Regional scale variations of atmospheric CO$_2$ and CH$_4$ from satellite observation

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Abstract. To identify the sources, sinks and changes of atmospheric CO$_2$ and CH$_4$, this study investigates the spatio-temporal changes of atmospheric CO$_2$ and CH$_4$ concentration on the regional scale by the satellite observations. In this paper, choosing the land region of China as the study area, we investigate the spatio-temporal changes of atmospheric CO$_2$ and CH$_4$ concentrations using the data of the CO$_2$ dry air mixing ratio (XCO$_2$), and the CH$_4$ dry air mixing ratio (XCH$_4$), retrieved by the Greenhouse Gases Observing Satellite (GOSAT) from Jan. 2010 to Dec. 2012. The results show that (1) both XCO$_2$ and XCH$_4$ show higher concentrations in southeastern regions than that in the northwestern, and tend to yearly increasing from 2010 to 2013; (2) XCO$_2$ shows obvious seasonal change with higher values in the spring than that in summer. The seasonal peak-to-peak amplitude is 8 ppm and the annual growth is about 2 ppm. XCH$_4$, however, does not show a seasonal change; (3) With regard to different land-use backgrounds, XCO$_2$ shows larger concentrations over the areas of urban agglomeration than that over the grasslands and deserts, and XCH$_4$ shows lower concentrations over deserts than that over the Yangtze River Delta region and Sichuan Basin.

1. Introduction

The concentration of carbon dioxide (CO$_2$) has increased from about 280 to 380 ppm over the past century because of the burning of fossil fuels associated with expanding industrial activities [1]. CO$_2$ absorbs infrared radiation from the Earth’s surface and hence an increase in CO$_2$ concentrations leads to a rise in atmospheric temperature. Methane (CH$_4$) is the second most significant greenhouse gas after CO$_2$. The variation of CH$_4$ concentration has an important role in atmospheric chemistry and climate change [2]. CO$_2$ and CH$_4$ account for over 80% of the total anthropogenic warming effect caused by all greenhouse gases, based on estimates of radiative forcing from 1750 to 2005 [1]. To accurately predict the future concentrations of atmospheric CO$_2$ and CH$_4$ and their impact on climate, it is first necessary to clarify the distribution and variations of their sources and sinks over the global and regional scales.

Satellite measurement is one of the most effective approaches for monitoring global and regional greenhouse gas distribution. The Japanese Ministry of the Environment (MOE), the National Institute for Environment Studies (NIES), and the Japan Aerospace Exploration Agency (JAXA) have jointly
developed the Greenhouse Gases Observing Satellite (GOSAT) for monitoring CO₂ and CH₄ distribution [3]. Satellite observation is sensitive to the lower troposphere because it detects light that is reflected from the Earth’s surface [4]. In this manuscript, we investigate the spatial and seasonal variations of the CO₂ dry air mixing ratio (XCO₂) and the CH₄ dry air mixing ratio (XCH₄) from GOSAT data in China.

2. GOSAT data and the study area

We collected the GOSAT Level 2 data in Version 2.xx from Jan. 2010 to Dec. 2012 released for Research Announcement (RA) users, which included the data of XCO₂ and XCH₄. GOSAT, which was launched on 23 January 2009, is designed to monitor the global CO₂ and CH₄ distributions from space. It was put into a sun-synchronous orbit at 666-km altitude with 3-day recurrence and descending node at around 13:00 local time [5, 6, 7]. GOSAT carries the Thermal And Near infrared Sensor for carbon Observation (TANSO), which actually are composed of two observational instruments: the TANSO-Fourier Transform Spectrometer (TANSO-FTS) for the observation of greenhouse gases, and the TANSO-Cloud and Aerosol Imager (TANSO-CAI) for the observation of clouds and aerosols [8]. The TANSO-FTS operation pattern is the footprint model. XCO₂ and XCH₄ are retrieved from the Short-Wavelength Infrared (SWIR) observation data of the TANSO-FTS onboard GOSAT [9], which are cloud-free and released as the SWIR Level 2 (L2) products. Figure 1 shows the annual total number of XCO₂ retrieval data within a 2.5° × 2.5° grid from Jan. 2010 to Dec. 2012 for the latest FTS-SWIR L2 products released in Version 2.xx.

The study area is located over China. The variations of CO₂ and CH₄ with different land cover located in the six areas in the study area are investigated (see Figure 2).

Figure 1. Number of GOSAT SWIR XCO₂ data retrieved annually within 2.5° × 2.5° grid from Jan. 2010 to Dec. 2012.

The study area is located over China. The variations of CO₂ and CH₄ with different land cover located in the six areas in the study area are investigated (see Figure 2).

Figure 2. Study area and the investigated areas with the different land covers. The red frames are for XCO₂: A-Urban agglomeration located in Beijing-Tianjin-Hebei region with high population density, B-Grassland in northern Inner Mongolia, C-Desert in Xinjiang; the green frames are for XCH₄: D-Rice fields in Sichuan Basin, E-Rice fields in Yangtze River Delta region, F-Desert in Xinjiang.
3. Results and discussion

3.1. Spatio-temporal variation of XCO2 and XCH4 in China

(a) XCO2

(b) XCH4

Figure 3. Spatio-temporal changes of (a) XCO2 and (b) XCH4 from 2010 to 2012.

Figure 3 show the seasonal changes, for spring from March to May, summer from June to August, fall from September to November and winter from December to February in the following year. It can be
seen from Figure 3 that XCO2 shows obvious seasonal change that the concentration is the highest in spring and the lowest in the summer. Both XCO2 and XCH4 are obviously higher in the southeastern region with high population density than that in the sparsely populated northwestern region [10].

The monthly variation of XCO2 and XCH4 averaged for the whole of land area from Jan 2010 to Dec 2012 is shown in Figure 4.

As shown in Figures 3 and Figure 4, XCO2 demonstrates a clear seasonal change. The annual maximum values, which are 390ppm, 392ppm and 394ppm for the 3 years of 2010 to 2012 respectively, are all around April. The annual minimum values, which are 382ppm, 384ppm and 386 ppm respectively, are all around July. The seasonal change of the peak-to-peak amplitude is 8ppm. The annual growth is 1.75ppmv from 2010 to 2011 and 2.21 ppm from 2011 to 2012. The annual mean growth is 2ppm during the 3 years.

XCH4, however, does not present seasonal change like XCO2 which is inconsistency to ground-based measurements. It is known from ground-based measurements that global atmospheric CH$_4$ concentration demonstrates seasonal variations [11, 12]. This inconsistency of the XCH4 retrieved data from GOSAT is necessarily investigated further.

3.2. Seasonal variation of XCO2 and XCH4 in the different land use

Figures 5 and Figure 6 show the variation of XCO2 and XCH4 retrieval footprints, respectively, from Jan. 2010 to Dec. 2012 over the six areas as shown in Figure 2.
It can be seen from Figure 5 that XCO2 demonstrates larger concentrations over urban areas than that over grassland and desert, and the amplitude of XCO2 seasonal variation is larger over grassland than that over other areas. It can be found from Figure 6 that XCH4 shows clearly larger values over rice fields than that over desert, which indicate the affection of XCH4 emission from rice fields. XCH4, however, does not show seasonal variation in any area like XCO2.

4. Conclusions

In this paper, we used the GOSAT-L2 data to investigate the spatio-temporal variations of XCO2 and XCH4 over the land area of China from Jan. 2010 to Dec. 2012. The results show that
(1) Both XCO2 and XCH4 tend to increase spatially from the northwestern to the southeastern region, which are responding to the variations of population density from low to high.
(2) XCO2 observed from GOSAT data shows clear seasonal variation, and XCO2 is the highest in spring and the minimum in summer; the peak-to-peak amplitude is 8ppm and the annual mean growth is 2ppm for the whole land area of China. XCH4 shows irregular seasonal variation.
(3) Over the different land-use backgrounds, XCO2 over urban agglomerations is larger concentrations than that over grassland and desert; XCH4 shows lower concentrations over desert than over the Yangtze Delta and Sichuan Basin.

Our results indicate that XCO2 data obtained from GOSAT demonstrate reasonable temporal and spatial variations of atmospheric CO₂ on a regional scale, which implies that GOSAT could be applied in potential to the quantitative monitoring of anthropogenic emissions. However, XCH4 data from GOSAT do not show reasonable seasonal variation, which needs further investigation and verification.

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