Remote Sensing of Environment 162 (2015) 344–362

Contents lists available at ScienceDirect

Remote Sensing of Environment

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

The Greenhouse Gas Climate Change Initiative (GHG-CCI): Comparison and quality assessment of near-surface-sensitive satellite-derived CO_2 and CH_4 global data sets

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ARTICLE INFO

Article history:
Received 14 September 2012
Received in revised form 26 March 2013
Accepted 20 April 2013
Available online 4 October 2013

Keywords:
SCIAMACHY
GOSAT
Greenhouse gases
Carbon dioxide
Methane
Climate change

ABSTRACT

The GHG-CCI project is one of several projects of the European Space Agency's (ESA) Climate Change Initiative (CCI). The goal of the CCI is to generate and deliver data sets of various satellite-derived Essential Climate Variables (ECVs) in line with GCOS (Global Climate Observing System) requirements. The "ECV Greenhouse Gases" (ECV GHG) is the global distribution of important climate relevant gases – atmospheric CO_2 and CH_4 – with a quality sufficient to obtain information on regional CO_2 and CH_4 sources and sinks. Two satellite instruments deliver the main input data for GHG-CCI: SCIAMACHY/ENVISAT and TANSO-FTS/GOSAT. The first order priority goal of GHG-CCI is the further development of retrieval algorithms for near-surface-sensitive column-averaged dry air mole fractions of CO_2 and CH_4, denoted XCO_2 and XCH_4, to meet the demanding user requirements. GHG-CCI focuses on four core data products: XCO_2 from SCIAMACHY and TANSO and XCH_4 from the same two sensors. For each of the four core data products at least two candidate retrieval algorithms have been independently further developed and the corresponding data products have been quality-assessed and inter-compared. This activity is referred to as "Round Robin" (RR) activity within the CCI. The main goal of the RR was to identify for each of the four core products which algorithms should be used to generate the Climate

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http://dx.doi.org/10.1016/j.rse.2013.04.024

Research Data Package (CRDP). The CRDP will essentially be the first version of the ECV GHG. This manuscript gives an overview of the GHG-CCI RR and related activities. This comprises the establishment of the user requirements, the improvement of the candidate retrieval algorithms and comparisons with ground-based observations and models. The manuscript summarizes the final RR algorithm selection decision and its justification. Comparison with ground-based Total Carbon Column Observing Network (TCCON) data indicates that the "breakthrough" single measurement precision requirement has been met for SCIAMACHY and TANSO XCO_2 (<3 ppm) and TANSO XCH_4 (<17 ppb). The achieved relative accuracy for XCH_4 is 3–15 ppb for SCIAMACHY and 2–8 ppb for TANSO depending on algorithm and time period. Meeting the 0.5 ppm systematic error requirement for XCO_2 remains a challenge: approximately 1 ppm has been achieved at the validation sites but also larger differences have been found in regions remote from TCCON. More research is needed to identify the causes for the observed differences. In this context GHG-CCI suggests taking advantage of the ensemble of existing data products, for example, via the EnseMble Median Algorithm (EMMA).

1. Introduction

Carbon dioxide (CO_2) is the most important anthropogenic greenhouse gas (GHG) contributing to global warming (Solomon et al., 2007). Despite its importance, our knowledge of the CO_2 sources and sinks has significant gaps (e.g., Canadell et al., 2010; Stephens et al., 2007) and despite efforts to reduce CO_2 emissions, atmospheric CO_2 continues to increase at a rate of approximately 2 ppm/year (Fig. 1 top panel; see also Schneising et al., 2011, and references given therein; for a detailed discussion of Fig. 1 see Section 4). An improved understanding of the CO_2 sources and sinks is needed for reliable prediction of the future climate of our planet (Solomon et al., 2007). This is also true for methane (CH_4, Fig. 1 bottom panel). Atmospheric methane levels increased until about the year 2000, were rather stable during ~2000–2006, but started to increase again in recent years (Dlugokencky et al., 2009; Frankenberg et al., 2011; Rigby et al., 2008; Schneising et al., 2011). Unfortunately, it is not well understood why methane was stable in the years before 2007 (e.g., Simpson et al., 2012) nor why it started to increase again at a rate of approximately 7–8 ppb/year (Schneising et al., 2011).

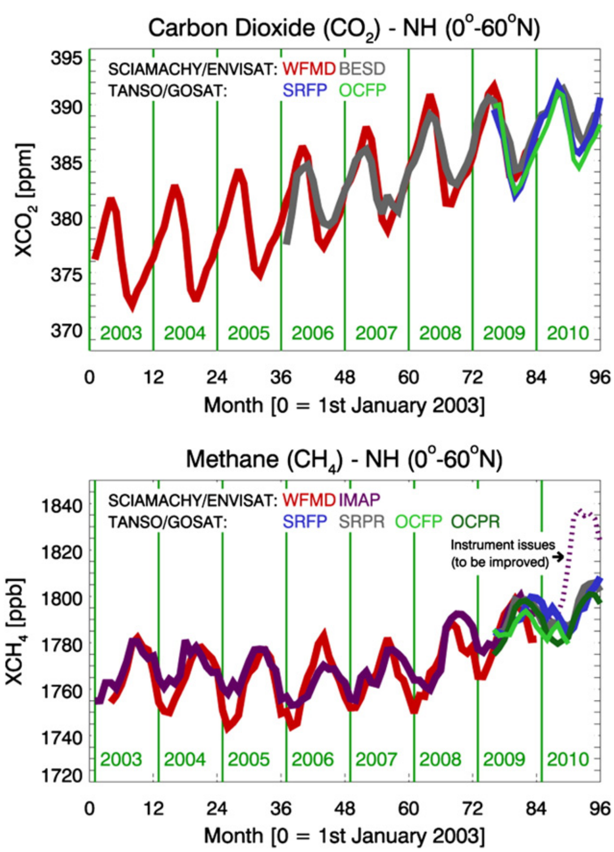

Fig. 1. Top: Northern hemispheric monthly mean XCO_2 time series retrieved from SCIAMACHY/ENVISAT (algorithms: WFMD and BESD) and TANSO/GOSAT (algorithms: SRFP and OCFP) satellite data. Shown are monthly mean values for the 0°–60°N latitude range. Clearly visible is the CO_2 increase primarily caused by the burning of fossil fuels and the seasonal cycle primarily caused by uptake and release of CO_2 by the terrestrial biosphere. Bottom: As top panel but for XCH_4 (algorithms: SCIAMACHY: WFMD and IMAP, TANSO: SRFP, SRPR, OCFP, OCPR). The seasonal cycle of methane is primarily due to wetland emissions, which are largest in summer/early autumn, when soils are warm and humid. Also clearly visible is the not yet well understood recent methane increase.

Global satellite observations sensitive to near-surface CO_2 and CH_4 variations can contribute to a better understanding of the regional sources and sinks of these important greenhouse gases. Information on GHG surface fluxes (emissions and uptake) can be obtained by inverse modeling of surface fluxes (e.g., Bergamaschi et al., 2009; Chevallier, Bréon, & Rayner, 2007), where satellite observations are compared with predictions of a (chemistry) transport model (e.g., Fig. 2) and satellite minus model mismatches are minimized by modifying the surface fluxes used by the model. This requires satellite retrievals to meet challenging requirements, as small errors of the satellite-retrieved atmospheric GHG distributions may result in large errors of the inferred GHG surface fluxes (e.g., Chevallier, Engelen, & Peylin, 2005; Meirink, Eskes, & Goede, 2006). Instead of direct optimization of surface fluxes it is also possible to optimize (other) model parameters used to model the fluxes, as done in Carbon Cycle Data Assimilation Systems (CCDAS) (e.g., Kaminski, Scholze, & Houweling, 2010; Kaminski et al., 2012) or other approaches (e.g., Bloom, Palmer, Fraser, Reay, & Frankenberg, 2010).

The goal of the GHG-CCI project is to generate the Essential Climate Variable (ECV) Greenhouse Gases (GHG) as defined by GCOS (Global Climate Observing System): "Distribution of greenhouse gases, such as CO_2 and CH_4, of sufficient quality to estimate regional sources and sinks" (GCOS, 2006). In order to get information on regional GHG sources and sinks, satellite measurements must be sensitive to near-surface GHG concentration variations. Currently only two satellite instruments deliver (or have delivered until recently) measurements which fulfill this requirement: SCIAMACHY on ENVISAT (March 2002–April 2012) (Bovensmann et al., 1999) and TANSO-FTS on-board GOSAT (launched in January 2009) (Kuze, Suto, Nakajima, & Hamazaki, 2009). Both instruments perform (or have performed) nadir observations of reflected solar radiation in the near-infrared/short-wave-infrared (NIR/SWIR) spectral region, covering the relevant absorption bands of CO_2 and CH_4. They also cover the O_2 A-band spectral region to obtain "dry-air columns" needed for computing GHG dry-air column averaged mole fractions and/or to obtain information on clouds and aerosols. These two instruments are therefore the two core sensors used by GHG-CCI and the near-surface-sensitive column-averaged dry air mole fractions of atmospheric CO_2 and CH_4, denoted XCO_2 (in ppm) and XCH_4 (in ppb), are the core data products of GHG CCI. In addition, other sensors or viewing modes are also used (e.g., MIPAS/ENVISAT and SCIAMACHY solar occultation mode for stratospheric CH_4 profiles and IASI/METOP for mid/upper tropospheric CO_2 and CH_4 columns) as they provide