

THE GHG-CCI PROJECT OF ESA'S CLIMATE CHANGE INITIATIVE: DATA PRODUCTS AND APPLICATION

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ABSTRACT

The goal of the GHG-CCI project (<http://www.esa-ghg-cci.org/>) of ESA's Climate Change Initiative (CCI) is to generate global atmospheric satellite-derived carbon dioxide (CO₂) and methane (CH₄) data sets as needed to improve our understanding of the regional sources and sinks of these important greenhouse gases (GHG). Here we present an overview about the latest data set called Climate Research Data Package No. 3 (CRDP3). We focus on the GHG-CCI project core data products, which are near-surface-sensitive column-averaged dry air mole fractions of CO₂ and CH₄, denoted XCO₂ (in ppm) and XCH₄ (in ppb) retrieved from SCIAMACHY/ENVISAT (2002-2012) and TANSO-FTS/GOSAT (2009-today) nadir mode radiance observations in the near-infrared/shortwave-infrared spectral region. The GHG-CCI products are primarily individual sensor Level 2 products. However, we also generate merged Level 2 products ("EMMA products"). Here we also present a first GHG-CCI Level 3 product, namely XCO₂ and XCH₄ in Obs4MIPs format (monthly, 5°x5°).

1. INTRODUCTION

Carbon dioxide (CO₂) is the most important anthropogenic greenhouse gas responsible for global warming (IPCC, 2013). Despite its importance, our knowledge of the CO₂ sources and sinks is inadequate and does not meet all needs for attribution, mitigation and the accurate prediction of future change (e.g., Ciais et al.,

2010, 2014; Canadell et al., 2010; IPCC, 2013; CEOS, 2014; Le Quééré et al., 2015), and despite efforts to reduce CO₂ emissions, atmospheric CO₂ continues to increase with approximately 2 ppm/year (Fig. 1). Appropriate knowledge concerning the various anthropogenic and natural CO₂ sources and sinks is needed for reliable prediction of the future climate of our planet. This is also true for methane (CH₄), whose various natural and anthropogenic sources are also only poorly understood (e.g., IPCC, 2013; Kirschke et al., 2013).

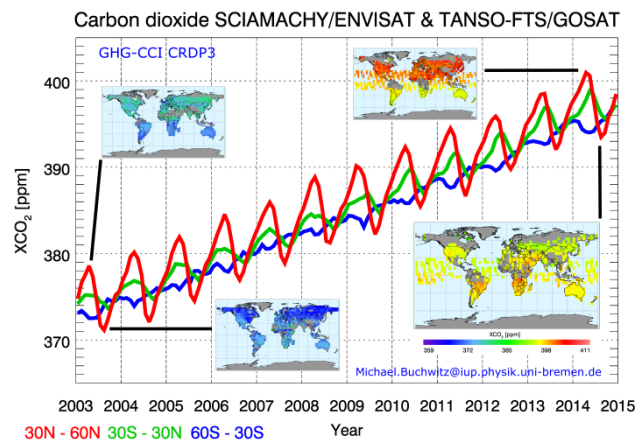


Fig. 1: (a) Timeseries of GHG-CCI CRDP3 XCO₂ in 3 latitude bands (see bottom left, e.g., the red line corresponds to northern mid-latitudes) and spatial maps for selected months at 5°x5° resolution obtained from merging the individual SCIAMACHY and GOSAT GHG-CCI XCO₂ Level 2 data products.

The main goal of the GHG-CCI project (Buchwitz et al., 2015a), which is one of several projects of ESA's Climate Change Initiative (CCI, Hollmann et al., 2013), is to generate global satellite-derived CO₂ and CH₄ data sets as needed to improve our understanding of the regional sources and sinks of these important atmospheric gases. Global near-surface-sensitive satellite observations of CO₂ and CH₄ combined with inverse modeling yields information on the regional sources and sinks of these gases (e.g., Reuter et al., 2014a, Bergamaschi et al., 2013, and references given therein). The GHG-CCI project generates Essential Climate Variable (ECV) Greenhouse Gases (GHG) data sets as required by GCOS. The GCOS definition of this ECV is (GCOS, 2011): "Product Number A.8.1: Retrievals of greenhouse gases, such as CO₂ and CH₄, of sufficient quality to estimate regional sources and sinks".

The GHG-CCI data products have been used to address a number of scientifically important carbon and climate issues (e.g., Schneising et al., 2013, 2014a, 2014b; Reuter et al., 2014a, 2014b; Chevallier et al., 2014a; Buchwitz et al., 2015b; Detmers et al., 2015; Feng et al., 2016). A list of GHG-CCI peer-reviewed publications is available from the GHG-CCI website (<http://www.esa-ghg-cci.org> -> Publications). As can be seen from that website, currently (May 2016) 53 peer-reviewed publications have been identified, where GHG-CCI data sets have been used. In the following we present an overview about the new CRDP3 data set.

2. OVERVIEW CRDP3 DATA SET

Table 1 presents an overview about the GHG-CCI CRDP3 data products and Tab. 2 presents additional details on the GHG-CCI core retrieval algorithms and corresponding Level 2 data products retrieved from SCIAMACHY/ENVISAT (Burrows et al., 1995; Bovensmann et al., 1999) and TANSO-FTS/GOSAT (Kuze et al., 2009; Yoshida et al., 2013). As can be seen, for (nearly) all core products listed in Tab. 2 a baseline algorithm and an alternative algorithm and corresponding data product has been defined. We encourage the users of our data products to take advantage of this. For users who want or can use only one product we recommend to use the baseline product. Note however, that the baseline product is not necessarily the best product for all applications. For example, the CO₂_SCI_BESD product has typically higher precision and accuracy compared to the CO₂_SCI_WFMD product but the BESD product is relatively sparse compared to the WFMD product. For some applications the WFMD product may therefore be the better or even the only choice. In general we recommend to use both products to investigate to what extent conclusions drawn are robust w.r.t. to algorithmic choices and tradeoffs, which have to be made when implementing a retrieval algorithm as complex as the GHG-CCI retrieval algorithms. Note that the product format is essentially identical for all GHG-CCI core products listed in Tab. 2. To achieve this, all GHG-CCI core products have been generated

according to the GHG-CCI Product Specification Document (PSD, version 3) (Buchwitz et al., 2014). This means that if a user is able to read and use one product, he/she can easily switch to another product.

For each product detailed information is available on the GHG-CCI Main Data Products website (http://www.esa-ghg-cci.org/sites/default/files/documents/public/documents/GHG-CCI_DATA.html) such as Product User Guide (PUG), Comprehensive Error Characterization Report (CECR) and Algorithm Theoretical Baseline Document (ATBD). Furthermore, two main documents are available covering all CRDP3 products: The Product Validation and Intercomparison Report (PVIR, version 4) (Buchwitz et al., 2016), written by the GHG-CCI validation and retrieval teams, and the Climate Assessment Report (CAR, version 3) (Chevallier et al., 2016), written by the GHG-CCI Climate Research Group (CRD), which documents the initial user assessment of the CRDP3 data set and contains model comparisons and CO₂ and CH₄ regional flux inversion results. As shown in document PVIR, the XCO₂ and XCH₄ data products are very stable, i.e., no long term drifts have been identified. However, some issues have been identified with SCIAMACHY XCH₄ in particular after mid 2010 due to detector degradation (e.g., the CH₄_SCI_IMAP product contains an approx. 20 ppb "jump" mid 2010). As also shown, the GCOS accuracy requirements are met for XCO₂ (< 1 ppm) and XCH₄ (< 10 ppb) (with the exception of SCIAMACHY during later years due to detector issues in the spectral region used for methane retrieval), not however the more demanding requirement of the GHG-CCI CRG for XCO₂ (< 0.5 ppm) as formulated in the GHG-CCI User Requirements Document (URD, version 2) (Chevallier et al., 2014b).

An overview about the XCO₂ data set has already been presented in Fig. 1. Fig. 2 shows a higher resolution map for south-east Asia obtained by gridding the CO₂_SCI_BESD product 0.5°x0.5° during 2010-2011. Note that all GHG-CCI data products are strictly quality filtered which essentially removes all observations which are affected by clouds. This is important in order to meet the demanding accuracy requirement. As a consequence, maps typically show a significant fraction of spatial gaps, even for multi-year averages. Fig. 3 shows the corresponding map for GOSAT (note that 2010-2011 are the two years where data from both sensors overlap). As can be seen, the GOSAT map is even sparser (over land) due to the sampling strategy of GOSAT combined with the fact that the GOSAT ground pixel size is smaller compared to SCIAMACHY (10 km versus approx. 50 km) and because the number of observations per time is much higher for SCIAMACHY compared to GOSAT. As can be seen, the spatial patterns agree reasonably well, with highest XCO₂ over large parts of south-east China but also over Thailand. Note that perfect agreement is not expected due to several reasons (e.g., different spatio-temporal resolution and sampling).

GHG-CCI Climate Research Data Package (CRDP#3)														
Main Product ID	Product (Level 2, mole fractions)	Years processed												
		2002	03	04	05	06	07	08	09	10	11	12	13	14
GHG-CCI Core Products: ECV Core Algorithm (ECA) Products														
XCO2_SCIA	XCO ₂													
XCH4_SCIA	XCH ₄													
XCO2_GOSAT	XCO ₂													
XCH4_GOSAT	XCH ₄													
XCO2_EMMA	XCO ₂													
XCH4_EMMA	XCH ₄													
Additional Constraints Algorithm (ACA) Products														
CO2_IASI	CO ₂ (1)													
CH4_IASI	CH ₄ (1)													
CH4_SCIAOCC	CH ₄ (2)													
CO2_SCIAOCC	CO ₂ (2)													
CH4_MIPAS	CH ₄ (2)													
CO2_AIRS	CO ₂ (1)													
CO2_ACEFTS	CO ₂ (2)													
Comments:		ECA Algorithms for column-averaged dry air mole fractions:												
ACA products:		XCO2_SCIA: BESD, WFMD												
(1) Mid / upper tropospheric column		XCH4_SCIA: WFMD, IMAP												
(2) Upper tropospheric / stratospheric profile		XCO2_GOSAT: SRFP (RemoTeC), OCFP (UoL-FP)												
CRDP#3		XCH4_GOSAT: SRFP & SRPR (RemoTeC), OCFP & OCPR (UoL-PR)												
Also available		XCO2_EMMA: Various (SCIA & GOSAT merged)												
		XCH4_EMMA: Various (GOSAT merged)												

Tab. 1: Overview about the GHG-CCI CRDP3 Level 2 CO₂ and CH₄ data products. Note that EMMA refers to the Ensemble Median Algorithm of Reuter et al., 2013. The EMMA products are merged SCIAMACHY and GOSAT Level 2 products. In this publication we focus on the GHG-CCI core products (ECA products). For details on the Additional Constraints Algorithm (ACA) products from, e.g., IASI and MIPAS, please see the GHG-CCI website.

GHG-CCI CRDP#3: ECV Core Algorithm (ECA) Products				
Algorithm / Product ID	Product	Sensor	Algorithm Institute	Comment (Reference)
CO2_SCI_BESD	XCO ₂	SCIAMACHY	BESD IUP	SCIAMACHY XCO ₂ baseline product (Reuter et al., 2011)
CO2_SCI_WFMD	XCO ₂	SCIAMACHY	WFM-DOAS IUP	SCIAMACHY XCO ₂ alternative product (Schneising et al., 2011)
CO2_GOS_OCFCP	XCO ₂	TANSO	UoL-FP UoL	GOSAT XCO ₂ product baseline product (Cogan et al., 2012)
CO2_GOS_SRFP	XCO ₂	TANSO	RemoteC SRON/KIT	GOSAT XCO ₂ alternative product (Butz et al., 2011)
CH4_SCI_WFMD	XCH ₄	SCIAMACHY	WFM-DOAS IUP	SCIAMACHY XCH ₄ proxy product (baseline not yet decided)(Schneising et al., 2011)
CH4_SCI_IMAP	XCH ₄	SCIAMACHY	IMAP SRON/JPL	SCIAMACHY XCH ₄ proxy product (baseline not yet decided) (Frankenberg et al., 2011)
CH4_GOS_OCPR	XCH ₄	TANSO	UoL-PR UoL	GOSAT XCH ₄ proxy baseline product (Parker et al., 2011)
CH4_GOS_SRPR	XCH ₄	TANSO	RemoteC SRON/KIT	GOSAT XCH ₄ proxy alternative product (Butz et al., 2010)
CH4_GOS_SRFP	XCH ₄	TANSO	RemoteC SRON/KIT	GOSAT XCH ₄ full physics baseline product (Butz et al., 2011)
CH4_GOS_OCFCP	XCH ₄	TANSO	UoL-PR UoL	GOSAT XCH ₄ full physics alternative product (Parker et al., 2011)

Tab. 2: Overview about the GHG-CCI CRDP3 XCO₂ and XCH₄ retrieval algorithms and corresponding data products. For a description and discussion of “proxy” and “full physics” retrievals see, e.g., Schepers et al., 2012. For details see GHG-CCI website.

Figure 4 presents an overview about the GHG-CCI CRDP3 XCH₄ data set. As can be seen, atmospheric methane is essentially constant (apart from the seasonal cycle) until about 2007 but shows an approximate linear increase afterwards. Why methane was stable for several years before 2007 and why it started to increase after 2007 is still not entirely clear. Very likely the current increase is due to a number of reasons such as increasing emissions from fossil fuel related sources but also from anthropogenic and natural biogenic sources (agriculture, wetlands) (e.g., Rigby et al., 2008; Dlugokencky et al., 2009; Schneising et al., 2011; Simpson et al., 2012; Bergamaschi et al., 2013; Kirschke et al., 2013; Houweling et al., 2014; Nisbet et al., 2014; Schaefer et al., 2016). Figure 4 shows that the increase is quite similar in all latitude bands. Concerning spatial pattern, Fig. 5 shows two spatial maps of 3-year averages of SCIAMACHY XCH₄, for 2003-2005 and 2008-2010, i.e., for time periods before and after 2007. The main difference between the two maps is a general increase of XCH₄ by about 30-35 ppb (nearly 2%).

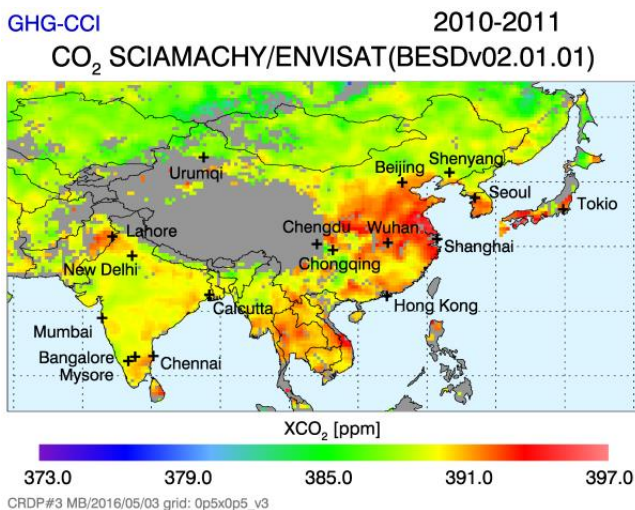


Fig. 2: SCIAMACHY XCO₂ over south-east Asia 2010-2011.

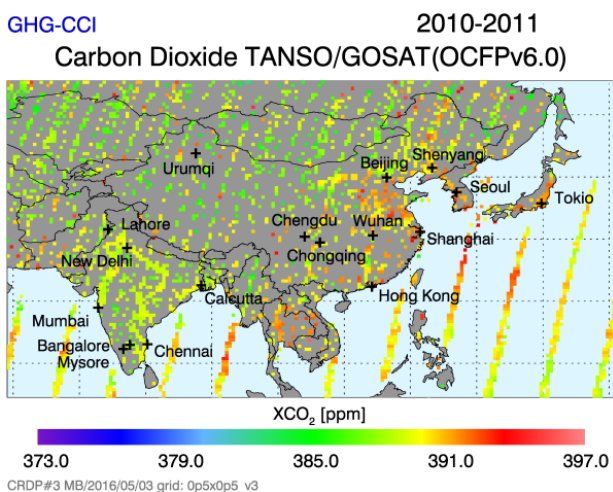


Fig. 3: As Fig. 2 but for GOSAT.

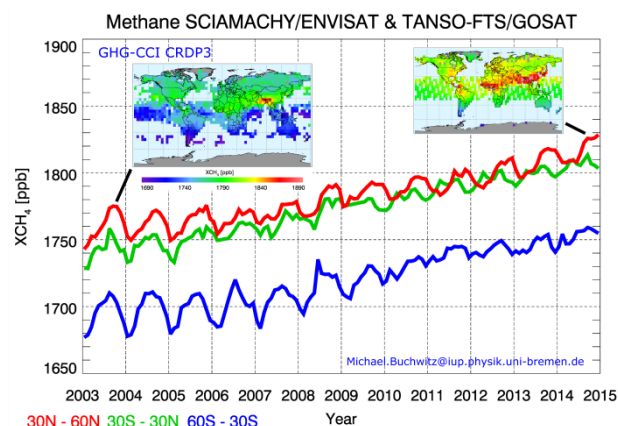


Fig. 4: As Fig. 1 but for XCH₄.

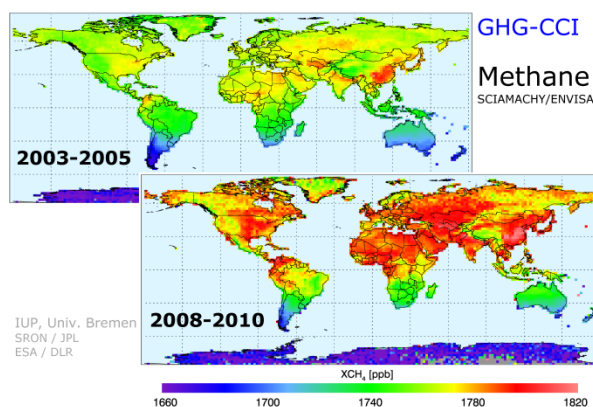


Fig. 5: SCIAMACHY XCH₄ 2003-2005 (top left) and 2008-2010 (bottom right).

3. ONGOING ACTIVITIES AND FUTURE PLANS

Among the ongoing activities within the GHG-CCI project are two major ones, namely the generation of XCO₂ and XCH₄ Level 3 products in Obs4MIPs format and the preparation for the generation of CRDP4. These two topics are briefly addressed in the following two subsections.

GHG-CCI team members are also involved in the EU Copernicus Climate Monitoring Service (CAMS, <http://www.ecmwf.int/en/about/what-we-do/copernicus/copernicus-atmosphere-monitoring-service>) by generating XCO₂ and XCH₄ products in quasi-Near-Real-Time (NRT) (currently within 4 days after GOSAT measurement). For example, Univ. Bremen is responsible for GOSAT XCO₂ retrievals (Heymann et al., 2015; Massart et al., 2016), which are delivered to ECMWF and which are available from the GOSAT/BESD website (http://www.iup.uni-bremen.de/~heymann/besd_gosat.php). These CAMS activities are highly complementary to the GHG-CCI activities, which focus on reprocessing to generate long-term consistent data sets with highest possible accuracy and precision, whereas the CAMS focus is on fast processing and delivery to meet the demanding CAMS NRT requirement.

Furthermore, GHG-CCI team members are also members of NASA's OCO-2 (Crisp et al., 2004) Science Team. Currently, focus is on comparisons of the GHG-CCI XCO₂ products with OCO-2 XCO₂ products and on initial OCO-2 XCO₂ retrievals. GHG-CCI team members are also involved in ESA's Sentinel-5-Precursor (S5P) mission (Veeffkind et al., 2012) which will deliver XCH₄ at high spatial resolution (approx. 7 km) with very good spatial coverage in the future.

3.1 Obs4MIPs products

Obs4MIPs (Observations for Model Intercomparisons Project,

<https://www.earthsystemcog.org/projects/obs4mips/>) is an activity to make observational products more accessible for climate model intercomparisons. Within this Obs4MIPs project a data format has been specified appropriate for comparisons with the output of climate models. Within GHG-CCI activities are ongoing to generate data products meeting the Obs4MIPs requirements. Initial XCO₂ and XCH₄ data products in Obs4MIPs format have been generated based on the GHG-CCI CRDP3 data set. These products have been generated from the individual SCIAMACHY and GOSAT Level 2 products listed in Tab. 2. Details on these products including links to initial (not yet officially released) product files are given in two Technical Notes (Buchwitz and Reuter, 2016a, 2016b). The Obs4MIPs files are NetCDF files (one for XCO₂ and one for XCH₄) which contain monthly averages at 5°x5° spatial resolution covering the time period 2003-2014. Figures 1 and 4 have been generated based on these Obs4MIPs products. As shown in Buchwitz and Reuter, 2016a, 2016b, also an initial validation of these products has been carried out using Total Carbon Column Observation Network (TCCON, Wunch et al., 2011, 2015) ground-based observations. Summary results are shown in Fig. 6 (for XCO₂) and Fig. 7 (for XCH₄). The comparisons are based on monthly averaged TCCON data. As can be seen, the agreement with TCCON is 0.3 +/- 1.2 ppm for XCO₂ and 2 +/- 11 ppb for XCH₄.

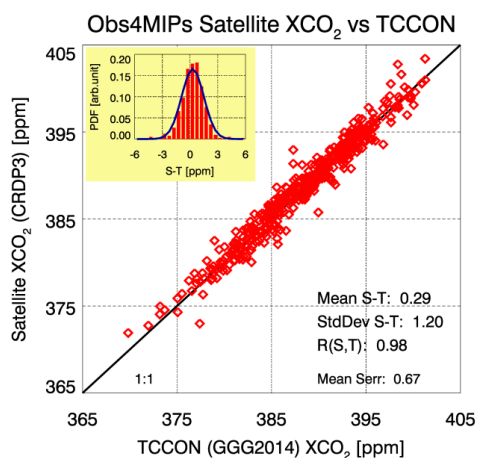


Fig. 6: Comparison of the initial GHG-CCI Obs4MIPs XCO₂ product obtained from the CRDP3 data set with TCCON ground-based observations.

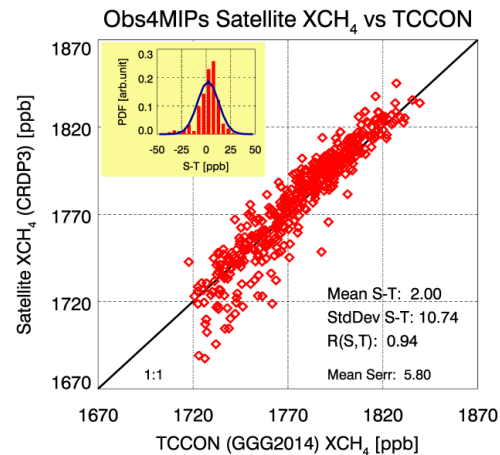


Fig. 7: As Fig. 6 but for Obs4MIPs XCH₄.

3.2 CRDP No. 4

Currently the GHG-CCI retrieval team is working on the generation of the next data set, i.e., on CRDP4. CRDP4 will be extended in time compared to CRDP3 by adding year 2015 data. Very likely all data products will be regenerated by reprocessing all data of the entire time period with improved retrieval algorithms to (further) increase the data quality. CRDP4 will be available along with all relevant documents via the GHG-CCI website end of February 2017.

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