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Comparisons of Satellite (GOSAT) and Ground-Based Spectroscopic Measurements of CO_2 Content near St. Petersburg

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Abstract—The column-average mole fractions of atmospheric carbon dioxide measured with ground-based Fourier-transform spectroscopy at the Peterhof station of St. Petersburg State University (59.9° N, 29.8° E) in 2009–2011 are compared with similar data obtained with the Japanese GOSAT satellite. The comparison shows that the average mole fractions of CO_2 from satellite data version V01.xx are lower by –9.8 ± 3 ppm than the corresponding values obtained from the ground-based measurements. For the GOSAT data version V02.xx, this difference is –4.7 ± 2.6 ppm on the average. Some overestimation of CO_2 values in measurements near St. Petersburg in comparison with the ground-based TCCON network data has been revealed indirectly, the causes of which require further explanation.

Keywords: carbon dioxide, total content, ground-based measurements, FTIR spectroscopy, GOSAT satellite, comparison, validation

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INTRODUCTION

Monitoring of atmospheric CO_2 is required for better comprehension of features of global carbon cycles and their effect on the climate change. Until recently, most CO_2 monitoring stations used the technique of airborne sampling and chemical analysis of surface or tropospheric air to determine the mole fraction of CO_2 (Convey et al., 2003). Optical spectrometry techniques can be used at monitoring stations located far from CO_2 sources and sinks for calculation of the total columnar CO_2. These techniques record IR solar radiation and measure the column-average mole fraction of CO_2, X_{CO_2}. Such a technique has been used by Russian and Kirghiz researchers at the Issyk-Kul' station since 1980. The results of the study are reviewed in (Kashin et al., 2007, 2008) in detail. In past years, high-resolution Fourier-transform spectroscopy is used for ground-based measurements of columnar CO_2 (Yang et al., 2002; Deutscher et al., 2010). Since 2009, ground-based measurements of direct solar radiation spectra in the IR range have been carried out at St. Petersburg State University (SPSU) in Peterhof (59.9° N, 29.8° E) with the use of a Bruker IFS 125 HR Fourier spectrometer having a high spectral resolution (Poberovskii et al., 2010).

Ground-based optical measurement data on CO_2 can be also useful for validation of satellite measurements, which provide data on the total columnar CO_2. Demonstration measurements of columnar CO_2 have been carried out with the use of a SCIAMACHY instrument onboard ENVISAT since 2002 (Barkley et al., 2006a, 2006b). The EOA Aqua satellite with an AIRS instrument was launched in 2004; the instrument also allows measurements of columnar CO_2. An international program of launching other instruments for global monitoring of spatiotemporal variations in the columnar CO_2 has been developed. To validate satellite monitoring data on greenhouse gases, a special ground-based Total Carbon Column Observing Network (TCCON) has been created; it uses ground-based Fourier transform infrared spectroscopy (FTIR) of direct solar radiation for routing measurements of the total content of CO_2 and other climate forcing gases (Wunch et al., 2011).

The GOSAT (Global Greenhouse Gas Observation by Satellite) satellite was launched in January 2009 for greenhouse gas monitoring. It was a joint project of the Japan Aerospace Exploration Agency and the National Institute for Environmental Studies (NIES, Tsukuba, Japan) (Kuze et al., 2009). The satellite was intended for space observation of global distributions of the total contents of CO_2 and CH_4. The column-average mole fractions of carbon dioxide X_{CO_2} and methane X_{CH_4} are retrieved from data of a TANSO-FTS sensor (Thermal And Near infrared Sensor for carbon Observations—Fourier Transform Spectrometer), which is a Fourier spectrometer focused to the study of carbon gases in the IR spectral range from onboard the GOSAT (Yoshida et al., 2011). Preliminary validation of X_{CO_2} values measured from the GOSAT was carried out by Morino et al. (2011), as well as their comparison with TCCON FTIR data.

In this work, we compare GOSAT data on X_{CO_2} with ground-based FTIR data measured near St. Petersburg in 2009–2011.

MEASURING TECHNIQUE

Rakitin et al. (2012) presented the altitude average CO_2 mole fractions X_{CO_2} retrieved from IR spectra measured with the Bruker IFS-125 HR spectrometer (Poberovskii, 2010) in the 2626.3–2627.0 cm^{-1} range at the Peterhof station of the St. Petersburg State University (about 35 km to the south-east from the center of St. Petersburg) from April 2009 to October 2011. The SFIT v3.92 software developed for NDACC (Network for the Detection of Atmospheric Composition Change) by a team of authors (Rinsland et al., 1998) was used for X_{CO_2} retrieval. The input parameters for SFIT v3.92 are solar radiation spectra, initial profiles of mole fractions of CO_2 and secondary gases, and their a priori variations. Relative a priori variations in theCO_2 mole fraction were set equal to 5% in the lower troposphere and 3% above. The software outputs assessments of the total content of CO_2 (mol/cm^2) and related random errors. To calculate the altitude average CO_2 mole fractions, daily radio sounding data of the atmosphere from Voeykovo station were used. The HITRAN data base (2004) was used as a source of data on parameters of the fine structure of molecular absorption lines.

The contents of CH_4 and HDO wer calculated as nuisance parameters during the retrieval of the total content of CO_2. Random errors of a single measurement of the CO_2 content did not exceed 1% (~4 ppm) according to assessments with the calculation of the error matrix of the optimal estimation technique (implemented in the SFIT). Variations in the mole fraction of CO_2 in runs and during a day usually did not exceed 1% under conditions of stable equipment operation and stable state of the atmosphere. The X_{CO_2} values given by Rakitin et al. (2012) were calculated as fractions of the total number of molecules (along with water vapor). The GOSAT data on X_{CO_2} relate to dry atmosphere (without contribution of water vapor); therefore, the data by Rakitin et al. (2012) were corrected to dry atmosphere with the use of reanalysis results of meteorological data from the European Center ECMWF (Dee et al., 2011) for time points and coordinates of the site of ground-based measurements near St. Petersburg.

The satellite-measured column-average X_{CO_2} are available on the GOSAT Project website of NIES (2010). Two data versions are available: V01.xx and V02.xx; they differ in the technique for analysis of spectra measured with the TANSO-FTS. This technique for data version V01.xx is described in detail by Yoshida et al. (2011). For simultaneous calculation of the total columnar CO_2, CH_4, and O_2, IR solar radiation absorption lines 6180–6380, 5900–6150, and 12950–13200 cm^{-1}, respectively, are used. The spectra measured are analyzed with the use of the GFIT algorithm (Toon et al., 1992; Wunch et al., 2011), which is also used at all TCCON stations (Wunch et al., 2011). Only those spectra that were measured without the influence of clouds were selected among all TANSO-FTS measured spectra. Clouds are controlled by a TANSO-CAI instrument, which operates in the visible, UV, and near-IR spectral regions.

Table 1. Time intervals and GOSAT data versions used for the comparison

Period	Version	Number
April 8, 2009–June 25, 2009	V01.10	4
August 2, 2009–September 9, 2009	V01.20	4
April 12, 2010–September 9, 2010	V01.30	8
April 25, 2010–September 12, 2011	V01.50	7
June 6, 2009–September 21, 2009	V02.00	16
April 12, 2010–July 31, 2010	V02.00	28
July 3, 2011–July 30, 2011	V02.11	3

Random measurement errors of X_{CO_2} are assessed as 2 ppm on the average, or 0.5%, and are determined by the instrument noise (main source of errors), averaging errors, and influence of secondary gases (Yoshida et al., 2011). There are subversions inside the above versions of GOSAT data processing, e.g., V01.10, V01.20, and V01.30, which differ in the algorithms for primary processing of the Fourier spectra measured (criterions for determination of saturation and emission of spectra, see (Yoshida et al., 2011; Kuze et al., 2012)). The last GOSAT data version V02.xx (with V02.00 and V02.11 subversions) differs by its improved algorithms for primary processing and analysis of spectra, accounting for clouds and aerosol haze, and an improved model for accounting for meteorological information.

COMPARISON RESULTS

To compare X_{CO_2} measured from the ground near St. Petersburg and from GOSAT, intervals of simultaneous measurements in 2009–2011 were chosen. For these intervals, cases of GOSAT measurements of X_{CO_2} in vicinities ±3° in latitude and longitude of the site of ground-based measurements were chosen. Time intervals, versions of data analysis programs, and the number of GOSAT measurements selected for the analysis are listed in Table 1. Ground-based measurements carried out near St. Petersburg at 12–15 h of local time, when the Sun was maximally high above the horizon, were selected for the comparison. In addition, only values falling in a 95% confidence