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Comparisons of CH_4 ground-based FTIR measurements near Saint Petersburg with GOSAT observations

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Abstract. Atmospheric column-average methane mole fractions measured with ground-based Fourier-transform spectroscopy near Saint Petersburg, Russia (59.9° N, 29.8° E, 20 m a.s.l.) are compared with similar data obtained with the Japanese GOSAT (Greenhouse gases Observing SATellite) in the years 2009–2012. Average CH_4 mole fractions for the GOSAT data version V01.xx are -15.0 ± 5.4 ppb less than the corresponding values obtained from ground-based measurements (with the standard deviations of biases at 13.0 ± 4.2 ppb). For the GOSAT data version V02.xx, the average values of the differences are -1.9 ± 1.8 ppb with standard deviations of 14.5 ± 1.3 ppb. This verifies that FTIR (Fourier transform infrared) spectroscopic observations near Saint Petersburg have similar biases with GOSAT satellite data as FTIR measurements at other ground-based networks and aircraft CH_4 estimations.

1 Introduction

Methane is the second most important anthropogenic greenhouse gas. Despite its low concentration in Earth's atmosphere, CH_4 is responsible for about 15 % of the anthropogenic contribution to the greenhouse effect. Currently, there are networks for local flask ground and aircraft measurements within GAW (Global Atmosphere Watch) and NOAA CMDL/ESRL (Climate Monitoring and Diagnostics Laboratory/Earth System Research Laboratory; Conway et al., 2003). The first global satellite data on the total methane content in the atmospheric column were obtained using the IMG/ADEOS (Interferometric Monitor for Greenhouse Gases/Advanced Earth Observing Satellite) equipment measuring the outgoing thermal radiation spectrum with high spectral resolution (Kobayashi et al., 1999). Further studies were carried out with satellite devices SCIAMACHY, AIRS, IASI, TES (e.g., Xiong et al., 2010; Sussmann et al., 2005; Razavi et al., 2009; Wecht et al., 2012). Despite extensive observation programs, CH_4 geographical distribution and its sources are not known sufficiently (Solomon et al., 2007). Regular global satellite methane measurements could lead to solutions of the problem.

In January 2009, the GOSAT (Greenhouse gases Observing SATellite) was launched. It is a joint project of the Japanese Aerospace Exploration Agency, Ministry of the Environment and the National Institute for Environmental Studies in Tsukuba, Japan (Kuze et al., 2009). The satellite is designed to monitor global distributions of column contents of atmospheric CO_2 and CH_4 from space. Dry-air, column-average mole fractions of carbon dioxide, X_{CO_2}, and methane, X_{CH_4} (called "column-averaged methane" below), are retrieved from the data of TANSO-FTS (Thermal And Nearinfrared Sensor for carbon Observation - Fourier transform spectrometer), which is a Fourier Transform Spectrometer for measurements of carbon-bearing gases in the infrared range from the GOSAT satellite (Yoshida et al., 2011).

Ground-based remote sensing optical measurements are made at the stations of international networks NDACC (Network for the Detection of Atmospheric Composition Change) and TCCON (Total Carbon Column Observation Network) which uses ground-based Fourier transform infrared (FTIR) spectroscopy of direct solar radiation for regular measurements of column contents of CO_2, CH_4 and other climate-forming gases (Wunch et al., 2011). To obtain gas species contents, devices of the NDACC and TCCON networks usually use, respectively, middle (MIR) and near (NIR) infrared spectral ranges. Sussmann et al. (2013)

described an intercalibration of the measurements at both networks. Several validations of GOSAT data were made recently (e.g., Butz et al., 2011; Parker et al., 2011; Cogan et al., 2012; Schepers et al., 2012; Tanaka et al., 2012; Dils et al., 2013).

In Saint Petersburg State University (SPbU), spectroscopic measurements of total column methane were started in 1991 (Mironenkov et al., 1996; Makarova et al., 2009). These measurements up to the year 2009 were carried out using a solar IR grating spectrometer with resolution of 0.4–0.6 cm^{-1}. Since January 2009, the Atmospheric Physics Department of SPbU started ground-based solar FTIR measurements using the Bruker IFS 125 HR interferometer giving high spectral resolution. Results of atmospheric trace gas retrievals in SPbU were described by Poberovskii et al. (2010), Polyakov et al. (2011), Virolainen et al. (2011) and Yagovkina et al. (2011).

Morino et al. (2011) have performed a preliminary validation of X_{CO_2} and X_{CH_4} observed with the GOSAT satellite comparing them with FTIR measurements from the TCCON network (see above). They found substantially lower satellite values compared to those obtained from ground-based observations. Later, comparisons between X_{CO_2} and X_{CH_4} obtained with other GOSAT retrievals and TCCON data gave better agreements between satellite and ground-based measurements (Cogan et al., 2012; Dils et al., 2013; Yoshida et al., 2013). These comparisons were performed for ground-based observation sites located at latitudes lower than 55°. Therefore, it is interesting to compare NIES (National Institute for Environmental Studies)-GOSAT and ground-based observations performed at higher latitudes and utilizing different retrieval algorithms.

In this paper, we compare X_{CH_4} obtained by the GOSAT satellite with ground-based FTIR spectroscopic observations near Saint Petersburg in the years 2009–2012, which are performed at latitude ∼ 60° N using modified NDACC retrieval algorithms. In particular, such comparisons may give indirect verifications of FTIR spectroscopic observations near Saint Petersburg, as long as our station does not apply the formal procedures required for inclusion into the measuring network NDACC.

2 Measurement and data processing

The FTIR measurement site of SPbU is located at the Peterhof campus (59.88° N, 29.82° E, 20 m a.s.l.), about 35 km southwest from the center of Saint Petersburg. This is a boundary between a megalopolis with a population of up to 5 million people and surrounding rural areas covered with multiple swamps. Therefore, the atmosphere around the observation site could be influenced by multiple anthropogenic and natural methane sources. The measurement tools include an automatic solar tracking system, solar flux input system, and an analogous channel for cloud monitoring during the measurements. We perform observations under a cloudless sky, or in large enough cloud cover breaks. An InSb (indium antimonide) detector usually records interferograms using optical path differences of 180 cm. We obtain a single spectrum in about 12 min averaging ten spectral runs with appropriate times of accumulation.

Several computer programs (e.g., SFIT, PROFFITT and GFIT) exist for retrieving atmospheric column gas abundances via fitting the spectra in ground-based FTIR network observations. Comparisons of the first two algorithms and a new approach (Kozlov information operator) showed very close estimates of the methane total content using the same a priori information (see, for example, Senten et al., 2012). In the present study, we performed retrievals of total column contents of greenhouse gases in the atmosphere from FTIR spectrometry using the standard software SFIT2 v 3.92 (Pougatchev et al., 1995; Rinsland et al., 1998; Hase et al., 2004) designed for the NDACC network. We used the optimal estimation technique in SFIT2 and retrievals of methane content profiles with their subsequent integration.

The main input data for SFIT2 are spectra of solar radiation (including related information on interferometer parameters), and a priori profiles of atmospheric trace gases and their variations. These profiles (recommended by NDACC) were created using WACCM (Whole Atmosphere Community Climate Model) for Peterhof's latitude, longitude and altitude (Garcia et al., 2007). Vertical profiles of atmospheric pressure and temperature required for greenhouse gas retrievals are taken from Voejkovo (Weather Web, 2013), the nearest site of upper air soundings located 50 km eastward of Peterhof.

Different infrared spectral intervals were used by the NDACC FTIR network for retrievals of the atmospheric column's CH_4 content (Goldman et al., 1988; Schneider et al., 2005; Griesfeller et al., 2006; Wunch et al., 2007; Angelbratt et al., 2011; Sussmann et al., 2011, 2012; Sepulveda et al., 2012). In the present study, we use the three spectral intervals (2613.7–2615.4, 2835.5–2835.8 and 2921.0–2921.6 cm^{-1}) recommended by Sussmann et al. (2011), as well as four spectral intervals (2613.7–2615.4, 2650.6–2651.3, 2835.5–2835.8 and 2903.6–2904.03 cm^{-1}) recommended in the NDACC documentation and used by Sepulveda et al. (2012). Two of these microwindows are shared between the Sussmann and Sepulveda approaches. Mean signal-to-noise ratios in these spectral bands are about 800. Following to Sussmann et al. (2011), we used the HITRAN (high-resolution transmission) 2000 (with additions of 2001) database of spectroscopic line parameters (Rothman et al., 2003) for the abovementioned three spectral windows, and the HITRAN 2004 database (Rothman et al., 2005) for the other four windows..

The mean value of freedom degrees for CH4 FTIR measurements at the Peterhof station is ∼ 1.7. Total column water content varies from ∼ 0.2 g cm^{-2} for cold seasons up to ∼ 4 g cm^{-2} for summertime. Random relative errors of individual X_{CH_4} measurements do not exceed 0.3–0.5 %

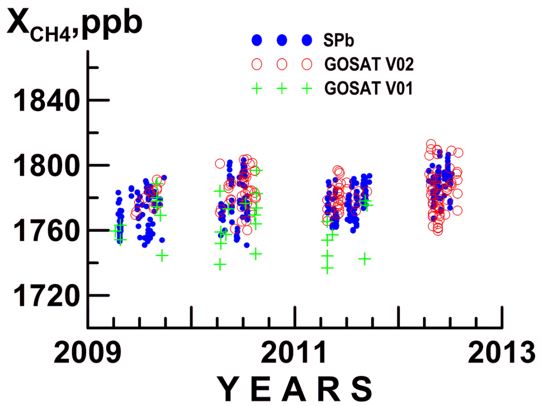

Fig. 1. Column-average methane mole fractions measured near Saint Petersburg with FTIR (SPb) and GOSAT (data versions V01.xx and V02.xx).

according to error matrix calculations within the optimal estimation method implemented in the SFIT2 software. Under stable atmospheric conditions, variations of measured X_{CH_4} throughout the day do not generally exceed 1 %.

3 Results of comparison

To compare ground-based and GOSAT X_{CH_4} near Saint Petersburg, we found intervals of simultaneous measurements in the years 2009–2012. For these time intervals, X_{CH_4} values measured with GOSAT in the ±3° latitude and longitude vicinity of the ground-based observation site were selected from the database of National Institute of Environmental Studies in Tsukuba, Japan (NIES, 2012). The ground-based X_{CH_4} values taken for the comparison were obtained at time intervals ±3 h from the local noon, as long as the methane retrievals near Saint Petersburg in the GOSAT database are usually given at times close to the local noon. We used only X_{CH_4} within the 95 % confidence interval around the mean values for the corresponding observation intervals. Because the GOSAT satellite X_{CH_4} is estimated for dry atmosphere (without water vapor), we calculated ground-based dry-air X_{CH_4} using the reanalyzed meteorological information from the ECMWF (European Centre for Medium-Range Weather Forecasts; Dee et al., 2011).

Figure 1 presents individual X_{CH_4} values from satellite and ground-based measurements using the three spectral intervals recommended by Sussmann et al. (2011). In many cases, the dates of measurements with those methods do not match exactly. However, Fig. 1 shows a systematically lower X_{CH_4} for the GOSAT data version V01.xx compared to the ground-based measurements near Saint Petersburg.

At present, the number of days with simultaneous ground-based X_{CH_4} measurements in Saint Petersburg and with GOSAT (data version V02.xx) is about 20, which is not enough for reliable statistical comparisons. To increase the amount of compared data, we analyzed the individual couples of ground-based and satellite X_{CH_4} values, for which the difference in dates of their measurements do not exceed two days. Figure 2 shows the corresponding pairs of $X_{CH_4\_SPB}$ and $X_{CH_4\_GOS}$ for both versions of the GOSAT satellite data. The solid line in Fig. 2 corresponds to $X_{CH_4\_SPB} = X_{CH_4\_GOS}$. One can see that almost all of the measured X_{CH_4} values for the GOSAT V01.xx data lie below the solid line in Fig. 2, while for the GOSAT V02.xx data the situation is different.

Table 1. Average characteristics (in ppb) for the data shown in Fig. 2. Shown uncertainties correspond to 0.95 confidence intervals. VMR units are parts per billion (ppb).

Data	Characteristic	$X_{CH_4\_SPB}$	$X_{CH_4\_GOS}$	δX_{CH_4}
V01.xx	Average	1774.6 ± 6.2	1759.6 ± 5.6	−15.0 ± 5.4
	Median	1775.5 ± 5.5	1759.6 ± 9.7	−11.5 ± 8.8
	σ_i	14.9 ± 4.9	13.4 ± 4.4	13.0 ± 4.2
	n	23	23	23
V02.xx	Average	1783.2 ± 1.4	1781.4 ± 1.6	−1.9 ± 1.8
	Median	1783.6 ± 1.1	1779.3 ± 1.2	−2.4 ± 1.2
	σ_i	11.1 ± 1.0	12.3 ± 1.1	14.5 ± 1.3
	n	256	256	256

Table 1 shows the mean, median characteristics and standard deviations σ_i calculated for the ground-based and satellite data presented in Fig. 2. Uncertainties of the parameters in Table 1 reveal 0.95 confidence intervals. These intervals on the standard deviations assume the χ^2 distribution and are calculated using Eq. (6) from Dils et al. (2013). The 0.95 confidence intervals on the medians in Table 1 are calculated using the method described by Bland (2000, Sect. 8.9).

The mean and median values in Table 1 for both types of measurements are closer to each other for the GOSAT V02.xx data. The long- and short-dashed lines in Fig. 2 have shifts relative to the solid line according to the average δX_{CH_4} values from Table 1 for the GOSAT data versions V01.xx and V02.xx, respectively. For the average δX_{CH_4} in Table 1, values $t = |\delta X_{CH_4\_aver}|/(\sigma_\delta/\sqrt{n}) \sim 4.3$ and 2.1 for the GOSAT data versions V01.xx and V02.xx, respectively. According to one sample t test (Rice, 2006), these values of t correspond to probabilities of the hypotheses about $\delta X_{CH_4\_aver} = 0$ to be less than 0.001 and 0.05, respectively. The same probabilities for the hypotheses that $\delta X_{CH_4\_SPB\_aver} = \delta X_{CH_4\_GOS\_aver}$ give two sample t tests based on the average values and standard deviations in Table 1. Verifications of the 0 hypotheses $\sigma_{SPB} = \sigma_{GOS}$ using F test for σ_i and n from Table 1 give probabilities of 0.3 and 0.05 for the GOSAT data versions V01.xx and V02.xx, respectively.

Figure 3 reveals histograms of differences δX_{CH_4} between pairs of measurements presented in Fig. 2. For the GOSAT data version V02.xx the deviations are almost symmetrical with respect to zero in Fig. 3b, while Fig. 3a demonstrates systematic underestimation of the X_{CH_4} from the GOSAT

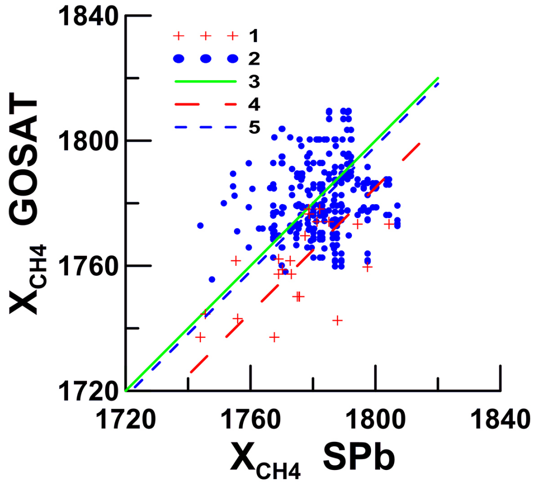

Fig. 2. Comparison of X_{CH_4} (in ppb) measured near Saint Petersburg and with GOSAT satellite (data versions V01.xx – 1 and V02.xx – 2) when differences between the dates of measurements do not exceed 2 days. Line 3 corresponds to $X_{CH_4\_SPB} = X_{CH_4\_GOS}$, lines 4 and 5 are shifted from line 3 by the average δX_{CH_4} presented in Table 1 for GOSAT data versions V01.xx and V02.xx, respectively.

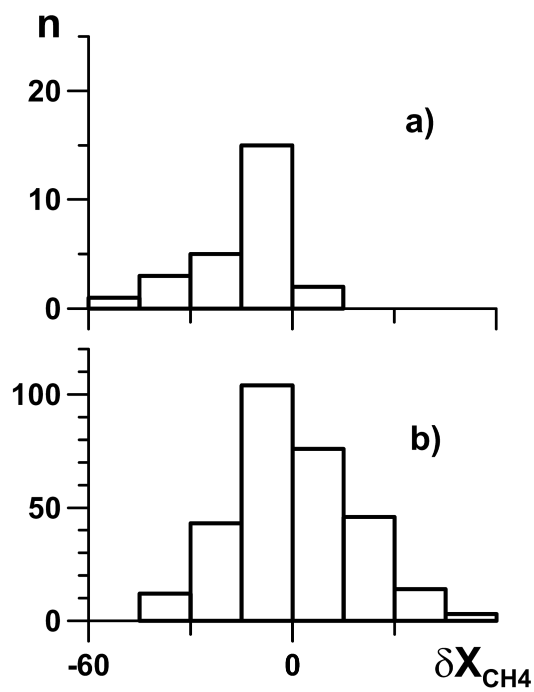

Fig. 3. Histograms of differences $\delta X_{CH_4} = X_{CO_2\_GOS} - X_{CO_2\_SPB}$ between pairs of measurements presented in Fig. 2 for GOSAT data versions V01.xx **(a)** and V02.xx **(b)**.

V01.xx data compared to the ground-based FTIR measurements.

The results presented above were obtained using the three spectral intervals listed in Sect. 2 and recommended by Sussmann et al. (2011). Similar estimations using another set of four spectral intervals (see Sect. 2) have small differences from the results considered above. Absolute average differences between the two sets of data are about 0.2 % for our measurements in Saint Petersburg. Average deviation (similar to that in Table 2) of GOSAT version V02.xx CH_4 data from ground-based FTIR measurements using four spectral intervals is $\delta X_{CH_4} \approx -2$ ppb, and its standard deviation ~ 16 ppb.

4 Discussion

Morino et al. (2011) made a comparison of the GOSAT version V01.xx and FTIR spectroscopic X_{CH_4} measurements in the years 2009–2010 at nine stations of the ground-based TCCON network at latitudes from 45° S to 53° N. They found a systematic underestimation of satellite column-average methane with $\delta X_{CH_4} \approx -20 \pm 19$ ppb (-1.2 ± 1.1 %). Determinations of biases between the GOSAT V01.xx data and CH_4 aircraft measurements in the troposphere gave δX_{CH_4} from -8 ± 10 ppb (Saitoh et al., 2012) to -39 ± 11 ppb (Tanaka et al., 2012). Values of δX_{CH_4} for GOSAT version V01.xx data in Table 1 fall within the specified ranges, with the mean and median $\delta X_{CH_4} \approx -(11\text{–}15)$ ppb with a standard deviation of 13 ppb. Gavrilov and Timofeev (2013) compared ground-based CO_2 measurements in Saint Petersburg with the same day GOSAT data version V01.xx. Similar analysis for $X_{CH_4\_SPB}$ and $X_{CH_4\_GOS}$ for matching dates of ground-based and GOSAT (data version V01.xx) measurements showed that the differences $\delta X_{CH_4} = X_{CH_4\_GOS} - X_{CH_4\_SPB}$ are negative in six of cases (up to -43 ppb, or ~ -2.4 %). The average for these nine cases is $\delta X_{CH_4} \approx -13$ ppb and its standard deviation ~ 26 ppb. The 0.95 confidence band for average V01.xx values of δX_{CH_4} in Table 1 is -15.0 ± 5.4, which overlaps with similar bands from Morino et al. (2011) and Saitoh et al. (2012) biases. Therefore, optical X_{CH_4} obtained from Earth's surface near Saint Petersburg are compatible with column-average methane measured with aircrafts and ground-based FTIR networks.

Several algorithms for X_{CH_4} retrieval from GOSAT data were compared recently with ground-based FTIR spectroscopic observations, for example UoL (Parker, 2013) and RemoTeC (Hasekamp et al., 2013). Parker et al. (2011) compared GOSAT X_{CH_4} measurements with data from the TCCON network and with results of numerical modeling. They estimated relative deviations of individual satellite measurements to be ~ 0.1–0.9 % depending on latitude. Dils et al. (2013) analyzed several different algorithms of methane retrievals and obtained average absolute values of differences between GOSAT and ground-based X_{CH_4} values in the range of 0.2–1.5 % and their standard deviations of 2.4–4 %. Schepers et al. (2012) studied their influence of radiation scattering and cirrus clouds and obtained average differences between GOSAT and ground-based FTIR X_{CH_4} as low as −0.3 or −0.4 %. Butz et al. (2011) also showed the existence of systematic biases of −0.3 %.

Yoshida et al. (2013) made comparisons of the GOSAT version V02.xx data with FTIR observations at 13 ground-based sites of TCCON. Global mean biases averaged for all individual pairs of spectral scans are -5.9 ± 0.9 ppb with standard deviations of 12.6 ± 0.6 ppb (uncertainties correspond to 0.95 confidence intervals). About 94 % of these individual pairs belong to TCCON sites located at altitudes lower than 50° N and in the Southern Hemisphere. Results by Yoshida et al. (2013) show a broad range of changes in the average biases at different sites from −12.3 to 10.3 ppb and some dependence of biases on latitudes of observation sites. Biases averaged for 13 TCCON observation sites with equal weights for each site are -2.2 ± 2.1 ppb with standard deviation of 7.3 ppb. The 0.95 confidence band for average V02.xx values of δX_{CH_4} shown in Table 1 overlaps with the respective band for the station bias and is somewhat smaller than the single-scan bias obtained by Yoshida et al. (2013) and reflecting mainly low-latitude and southern TCCON sites.

About 6 % of the GOSAT and ground-based TCCON data compared by Yoshida et al. (2013) were obtained at four observation sites at latitudes higher than 50° N. They show a broad scattering of average biases between −8 and 10 ppb. The latitude of Saint Petersburg's site of ground-based FTIR observations is between the TCCON sites Bremen (53.1° N), Bialystok (53.2° N) and Sodankyla (67.4° N). According to average values, standard deviations and data numbers obtained by Yoshida et al. (2013) the average biases between the GOSAT and ground-based X_{CH_4} with 0.95 confidence intervals are 2.6 ± 6.4, 7.8 ± 9.7 and -7.8 ± 3.6 ppb for the mentioned TCCON sites, respectively. One can notice possible latitude dependence with more negative biases at the more northern Sodankyla site. The 0.95 confidence band for average V02.xx values of δX_{CH_4} in Table 1 is between and partly overlaps with the respective bands for for Sodankyla, Bremen and Bialystok sites, although the uncertainties are big for all of these stations.

Dils et al. (2013) made comparisons of different algorithms for CH_4 retrieval from GOSAT and ground-based FTIR observations at TCCON network stations. They found changes of the global mean biases between the GOSAT and TCCON data between −2.5 and 7.0 ppb depending on the retrieval algorithm. Average biases vary from 2.9 to 5.4 ppb for the Bremen site, and from 3.4 to 8.3 ppb for Bialystok. These values lie within the above-mentioned, broad 0.95 confidence bands obtained by Yoshida et al. (2013). Some differences of data in Table 1 from estimations by Yoshida et al. (2013) may be caused by substantial statistical errors (because of substantial variability and limited number of measurements at Saint Petersburg). However, the absolute values of average and median deviations in Table 1 for the data version V02.xx, on the order of a few parts per billion, show that Saint Petersburg FTIR observations using the retrieval algorithms from the NDACC network can reach a reasonable agreement with GOSAT satellite data compatible with estimations at other TCCON stations.

The standard deviation of individual δX_{CH_4} values for the data version V02.xx in Table 1 is 14.5 ± 1.3 ppb, which is compatible with compound errors of both types of measurements and is comparable with the standard deviations obtained by Yoshida et al. (2013) and Dils et al. (2013). Such substantial standard deviations show that individual differences between satellite and ground-based X_{CH_4} may be much larger than the respective average biases at any particular site.

The mentioned value of standard deviations of individual differences, 14.5 ± 1.3 ppb, in Table 1 is larger than the global average value, 12.6 ± 0.6 ppb, but it is smaller than the maximum standard deviations of 15 – 16 ppb obtained by Yoshida et al. (2013) for the Garmish and Lauder sites. It is also larger than the standard deviations (8–10 ppb) of differences between the GOSAT version V02.xx and ground-based FTIR measurements at Bremen, Bialystok and Sodankyla TCCON sites obtained by Yoshida et al. (2013). One should keep in mind that our measurements are carried out near the Saint Petersburg megalopolis, so the total methane variability there might be higher than that for background measurements. Makarova et al. (2006) estimated that emissions from Saint Petersburg may contribute up to 2 % to the overall CH_4 column content. This enhanced variability of X_{CH_4} near Saint Petersburg may partly contribute to some differences in average δX_{CH_4} and their standard deviations obtained in the present paper compared to the estimations by Yoshida et al. (2013) for different TCCON sites.

The additional contribution to Saint Petersburg's standard deviation of ground-based X_{CH_4} may lead to use of the measuring instrument and algorithms similar to those of the NDACC network using a MIR spectral range. Sussmann et al. (2013) showed that differences between MIR measurements and the respective NIR data obtained with the TCCON network may have standard deviations of about 7.2 ppb for standard a priori information at middle latitudes of the Northern Hemisphere. Sussmann et al. (2013) recommended corrections to a priori information decreasing this standard deviation to 5.2 ppb. As long as GOSAT performs NIR measurements, the standard deviation of differences between the satellite and Saint Petersburg ground-based measurements can differ from that obtained from the TCCON network. Sussmann et al. (2013) and Dils et al. (2013) also demonstrated possible latitude and seasonal changes in biases between GOSAT and TCCON as well as between MIR and NIR measurements.

In our study, we compared X_{CH_4} measured with GOSAT in the ±3° latitude and longitude vicinity of the ground-based observation site. We also tried to use ±1 and ±5° co-location criteria. In these cases, we obtained differences of biases between ground-based and satellite measurements within ±2 ppb (or ±0.1 %) compared to those in Tables 2 and 3. The absolute values of biases are smaller for the ±1° latitude and longitude vicinity.

Comparisons of ground-based and satellite FTIR column-average methane measurements do not take into account some characteristics that may influence the measurements and data processing. For example, differences in averaging kernels of remote sensing methods (Parker et al., 2011), or uncertainties in the parameters of the fine structure of spectral lines (Chesnokova et al., 2011). Additionally, Sussmann et al. (2013) concluded that for validations of satellite and ground-based FTIR data it is essential to use the same a priori information. Also, due to a relatively small number of sunny days for FTIR measurements near Saint Petersburg, we should consider the present comparison as preliminary.

5 Conclusions

We compared the atmospheric column-average methane mole fractions, measured with FTIR spectroscopy from Earth's surface at the Peterhof campus of Saint Petersburg State University (59.9° N, 29.8° E) in the years 2009–2012 with similar observations to those of the Japanese GOSAT satellite (data versions V01.xx and V02.xx). Average and median differences between the GOSAT data version V01.xx and ground-based FTIR measurements are $\delta X_{CH_4} \approx -(11$–$15)$ ppb and their standard deviations ∼ 13–26 ppb, which is consistent with literature data about comparisons of this version of GOSAT data with the network of ground-based FTIR stations of TCCON and with airplane in situ measurements. The same average differences for the GOSAT data version V02.xx are smaller ($|\delta X_{CH_4}/X_{CH_4}| \approx 0.2\,\%$) and show that Saint Petersburg FTIR observations could provide reasonable agreement with satellite data. Standard deviation of δX_{CH_4} values is 14–16 ppb (0.8–0.9 %), which is compatible with combined errors of both types of measurements. This verifies that FTIR spectroscopic observations near Saint Petersburg have similar biases with GOSAT satellite data as FTIR measurements at other ground-based networks and aircraft CH_4 estimations. The relatively small number of sunny days for FTIR measurements near Saint Petersburg requires the further accumulation of data from ground-based and satellite FTIR measurements and their comparisons to reduce the still large uncertainty on the obtained validation results and to analyze possible latitude and seasonal changes in biases between satellite and ground-based observations.

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