ESA Climate Change Initiative (CCI)

GHG-CCI Sentinel Data Use

for the Essential Climate Variable (ECV)

Greenhouse Gases (GHG)

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Version 1 – Draft 1	June 13, 2014	Internal draft	New document
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1 Planned GHG-CCI Sentinel Data Use

This document describes the planned use of Sentinel satellite data within Phase 2 (2014-2016) of the ESA project GHG-CCI (http://www.esa-ghg-cci.org), which is one of several sub-projects of the ESA Climate Change Initiative (CCI).

The GHG-CCI core data products are the products generated with ECV Core Algorithms (ECAs). These products are:

- Column-averaged dry-air mole fractions of atmospheric carbon dioxide (CO_2), denoted XCO_2 (in micromol/mol, appreviated ppm)
- Column-averaged dry-air mole fractions of atmospheric methane (CH_4), denoted XCH_4 (in nanomol/mol, abbreviated ppb)

The main goal of GHG-CCI is to generate accurate and precise long-term consistent data sets of these parameters meeting GCOS requirements **/GCOS 2011/** and the user requirements as formulated by the GHG-CCI Climate Research Group (CRG) in the GHG-CCI User Requirements Document (URD) **/GHG-CCI URDv1/**.

These time series start with SCIAMACHY/ENVISAT (2002-2012) **/Bovensmann et al., 1999/** and are currently being continued with TANSO/GOSAT (launch 2009) **/Kuze et al., 2009/**. In addition, a number of other products are generated with so-called Additional Constraints Algorithms (ACAs).

An overview of all GHG-CCI data products (ECA and ACA products) including data format (see in particular **/GHG-CCI PSDv3/**) and data access info etc. is given on the GHG-CCI main data products website:

http://www.esa-ghg-cci.org/ -> CRDP (Data) -> GHG-CCI Data Products Main Website

The existing XCO_2 and XCH_4 time series derived from SCIAMACHY and TANSO satellite data will be further improved and extended during the recently started and currently ongoing Phase 2 of the GHG-CCI project (2014-2016).

To achieve this all future satellites providing near-surface sensitive atmospheric CO_2 and CH_4 information will be considered. This includes the following satellites which are planned to be launched during GHG-CCI Phase 2:

- NASA's OCO-2 mission (planned launch July 2014): Main product: XCO_2 **/Boesch et al., 2010/**
- ESA's Sentinel-5-Precursor (S-5P) mission (planned launch early 2016): GHG product: XCH_4. **/Butz et al., 2012/ /Krings et al., 2013/**
- The Chinese TanSat mission (planned launch mid 2016). Main product: XCO_2. Details please see: https://directory.eoportal.org/web/eoportal/satellite-missions/t/tansat
- The German-French MERLIN mission (planned launch 2016): Main product: XCH_4. Details please see: http://www.dlr.de/rd/desktopdefault.aspx/tabid-2440/3586_read-31672/

Furthermore, a number of other satellite missions are in preparation which will or may be launched after GHG-CCI Phase 2. They will be used should the GHG-CCI project be extended beyond Phase 2 to further extend the GHG-CCI XCO_2 and XCH_4 time series. These satellites include the following approved or proposed missions: GOSAT-2, Sentinel-5

(S5), OCO-3, CarbonSat (http://www.iup.uni-bremen.de/carbonsat/), and possibly other missions.

In summary, the GHG-CCI main data products are XCO_2 and XCH_4 Level 2 products. They are generated from the Level 1 products of these sensors. It is therefore planned to use the following Sentinel data within GHG-CCI Phase 2:

- **S-5P products to be used within GHG-CCI Phase 2:**
  - Level 2 XCH_4: Initially comparisons are planned with the operational Level 2 XCH_4 product (RemoTeC algorithm **/Butz et al., 2012/**) and with other planned products such as the XCH_4 product generated with the scientific product generated with the verification algorithm BESD **/Krings et al., 2013/**. A focus of these comparisons will be to assess the consistency between the existing GHG-CCI time series and the available S-5P XCH_4 product(s).
  - Level 1: In order to investigate the reason or the reasons for potential inconsistencies or to generate a product which better meets the GHG-CCI user requirements it is mandatory to process at least sub-sets of the S-5P Level 1 data to Level 2. Important input data for GHG-CCI are therefore also the S-5P Level 1 data.

Should GHG-CCI be extended beyond the currently Phase 2, which will finish in 2016, also Sentinel-5 (S-5) data will be used:

- **S-5 products to be used within GHG-CCI after Phase 2 (if approved):**
  - Level 2 XCH_4 and (if available) XCO_2: Initially comparisons are planned with the operational Level 2 products. A focus of these comparisons will be to assess the consistency between the existing GHG-CCI time series and the available S-5 XCH_4 and possibly XCO_2 products.
  - Level 1: In order to investigate the reason or the reasons for potential inconsistencies or to generate a product which better meets the GHG-CCI user requirements it is mandatory to process at least sub-sets of the S-5 Level 1 data to Level 2. Important input data for GHG-CCI are therefore also the S-5 Level 1 data.

Furthermore it is likely that also data from **other Sentinels (e.g., Sentinel 3 or Sentinel 4)** will be used and that also **other data products from S-5P and S-5**, e.g., to obtain additional information on clouds and aerosols and/or surface properties. However, at this point in time, no specific requirements can be given as this requires additional studies not yet available.

2 References

The following list contains references to publications listed in this document but also to other important publications relevant for the GHG-CCI project related to product requirements, retrieval algorithms, satellite missions and GHG-CCI achievements:

/Bennett and James, 2013/ Bennett, V. and James, S., Data Standards Requirements for CCI Data Producers, ESA Technical Note, Reference: CCI-PRGM-EOPS-TN-13-0009, Issue 1, Revision 1, Date of Issue 24/05/2013, Link: http://46.137.76.174/?q=webfm_send/76, 2013.

/Bergamaschi el al., 2007/ Bergamaschi, P., C. Frankenberg,J. F. Meirink,M. Krol,F. Dentener,T. Wagner, U. Platt, J. O. Kaplan, S. Körner,M. Heimann, E. J. Dlugokencky,and A. Goede, Satellite chartography of atmospheric methane from SCIAMACHY on board ENVISAT: 2. Evaluation based on inverse model simulations, J. Geophys. Res., Vol. 112, D02304, doi:10.1029/2006JD007268, 2007.

/Boesch et al., 2006/ Bösch, H., Toon, G. C., Sen, B., Washenfelder, R. A., Wennberg, P. O., Buchwitz, M., de Beek, R., Burrows, J. P., Crisp, D., Christi, M., Connor, B. J., Natraj, V., and Yung, Y. L.: Space-based near-infrared CO_2 measurements: Testing the Orbiting Carbon Observatory retrieval algorithm and validation concept using SCIAMACHY observations over Park Falls, Wisconsin, J. Geophys. Res., 111, D23302, doi:10.1029/2006JD007080, 2006.

/Boesch et al., 2010/ Boesch, H., D. Baker, B. Connor, D. Crisp, and C. Miller, Global characterization of CO_2 column retrievals from shortwave-infrared satellite observations of the orbiting carbon observatory-2 mission, Remote Sensing, 2010.

/Bovensmann et al., 1999/ Bovensmann, H., J. P. Burrows, M. Buchwitz, J. Frerick, S. Noël, V. V. Rozanov, K. V. Chance, and A. H. P. Goede, SCIAMACHY – Mission objectives and measurement modes, J. Atmos. Sci., 56, (2), 127-150, 1999.

/Butz et al., 2009/ Butz, A. O., P. Hasekamp, C. Frankenberg, and I. Aben, Retrievals of atmospheric CO_2 from simulated space-borne measurements of backscattered near-infrared sunlight: accounting for aerosol effects, *Appl. Opt.* **48**, 3322-3336, doi:10.1364/AO.48.003322, 2009.

/Butz et al., 2010/ Butz, A., O. P. Hasekamp, C. Frankenberg, J. Vidot, and I. Aben, CH_4 retrievals from space-based solar backscatter measurements: Performance evaluation against simulated aerosol and cirrus loaded scenes, *J.Geophys.Res*., **115,** D24302, doi:10.1029/2010JD014514, 2010.

/Butz et al., 2012/ Butz, A., Galli, A., Hasekamp, O., Landgraf, J., Tol., P., Aben, I., TROPOMI aboard Sentinel-5 Precursor: Prospective performance of CH4 retrievals for aerosol and cirrus loaded atmospheres, Remote Sensing of Environment, Vol. 120, p. 267–276, 2012.

/CMUG-RBD, 2010/ Climate Modelling User Group Requirements Baseline Document, Deliverable 1.2, Number D1.2, Version 1.3, 2 Nov 2010.

/Connor et al., 2008/ Connor, B. J., H. Boesch, G. Toon, B. Sen, C. Miller, and D. Crisp, Orbiting Carbon Observatory: Inverse method and prospective error analysis, J. Geophys. Res., 113, D05305, doi:10.1029/2006JD008336, 2008.

/Dils et al., 2013/ Dils, B., M. Buchwitz, M. Reuter, O. Schneising, H. Boesch, R. Parker, S. Guerlet, I. Aben, T. Blumenstock, J. P. Burrows, A. Butz, N. M. Deutscher, C. Frankenberg, F. Hase, O. P. Hasekamp, J. Heymann, M. De Maziere, J. Notholt, R. Sussmann, T. Warneke, D. Griffith, V. Sherlock, and D. Wunch, The Greenhouse Gas Climate Change Initiative (GHG-CCI): comparative validation of GHG-CCI SCIAMACHY/ENVISAT and TANSO-FTS/GOSAT CO_2 and CH_4 retrieval algorithm products with measurements from the TCCON network, Atmos. Meas. Tech. Discuss., 6, 8743-8782, 2013.

/Frankenberg et al., 2011/ Frankenberg, C., I. Aben,P. Bergamaschi, E. J. Dlugokencky, R. van Hees, S. Houweling, P. van der Meer,R. Snel,and P. Tol: "Global column-averaged methane mixing ratios from 2003-2009 as derived from SCIAMACHY: Trends and variability" J. Geophys. Res., doi:10.1029/2010JD014849, 2011.

/Frankenberg et al., 2005/ Frankenberg, C., Meirink, J. F., van Weele, M., Platt, U., and Wagner, T.: Assessing methane emissions from global spaceborne observations, Science, 308, 1010-1014, 2005.

/GCOS 2011/ Global Climate Observing System (GCOS), SYSTEMATIC OBSERVATION REQUIREMENTS FOR SATELLITE-BASED DATA PRODUCTS FOR CLIMATE, 2011 Update, Supplemental details to the satellite-based component of the “Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (2010 Update)”, December 2011, GCOS – 154, 2011.

/GHG-CCI ASR/ Buchwitz, M. et al., Algorithm Selection Report (ASR) for the Essential Climate Variable (ECV) Greenhouse Gases (GHG), Technical Report, 29. Aug. 2012, 2012. Link: http://www.esa-ghg-cci.org/?q=webfm_send/158

/GHG-CCI PSDv3/ Buchwitz, M., Detmers, R. et al., Product Specification Document (PSD) for the Essential Climate Variable (ECV) Greenhouse Gases (GHG), Technical Report, version 3, 6 June 2014, 2014. Link: http://www.esa-ghg-cci.org/index.php?q=webfm_send/160

/GHG-CCI PVIRv2/ Notholt, J., et al., Product Validation and Intercomparison Report (PVIR) for the Essential Climate Variable (ECV) Greenhouse Gases (GHG), Technical Report, version 2.0, 4 Nov. 2013, 2013. Link: http://www.esa-ghg-cci.org/index.php?q=webfm_send/152

/GHG-CCI URDv1/ Buchwitz, M., F. Chevallier, P. Bergamaschi, I. Aben, H. Bösch, O. Hasekamp, J. Notholt, M. Reuter, et al., User Requirements Document for the GHG-CCI project of ESA’s Climate Change Initiative, pp. 45, version 1, 3. February 2011, 2011. Link: http://www.esa-ghg-cci.org/?q=webfm_send/21

/Guerlet et al., 2013a/ Guerlet, S., S. Basu, A. Butz, M. Krol, P. Hahne, S. Houweling, O. P. Hasekamp and I. Aben, Reduced carbon uptake during the 2010 Northern Hemisphere summer from GOSAT, Geophys. Res. Lett., doi: 10.1002/grl.50402, 2013b.

/Guerlet et al., 2013b/ Guerlet, S., A. Butz, D. Schepers, S. Basu, O. P. Hasekamp, A. Kuze, T. Yokota, J.-F. Blavier, N. M. Deutscher, D. W. T. Griffith, F. Hase, E. Kyro, I. Morino, V. Sherlock, R. Sussmann, A. Galli and I. Aben, Impact of aerosol and thin cirrus on retrieving and validating XCO_2 from GOSAT shortwave infrared measurements, J. Geophys. Res., doi: 10.1002/jgrd.50332, 2013a.

/Krings et al., 2013/ Krings, T., M. Reuter, M. Buchwitz, J. Heymann, M. Hilker, H. Bovensmann, and J.P. Burrows, SENSITIVITY STUDIES FOR METHANE AND CARBON MONOXIDE RETRIEVALS FROM SENTINEL-5 PRECURSOR, ESA Living Planet Symposium, Sept 9-13, 2013, Edinburgh, UK, conference proceedings ESA Special Publication SP-722 (available from: http://www.iup.uni-bremen.de/sciamachy/NIR_NADIR_WFM_DOAS/2847458krings.pdf), 2013.

/Kuze et al., 2009/ Kuze, A., H. Suto, M. Nakajima, and T. Hamazaki, Thermal and near infrared sensor for carbon observation fourier-transform spectrometer on the greenhouse gases observing satellite for greenhouse gases monitoring, Applied Optics, 48(35), 6716-6733, 2009.

/Natraj et al., 2008/ Natraj, V., H. Boesch, R. J. D. Spurr, and Y. L. Yung, Retrieval of XCO_2 from simulated orbiting carbon observatory measurements using the fast linearized r-2os radiative transfer model, Journal of Geophysical Research D: Atmospheres, 113(11), 2008.

/O'Dell et al., 2010/ O'Dell, C. W., Acceleration of multiple-scattering, hyper-spectral radiative transfer calculations via low-streams interpolation, Journal of Geophysical Research D: Atmospheres, 115(10), 2010.

/Parker et al., 2011/ R. Parker, H. Boesch, A.Cogan, A. Fraser, L. Feng, P.I. Palmer, J. Messerschmidt, N. Deutscher, D.W.T. Griffith, J. Notholt, P. Wennberg and D. Wunch, Methane observations from the Greenhouse Gases Observing SATellite: Comparison to ground-based TCCON data and model calculations, *Geophys. Res. Lett.*, 38, L15807, doi:10.1029/2011GL047871, 2011.

/Reuter et al., 2010/ M. Reuter, M. Buchwitz, O. Schneising, J. Heymann, H. Bovensmann, J. P. Burrows: A method for improved SCIAMACHY CO_2 retrieval in the presence of optically thin clouds. Atmospheric Measurement Techniques, 3, 209-232, 2010.

/Reuter et al., 2011/ M. Reuter, H. Bovensmann, M. Buchwitz, J. P. Burrows, B. J. Connor, N. M. Deutscher, D. W. T. Griffith, J. Heymann, G. Keppel-Aleks, J. Messerschmidt, J. Notholt, C. Petri, J. Robinson, O. Schneising, V. Sherlock, V. Velazco, T. Warneke, P. O. Wennberg, D. Wunch: Retrieval of atmospheric CO_2 with enhanced accuracy and precision from SCIAMACHY: Validation with FTS measurements and comparison with model results. Journal of Geophysical Research - Atmospheres, *J. Geophys. Res*., 116, D04301, doi:10.1029/2010JD015047, 2011.

/Reuter et al., 2013/ Reuter, M., H. Boesch, H. Bovensmann, A. Bril, M. Buchwitz, A. Butz, J. P. Burrows, C. W. O'Dell, S. Guerlet, O. Hasekamp, J. Heymann, N. Kikuchi, S. Oshchepkov, R. Parker, S. Pfeifer, O. Schneising, T. Yokota, and Y. Yoshida, A joint effort to deliver satellite retrieved atmospheric CO_2 concentrations for surface flux inversions: the ensemble median algorithm EMMA, Atmos. Chem. Phys., 13, 1771-1780, 2013.

/Saitoh et al., 2009/ Saitoh, N., R. Imasu, Y. Ota, and Y. Niwa, CO_2 retrieval algorithm for the thermal infrared spectra of the greenhouse gases observing satellite: Potential of retrieving CO_2 vertical profile from high-resolution FTS sensor, Journal of Geophysical Research D: Atmospheres, 114(17), 2009.

/Schneising et al., 2011/ Schneising, O., Buchwitz, M., Reuter, M., Heymann, J., Bovensmann, H., and Burrows, J. P.: Long-term analysis of carbon dioxide and methane column-averaged mole fractions retrieved from SCIAMACHY, Atmos. Chem. Phys., 11, 2863-2880, doi:10.5194/acp-11-2863-2011, 2011.

/Schneising et al., 2012/ Schneising, O., Bergamaschi, P., Bovensmann, H., Buchwitz, M., Burrows, J. P., Deutscher, N. M., Griffith, D. W. T., Heymann, J., Macatangay, R., Messerschmidt, J., Notholt, J., Rettinger, M., Reuter, M., Sussmann, R., Velazco, V. A., Warneke, T., Wennberg, P. O., and Wunch, D.: Atmospheric greenhouse gases retrieved from SCIAMACHY: comparison to ground-based FTS measurements and model results, Atmos. Chem. Phys., 12, 1527-1540, doi:10.5194/acp-12-1527-2012, 2012.

/Wunch et al., 2010/ Wunch, D., Toon, G. C., Wennberg, P. O., Wofsy, S. C., Stephens, B. B., Fischer, M. L., Uchino, O., Abshire, J. B., Bernath, P., Biraud, S. C., Blavier, J.-F. L.,

Boone, C., Bowman, K. P., Browell, E. V., Campos, T., Connor, B. J., Daube, B. C., Deutscher, N. M., Diao, M., Elkins, J. W., Gerbig, C., Gottlieb, E., Griffith, D. W. T., Hurst, D. F., Jimenez, R., Keppel-Aleks, G., Kort, E. A., Macatangay, R., Machida, T., Matsueda, H., Moore, F., Morino, I., Park, S., Robinson, J., Roehl, C. M., Sawa, Y., Sherlock, V., Sweeney, C., Tanaka, T., and Zondlo, M. A.: Calibration of the Total Carbon Column Observing Network using aircraft profile data, Atmos. Meas. Tech., 3, 1351–1362, doi:10.5194/amt-3-1351-2010, 2010.

/Wunch et al., 2011/ Wunch, D., Wennberg, P. O., Toon, G. C., Connor, B. J., Fisher, B., Osterman, G. B., Frankenberg, C., Mandrake, L., O'Dell, C., Ahonen, P., Biraud, S. C., Castano, R., Cressie, N., Crisp, D., Deutscher, N. M., Eldering, A., Fisher, M. L., Griffith, D. W. T., Gunson, M., Heikkinen, P., Keppel-Aleks, G., Kyro, E., Lindenmaier, R., Macatangay, R., Mendonca, J., Messerschmidt, J., Miller, C. E., Morino, I., Notholt, J., Oyafuso, F. A., Rettinger, M., Robinson, J., Roehl, C. M., Salawitch, R. J., Sherlock, V., Strong, K., Sussmann, R., Tanaka, T., Thompson, D. R., Uchino, O., Warneke, T., and Wofsy, S. C.: A method for evaluating bias in global measurements of CO_2 total columns from space, Atmos. Chem. Phys., 11, 20899–20946, doi:10.5194/acpd-11-20899-2011, 2011.

/Yoshida et al., 2013/ Yoshida, Y. Kikuchi, N., Morino, I., et al., Improvement of the retrieval algorithm for GOSAT SWIR XCO_2 and XCH_4 and their validation using TCCON data, Atmos. Meas. Tech., 6, 1533–1547, www.atmos-meas-tech.net/6/1533/2013/, doi:10.5194/amt-6-1533-2013, 2013.

3 Acronyms

Abbreviation	Meaning
ACA	Additional Constraints Algorithm (of GHG-CCI)
AK	Averaging Kernel
ASR	Algorithm Selection Report
ATBD	Algorithm Theoretical Basis Document
BESD	Bremen optimal EStimation DOAS
CCI	Climate Change Initiative
CRDP	Climate Research Data Package
DMF	Dry Mole Fraction
DOAS	Differential Optical Absorption Spectroscopy
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V.
ECA	ECV Core Algorithm (of GHG-CCI)
ECV	Essential Climate Variable
EMMA	Ensemble Median Algorithm
ESA	European Space Agency
FCDR	Fundamental Climate Data Record
FP	Full Physics
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
GMES	Global Monitoring for Environment and Security
GOSAT	Greenhouse Gas Observing Satellite
IMAP-DOAS	Iterative Maximum A posteriori (IMAP) DOAS

IPCC	International Panel in Climate Change
IUP	Institute of Environmental Physics (IUP) of the University of Bremen, Germany
MACC	Monitoring Atmospheric Composition and Climate, EU GMES project
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
NASA	National Aeronautics and Space Administration
NIES	National Institute for Environmental Studies
NOAA	National Oceanic and Atmospheric Administration
OCO	Orbiting Carbon Observatory
OE	Optimal Estimation
PBL	Planetary Boundary Layer
PR	PRoxy algorithm
PUG	Product User Guide
PVIR	Product Validation and Intercomparison Report
RTM	Radiative transfer model
SCIATRAN	Radiative transfer model for SCIAMACHY developed and continuously improved at IUP
SCIAMACHY	SCanning Imaging Absorption spectroMeter for Atmospheric CHartograghY
TANSO	Thermal And Near infrared Sensor for carbon Observation
TBC	To be confirmed
TCCON	Total Carbon Column Observing Network
TBD	To be defined / to be determined
VMR	Volume Mixing Ratio
WFM-DOAS (or WFMD)	Weighting Function Modified DOAS

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