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Variations in satellite-derived carbon dioxide over different regions of China from 2003 to 2011

Yuyue Xu [a, b, c, *], Changqing Ke [a, b, **], Wenfeng Zhan [a, d], Haidong Li [e], Ling Yao [f]

[a] Jiangsu Provincial Key Laboratory of Geographic Information Science and Technology, Nanjing University, Nanjing 210023, China
[b] Key Laboratory for Satellite Mapping Technology and Applications of State Administration of Surveying, Mapping and Geoinformation of China, Nanjing University, Nanjing 210023, China
[c] Collaborative Innovation Center of Novel Software Technology and Industrialization, Nanjing University, Nanjing 210023, China
[d] International Institute of Earth System Science, Nanjing University, Nanjing 210023, China
[e] Nanjing Institute of Environmental Sciences, Ministry of Environmental Protection, Nanjing 210042, China
[f] State Key Laboratory of Resources and Environmental Information System, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China

HIGHLIGHTS

- The CO_2 of China increased from 375.7 ± 3.3 to 392.5 ± 3.5 ppm during 2003–2011.
- The seasonal CO_2 fluctuations over the North-East are larger than other regions.
- The lowest CO_2 is September for southern China and January for northern China.

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ABSTRACT

Variations of CO_2 mole fraction (XCO_2) on a global or country-wide scale have been widely examined, while the regional differences within China remain unclear because of the huge differences in the stage of economic development and climatic diversities. In this study, the variations of monthly and yearly XCO_2 from 2003 to 2011 are analyzed for the entire China and its six geographical regions. Atmospheric Infrared Sounder (AIRS) data, which are mainly sensitive in the mid-troposphere, were used. During 2003–2011, the mean annual XCO_2 increased from 375.7 ± 3.3 to 392.5 ± 3.5 ppm, at a rate of +2.10 ppm/year, which is similar to the previous rate during 2003–2008 (+2.09 ppm/year). However, there are two new findings for different regions of China. First, the XCO_2 growth rate and its seasonal amplitude were higher in Northern China than in Southern China. The growth rates of XCO_2 over North-East, North, and North-West during 2003–2011 are 2.18, 2.17, and 2.13 ppm/year, respectively, while they are 2.03, 2.05, and 2.09 ppm/year over South-East, Central, and South-West, respectively. The seasonal CO_2 fluctuations over the North-East and North are larger than other regions. Second, the highest monthly mean XCO_2 of mid-troposphere occurs during April to May for different regions of China in 2003–2011, while the lowest XCO_2 is September for southern China and January for northern China. These results offer valuable insights into the regional differences of XCO_2 within China.

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1. Introduction

Carbon dioxide (CO_2) is the most important anthropogenic greenhouse gas, and it contributes to more than 50% of total climate forcing due to long-lived greenhouse gases (Hofmann et al., 2008, 2009; IPCC-AR5, 2013). The current global average tropospheric mixing ratio of CO_2 is approximately 404 parts per million (ppm), and its atmospheric concentration is still increasing at ~ 2 ppm per year (Conway et al., 1994; Masarie and Tans, 1995; Engelen et al., 2009; Ballantyne et al., 2012; Dlugokencky and Tans, 2014). Evidence shows that recent emissions of CO_2 from fossil fuel combustion have been increasing even more rapidly (Boden et al., 2013). China, the world's third largest country in area and home to 1.3 billion people, is also one of the most rapidly developing nations. Since the early 1980s, the unprecedented growth of

* Corresponding author. Jiangsu Provincial Key Laboratory of Geographic Information Science and Technology, Nanjing University, Nanjing 210023, China.
** Corresponding author. Jiangsu Provincial Key Laboratory of Geographic Information Science and Technology, Nanjing University, Nanjing 210023, China.
E-mail addresses: xuyy@nju.edu.cn (Y. Xu), kecq@nju.edu.cn (C. Ke).

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economic and population in China has led to increasing CO_2 emissions (Guan et al., 2008; Zhang et al., 2013). Among the world's countries, China now has the highest CO_2 emissions from industrial sources (Piao et al., 2009; Li et al., 2010). Therefore, it is urgent to conduct a further comprehensive examination of the CO_2 mole fraction (XCO_2) over China.

The variations of CO_2 over China have been investigated using two types of data, statistical or satellite data. Using statistical data, studies were focused on the main factors that could affect Chinese CO_2 emissions, including economic growth, population dynamics and urbanization, changing consumption patterns, technical and structural change, energy demand and fuel mixing (Guan et al., 2008; Zhang et al., 2013). However, there was considerable uncertainty in CO_2 emissions within the statistical data sources. For example, in China, national and provincial energy statistics were published by the aegis of the National Bureau of Statistics at the central government level, which oversees and coordinates the corresponding statistical departments at provincial and county levels. The CO_2 emissions calculated on the basis of annually national and provincial energy statistics differed by 1.4 gigatonnes for 2010 (Guan et al., 2012).

Remote-sensing data have been used to monitor XCO_2 since 2002. Currently, the more popular sources of space-borne estimates of XCO_2 are as follows: Atmospheric Infrared Sounder (AIRS) (Chahine et al., 2005, 2008; Jiang et al., 2010, 2012; Kulawik et al., 2010), SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) (Bovensmann et al., 1999; Buchwitz et al., 2004), the Japanese Greenhouse Gases Observing Satellite (GOSAT) (Yokota et al., 2008, 2009), and the Orbiting Carbon Observatory-2 (OCO-2) (Frankenberg et al., 2015). AIRS/Aqua was launched in May 2002 and has been producing a CO_2 product since then (Aumann et al., 2003). SCIAMACHY was launched in February 2002, while GOSAT was launched in January 2009. OCO-2 was launched in July 2014. Compared with them, the AIRS's CO_2 product has the advantages of wide swath and global coverage capability (Jiang et al., 2010; Xu et al., 2012). This study uses AIRS XCO_2 data, partly because it currently provides the longest XCO_2 time series (from September 2002 to February 2012) (Crevoisier et al., 2004; Chevallier et al., 2005; Xiong et al., 2010; Tangborn et al., 2013). AIRS is mainly sensitive in the mid-troposphere, and the results from AIRS in this study will be about the mid-troposphere XCO_2. Using AIRS mid-troposphere XCO_2 retrieval, Bai et al. (2010) analyzed the spatial and temporal distribution of XCO_2 over China from 2003 to 2008. However, previous studies are insufficient to explain regional differences of CO_2 in China.

In order to study the regional differences of CO_2, China is divided into six regions to analyze the differences of XCO_2 trend over each region of China. Also, multi-source statistical data and satellite data are integrated to show the trend of possible driving factors and the

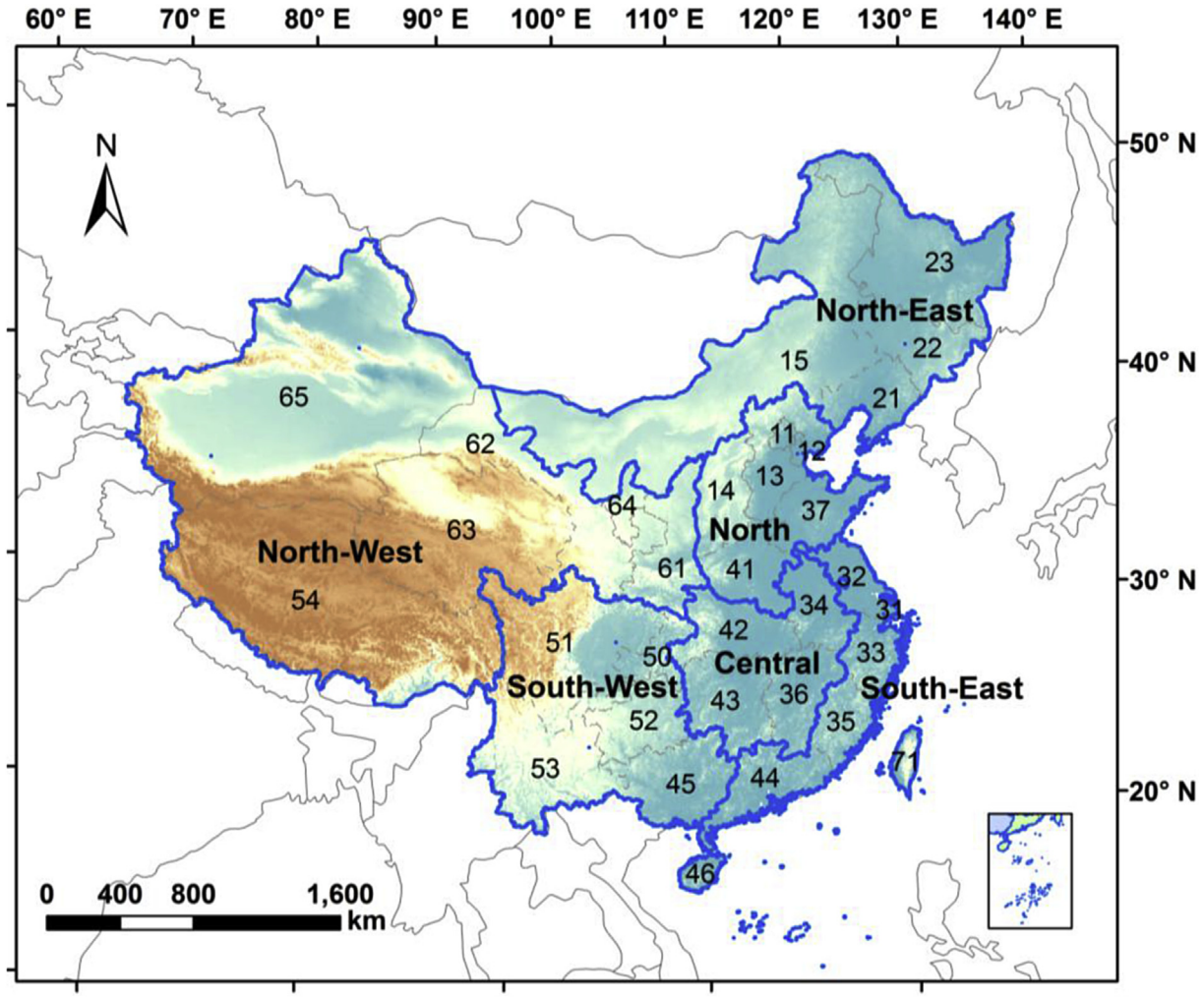

Fig. 1. Geographical regions of China. The map data were downloaded from http://www.geodata.cn (Administrative Boundaries of Province in China).

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