



Copernicus Climate Change Service



Product User Guide and Specification (PUGS) – ANNEX D for products XCO2_EMMA and XCH4_EMMA

C3S_312a_Lot6_IUP-UB – Greenhouse Gases

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History of modifications

| Version | Date | Description of modification | Chapters / Sections |
|---------|-------------------|-----------------------------|---------------------|
| 1.0 | 20-September-2017 | New document | All |
| 1.0b | 11-October-2017 | Page header logo replaced | Page header |
| 1.3 | 20-October-2017 | References updated | Page 6 |



Related documents

| Reference ID | Document |
|--------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| D1 | Main PUGS: Buchwitz, M., et al., Product User Guide and Specification (PUGS) – Main document, C3S project C3S_312a_Lot6_IUP-UB – Greenhouse Gases, v1.3, 2017. <i>(this document is an ANNEX to the Main ATBD)</i> |
| D2 | Corresponding ATBD: ATBD ANNEX D: Reuter, M., et al., Algorithm Theoretical Basis Document (ATBD) – ANNEX D for products XCO ₂ _EMMA and XCH ₄ _EMMA, C3S project C3S_312a_Lot6_IUP-UB – Greenhouse Gases, 18.09.2017, pp. 32, 2017. |
| D3 | TRD GHG, 2017: Buchwitz, M., Aben, I., Anand, J., Armante, R., Boesch, H., Crevoisier, C., Detmers, R. G., Hasekamp, O. P., Reuter, M., Schneising-Weigel, O., Target Requirement Document, Copernicus Climate Change Service (C3S) project on satellite-derived Essential Climate Variable (ECV) Greenhouse Gases (CO ₂ and CH ₄) data products (project C3S_312a_Lot6), Version 1.3, 20-October-2017, pp. 53, 2017. |



Acronyms

| Acronym | Definition |
|---------|------------------------------------------------------|
| AIRS | Atmospheric Infrared Sounder |
| AMSU | Advanced Microwave Sounding Unit |
| ATBD | Algorithm Theoretical Basis Document |
| BESD | Bremen optimal ESTimation DOAS |
| CAR | Climate Assessment Report |
| C3S | Copernicus Climate Change Service |
| CCDAS | Carbon Cycle Data Assimilation System |
| CCI | Climate Change Initiative |
| CDR | Climate Data Record |
| CDS | (Copernicus) Climate Data Store |
| CMUG | Climate Modelling User Group (of ESA's CCI) |
| CRG | Climate Research Group |
| D/B | Data base |
| DOAS | Differential Optical Absorption Spectroscopy |
| EC | European Commission |
| ECMWF | European Centre for Medium Range Weather Forecasting |
| ECV | Essential Climate Variable |
| EMMA | Ensemble Median Algorithm |
| ENVISAT | Environmental Satellite (of ESA) |
| EO | Earth Observation |
| ESA | European Space Agency |
| EU | European Union |



| | |
|---------------------|-------------------------------------------------------------------------------|
| EUMETSAT | European Organisation for the Exploitation of Meteorological Satellites |
| FCDR | Fundamental Climate Data Record |
| FoM | Figure of Merit |
| FP | Full Physics retrieval method |
| FTIR | Fourier Transform InfraRed |
| FTS | Fourier Transform Spectrometer |
| GCOS | Global Climate Observing System |
| GEO | Group on Earth Observation |
| GEOSS | Global Earth Observation System of Systems |
| GHG | GreenHouse Gas |
| GOME | Global Ozone Monitoring Experiment |
| GMES | Global Monitoring for Environment and Security |
| GOSAT | Greenhouse Gases Observing Satellite |
| IASI | Infrared Atmospheric Sounding Interferometer |
| IMAP-DOAS (or IMAP) | Iterative Maximum A posteriori DOAS |
| IPCC | International Panel in Climate Change |
| IUP | Institute of Environmental Physics (IUP) of the University of Bremen, Germany |
| JAXA | Japan Aerospace Exploration Agency |
| JCGM | Joint Committee for Guides in Metrology |
| L1 | Level 1 |
| L2 | Level 2 |
| L3 | Level 3 |
| L4 | Level 4 |
| LMD | Laboratoire de Météorologie Dynamique |
| MACC | Monitoring Atmospheric Composition and Climate, EU GMES project |
| NA | Not applicable |
| NASA | National Aeronautics and Space Administration |



| | |
|-----------|-----------------------------------------------------------------------------------------------------------------|
| NetCDF | Network Common Data Format |
| NDACC | Network for the Detection of Atmospheric Composition Change |
| NIES | National Institute for Environmental Studies |
| NIR | Near Infra Red |
| NLIS | LMD/CNRS <i>neuronal</i> network mid/upper tropospheric CO ₂ and CH ₄ retrieval algorithm |
| NOAA | National Oceanic and Atmospheric Administration |
| Obs4MIPs | Observations for Climate Model Intercomparisons |
| OCO | Orbiting Carbon Observatory |
| OE | Optimal Estimation |
| PBL | Planetary Boundary Layer |
| ppb | Parts per billion |
| ppm | Parts per million |
| PR | (light path) PROxy retrieval method |
| PVIR | Product Validation and Intercomparison Report |
| QA | Quality Assurance |
| QC | Quality Control |
| REQ | Requirement |
| RMS | Root-Mean-Square |
| RTM | Radiative transfer model |
| SCIAMACHY | SCanning Imaging Absorption spectroMeter for Atmospheric ChartographY |
| SCIATRAN | SCIAMACHY radiative transfer model |
| SRON | SRON Netherlands Institute for Space Research |
| SWIR | Short Wava Infra Red |
| TANSO | Thermal And Near infrared Sensor for carbon Observation |
| TANSO-FTS | Fourier Transform Spectrometer on GOSAT |
| TBC | To be confirmed |
| TBD | To be defined / to be determined |



| | |
|--------------------|-----------------------------------------|
| TCCON | Total Carbon Column Observing Network |
| TIR | Thermal Infra Red |
| TR | Target Requirements |
| TRD | Target Requirements Document |
| WFM-DOAS (or WFMD) | Weighting Function Modified DOAS |
| UoL | University of Leicester, United Kingdom |
| URD | User Requirements Document |
| WMO | World Meteorological Organization |
| Y2Y | Year-to-year (bias variability) |



General definitions

Table 1 lists some general definitions relevant for this document.

Table 1: General definitions.

| Item | Definition |
|------------------|-------------------------------------------------------------------------------------------------------------------------------|
| XCO ₂ | Column-averaged dry-air mixing ratios (mole fractions) of CO ₂ |
| XCH ₄ | Column-averaged dry-air mixing ratios (mole fractions) of CH ₄ |
| L1 | Level 1 satellite data product: geolocated radiance (spectra) |
| L2 | Level 2 satellite-derived data product: Here: XCO ₂ and XCH ₄ information for each ground-pixel |
| L3 | Level 3 satellite-derived data product: Here: Gridded XCO ₂ and XCH ₄ information, e.g., 5°x5°, monthly |
| L4 | Level 4 satellite-derived data product: Here: Surface fluxes (emission and/or uptake) of CO ₂ and CH ₄ |



Scope of document

This document is an ANNEX to a Product User Guide and Specification (PUGS, see *D1*) for the Copernicus Climate Change Service (C3S, <https://climate.copernicus.eu/>) component as covered by project C3S_312a_Lot6 led by University of Bremen, Germany.

Within project C3S_312a_Lot6 satellite-derived atmospheric carbon dioxide (CO₂) and methane (CH₄) Essential Climate Variable (ECV) data products will be generated and delivered to ECMWF for inclusion into the Copernicus Climate Data Store (CDS) from which users can access these data products and the corresponding documentation.

The C3S_312a_Lot 6 satellite-derived data products are:

- Column-averaged dry-air mixing ratios (mole fractions) of CO₂ and CH₄, denoted XCO₂ (in parts per million, ppm) and XCH₄ (in parts per billion, ppb), respectively.
- Mid/upper tropospheric mixing ratios of CO₂ (in ppm) and CH₄ (in ppb).

This document describes the C3S products XCO₂_EMMA and XCH₄_EMMA.

These products are merged multi-sensor XCO₂ and XCH₄ Level 2 products generated using algorithms developed at University of Bremen, Germany (see *D2*).



Executive summary

The EMMA database consists of individual level 2 soundings retrieved by algorithms which can change from grid box to grid box and month to month. Therefore, it can be used in the same manner as any other XCO₂ or XCH₄ satellite retrieval, i.e., the EMMA database includes all information needed for inverse modeling (geo-location, time, XCO₂ or XCH₄, averaging kernels, etc.).

The data fields and guidance on their use are provided in the main PUGS document (*D1*) describing, e.g., the common variables of all XCO₂ and XCH₄ L2 data sets provided by the Copernicus C3S_312a_Lot6 sub-project.

Additionally, to the common variables, EMMA includes information on, e.g., the inter-algorithm spread which informs about potential regional uncertainties and on the source-algorithm of each individual sounding within the EMMA data base. Such variables are subject to this ANNEX describing only the EMMA v3.0 CO₂ and EMMA v3.0 CH₄ specific aspects of the EMMA L2 data base.



1. Product description

Additionally to the common variables described in the main PUGS document (*D1*) the EMMA L2 data base includes the variables listed in **Table 2** and described in the following.

Table 2: EMMA v3.0 CO₂ and EMMA v3.0 CH₄ specific variables.

| Name | Type | Dimension | Units | Short Description |
|-------------------------|---------|-----------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|
| median_processor_id | Integer | n | [-] | A unique ID for each L2 algorithm contributing to EMMA |
| median_uncertainty | Float | n | For XCO ₂ : ppm, i.e., 10 ⁻⁶ For XCH ₄ : ppb, i.e., 10 ⁻⁹ | Inter algorithm spread defined as standard deviation of the L3 products in the corresponding grid box (see <i>D2</i>) |
| median_uncertainty_se | Float | n | For XCO ₂ : ppm, i.e., 10 ⁻⁶ For XCH ₄ : ppb, i.e., 10 ⁻⁹ | Standard error of the median uncertainty (see <i>D2</i>) |
| median_uncertainty_ex | Float | n | For XCO ₂ : ppm, i.e., 10 ⁻⁶ For XCH ₄ : ppb, i.e., 10 ⁻⁹ | Inter-algorithm spread as expected from measurement noise (see <i>D2</i>) |
| <xco2 xch4>_accuracy | Float | n | For XCO ₂ : ppm, i.e., 10 ⁻⁶ For XCH ₄ : ppb, i.e., 10 ⁻⁹ | Potential spatio/temporal XCO ₂ or XCH ₄ bias (1-sigma) estimated from TCCON co-locations (see <i>D2</i>) |
| contributing_algorithms | Byte | n | [-] | Number of L2 algorithms contributing to median calculation in a specific grid box |

Table 3: Unique L2 algorithm IDs used in EMMA v3.0 CO₂ and CH₄.

| ID | Quantity | Name | Version | Institution |
|----|------------------|------------|-----------|-------------|
| 1 | XCO ₂ | BESD | v02.01.02 | IUP |
| 2 | XCO ₂ | ACOS | v7.3.10a | NASA |
| 3 | XCO ₂ | RemoTeC | v2.3.8 | SRON |
| 4 | XCO ₂ | UoL-FP | v7.1 | UoL |
| 6 | XCO ₂ | NIES | v02 | NIES |
| 30 | XCH ₄ | RemoTeC-PR | v2.3.8 | SRON |
| 31 | XCH ₄ | RemoTeC-FP | v2.3.8 | SRON |
| 40 | XCH ₄ | UoL-PR | v7.0 | UoL |
| 41 | XCH ₄ | UoL-FP | v7.1 | UoL |
| 60 | XCH ₄ | NIES | V02 | NIES |
| 70 | XCH ₄ | WFMD | v4.0 | IUP |

**Description of each parameter:*****median_processor_id***

A unique ID for each L2 algorithm contributing to EMMA v3.0 CO₂ and CH₄. See listing in **Table 3**.

median_uncertainty

Inter algorithm spread defined as standard deviation of the L3 products in the corresponding grid box (see D2).

median_uncertainty_se

Standard error of the median uncertainty (see D2).

median_uncertainty_ex

Inter-algorithm spread as expected from measurement noise (see D2).

<xco2/xch4>_accuracy

Potential spatio/temporal XCO₂ or XCH₄ bias (1-sigma) estimated from TCCON co-locations (see D2).

contributing_algorithms

Number of L2 algorithms contributing to median calculation in a specific grid box.



2. Target requirements

The target requirements for these products are described in the Target Requirement Document (TRD) (*TRD GHG, 2017*), see *D3*.



3. Data usage information

The EMMA database consists of individual level 2 soundings which can be used in the same manner as any other XCO₂ or XCH₄ satellite retrieval, i.e., the EMMA database includes all information needed for inverse modeling (geo-location, time, XCO₂ or XCH₄, averaging kernels, etc.). The main PUGS document (*D1*) provides guidance on how to use the information.

Figure 1 shows for an example month (September 2009) the EMMA XCO₂ and XCH₄ and the corresponding algorithm selected by the median (see *D2*). **Figure 2** shows the average inter-algorithm spread (01/2003 – 12/2016) and the expected average inter-algorithm spread due to measurement noise for XCO₂ and XCH₄.

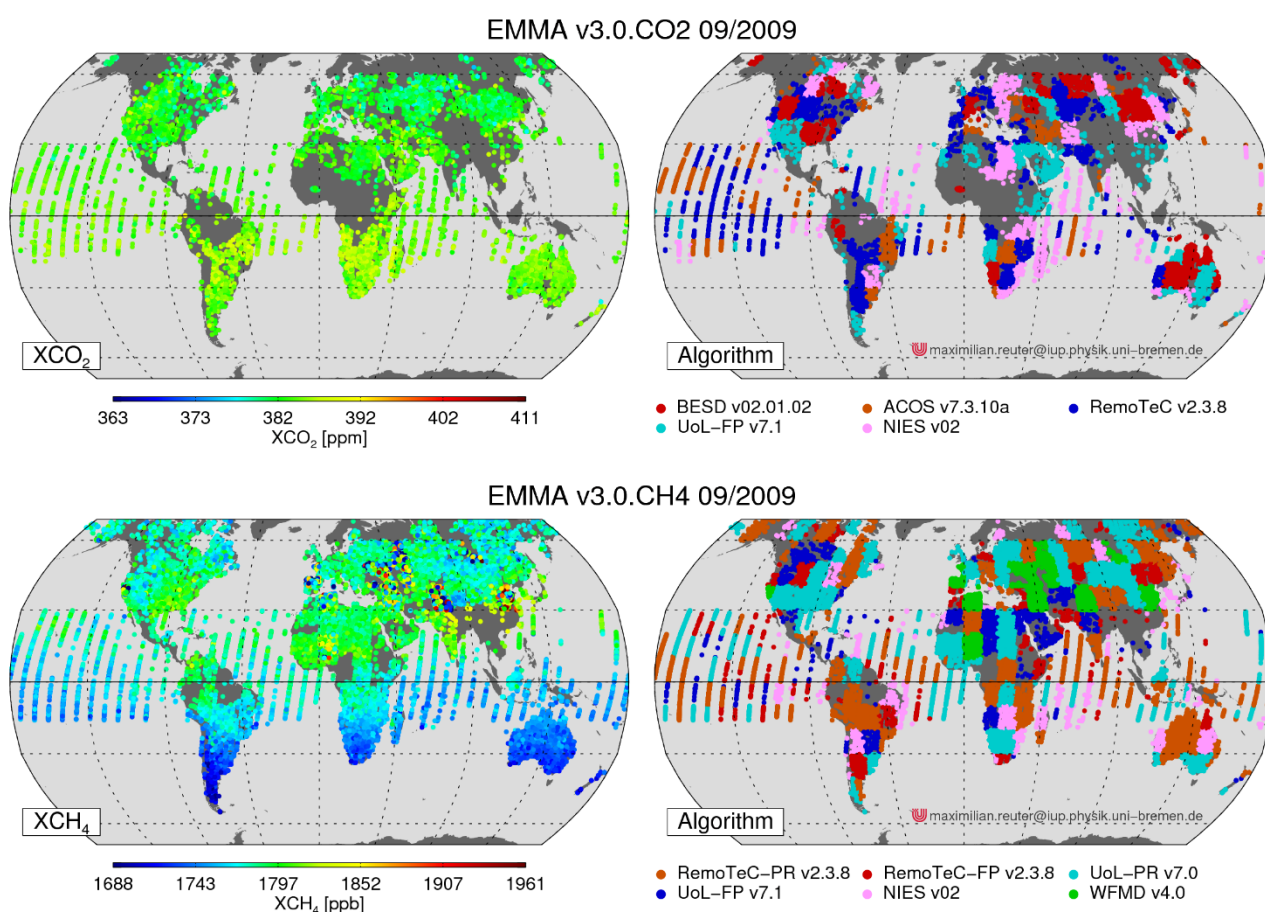


Figure 1: EMMA L2 XCO₂ and XCH₄ (**left**) and corresponding selected algorithm (**right**) for EMMA v3.0 CO₂ (**top**) and EMMA v3.0 CH₄ (**bottom**) at the example of September 2009.

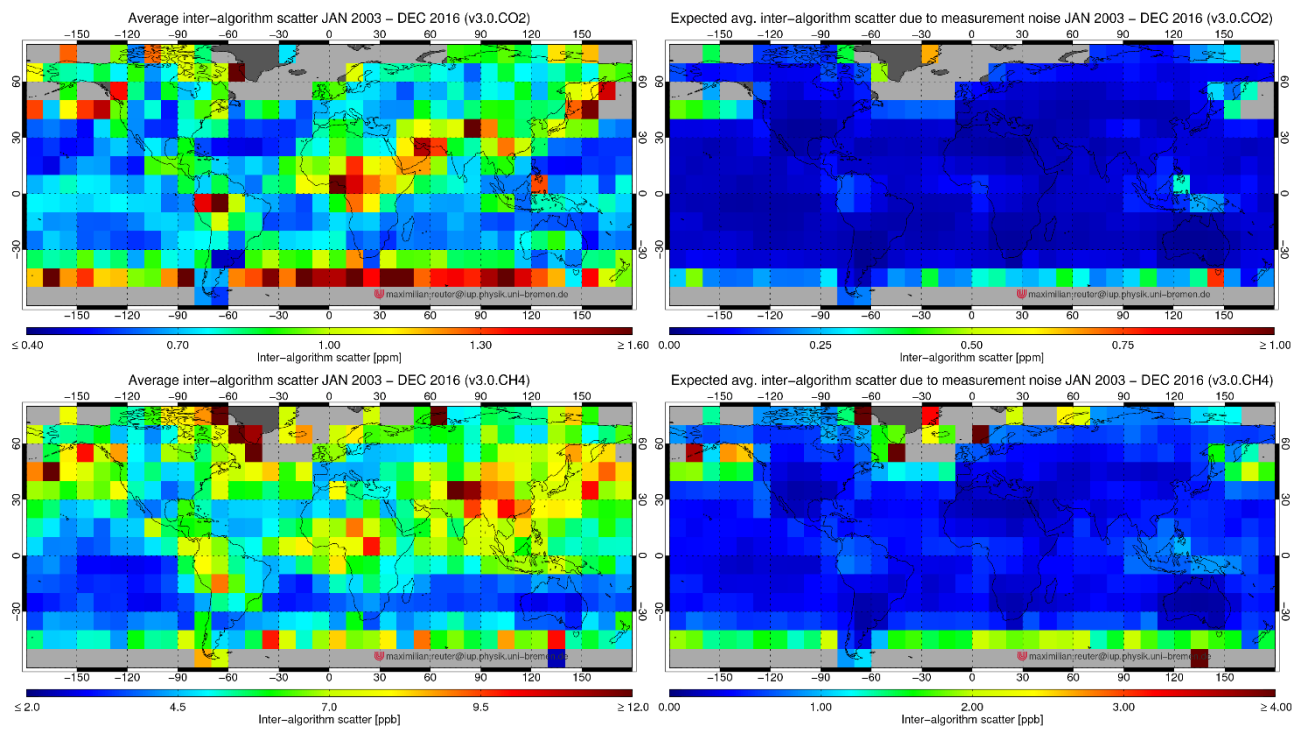


Figure 2: Average inter-algorithm spread (01/2003 – 12/2016) (**left**) and expected average inter-algorithm spread due to measurement noise (**right**) for EMMA v3.0 CO₂ (**top**) and EMMA v3.0 CH₄ (**bottom**).



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