

IWGGMS-14, U. Toronto, Canada, 8-10 May 2018

# First Copernicus Climate Change Service (C3S) satellite-derived greenhouse gas (CO<sub>2</sub>, CH<sub>4</sub>) data sets



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Research conducted under the framework of the GOSAT RA (Project CONSCIGO)



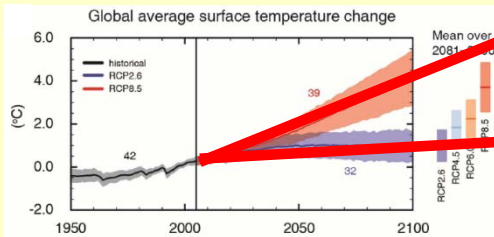
*Funding:*



# Essential Climate Variable (ECV) „Greenhouse Gases“

**CO<sub>2</sub> and CH<sub>4</sub> are the two most important greenhouse gases emitted by humans & increasing atmospheric concentrations result in global warming.**

**Observed and predicted temperature change (AR5)**



**Future?**

**Economie?**

**Population?**

**Technology?**

**GHG sources and sinks?**

Reliable climate prediction requires a good understanding of the natural and anthropogenic (surface) **sources and sinks of CO<sub>2</sub> and CH<sub>4</sub>**.

Important questions are, for example

- Where are they ?
- How strong are they ?
- How do they respond to a changing climate ?

A better understanding requires appropriate global observations and (inverse) modelling.

**ECV GHG (GCOS-154\*):**

**“Retrievals of greenhouse gases, such as CO<sub>2</sub> and CH<sub>4</sub>, of sufficient quality to estimate regional sources and sinks.”**

**\*) „SYSTEMATIC OBSERVATION REQUIREMENTS FOR SATELLITE-BASED DATA PRODUCTS FOR CLIMATE“**

# Overview key European programmes / projects

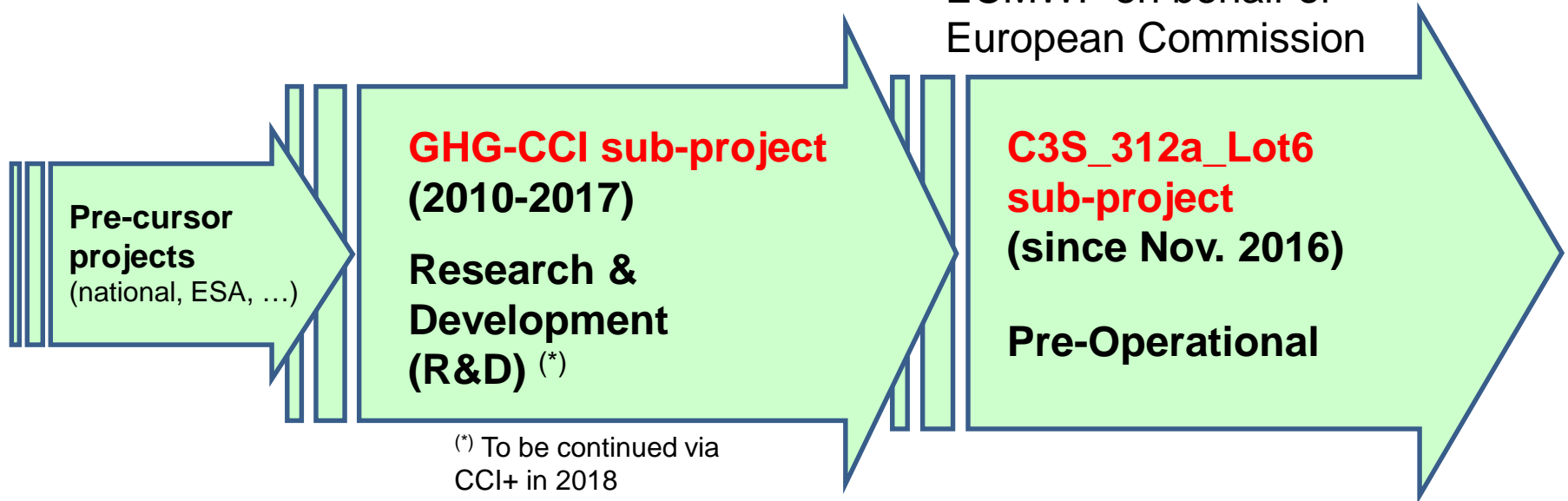
Long-term accurate satellite derived CO<sub>2</sub> and CH<sub>4</sub> for climate applications:

<http://www.esa-ghg-cci.org/>

<https://climate.copernicus.eu/>

**Climate Change Initiative (CCI):** ESA

**Copernicus Climate Change Service (C3S):**  
ECMWF on behalf of European Commission



Fast (Near-Real-Time) satellite derived CO<sub>2</sub> and CH<sub>4</sub> for, e.g., forecasting:

<http://atmosphere.copernicus.eu/>

**Copernicus Atmosphere Monitoring Service (CAMS):**  
ECMWF on behalf of EC

# C3S GHG satellite data products

## Individual sensor Level 2 (L2) products:

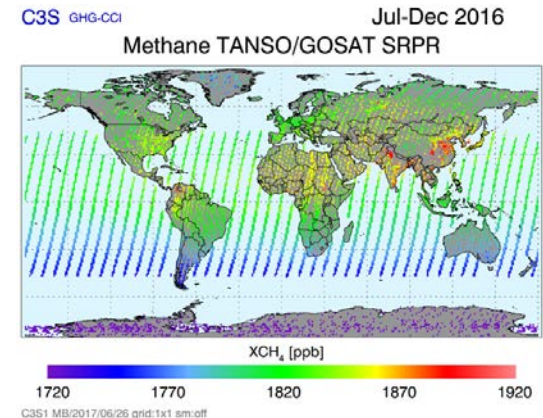
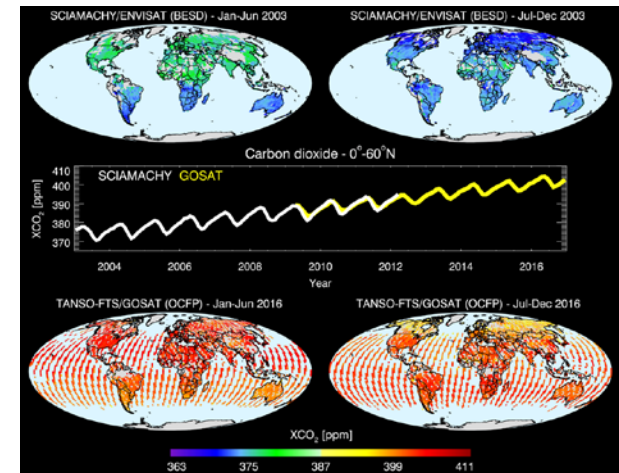
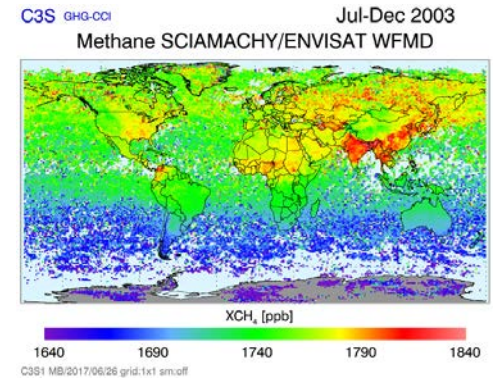
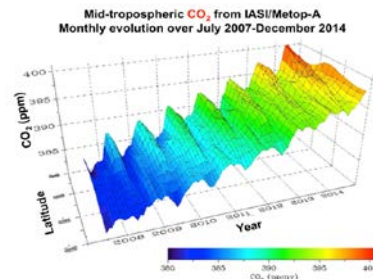
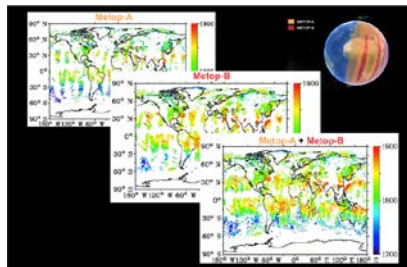
- **SCIAMACHY XCO<sub>2</sub>** (CO2\_SCI\_BESD, CO2\_SCI\_WFMD)
- **SCIAMACHY XCH<sub>4</sub>** (CH4\_SCI\_WFMD, CH4\_SCI\_IMAP)
- **GOSAT XCO<sub>2</sub>** (CO2\_GOS\_OCFP, CO2\_GOS\_SRFP)
- **GOSAT XCH<sub>4</sub>** (CH4\_GOS\_OCFP, CH4\_GOS\_SRFP, CH4\_GOS\_OCPR, CH4\_GOS\_SRPR)
- **IASI mid-trop CO<sub>2</sub>** (CO2\_IASA\_NLIS, CO2\_IASB\_NLIS)
- **IASI mid-trop CH<sub>4</sub>** (CO2\_IASA\_NLIS, CO2\_IASB\_NLIS)
- **AIRS mid-trop CO<sub>2</sub>** (CO2\_AIR\_NLIS)

## Merged L2 products:

- **XCO<sub>2</sub>\_EMMA** (based on listed indiv. sensor L2 products + GOSAT/NIES + GOSAT/NASA/ACOS)
- **XCH<sub>4</sub>\_EMMA** (based on listed indiv. sensor L2 products + GOSAT/NIES)

## Merged L3 products:

- **XCO<sub>2</sub>\_OBS4MIPS** (based on merged L2 product)
- **XCH<sub>4</sub>\_OBS4MIPS** (based on merged L2 product)



# GHG-CCI: <http://www.esa-ghg-cci.org/>

Datei Bearbeiten Ansicht Chronik Lesezeichen Extras Hilfe


ESA GHG CCI website | CO2 will X

www.esa-ghg-cci.org 90% Suchen

**esa** climate change initiative European Space Agency

ESA | CCI | aerosol | cloud | cmug | fire | ghg | glaciers | land cover | ocean col. | ozone | sea ice | sea level | soil moi. | sst | ice sheets

## ghg

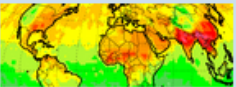



### GHG-CCI

Carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>) are the two most important anthropogenic greenhouse gases (GHGs). Satellite observations combined with modelling helps to improve our knowledge on CO<sub>2</sub> and CH<sub>4</sub> sources and sinks as required for better climate prediction. GHG-CCI aims at delivering the high quality satellite retrievals needed for this application.

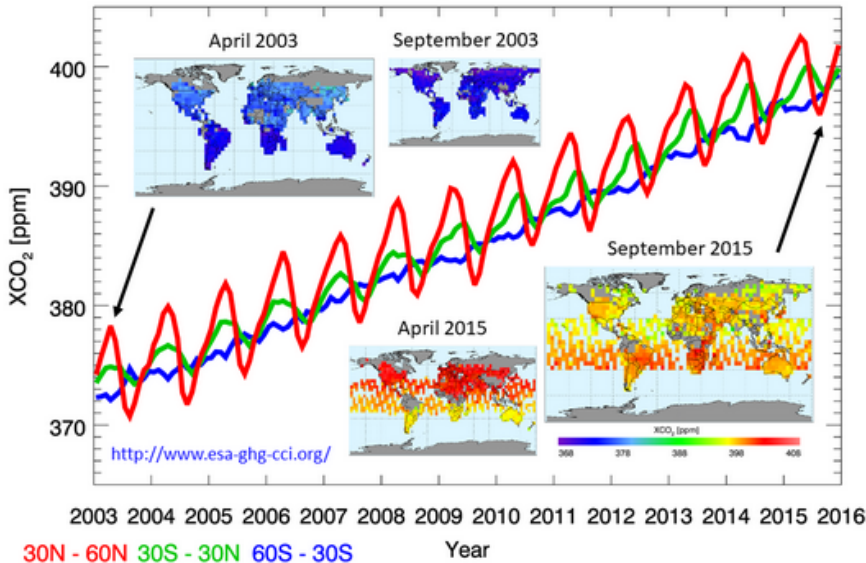
### Navigation

- Overview
- Project Team
- Product Description
- Round Robin
- CRDP (Data)
- Validation
- Publications
- Contact
- Documents
- Image Gallery
  - Carbon Dioxide
  - Methane



Hosted by IUP  
 Universität Bremen

### Carbon dioxide SCIAMACHY/ENVISAT & TANSO-FTS/GOSAT



30N - 60N 30S - 30N 60S - 30S

### User login

Username: \*

Password: \*

Log in

Request new password

### Search

Search this site:

Search

### Calendar

<< April 2018 >>

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2	3	4	5	6	7	8

# C3S: <https://climate.copernicus.eu/>

The screenshot shows the homepage of the Copernicus Climate Change Service (C3S). The browser address bar displays <https://climate.copernicus.eu>. The website header includes the Copernicus logo (Europe's eyes on Earth) and the Climate Change Service logo. A navigation menu contains links for ABOUT C3S, NEWS & MEDIA, EVENTS, TENDERS, PRODUCTS, SERVICES, and HELP & SUPPORT. A search bar is located in the top right corner. The main banner features a composite image of an airplane, a field of wheat, and a dam, with the text "CLIMATE SERVICES FOR YOUR OPERATIONS". Below the banner, there are three main sections: "IN FOCUS" with a workshop photo and a "READ MORE" button; "MONTHLY MAPS & CHARTS" with a globe and charts and an "ARCHIVE" button; and "NEWS" with three articles: "C3S Attribution workshop organised in Prague" (18 Oct 2017), "Sentinel-5P successfully launched" (13 Oct 2017), and "The warmest 24 months on record - highlights from the September monthly summaries of C3S" (10 Oct 2017). A footer contains a cookie consent message and "OK, I agree" and "No, give me more info" buttons.

## Our contributions:

- Long-term accurate satellite-derived CO<sub>2</sub> and CH<sub>4</sub>
- Extended each year by one year (data set No. 1: 2003-2016)

# CAMS: <http://atmosphere.copernicus.eu/>

File Bearbeiten Ansicht Chronik Lesezeichen Extras Hilfe

Copernicus Atmosphäre Monitoring Service

Suchen

CONTACT US

Search

ABOUT CAMS NEWS & MEDIA EVENTS CATALOGUE RESOURCES TENDERS HELP & SUPPORT

Global total column forecasts  
Live Map

IN FOCUS

Sentinel-5P successfully launched  
12 Oct 2017

READ MORE

CATALOGUE

FIRE MONITORING  
Observed Distribution of the Fire Thermal Radiation

HEADLINE PRODUCTS

NEWS

16 Oct 2017  
Saharan dust and smoke over France and UK

12 Oct 2017  
Sentinel-5P successfully launched

04 Oct 2017  
Results of the CAMS User Satisfaction Survey 2017 now available

ARCHIVE

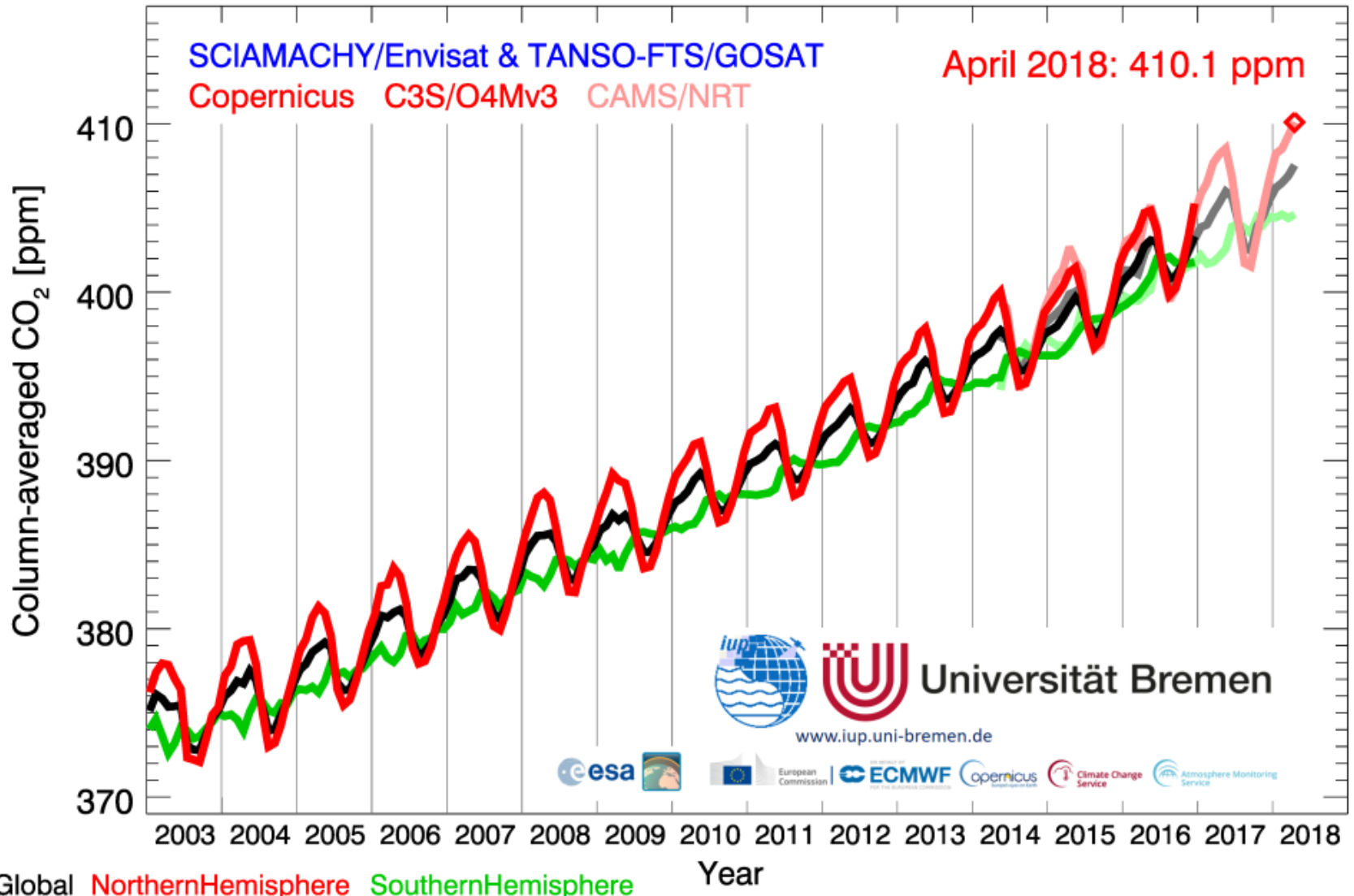
This website uses Cookies and Social Media Plugins to improve the user experience. By browsing this site without changing the settings of your browser, you will accept the Cookies.

OK, I agree No, give me more info

Our contributions: Satellite-derived products in quasi-NRT:  
GOSAT XCO<sub>2</sub> (U. Bremen), GOSAT XCH<sub>4</sub> (SRON),  
IASI mid-trop CH<sub>4</sub> (LMD/CNRS), GOSAT SIF (U. Leicester)

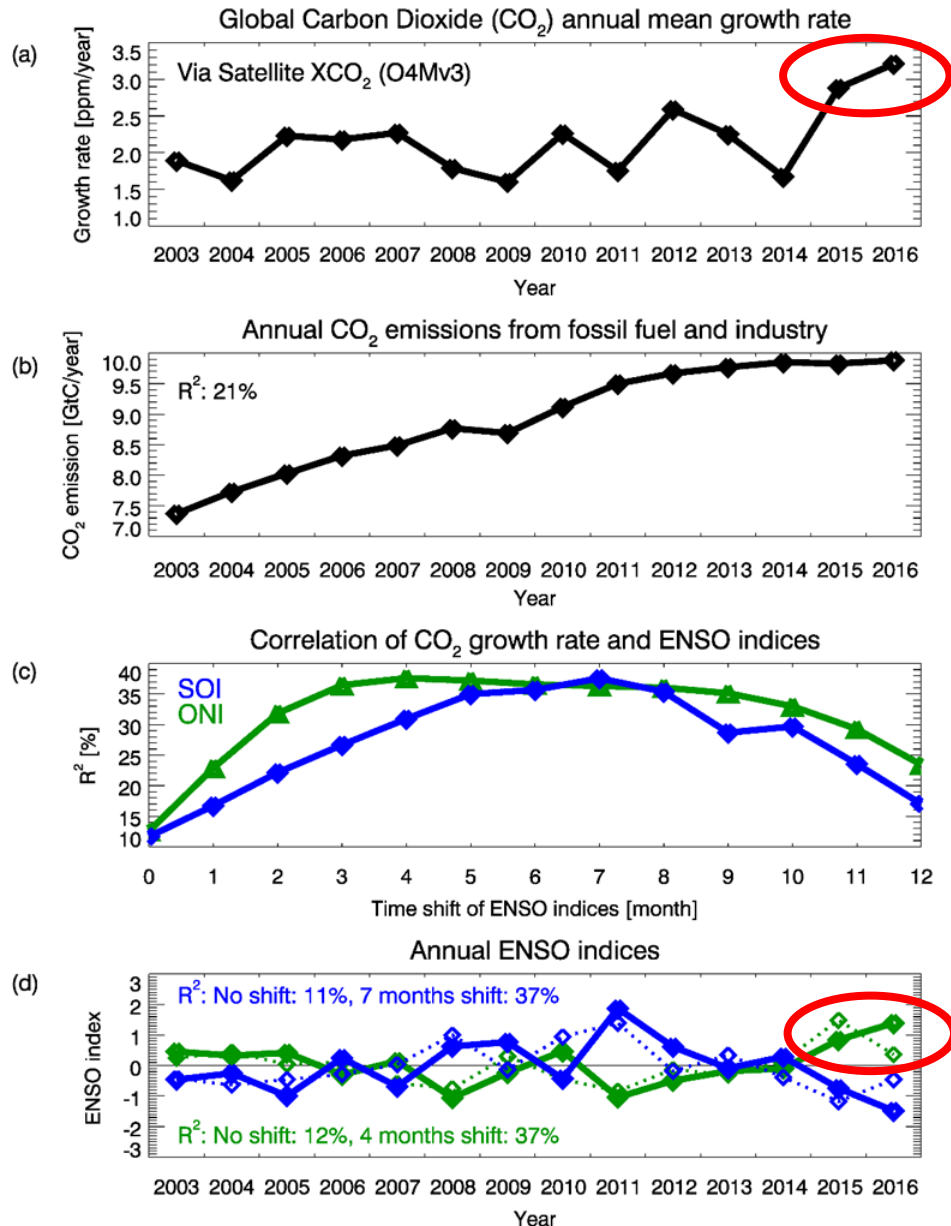
# C3S and CAMS XCO<sub>2</sub> time series

## Atmospheric Carbon Dioxide (CO<sub>2</sub>) from Satellites





# XCO2\_OBS4MIPS: Annual mean XCO<sub>2</sub> growth rates



Large increase of atmospheric CO<sub>2</sub> during 2015 & 2016 (~ 3 ppm/year)

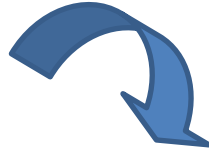
... despite nearly constant CO<sub>2</sub> emissions

Reason: 2015 / 2016 El Nino

Buchwitz et al.,  
ACPD (in review), 2018

# Requirements

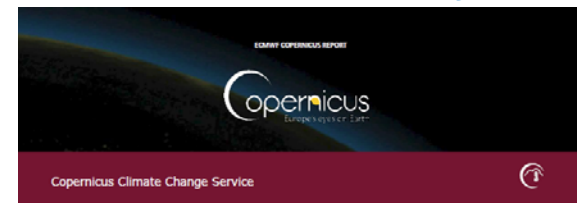
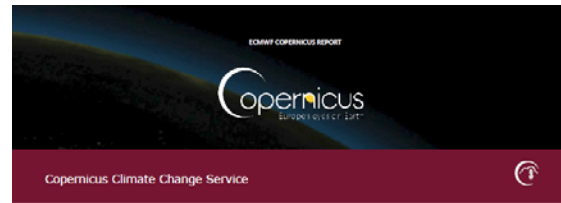
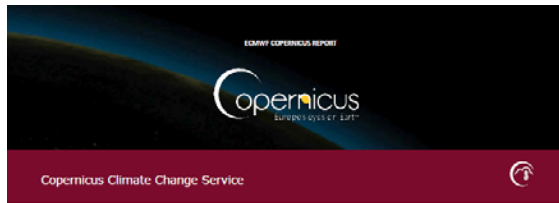
# C3S GHG: Documentation



## User Guide

## ATBD

## Product Quality



### Product User Guide and Specification (PUGS) – Main document

C3S\_312a\_Lot6\_IUP-UB – Greenhouse Gases

Issued by: Michael Buchwitz, University of Bremen,  
Institute of Environmental Physics (IUP)  
Date: 20/10/2017  
Ref: C3S\_D312a\_Lot6.3.1.5\_v1\_PUGS\_MAIN\_v1.3  
Official reference number service contract: 2016/C3S\_312a\_Lot6\_IUP-UB/SC1

### Algorithm Theoretical Basis Document (ATBD) – Main document

C3S\_312a\_Lot6\_IUP-UB – Greenhouse Gases

Issued by: Michael Buchwitz, University of Bremen,  
Institute of Environmental Physics (IUP)  
Date: 20/10/2017  
Ref: C3S\_D312a\_Lot6.2.1.2-v1\_ATBD\_MAIN\_v1.1  
Official reference number service contract: 2016/C3S\_312a\_Lot6\_IUP-UB/SC1

### Product Quality Assessment Report (PQAR) – Main document

C3S\_312a\_Lot6\_IUP-UB – Greenhouse Gases

Issued by: Michael Buchwitz, University of Bremen,  
Institute of Environmental Physics (IUP)  
Date: 20/10/2017  
Ref: C3S\_D312a\_Lot6.3.1.7-v1\_PQAR\_v1.1  
Official reference number service contract: 2016/C3S\_312a\_Lot6\_IUP-UB/SC1




Main document + several ANNEXes per product / groups of products

# GHG-CCI: Data quality: XCO<sub>2</sub>

Based on comparisons with



	ESA Climate Change Initiative (CCI)	Page 1
	Product Validation and Intercomparison Report (PVIR)	Version 5.0 Final
	for the Essential Climate Variable (ECV) Greenhouse Gases (GHG)	9 Feb 2017



ESA Climate Change Initiative (CCI)

## Product Validation and Intercomparison Report (PVIR)

for the Essential Climate Variable (ECV)

### Greenhouse Gases (GHG)

for data set

### Climate Research Data Package No. 4 (CRDP#4)

Written by:

GHG-CCI Validation Team (VALT) and Earth Observation Science Team (EOST):

Michael Buchwitz (lead author, IUP-UB), Bart Dils (BIRA), Hartmut Boesch (Univ. Leicester), Dominik Brunner (Empa), André Butz (KIT/DLR), Cyril Crevoisier (LMD), Robert Detmers (SRON), Christian Frankenberg (JPL/CalTech), Otto Hasekamp (SRON), William Hewson (Univ. Leicester), Alexandra Laeng (KIT), Stefan Noël (IUP-UB), Justus Notholt (IUP-UB), Robert Parker (Univ. Leicester), Maximilian Reuter (IUP-UB), Oliver Schneising (IUP-UB), Peter Somkuti (Univ. Leicester), Anu-Maija Sundström (Empa), Evelyn De Wachter (BIRA)

[http://www.esa-ghg-cci.org/?q=webfm\\_send/352](http://www.esa-ghg-cci.org/?q=webfm_send/352)

(253 pages)

## GHG-CCI: Estimates of achieved data quality (#): CRDP#4 XCO<sub>2</sub>

Sensor	Algorithm	Random error [ppm]	Systematic error [ppm]	Stability [ppm/year]		Details (section)
				Long-term drift	Year-to-year	
SCIAMACHY on ENVISAT	BESD v02.01.02	1.9	0.37 - 0.56	-0.03 +/- 0.06 (*)	0.32 +/- 0.08	VAL (Sect. 3)
		1.9	0.38 - 0.40	-0.13 +/- 0.28 (?)	0.34 (?)	DP (6.1.1)
		2.0	0.39 - 0.43	-0.02 +/- 0.33 (?)	0.23 (?)	EMMA (6.1.5)
		1.9	0.4 - 0.8	-0.01 +/- 0.08 (*)	1.68 +/- 2.03 (*)	QA/QC (7.1)
SCIAMACHY on ENVISAT	WFMD V4.0	2.7	0.57 - 0.71	-0.03 +/- 0.10 (*)	0.31 +/- 0.11	VAL (3)
		2.6	0.48 - 0.52	[0.00, 0.04] (?)	0.21 (?)	DP (6.1.2)
		2.9	0.60 - 0.75	0.14 +/- 0.21 (?)	0.46 (?)	DP (6.1.1)
		3.0	0.60 - 0.63	0.23 +/- 0.42 (?)	0.33 (?)	EMMA (6.1.5)
		2.7	0.5 - 1.0	-0.04 +/- 0.09 (*)	1.86 +/- 2.41 (*)	QA/QC (7.1)
TANSO on GOSAT	OCFP v7.0 (UoL-FP)	1.8	0.36 - 0.58	-0.07 +/- 0.07 (*)	0.29 +/- 0.06	VAL (3)
		1.9	0.47	0.11 (?)	0.9 (?)	DP (6.1.3)
		1.8	0.36 - 0.42	-0.15 +/- 0.11 (?)	0.23 (?)	EMMA (6.1.5)
		1.7	0.3 - 0.5	-0.09 +/- 0.08	1.48 +/- 2.06 (*)	QA/QC (7.1)
TANSO on GOSAT	SRFP v2.3.8 (RemoTeC)	2.0	0.36 - 0.51	0.02 +/- 0.04 (*)	0.27 +/- 0.12	VAL (3)
		1.9	0.43	-0.05 +/- 0.12 (*)	0.34 +/- 0.12	DP (6.1.4)
		2.1	0.28 - 0.48	0.00 +/- 0.16 (*)	0.24 (?)	EMMA (6.1.5)
		1.9	0.4 - 0.5	-0.06 +/- 0.11 (*)	1.30 +/- 2.11 (*)	QA/QC (7.1)
SCIAMACHY & GOSAT	EMMA v2.2a	2.0	0.37 - 0.45	0.08 +/- 0.22 (*)	0.18 +/- 0.12	VAL (3)
		2.4	0.47 - 0.54	-0.30 +/- 0.64 (?)	0.25 (?)	EMMA (6.1.5)
SCIAMACHY & GOSAT	EMMA v2.2b	1.7	0.29 - 0.38	-0.08 +/- 0.20 (*)	0.16 +/- 0.11	VAL (3)
		1.8	0.32 - 0.40	-0.13 +/- 0.42 (?)	0.20 (?)	EMMA (6.1.5)
TANSO on GOSAT	EMMA v2.2c	1.7	0.30 - 0.39	-0.14 +/- 0.20 (*)	0.16 +/- 0.12	VAL (3)
		1.8	0.24 - 0.44	-0.04 +/- 0.16 (?)	0.26 (?)	EMMA (6.1.5)
Required	G / B / T	< 1 / 3 / 8	< 0.2 / 0.3 / 0.5	< 0.2 / 0.3 / 0.5		/URD GHG-CCI v2.1/
Required	Target	< 0.5 ppm (uncertainty, 1-sigma)		< 0.15 ppm/year		/GCOS-200/

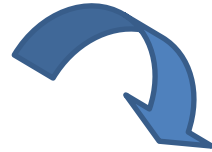
(#) As estimated (mostly) by comparison with ground-based TCCON observations neglecting TCCON accuracy (1-sigma) of 0.4 ppm

(\*) NOT significant; (?) Significance unclear

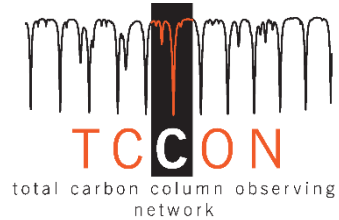
Green numbers: at least URDV2.1 threshold requirement met; single values random and systematic errors are 1-sigma

# Product Quality Assessment Report (PQAR): Overview XCO<sub>2</sub>

## Product Quality



Based on comparisons with



Product Quality Assessment Report (PQAR) – Main document

C35\_312a\_Lot6\_IUP-UB – Greenhouse Gases

Issued by: Michael Buchwitz, University of Bremen,  
Institute of Environmental Physics (IUP)  
Date: 20/10/2017  
Ref: C35\_D312a\_Lot6.3.1.7-v1\_PQAR\_v1.1  
Official reference number service contract: 2016/C35\_312a\_Lot6\_IUP-UB/SC1



Threshold requirement:

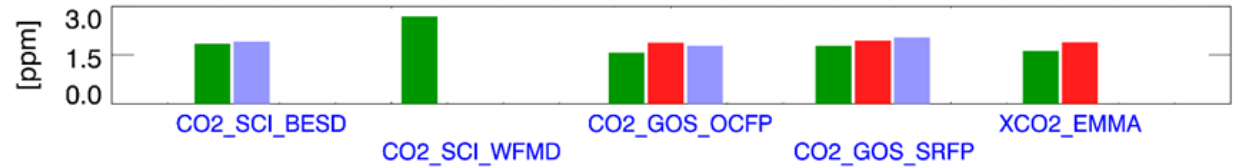
Accuracy: < 0.5 ppm

Stability: < 0.5 ppm/year

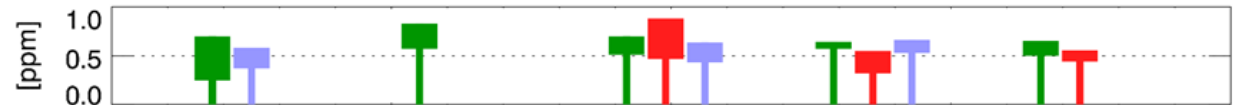
### C3S Level 2 products: XCO<sub>2</sub>

QA/QC method (applied to all products)  
DP methods (applied by data provider) EMMA method

#### Single measurement random error (precision, 1-sigma)

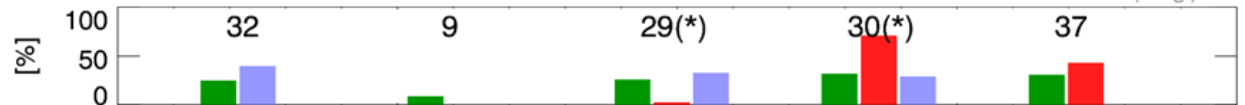


#### Accuracy (spatial/spatio-temporal bias range)



#### Accuracy: Probability that TR is met

Unc.reference (1-sig.): 0.4



#### Stability (drift, +/- 3-sigma)



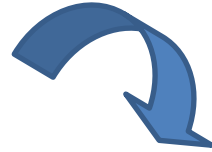
#### Stability: Probability that TR is met

Unc.reference (1-sig.): 0.2

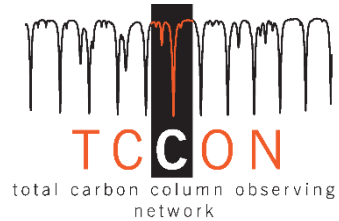


# Product Quality Assessment Report (PQAR): Overview XCH<sub>4</sub>

## Product Quality



Based on comparisons with



Product Quality Assessment Report (PQAR) – Main document

C35\_312a\_Lot6\_IUP-UB – Greenhouse Gases

Issued by: Michael Buchwitz, University of Bremen,  
Institute of Environmental Physics (IUP)  
Date: 20/10/2017  
Ref: C35\_D312a\_Lot6.3.1.7-v1\_PQAR\_v1.1  
Official reference number service contract: 2016/C35\_312a\_Lot6\_IUP-UB/SCI



Threshold requirement:

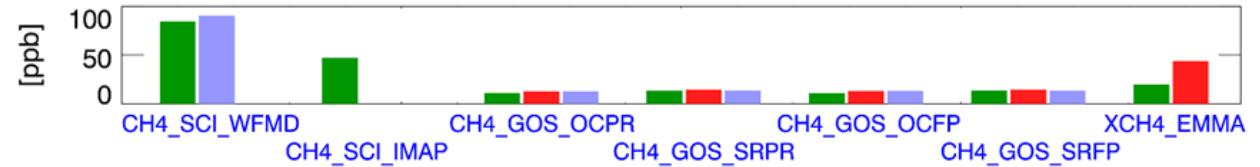
Accuracy: < 10 ppb

Stability: < 3 ppb/year

C3S Level 2 products: XCH<sub>4</sub>

QA/QC method (applied to all products)  
DP methods (applied by data provider) EMMA method

Single measurement random error (precision, 1-sigma)



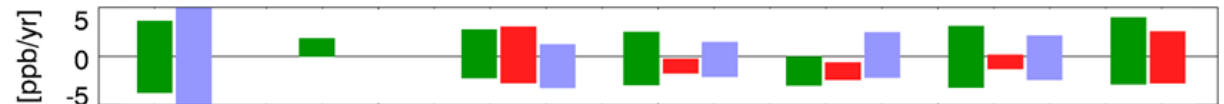
Accuracy (spatial/spatio-temporal bias range)



Accuracy: Probability that TR is met



Stability (drift, +/- 3-sigma)

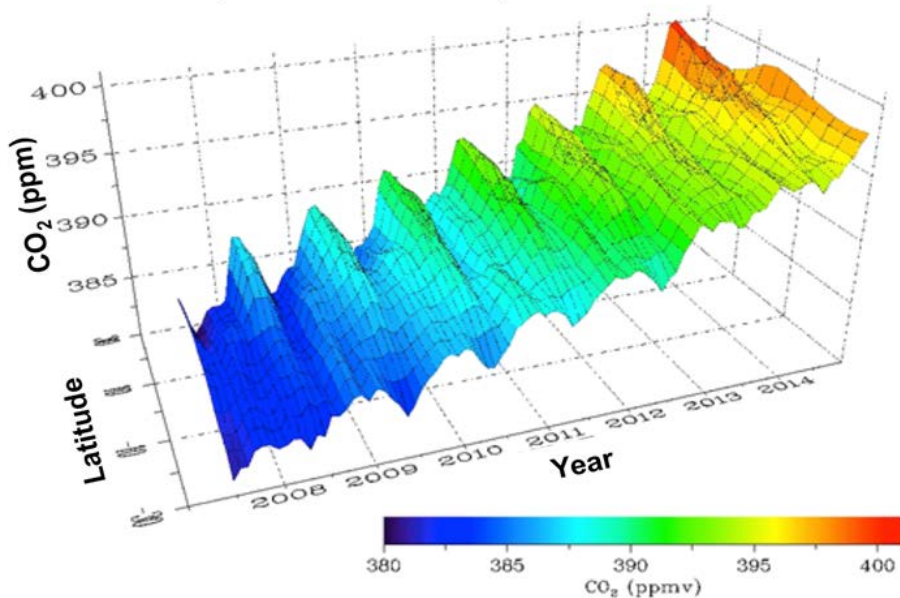


Stability: Probability that TR is met



# Mid-tropospheric CO<sub>2</sub> and CH<sub>4</sub> IASI Metop-A & Metop-B

Mid-tropospheric CO<sub>2</sub> from IASI/Metop-A  
Monthly evolution over July 2007-December 2014



CH<sub>4</sub> IASA\_NLIS: 2007-2015

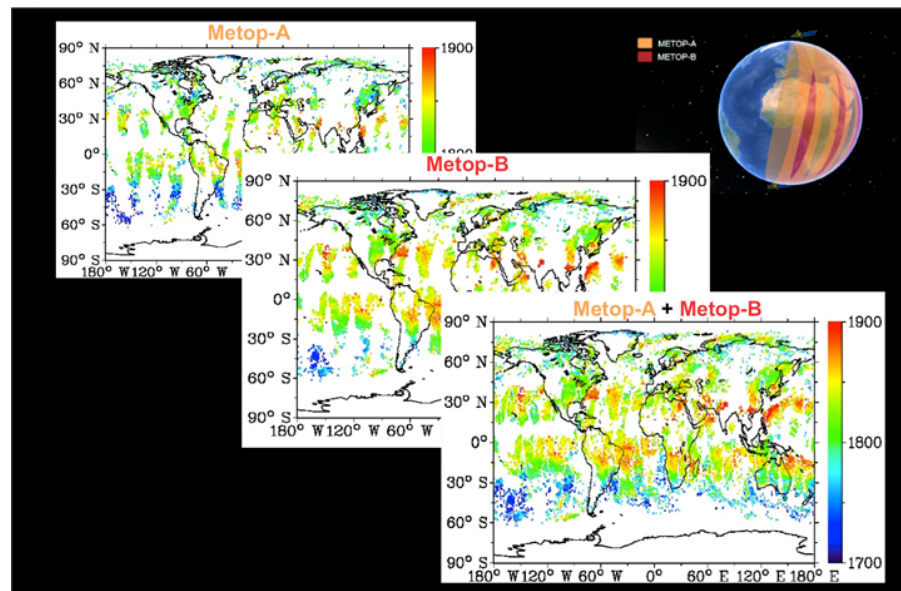
CH<sub>4</sub> IASB\_NLIS: 2013-2016

First data set:

- Daily NetCDF as for all other L2 products

CO<sub>2</sub>\_IASA\_NLIS: 2007-2015

CO<sub>2</sub>\_IASB\_NLIS: 2013-2016



# Summary & conclusions

- The GHGs CO<sub>2</sub> and CH<sub>4</sub> are „Essential Climate Variables“ (**ECVs**)
- Key European projects & related GHG satellite contributions:
  - **GHG-CCI** (R&D) and **C3S** ((pre-)operational processing) for carbon & climate applications
  - **CAMS** NRT, e.g., for ECMWF forecasting
- First C3S satellite-derived GHG data set (2003-2016) soon available via **Copernicus Climate Data Store** (CDS; <https://climate.copernicus.eu/>)
- Second C3S data set (2003-2017) available end of 2018
- Future versions will also include other sensors: OCO-2, Sentinel-5-Precursor, GOSAT-2, ...

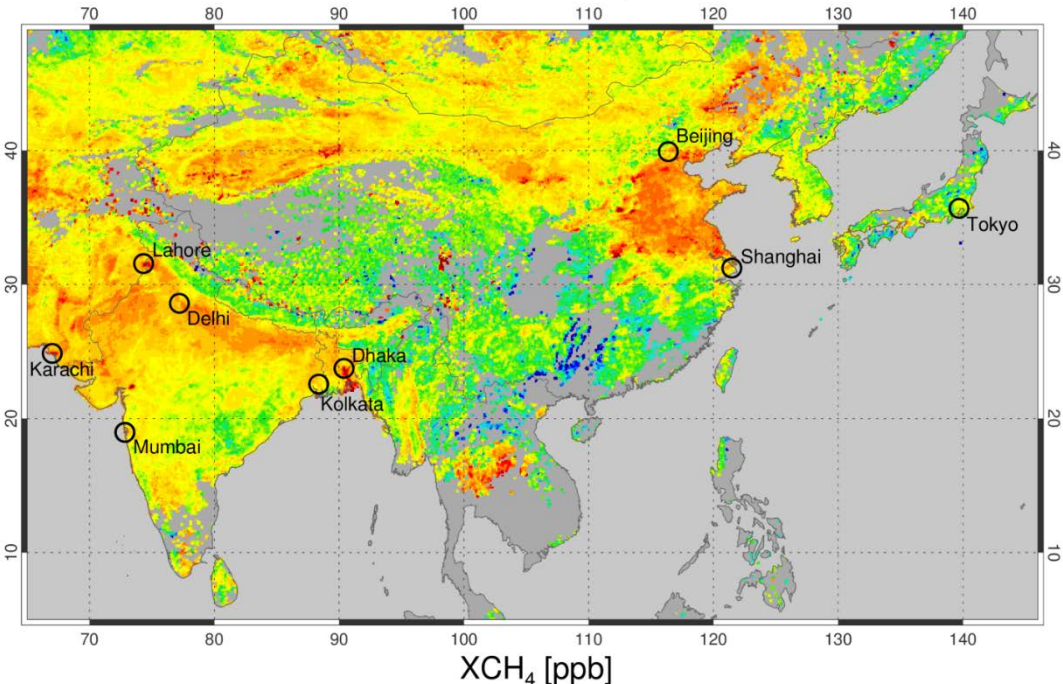
# First preliminary results from S5P via scientific algorithm WFM-DOAS



Universität Bremen

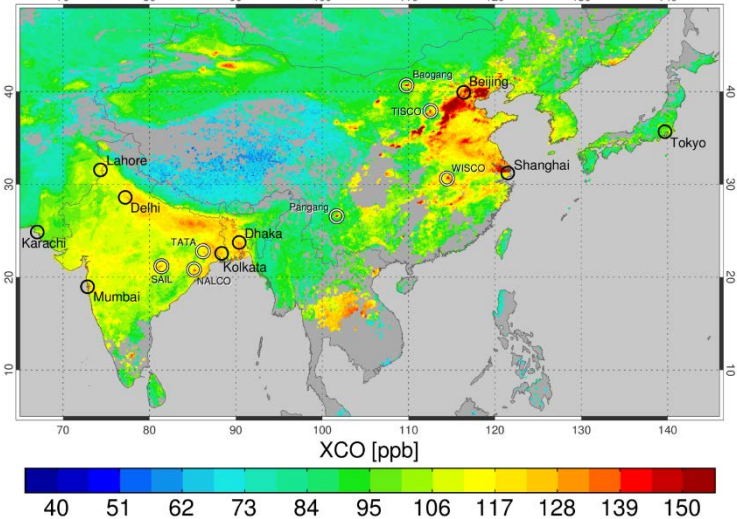


TROPOMI/WFMD XCH<sub>4</sub> 20171116-29

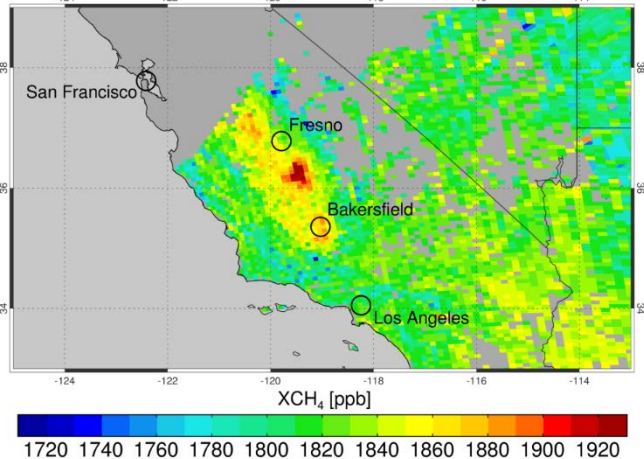


1700 1719 1738 1757 1776 1795 1814 1833 1852 1871 1890

TROPOMI/WFMD XCO 20171116-29



TROPOMI/WFMD XCH<sub>4</sub> 20171122



**Disclaimer:** The presented work has been performed within the framework of the Sentinel-5 Precursor Validation Team or Level 1/Level 2 Product Working Group activities. Results are based on preliminary (not fully calibrated/validated) Sentinel-5 Precursor data that are still subject to change.

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