 ppb yr⁻¹. Therefore, the growths in July and August after 2013 significantly contributed to the large growth rate in JJA over West Siberia as shown in Fig. 2b.

The CH₄ growth rate is reported to have increased since 2014 (Zhang et al. 2018; Nisbet et al. 2019). Nisbet et al. (2019) investigated the zonal mean growth rates and revealed that growth rates were high in the northern boreal zone in 2014 and 2016. Our analysis also shows the global growth rates in JJA were 6.01 ± 0.05 ppb yr⁻¹ from 2009 to 2013 and 8.04 ± 0.03 ppb yr⁻¹ from 2013 to 2019. However, this increase is greater in West Siberia—6.08 ± 0.25 and 8.90 ± 0.17 ppb yr⁻¹ because of the large growth in July and August as shown previously. In particular, the increases from 2013 to 2014 and from 2015 to 2016 were significantly larger as shown in Fig. 2b. This is consistent with the large growth reported by Nisbet et al. (2019). If we compare the JJA mean XCH₄ in West Siberia and the northern high latitudes (≥ 46°N), as shown in Fig. 3, the difference is large in 2016, but not as large in 2014. This likely implies that the emissions from West Siberia largely contributed to the large growth in the northern boreal zone in 2016, but in 2014, its contribution was not as large. The JJA mean growth rate in boreal area (Fig. 3) between 2013 and 2019 is 7.79 ± 0.04 ppb yr⁻¹. This is similar to the global value and much lower than the value for West Siberia. Therefore, enhancement of the CH₄ emission from West Siberia is likely larger than that from the other northern high-latitude areas in this decade. This can also be seen as a large growth rate for West Siberia compared to the rate of increase in the other areas (Fig. S6).

Finally, we show the XCH₄ distributions in Siberia for JJA in 2009 and 2019 in Fig. 4. The color scale differs for 70 ppb because the global growth rate shown in Fig. 2 is 7.15 ppb yr⁻¹. In 2009, XCH₄ in West Siberia was slightly higher than that in the...
other surrounding areas. On the other hand, in 2019, a larger contrast is seen in West Siberia. In this season, XCH$_4$ in West Siberia is close to the level in Japan and eastern China where large cities are located.

Only from our analysis, the cause of the large XCH$_4$ growth in West Siberia is undetermined. Several possible causes exist, such as the emission increase from wetlands, fossil fuel, biomass burning, agricultural activity, and the destruction decrease due to the reaction with OH radicals. Umezawa et al. (2012) investigated the variations of methane concentration in West Siberia using its isotopes and revealed that the predominant emission is fossil fuel during winter and wetlands during summer. They also showed that the effect of the OH reaction was overwhelmed by local methane emissions from wetlands even during summer when OH density reached the maximum. Owing to this and the obtained distribution of the large growth rate shown in Fig. 1, it is implied that the large growth in West Siberia during summer is caused by increase in wetland emissions. Nevertheless, further investigations to quantify the contributions from these sectors are required.

4. Summary and conclusions

We investigated the local growth rates of XCH$_4$ in Siberia during the summer using GOSAT data for the period 2009–2019. The data analysis showed a larger growth rate in West Siberia, which has extensive wetlands, compared to the global value. The JJA mean growth rate in West Siberia for all periods is $8.39 \pm 0.09$ ppb yr$^{-1}$, while the global value is $7.15 \pm 0.01$ ppb yr$^{-1}$. This difference is statistically significant. The growth rates were especially high in July and August after 2013. The rapid increase in XCH$_4$ corresponded to wetlands, implying that CH$_4$ emission from wetlands especially in July and August in West Siberia has been increasing in this decade. In particular, the growth rate after 2013 is higher than that before 2013. The growth rate in West Siberia is higher than the global value even after 2013. A comparison with other northern high-latitude areas indicated that the increase in
CH₄ emission from West Siberia is higher than that from the other areas. Moreover, the enhancement in CH₄ growth in 2016 may be largely attributed to the West Siberian wetlands. Although we found a large increase of XCH₄ in West Siberia in this study, wetlands are distributed in the other high latitudinal areas and it is possible that the CH₄ emission will increase in the future even in those areas. Further, permafrost has a large potential to emit CH₄. We have to monitor carefully emissions from these areas for more precise evaluation and understanding of global warming.

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Supplements

Supplement 1: Supporting information.

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