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Comparing simulated atmospheric carbon dioxide concentration with GOSAT retrievals

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Abstract Satellite observations of atmospheric carbon dioxide (CO_2) provide a useful way to improve the understanding of global carbon cycling. In this paper, we present a comparison between simulated CO_2 concentrations from an inversion model of the CarbonTracker Data Assimilation System (CTDAS) and satellite-based CO_2 measurements of column-averaged dry air mole fraction (denoted XCO_2) derived from version 3.3 Atmospheric CO_2 Observations from Space retrievals of the Greenhouse Gases Observing SATellite (ACOS–GOSAT) L2 data products. We examine the differences of CTDAS and GOSAT to provide important guidance for the further investigation of CTDAS in order to quantify the corresponding flux estimates with satellite-based CO_2 observations. We find that the mean point-by-point difference (CTDAS–GOSAT) between CTDAS and GOSAT XCO_2 is -0.11 ± 1.81 ppm, with a high agreement (correlation $r = 0.77$, $P < 0.05$) over the studied period. The latitudinal zonal variations of CTDAS and GOSAT are in general agreement with clear seasonal fluctuations. The major exception occurs in the zonal band of 0°–15°N where the difference is approximately 4 ppm, indicating that large uncertainty may exist in the assimilated CO_2 for the low-latitude region of the Northern Hemisphere (NH). Additionally, we find that the hemispherical/continental differences between CTDAS and GOSAT are typically less than 1 ppm, but obvious discrepancies occur in different hemispheres/continents, with high consistency (point-by-point correlation $r = 0.79$, $P < 0.05$) in the NH and a weak correlation (point-by-point correlation $r = 0.65$, $P < 0.05$) in the Southern Hemisphere. Overall, the difference of CTDAS and GOSAT is small, and the comparison of CTDAS and GOSAT will further instruct the inverse modeling of CO_2 fluxes using GOSAT.

Keywords CTDAS model · Satellite-based CO_2 concentration · GOSAT · Comparison · Inversion method

1 Introduction

Accurate quantification of biosphere fluxes of CO_2 is critical to understanding global and regional carbon cycles [1, 2]. The atmospheric inversion method provides an effective way to quantify the biosphere CO_2 concentration/flux at the full-coverage spatial resolutions [3–7]. This approach derives the CO_2 concentrations and fluxes jointly from an atmospheric transport model and data assimilation technique. Unlike ecosystem modeling [8–15], the inverted method uses the atmospheric CO_2 transport process mechanism to describe the CO_2 spatiotemporal variations and uses the time-dependent Bayesian synthesis method to optimize the CO_2 concentrations and fluxes. This is advantageous for CO_2 estimation because the

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concentrations and fluxes can be constrained well by the observations in the inversion model. However, because of the sparseness of the existing CO_2 mixing ratio observation sites, the inversion estimate of CO_2 concentrations and CO_2 source and sink information remain unclear [16–19].

Satellite-based CO_2 observations of column-averaged dry air mole fraction (XCO_2) offer a new insight into the pattern of CO_2 mixing ratios and provide an additional constraint on the estimated CO_2 concentrations and fluxes of the atmospheric inversion method [16, 19–22]. These satellite-based measurements (e.g., GOSAT [23], AIRS [24], SCIAMACHY [25] and IASI [26]) allow for the quantification of large-scale temporal, spatial and seasonal variations in CO_2. As the first-dedicated greenhouse gas sensor [19, 23], GOSAT has been particularly useful for improving estimates of CO_2 concentrations and decreased uncertainties of CO_2 sources and sinks by providing further constrains on the inversion method [26–28], since it was specifically designed for monitoring high-precision observations of CO_2 concentrations with sensitivity in the lower troposphere [23, 29]. However, errors in GOSAT observations and models still need to be identified and minimized before these satellite-based measurements are assimilated into the inversion model, as they could lead to additional uncertainties of the inferred CO_2 concentrations and fluxes and result in misinterpretation of the global and regional carbon cycles. In this context, we present a comparison between GOSAT XCO_2 retrieved from version 3.3 Atmospheric CO_2 Observations from Space retrievals of the Greenhouse Gases Observing SATellite (ACOS–GOSAT) L2 data products [30–32] with the CarbonTracker Data Assimilation System (CTDAS) [6, 33] CO_2 concentrations during April 2009–December 2010. We examined the differences of CTDAS and GOSAT to provide important guidance for the further investigation of CTDAS in order to quantify the corresponding flux estimates with satellite-based CO_2 observations.

2 Methods and data

2.1 GOSAT XCO_2 retrievals

We use the GOSAT XCO_2 L2 data products (Version 3.3) from the NASA Atmospheric CO_2 Observations from Space (ACOS3.3) XCO_2 retrievals [30–32] to compare with our CTDAS XCO_2 retrievals during April 2009–December 2010. These ACOS3.3 XCO_2 retrievals have already been evaluated by comparison with ground-based measurements of XCO_2 from Total Column Observing Network (TCCON) stations [30, 31] and have been successfully employed in many previous works [32, 34–36]. The ACOS3.3 XCO_2 retrievals were downloaded from NASA Goddard Earth Sciences Data (http://disc.sci.gsfc.nasa.gov/acdisc/documentation/ACOS.shtml) for this study. Compared to the ACOS2.9, ACOS3.3 XCO_2 retrievals have changed their CO_2 absorption cross sections to 2.06 micro-bands, which are systematically $\sim$1 % lower than the XCO_2 retrievals using 1.61 micro-bands, resulting in large differences in measurement values. Note that before the ACOS3.3 XCO_2 were used in this study, we applied an updated screening criteria to filter out the ACOS3.3 XCO_2 measurements and corrected their biases according to the reference of "ACOS Level 2 Standard Product Data User's Guide, version 3.3" (available from http://disc.sci.gsfc.nasa.gov/datareleases/acos-version-3.3).

2.2 CTDAS model

CTDAS (http://carbontracker.eu/ctdas/) [6, 33] was developed to estimate the global CO_2 surface fluxes and atmospheric CO_2 concentration distribution with high accuracy and precision [4, 6, 37–41]. First, the system forecasted the atmospheric CO_2 concentrations using the transport model TM5 [42] and then optimized these modeled CO_2 concentrations and flux fields using the data assimilation technique in CTDAS. In this study, we ran CTDAS using weekly resolution and a 5-week lag window to retrieve the volume mixing ratio of CO_2 (CTDAS XCO_2) sampled at GOSAT locations and times, based on method of Rodgers and Connor [43]. The CTDAS simulation spanned the period from 2008 to 2010, but the period from January 2008 to March 2009 was used as a spin-up period to initialize the model and was therefore excluded from our analysis. The driving meteorological data in CTDAS were from the European Centre for Medium-Range Weather Forecasts (ECMWF, http://www.ecmwf.int/research/ifsdocs/CY28r1/index.html), and CTDAS was forced by four prior surface fluxes: (1) the first guess biosphere flux extracted from the Carnegie–Ames–Stanford Approach (CASA, http://geo.arc.nasa.gov/sge/casa/index4.html) [44]; (2) the fossil fuel emissions integrated from the Carbon Dioxide Information and Analysis Center (CDIAC) [45] and the Emission Database for Global Atmospheric Research (EDGAR) database [46]; (3) the biomass burning emissions obtained from Global Fire Emission Database version 2 (GFED2, http://ess1.ess.uci.edu/jranders/data/GFED2); and (4) the prior ocean fluxes derived from air–sea partial pressure difference [47]. The CO_2 measurements at the surface were assimilated in this system from the National Oceanic and Atmospheric Administration's Earth System Research Laboratory (NOAA-ESRL, http://www.esrl.noaa.gov/gmd/ccgg/obspack/). The simulated 4-D (x, y, z, t) CO_2 concentration fields contain 25 vertical layers with a global horizontal resolution of 6° × 4°.