Copernicus Climate Change Service (C3S) Global Satellite Observations of Atmospheric Carbon Dioxide and Methane

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Abstract

Carbon dioxide (CO₂) and methane (CH₄) are important atmospheric greenhouse gases (GHG) and, therefore, classified as essential climate variables (ECVs). Previously, satellite-derived atmospheric CO₂ and methane CH₄ ECV data sets have been generated and made available via the GHG-CCI project of the European Space Agency's (ESA) Climate Change Initiative (CCI, <http://www.esa-ghg-cci.org/>). The latest GHG-CCI data set, Climate Research Data Package No. 4 (CRDP 4), covers the time period 2003–2015 and is available since February 2017. Currently, the production and provision of these data sets is being continued (pre-)operationally via the Copernicus Climate Change Service (C3S, <https://climate.copernicus.eu/>), which is implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF) on behalf of the European Commission. The C3S satellite GHG sub-project (C3S_312a_Lot6) is led by University of Bremen supported by University of Leicester (UK), SRON (The Netherlands) and CNRS-LMD (France). The first Climate Data Record (CDR) data set produced and delivered within the C3S framework covers the time period 2003–2016 and consists of column-average dry-air mole fraction CO₂ and CH₄ products, i.e., XCO₂ and XCH₄, from SCIAMACHY/ENVISAT and TANSO-FTS/GOSAT. Furthermore, mid-tropospheric CO₂ and CH₄ mixing ratios from IASI Metop-A and Metop-B are part of this data set. It is planned to extend this data set each year by one additional year. The data products are available via the Climate Data Store (CDS) of C3S. Here a short overview about this new Earth Observation data set is presented.

Keywords Climate change · Essential climate variables · Greenhouse gases · Satellite · Carbon dioxide · Methane

1 Introduction

Increasing concentrations of atmospheric carbon dioxide (CO₂) result in global warming with adverse consequences such as global sea level rise [1]. Despite its importance, our knowledge concerning the various natural and anthropogenic sources and sinks of this greenhouse gas (GHG) has significant gaps. Global satellite observations of CO₂ in combination with (inverse) modelling helps to obtain a better understanding of the CO₂ sources and sinks (e.g., [2] and references given therein). This requires satellite observations, which are sensitive to CO₂ concentration changes close to the Earth's surface as can be obtained from radiance measurements in the short-wave-infrared (SWIR) spectral range, which permit to retrieve column-average dry-air mole fractions of CO₂, denoted XCO₂, shown in Fig. 1.

Figure 1 shows global maps of XCO₂ for selected months in the time period beginning of 2003 to end of 2016 as gener-

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Fig. 1 Time series and global maps of satellite observations of atmospheric carbon dioxide (colour figure online)

ated for the Copernicus Climate Change Service (C3S) and available via the C3S website [3]. Also shown are XCO_2 time series for three latitude bands: northern mid-latitudes (red), tropics (green) and southern mid-latitudes (blue). As can be seen, all time series show an increasing trend primarily due to burning of fossil fuels. As can also be seen, CO_2 varies significantly within each year (especially over the northern hemisphere) due to quasi-regular seasonal uptake and release of atmospheric CO_2 by the terrestrial biosphere (photosynthesis, respiration, decay of organic matter). Fortunately, land and ocean sinks currently take up about half of the emitted CO_2 [4]. Without these natural sinks the atmospheric increase would be approximately twice as high. However, our knowledge about these important natural CO_2 sinks is currently not appropriate for reliable climate prediction as we currently do not know well enough how these natural sinks will respond to a changing climate [1]. Satellite observations such as the ones shown in Fig. 1 are used to obtain a better understanding of the CO_2 sources and sinks (e.g., [2] and references given therein).

Atmospheric methane (CH_4) is also an important greenhouse gas with many natural and anthropogenic sources [1]. Satellite radiance measurements in the SWIR spectral region are also sensitive to near-surface CH_4 concentration variations and therefore permit to retrieve column-average dry-air mole fractions of CH_4 , denoted XCH_4 , shown in Fig. 2. Atmospheric methane increased by about 150% since pre-industrial times, but concentrations were nearly constant since the late 1990s. However, since 2007 CH_4 concentrations started to increase again (Fig. 2). The identification of the reason for this is currently undergoing scientific research (e.g., [5, 6] and references given therein).

In the following, a short overview about this new data set is presented.

Fig. 2 Time series and global maps of satellite observations of atmospheric methane

2 C3S Satellite-Derived CO_2 and CH_4 Data Set

2.1 Overview

The C3S satellite-derived CO_2 and CH_4 data set has been generated by applying dedicated retrieval algorithms (e.g., [2, 7] and references given therein) to the satellite radiance measurements in order to obtain individual satellite-sensor Level 2 data products, which provide atmospheric CO_2 and/or CH_4 information for individual satellite footprints (ground pixel). These data products contain for each satellite footprint in addition to information on CO_2 and CH_4 (and corresponding uncertainty estimates) also a number of other important quantities such as exact location and time of each observation, used a priori information (e.g., a priori profiles) and information on the altitude sensitivity of the retrievals (averaging kernels) [7].

As described in more detail below, these fundamental individual-sensor Level 2 data products are (depending on product type) merged to generate higher-level data products (“merged Level 2” and “merged Level 3” products).

The current C3S CO_2 and CH_4 data set has been generated using these satellite instruments (see [2, 7] and references given therein):

- SCIAMACHY on ENVISAT (2002–2012) and TANSO-FTS/GOSAT (since mid 2009) for the XCO_2 and XCH_4 data products (see Figs. 1, 2)
- IASI on Metop-A and Metop-B for CO_2 and CH_4 mid-tropospheric mixing ratios and AIRS for mid-tropospheric CO_2 .

The current (and first) C3S data set covers the years 2003–2016. It is planned to add each year one additional year. This may include re-processing of entire individual-sensor

time series if improved retrieval algorithms are available; the merged products will always be based on re-processing for each new data set. The next data set will cover the time period 2003–2017 and will be available end of 2018 including documentation (updated user guide, algorithm descriptions, initial data quality documentation, etc.).

2.2 Requirements

Requirements for satellite-derived essential climate variable (ECV) data products have been formulated by Global Climate Observing System (GCOS) [9] and these requirements have been considered for the generation of the data products described here and for the corresponding User Requirements Document (URD) of the GHG-CCI pre-cursor project (available from [10]) and for the corresponding C3S Target Requirements Document (TRD) (available from [3]).

The most challenging requirement is the accuracy or bias requirement for XCO₂, where a relative accuracy of better than 0.5 ppm (approx. 0.1%) is required. The reason for this demanding requirement is that even very small errors can result in large regional-scale CO₂ surface flux errors depending on the spatio-temporal structure of the XCO₂ biases.

2.3 Data Products

The C3S satellite-derived CO₂ and CH₄ data set consists of three types of data products (see [7] for details):

1. Individual-sensor Level 2 (L2) products: XCO₂, XCH₄ and mid-tropospheric CO₂ and CH₄ information for individual footprints of individual satellites as generated using dedicated retrieval algorithms
2. Merged L2 products: a single XCO₂ and a single XCH₄ product covering the entire time period (currently 2003–2016) generated by merging individual sensor L2 products [including GOSAT products from National Aeronautics and Space Administration (NASA) and Japan's National Institute for Environmental Studies (NIES)] using the Ensemble Median Algorithm (EMMA) [11]
3. Merged Level 3 (L3) products: gridded monthly XCO₂ and XCH₄ products (at 5° × 5° spatial resolution) in Obs4MIPs format (see [7]) as generated from the merged L2 products (see Figs. 1, 2).

The products are listed in Table 1. Each individual product has a product ID indicating if it is a CO₂ or CH₄ product, the corresponding satellite (SCI=SCIAMACHY, GOS=GOSAT, IASA/IASB=IASI Metop-A or B, AIR=AIRS) and the used retrieval algorithm.

Table 1 List of data products

Type	Quantity	Product ID
L2	XCO ₂	CO2_SCI_BESD CO2_SCI_WFMD CO2_GOS_OCFP CO2_GOS_SRFp
L2	Mid-tropospheric CO ₂	CO2_IASA_NLIS CO2_IASB_NLIS CO2_AIR_NLIS
L2	XCH ₄	CH4_SCI_WFMD CH4_SCI_IMAP CH4_GOS_OCFP CH4_GOS_SRFp CH4_GOS_OCPR CH4_GOS_SRPR
L2	Mid-tropospheric CH ₄	CH4_IASA_NLIS CH4_IASB_NLIS
Merged L2	XCO ₂	XCO2_EMMA
Merged L2	XCH ₄	XCH4_EMMA
Merged L3	XCO ₂	XCO2_OBS4MIPS
Merged L3	XCH ₄	XCH4_OBS4MIPS

2.4 Data Quality

The data quality of the XCO₂ and XCH₄ data products has been estimated by comparisons with the corresponding ground-based data products of the Total Carbon Column Observing Network (TCCON) [12]. The overall L2 products comparison results are shown in Fig. 3 for the XCO₂ and in Fig. 4 for XCH₄. As can be seen, the single footprint random error is about 2 ppm for XCO₂ and 50–90 ppb for SCIAMACHY XCH₄ and around 20 ppb for GOSAT XCH₄. The relative accuracy is around 0.5 ppm for XCO₂ and around 10 ppb for SCIAMACHY XCH₄ and around 5 ppb for GOSAT XCH₄. Stability in terms of linear bias drift is high for all products.

The IASI and AIRS mid-tropospheric products have been compared with aircraft observations [8] and it has been estimated that the single footprint random errors are around 1 ppm for IASI CO₂, around 1.3 ppb for AIRS CO₂ and 12 ppb for CH₄. Relative accuracy is approx. 0.5 ppm for IASI CO₂ and around 5 ppb for IASI CH₄.

3 Summary and Conclusions

An overview about a new data set of satellite-derived CO₂ and CH₄ data products relevant for carbon and climate related research has been presented.

The data products have been generated in the framework of the Copernicus Climate Change Service (C3S) and they are publicly and free-of-charge available for interested users

Fig. 3 Data quality overview XCO₂ L2 products. From top to bottom: random error, relative accuracy, probability that relative accuracy is <0.5 ppm, stability, probability that stability is <0.5 ppm/year. From [8]

Fig. 4 Data quality overview XCH₄ L2 products. From top to bottom: random error, relative accuracy, probability that relative accuracy is <10 ppb, stability, probability that stability is <3 ppb/year. From [8]

including documentation via the Copernicus Climate Data Store (CDS) accessible via the C3S website [3].

Currently, the data set covers the time period 2003–2016, but it is planned to extend it each year by year one additional year. The next data set will cover the time period 2003–2017 and will be available end of 2018.

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