Optik 127 (2016) 4422–4425

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

CO_2 retrieval model and analysis in short-wave infrared spectrum

Yanfen Li[a], Chunmin Zhang[a,*], Dongdong Liu[a], Jie Chen[a,b], Piao Rong[a], Xingying Zhang[c], Shupeng Wang[c]

[a] Ministry of Education Key Laboratory for Nonequilibrium Synthesis and Modulation of Condensed Matter, School of Science, Xi'an Jiaotong University, Xi'an 710049, Shaanxi, China
[b] 63892 PLA, Luoyang 471003, Henan, China
[c] Key Laboratory for Radiometric Calibration and Validation for Environmental Satellites, National Satellite Meteorological Center, Beijing 100081, China

ARTICLE INFO

Article history:
Received 11 December 2015
Accepted 18 January 2016

Keywords:
GF_VRTM
GOSAT-FTS
XCO_2 retrieval
Error analysis

ABSTRACT

The global carbon dioxide hyperspectral remote sensing inversion system GF_VRTM is established for the greenhouse gas carbon dioxide remote sensing detection of GF-5 satellite. The validation and error analysis of global inversion is performed by using GF_VRTM with 21 June 2013 observation data of GOSAT-FTS in this study. The simulation results show that the CO_2 averaged column concentrations (XCO_2) overall trends are basically identical between GF_VRTM retrievals and GOSAT-FTS observations. There are 138 exposure points in whole observation points, and the relative error less than 2% is about 85%. The mean square error is 5.00 ppm, but the global average error is 1.09 ppm. If the assumption that GOSAT-FTS observation data is true, GF_VRTM satisfies the average precision requirements (less than 1%) of XCO_2 global inversion. For the results of the comparison, the minimum error scenario and maximum error scenario are selected for error analysis. Error sources are smooth error, measurement noise error, the forward model parameter error and forward model error, respectively. For the minimum error scenario and maximum error scenario, the relative error of XCO_2 inversion caused by smooth error and measurement noise error are 0.44% and −1.62%, respectively, and the relative error of XCO_2 inversion caused by the forward model parameter error are −0.43% and −1.53%, respectively. At the same time, the forward model error is ignored.

1. Introduction

The atmospheric CO_2 is the most important anthropogenic greenhouse gas, and the increase of CO_2 concentration is increasingly being people's attention. The CO_2 concentration has increased from about 280 ppm in pre-industrial times (before 1750) to 389 ppm in 2010. This is primarily resulted from the burning of fossil fuels, reduction in forest area and the exhausting automobile emissions [1,4,15]. Because the ground monitoring greenhouse gas has certain limitation on the space scale and coverage, satellite remote sensing detection of CO_2 becomes an important and effective means [7]. The information is useful to predict the future trend of the global climate change [2]. For the study of satellite remote sensing detection of CO_2, the Japan GOSAT (Greenhouse gases Observing Satellite) and the NASA OCO-2 (Orbiting Carbon Observatory 2) were successfully launched one after another. At present, China is developing a High-resolution Satellite (GF-5) to observe CO_2, and it expected to be launched in 2016. The channels of carbon dioxide observation sensor on GF-5 will be similar to that of TANSO-FTS and OCO-2, including O_2-A band (0.76 μm), weakly absorption CO_2 band (WCO_2: 1.58 μm) and strong absorption CO_2 band (SCO_2: 2.06 μm). So it is necessary to establish a global carbon dioxide hyperspectral remote sensing inversion system before the satellite is sent into space.

TANSO-FTS (Thermal And Near infrared Sensor for carbon Observation Fourier Transform Spectrometer) and CAI (Cloud Aerosol Imager) are carried on GOSAT [11]. The reflected solar short-wave infrared radiation (SWIR) of the earth surface and thermal infrared (TIR) radiation of the atmosphere and surface are observed by TANSO-FTS, which includes three SWIR bands (O_2-A band: 0.76 μm, weakly absorption CO_2 band: 1.6 μm, strong absorption CO_2 band: 2.0 μm) and a wide TIR band (5.5–14.3 μm) [5]. The GOSAT team has done much study in retrieval dry-air column abundance of CO_2 (XCO_2) from TANSO-FTS observations [6,8,12,13].

The objective of this paper is to establish global carbon dioxide hyperspectral remote sensing inversion system GF_VRTM for GF-5 satellite, and perform validation and error analysis. Section 2 gives

* Corresponding author.
E-mail address: zcm@mail.xjtu.edu.cn (C. Zhang).

http://dx.doi.org/10.1016/j.ijleo.2016.01.144
0030-4026/

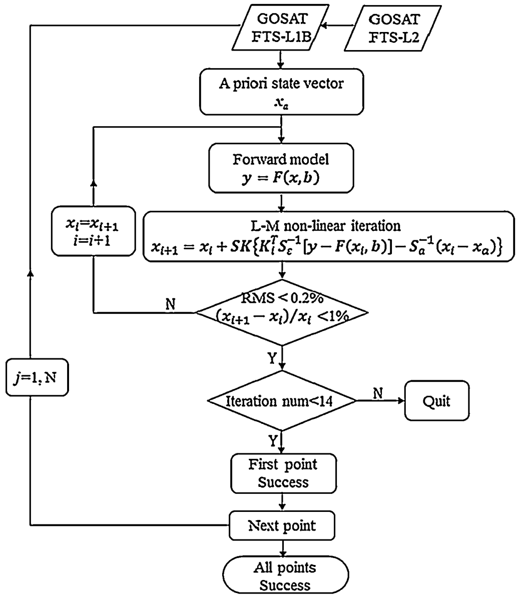

Fig. 1. Flow chart of GF_VRTM retrieval algorithm using GOSAT-FTS data.

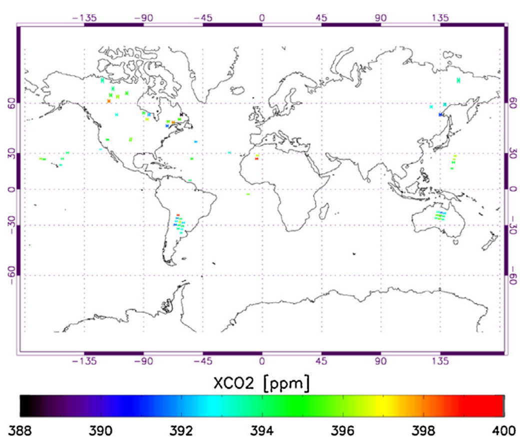

Fig. 2. XCO_2 distribution of GOSAT-FTS observation points.

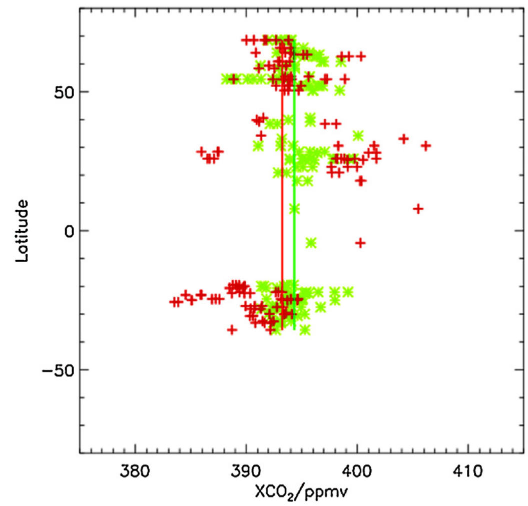

Fig. 3. The XCO_2 comparisons between GOSAT-FTS observations (green "*") and GF_VRTM retrievals (red "+"), green line represents the mean value of GOSAT-FTS observations, red line represents the mean value of GF_VRTM retrievals (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

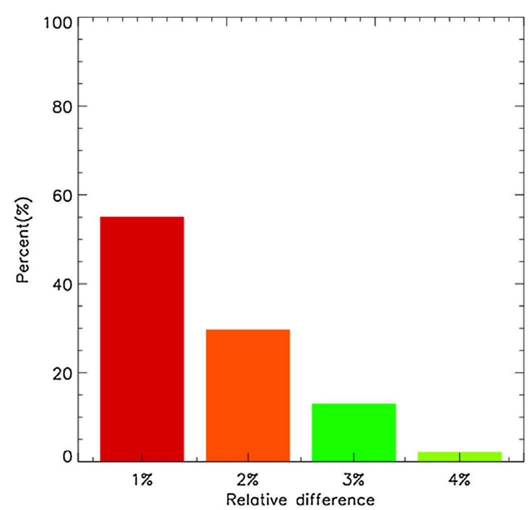

Fig. 4. The relative errors of XCO_2 between GF_VRTM retrievals and GOSAT-FTS observations, red represents the relative errors in 0–1%, orange represents the relative errors in 1–2%, green represents the relative errors in 2–3%, and yellow green represents the relative errors in 3–4% (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

an introduction of retrieval algorithm for GF_VRTM. The validation experiment with GOSAT-FTS observations are showed in Section 3. The error analysis is performed in Section 4. The result is discussed in Section 5.

2. Retrieval algorithm

The optimal estimation method is used in GF_VRTM for XCO_2 retrieval, and Levenberg–Marquardt (L–M) non-linear iteration method is used to acquire the optimization solution [9]. The forward model input parameters in GF_VRTM mainly include Kurucz solar spectrum (http://kurucz.harvard.edu), lambert reflection model, spherical atmospheric scattering model, satellite instrument parameters and geometric parameters. Surface albedo from MODIS database, temperature profile from ECMWF database and atmospheric molecular spectral information from HITRAN2012 database are used in GF_VRTM [10]. In this model, line by line (LBL) model is employed to calculate gas absorption [3].

The flowchart of GF_VRTM retrieval algorithm is shown in Fig. 1, the retrieval steps are as follows. Step 1: The GOSAT-L1B spectra data are selected corresponding to GOSAT-L2 data, which are downloaded from GOSAT website (https://data.gosat.nies.go.jp). Step 2: The priori state vector is inputted into the forward model to simulate observed radiance, updating the state vector via L–M non-linear iteration and adjusting O_2 profile and CO_2 profile. Step 3: if the spectrum matching residual $\boldsymbol{R} = \left\|\boldsymbol{y}_{i+1} - \boldsymbol{y}\right\| \le 0.2\%$ or the inversion value relative change $\left(\hat{\boldsymbol{x}}_{i+1} - \hat{\boldsymbol{x}}_i\right)/\hat{\boldsymbol{x}}_i \le 1\%$ achieves the convergence criteria, the $\hat{\boldsymbol{x}}_{i+1}$ is the final retrieval value; otherwise it need $\boldsymbol{x}_i = \boldsymbol{x}_{i+1}$ and $i = i+1$ to repeat step 2, until reach the convergence criteria or iteration number. Step 4: The next point repeats all steps when the previous point finish the retrieval, until output retrieval results of all points.

3. Validation experiment

GOSAT-FTS L1B (V161.160) data and GOSAT-FTS L2 (V02.21) data are downloaded from GOSAT website. Fig. 2 shows the XCO_2 distribution for GOSAT-FTS observations in 21 June 2013. GOSAT-FTS L1B observation spectra and corresponding geometric information are inputted GF_VRTM system to retrieve the total