A Ground-based validation of GOSAT-observed atmospheric CO₂ in Inner-Mongolian grasslands

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Abstract. Atmospheric carbon dioxide (CO₂) is a long-lived greenhouse gas that significantly contributes to global warming. Long-term and continuous measurements of atmospheric CO₂ to investigate its global distribution and concentration variations are important for accurately understanding its potential climatic effects. Satellite measurements from space can offer atmospheric CO₂ data for climate change research. For that, ground-based measurements are required for validation and improving the precision of satellite-measured CO₂. We implemented observation experiment of CO₂ column densities in the Xilinguole grasslands in Inner Mongolia, China, using a ground-based measurement system, which mainly consists of an optical spectrum analyzer (OSA), a sun tracker and a notebook controller. Measurements from our ground-based system were analyzed and compared with those from the Greenhouse gas Observation SATellite (GOSAT). The ground-based measurements had an average value of 389.46 ppm, which was 2.4 ppm larger than from GOSAT, with a standard deviation of 3.4 ppm. This result is slightly larger than the difference between GOSAT and the Total Carbon Column Observing Network (TCCON). This study highlights the usefulness of the ground-based OSA measurement system for analyzing atmospheric CO₂ column densities, which is expected to supplement the current TCCON network.

1. Introduction
Long-term and continuous measurements of atmospheric CO₂ to investigate its global distribution and concentration variations are important for accurately understanding potential climate change effects caused by this long-lived greenhouse gas[1]. With the development of remote sensing technologies, a series of satellites that are able to measure atmospheric CO₂ have been launched, including the Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY), the Greenhouse gas Observation SATellite (GOSAT) and the Atmospheric Infrared Sounder (AIRS). Global CO₂ data obtained by these satellites are currently available[2].

The Total Carbon Column Observing Network (TCCON) is a network of ground-based Fourier transform spectrometers recording direct solar spectra in the near-infrared spectral region to derive the column densities of several atmospheric gases, including CO₂. The TCCON supports the validation of the satellite measurements[3]. Despite being highly reliable and used for validation purposes, the establishment of TCCON sites require significant basic infrastructure with high costs, and its measurement system is too large and heavy, and not flexible to move around. The limited TCCON...
sites (currently 21 sites globally) are not sufficient for the validations of satellite data. For that, a flexible and easy-to-operate ground-based measurement system is required to provide supplemental measurements of the existing TCCON network. In order to address this problem, Kobayashi N et al. [4] and Kawasaki M et al. [5] developed a ground-based optical spectrum analyzer (OSA) system for analyzing atmospheric CO$_2$ column densities. The system is compact, portable, low cost, rugged and essentially maintenance-free.

In this study, we implemented the field observations over the Xilinguole grasslands in Inner Mongolia, China using the OSA system. The CO$_2$ column densities measured by OSA were analyzed and compared with those from GOSAT observation to assess the potential usefulness of OSA measurement system.

2. Instrumental and retrieval algorithm

2.1. Instrumental

The ground-based OSA system for measuring atmospheric CO$_2$ was mainly composed of a desktop OSA and a portable sun tracker, as described in detail in Kobayashi et al. [4]. Direct sunlight was collimated via a small telescope installed on a portable sun tracker and then transmitted through an optical fiber into the OSA for optical analysis. The OSA system then measured the photoabsorption spectra of the atmospheric CO$_2$ (wavelengths from 1569–1575 nm), which were then transformed to CO$_2$ column densities at the measurement sites using a peak fitting algorithm [4].

2.2. Retrieval algorithm of CO$_2$ column densities

Photoabsorption spectra of the atmospheric CO$_2$ measured using the OSA were used to retrieval CO$_2$ column densities (xCO$_2$) using the peak fitting algorithm, proposed by Kobayashi et al. [4]. xCO$_2$ is defined by the ratio of the total number of CO$_2$ molecules to that of dry molecules, not only near the earth’s surface, but also in the entire vertical column to the top of atmosphere. First, the initial concentration of CO$_2$, determined empirically, was set to the forward model calculations to obtain a series of simulated CO$_2$ spectra. The simulated spectra were corrected considering the effect caused by the Fraunhofer line [6]. The peak fitting algorithm was applied to fit the observed spectra to the simulated spectra until the calculating residual was less than the set reference value, which was $2.5 \times 10^{-4}$ in this study. The simulated spectra that best fit the observed CO$_2$ spectra were then selected to calculate the column densities. This processing flow is shown in Figure 1.
3. GOSAT data

GOSAT, launched on January 23, 2009, was the first spacecraft designed to measure the concentrations of the two major greenhouse gases, CO$_2$ and methane, from space [7]. The analytical instrument onboard the satellite is the Thermal and Near-infrared Sensor for carbon Observation (TANSO). TANSO is composed of two subunits, the Fourier Transform Spectrometer (FTS) and the Cloud and Aerosol Imager (CAI). GOSAT Level 2 data are retrieval XCO$_2$ based on the short wavelength infrared (SWIR) spectra of FTS observation. The GOSAT Level 2 XCO2 data product (Ver. 2.xx) was released in April 2012. Validation results indicated that GOSAT-observed XCO$_2$ were lower than those measured from the Total Carbon Column Observing Network by 0.3 % (1.2 ppm) and the standard deviation of differences was 0.5 % (2.0 ppm) [8].

The data of GOSAT-XCO2 were collected around our OSA measurement site within a radius of 500 km GOSAT during July-October 2012.

4. Results and discussions

4.1. Ground-based Measurements

Measurements were implemented at the site of Xilinguole grassland (E 116.70°, N 43.63°) in Inner Mongolia from 10 July to 20 October, 2012. The OSA measurement system was set to perform a measurement each three minutes from 08:00 to 18:00 in daytime. A total of 23280 measurements were obtained during this period and are shown in Figure 2. Some anomalous low values were recorded on 13 July, 25 August and 26 August and 6-8 September, while the anomalous high values were recorded during 13-20 October. These anomalous may be caused by the unstable cloudy and metrological condition, system malfunctioning because of unstable electricity at the measurement site.

The anomalous measurements observed in cloudy and abnormal instruments working days were filtered. Figure 3 presents the examples of measurements on 15, 16, 17 July, on which the average XCO2 is 385.72 (± 3.8) ppm, 387.63 (± 4.8) ppm and 386.26 (± 5.1) ppm, respectively. As indicated from Figure 3, higher values occurred around 9 am, while lower values occurred at noon, which may be related to CO2 absorptions by the grassland photosynthesis activities.
Figure 2. XCO2 derived from measurements of the OSA system at the site of Xilinhot grassland from 10 July to 20 October, 2012.

(a) 15 July

(b) 16 July

(c) 17 July

Figure 3. Timely variation of XCO2 (in blue points) and the retrieval spectral fitting residuals (in red points) on (a) 15 July, (b) 16 July, and (c) 17 July, 2012.
4.2. Comparing with GOSAT
The filtered XCO2 based-ground measurements, described in section 4.1, were further filtered by the measuring time within 1 hour difference to 1:30 pm when GOSAT is locally crossing the ground measurement site. The filtered data is then compared with the GOSAT data described in section 3. The results are presented in Figure 4 and Table 1. Table 1 show that the maximum difference between OSA and GOSAT is 5.82 ppm, the minimum is 0.10ppm, and the average value of their differences is 2.53 ppm. The standard deviation of differences is 1.93 ppm. The result is slightly larger than that between GOSAT and TCCON measurements which is 1.2ppm. TCCON sites are located far from human emission, while our measurements site is located in the grasslands where there are some open-coalmines nearby.

![Figure 4](image)

**Figure 4.** Comparison of XCO2 between the ground-based OSA measurements (Local time:12:30-14:30) and GOSAT data (Within the range of 500km around the ground site) from July to October, 2012.

| Date     | OSA observation | GOSAT Observation | OSA- GOSAT |
|----------|-----------------|-------------------|------------|
|          | Daily mean      | Standard deviation|            |
| 20120715 | 387.45          | 3.81              | 2.76       |
| 20120718 | 384.72          | 5.16              | 1.79       |
| 20120727 | 389.76          | 5.87              | 5.82       |
| 20120805 | 389.32          | 4.61              | 4.32       |
| 20120829 | 393.05          | 5.52              | 5.02       |
| 20120922 | 383.51          | 3.74              | 0.10       |
| 20120928 | 392.34          | 4.83              | 2.28       |
| 20120929 | 390.53          | 5.77              | 1.56       |
| 20121001 | 389.17          | 3.58              | 0.65       |
| 20121005 | 389.32          | 4.93              | 1.03       |

5. Conclusions
In this study, we implemented the measurements of CO2 column densities at the Xilinguole grassland site in Inner Mongolia using a ground-based OSA system. The measurements were analyzed and
compared to GOSAT observations. The result showed that the difference between OSA measurements and GOSAT-XCO2 was 2.4 ppm, which may be affected by the emission from open-coalmines near the measure site. The system, which is compact, portable, low cost, and maintenance-easy, is expected to give the supplemental measurements to the existing TCCON network and play an important role in future scientific research.

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