Atmospheric Environment 180 (2018) 216–225

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Comparison of atmospheric CO_2 mole fractions and source–sink characteristics at four WMO/GAW stations in China

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ARTICLE INFO

Keywords:
Atmospheric CO_2
Flask sampling observation
GOSAT
Source–sink characteristic
Atmospheric background station

ABSTRACT

As CO_2 is a primary driving factor of climate change, the mole fraction and source–sink characteristics of atmospheric CO_2 over China are constantly inferred from multi-source and multi-site data. In this paper, we compared ground-based CO_2 measurements with satellite retrievals and investigated the source–sink regional representativeness at China's four WMO/GAW stations. The results indicate that, firstly, atmospheric CO_2 mole fractions from ground-based sampling measurement and Greenhouse Gases Observing Satellite (GOSAT) products reveal similar seasonal variation. The seasonal amplitude of the column-averaged CO_2 mole fractions is smaller than that of the ground-based CO_2 at all stations. The extrema of the seasonal cycle of ground-based and column CO_2 mole fractions are basically synchronous except a slight phase delay at Lin'an (LAN) station. For the two-year average, the column CO_2 is lower than ground-based CO_2, and both of them reveal the lowest CO_2 mole fraction at Waliguan (WLG) station. The lowest (~4 ppm) and largest (~8 ppm) differences between the column and ground-based CO_2 appear at WLG and Longfengshan (LFS) stations, respectively. The CO_2 mole fraction and its difference between GOSAT and ground-based measurement are smaller in summer than in winter. The differences of summer column CO_2 among these stations are also much smaller than their ground-based counterparts. In winter, the maximum of ground-based CO_2 mole fractions and the greatest difference between the two (ground-based and column) datasets appear at the LFS station. Secondly, the representative areas of the monthly CO_2 background mole fractions at each station were found by employing footprints and emissions. Smaller representative areas appeared at Shangdianzi (SDZ) and LFS, whereas larger ones were seen at WLG and LAN. The representative areas in summer are larger than those in winter at WLG and SDZ, but the situation is opposite at LAN and LFS. The representative areas for the stations are different in summer and winter, distributed in four typical regions. The CO_2 net fluxes in these representative areas show obvious seasonal cycles with similar trends but different varying ranges and different time of the strongest sink. The intensities and uncertainties of the CO_2 fluxes are different at different stations in different months and source-sink sectors. Overall, the WLG station is almost a carbon sink, but the other three stations present stronger carbon sources for most of the year. These findings could be conducive to the application of multi-source CO_2 data and the understanding of regional CO_2 source–sink characteristics and patterns over China.

1. Introduction

CO_2 contributes more than 50% of the total climate forcing caused by long-lived greenhouse gases, which is the primary driving factor of climatic changes involving surface temperature, hydrological cycle, sea level rise, and extreme weather events (IPCC-AR5, 2013). The global average tropospheric mole fraction of monthly CO_2 was approximately 404 parts per million (ppm) in April 2016, and the rate of increase was at a record high during 2015 and 2016 (www.esrl.noaa.gov/gmd/ccgg/trends/). The anthropogenic CO_2 emissions from fossil-fuel combustion and cement production amounted to approximately 9.1 PgC in 2010, and about 55% of these emissions were absorbed by the terrestrial ecosystem and ocean (Ballantyne et al., 2012; Peters et al., 2011). As unprecedented population growth and resource consumption have led to highly increased CO_2 emissions since the early 1980s, it is significant to understand further the patterns of atmospheric CO_2 mole fraction and source–sink characteristics over China through multi-source and multi-site data (Piao et al., 2009; Zhang et al., 2014c).

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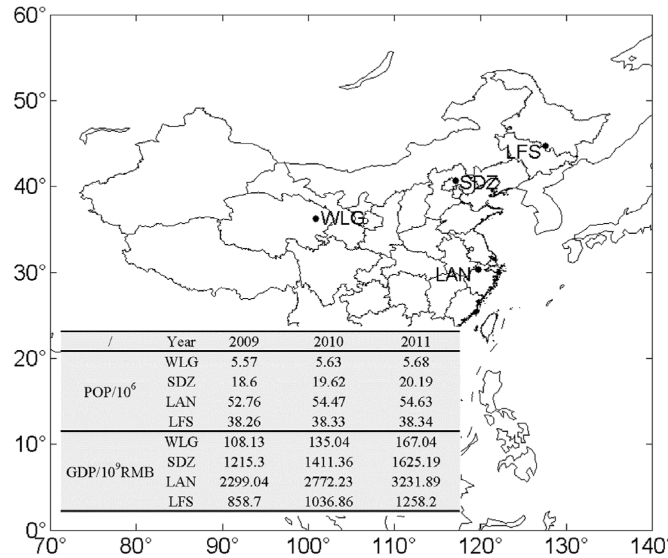
https://doi.org/10.1016/j.atmosenv.2018.03.010
Received 30 August 2017; Received in revised form 2 March 2018; Accepted 5 March 2018
Available online 05 March 2018
1352-2310/

The mole fraction of CO_2 is almost the same everywhere, but relatively small differences, especially near the surface, are caused by recent emissions and removals (Zhang et al., 2013b). The variation and source–sink characteristics of CO_2 over China have been investigated by using observation data from different platforms and statistical data (Xu et al., 2017). In the framework of the World Meteorological Organization's Global Atmosphere Watch (WMO/GAW), atmospheric greenhouse gases have been observed continuously at four background stations in China (WLG: Waliguan, SDZ: Shangdianzi, LAN: Lin'an, LFS: Longfengshan) (Fang et al., 2014; Liu et al., 2009; Zhou et al., 2006). The traceable, comparable, and high-precision CO_2 data obtained at these stations have been used widely in many studies, such as source–sink inversion studies (Jiang et al., 2013; Zhang et al., 2014a). Although the variation of CO_2 mole fraction can be obtained accurately by the WMO/GAW network of ground stations, this measurement with sparse spatial coverage is time consuming and easily affected by surrounding environment (Liu et al., 2014). Satellite remote sensing has been used to monitor CO_2 column mole fraction since 2002 because it has the advantages of spatial coverage, speed, and continuity (Boesch et al., 2011; Buchwitz et al., 2004; Clerbaux et al., 2009; Jiang et al., 2010; Kulawik et al., 2010; Tangborn et al., 2013; Xu et al., 2017; Yokota et al., 2009; Zhang et al., 2015). However, satellite retrievals of CO_2 (and other greenhouse gases) cannot be calibrated. They are only useable if systematic biases, many of which remain unknown, can be reduced to extremely low levels, to less than 0.1 ppm in the case of CO_2 (Fang et al., 2016; Masarie et al., 2001). Several detectors have been launched into space, including the Atmospheric Infrared Sounder (AIRS), the Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY), the Greenhouse Gases Observing Satellite (GOSAT), the second Orbiting Carbon Observatory (OCO-2), and the Chinese Carbon Dioxide Observation Satellite (TanSat) (Aumann et al., 2003; Bovensmann et al., 1999; Chen et al., 2017; Frankenberg et al., 2015; Kuze et al., 2009). The retrievals from these satellites need to be compared to calibrated in-situ (at the surface and in the vertical column) measurements to discover, and then eliminate, retrieval biases. Currently, atmospheric transport models are used to combine the two types of data and study their level of compatibility, but this method has its own limitations because transport model biases cause discrepancies in addition to those between the two types of data (Baker et al., 2010; Chevallier et al., 2009, 2011; Cogan et al., 2012; Houweling et al., 2004; Jiang et al., 2013; Lauvaux et al., 2009; Miller et al., 2007; Nassar et al., 2011; Peters et al., 2007; Pillai et al., 2010; Reuter et al., 2011; Streets et al., 2013; Zhang et al., 2014a). Here, we use satellite retrievals of atmospheric CO_2 over four WMO/GAW stations in China to reveal the CO_2 pattern and assess the coherence of different datasets (Zhou et al., 2013).

The pattern of CO_2 mole fraction at each station is highly correlated to the source and sink characteristics of CO_2 in a specific area, which is called "source–sink regional representativeness." The key for this representativeness is to find the representative area, which has been explored at the WLG station through simulation results (Cheng et al., 2017a). The representative area and source–sink characteristics of this area are important for understanding the regional differences of CO_2 mole fraction, evaluating the site layout, and developing emission reduction strategies because of the differences in the stage of economic development and the diverse climates in China (Xu et al., 2017). Some studies have focused on the representativeness of fluxes, radiation, temperature, and air pollutants (e.g., Xu et al., 2015). Researches on the patterns and sources of CO_2 mole fraction at the WMO/GAW stations in China have also been conducted by using the method of isotope tracing and individual trajectories (Xia et al., 2015; Zhang and Zhou, 2013). However, to the best of our knowledge, there are no comparison studies on the representative areas of CO_2 background mole fractions at the four WMO/GAW stations in China, as well as the source–sink characteristics in the representative areas.

This study aims to examine the variation of CO_2 mole fractions using calibrated in-situ sampling observations and the GOSAT retrieval products and compare the source–sink regional representativeness of the CO_2 background mole fractions at China's four WMO/GAW stations. Section 2 introduces the sites, CO_2 sampling, GOSAT products, and the statistical analysis methods for source–sink regional representativeness. Section 3 presents the results with discussion and consists of two parts: (1) a comparison of CO_2 mole fraction between the surface observations at the four WMO/GAW stations and the GOSAT products and (2) an evaluation of the representative areas of CO_2 background mole fractions and a comparison of the source–sink characteristics corresponding to the CO_2 background mole fractions at the four WMO/GAW stations. Finally, the summary and conclusions are presented in Section 4.



/	Year	2009	2010	2011
$POP/10^6$	WLG	5.57	5.63	5.68
	SDZ	18.6	19.62	20.19
	LAN	52.76	54.47	54.63
	LFS	38.26	38.33	38.34
$GDP/10^9 RMB$	WLG	108.13	135.04	167.04
	SDZ	1215.3	1411.36	1625.19
	LAN	2299.04	2772.23	3231.89
	LFS	858.7	1036.86	1258.2

Fig. 1. Geographical locations of the four WMO/GAW stations in China (black dots). The population (POP) and gross domestic product (GDP) in the affiliated provinces are shown in the inserted table.

2. Data and methods

2.1. Sites and CO_2 sampling observations

Atmospheric CO_2 samples were collected by flasks during 2009–2011 at the four stations of the WMO/GAW network in China (Fig. 1). The population and gross domestic product (http://data.stats.gov.cn/) of the provinces affiliated with these sites are also shown by the table inserted into Fig. 1. These stations are global or regional background stations, representing atmospheric conditions in different climate features, vegetation types, and economic zones in China (Fang et al., 2014; Liu et al., 2009).

The WLG station (36°17′ N, 100°54′ E; 3810 m asl) is located on the northeastern edge of the Tibetan Plateau (Liu et al., 2014). This station is isolated from industrial and population centers. Yak and sheep grazing is the main economic activity in summer. The area surrounding the WLG station has maintained its natural environment of arid/semi-arid grassland and desert steppe and has a typical plateau continental climate with predominant wind directions of southwest in winter and northeast/southeast in summer (Zhang et al., 2013a; Zhou et al., 2005).

The SDZ station (40°39′ N, 117°07′ E; 293 m asl) is about 120 km northeast of Beijing. The area surrounding the SDZ station consists primarily of shrubs, orchards, and farmland. No large industrial zone exists within 30 km of the station. The dominant wind directions are ENE in autumn and winter and WSW in spring and summer (An et al., 2012).

The LAN station (30°18′ N, 119°44′ E; 138.6 m asl) lies on the top of a hill in Zhejiang Province and is surrounded by forest, farming areas,