# On Question # 12

# SCIAMACHY's capabilities to measure GHG

**H. Bovensmann, M. Reuter, O. Schneising, M. Buchwitz, John P. Burrows**
**University of Bremen, Institute of Environmental Physics**

EUMETSAT

Universität Bremen

Netherlands Space Office

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# SCIAMACHY Project Partners

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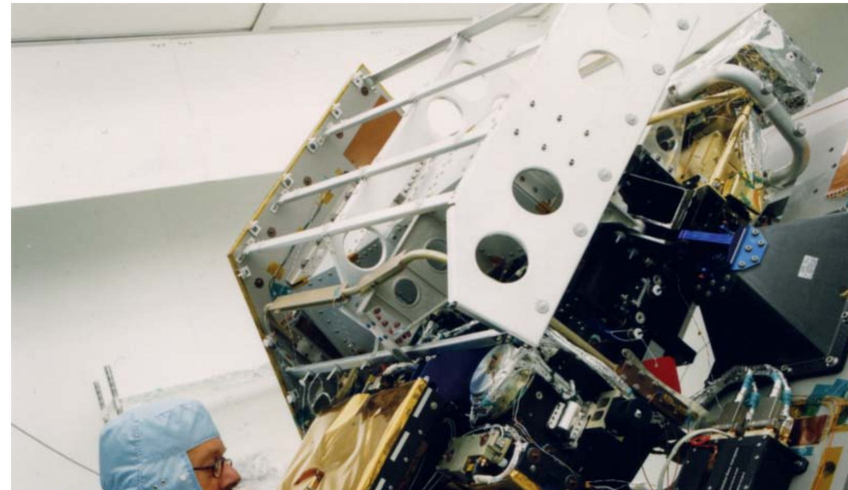
TNO

# SCIAMACHY: History

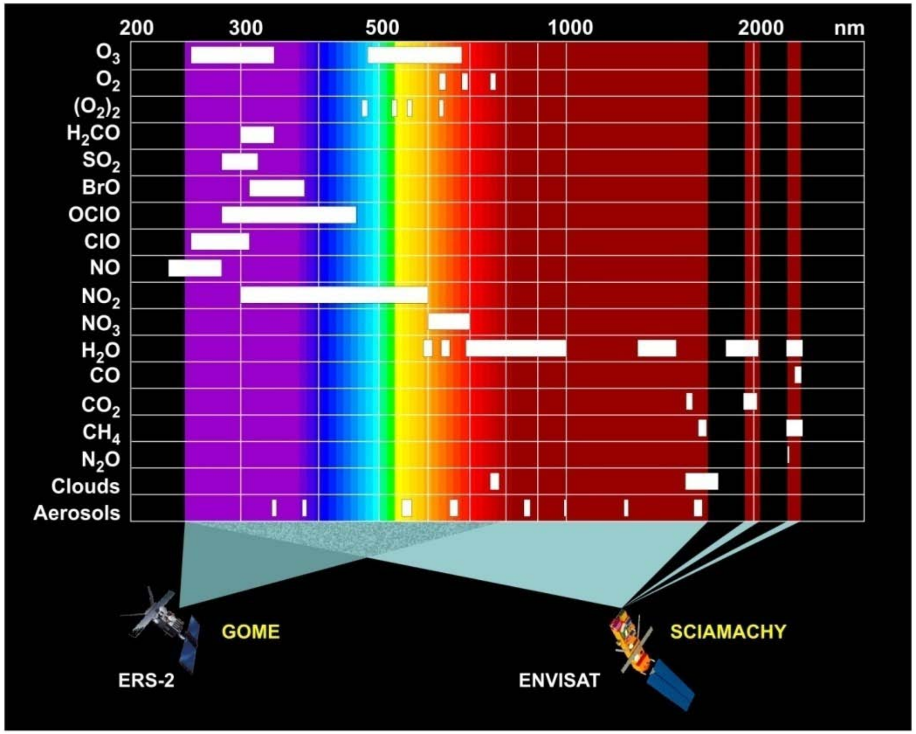
| | |
|---|---|
| 1984 | First space-DOAS proposal to ESA |
| 1985 | Stratospheric ozone hole observed by Farman et al. (Nature) |
| ***1988*** | ***SCIAMACHY proposed to ESA*** |
| 1988/89 | SCIA-mini/GOME (Global Ozone Monitoring Experiment) for ERS-2 |
| ***1989 – 2002*** | ***Design and Development of SCIAMACHY for ENVISAT*** |
| April 1995 | Launch of ERS-2 with GOME |
| 1997-2000 | Selection of GOME-2 for the EUMETSAT operational series MetOp |
| ***February 2002*** | ***Launch of ENVISAT with SCIAMACHY*** |
| July 2004 | AURA launch with OMI |
| October 2006 | MetOp launch with GOME-2 |
| *2014/15* | *Launch of Sentinel 5 Precursor* |
| *2018* | *Launch of CarbonSat EE8 (tbd)* |
| *2018/19* | *Launch of Sentinel 4 on MTG* |
| *~ 2020* | *Launch of Sentinel 5 on PostEPS* |

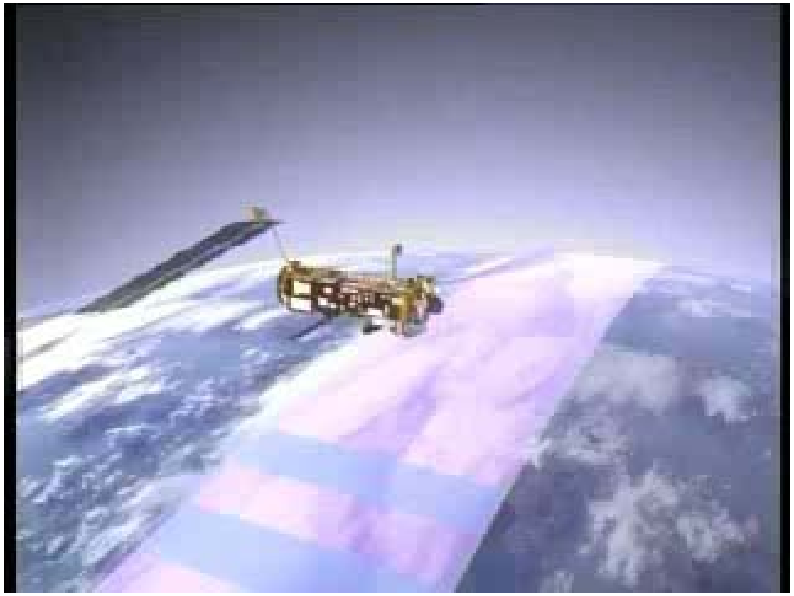
**sciamachy** /sʌɪˈaməki/ *n.* (also **skiamachy** /skʌɪ-/) *formal* **1** fighting with shadows. **2** imaginary or futile combat. [Greek *skiamakhia* (as SCIAGRAPHY, *-makhia* '-fighting')]



# SCIAMACHY Measurements

- grating spectrometer 240 - 2380 nm
- Spectral reolution 0.2 – 1.6 nm
- Spatial resolution typically 30 × 60 km$^2$
- Nadir, limb scattering and solar & lunar occultation measurements



- Global coverage in 6 days
- Mainly absorption spectroscopy is used to derive trace gas distributions in the **troposphere, stratosphere and mesosphere**

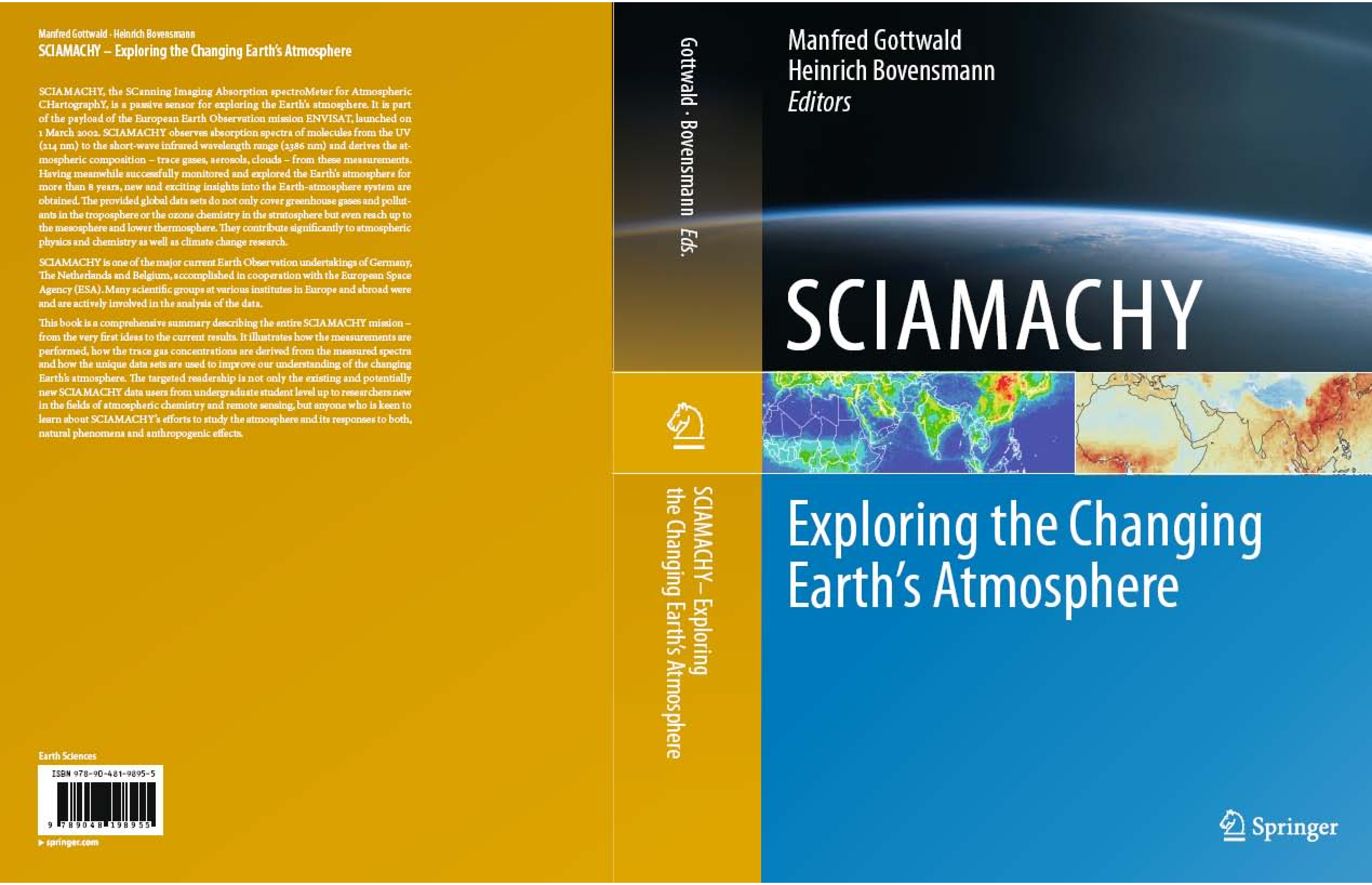
**sciamachy** /sʌɪˈaməki/ *n.* (also **skiamachy** /skʌɪ-/) *formal* **1** fighting with shadows. **2** imaginary or futile combat. [Greek *skiamakhia* (as SCIAGRAPHY, *-makhia* '-fighting')]

**SCIAMACHY: SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY**

# SCIAMACHY Key Achievements

- SCIAMACHY provides unique global data sets and their temporal change e.g.
  - change in atmospheric pollutants
  - greenhouse gases distributions
  - stratospheric and mesospheric composition and its interaction with the sun
  - Top of the Atmosphere Solar Radiance 240 nm – 2.4µm
  - Land and Ocean Colour with high spectral resolution

- SCIAMACHY and ENVISAT are both performing excellently; mission extended until 2013/14, discussion on further extension ongoing
- Over 500 SCIAMACHY peer-reviewed publications thus far!
- SCIAMACHY data was and is used in more then 50 international and national projects
- SCIAMACHY, a pathfinder mission, generating
  - GMES atmosphere prototype service demonstration
  - Improved mission concepts for atmospheric monitoring (GOME, OMI, GMES Sentinel 5P, 4 & 5 and CarbonSat)


Manfred Gottwald · Heinrich Bovensmann

SCIAMACHY – Exploring the Changing Earth's Atmosphere

SCIAMACHY, the SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY, is a passive sensor for exploring the Earth's atmosphere. It is part of the payload of the European Earth Observation mission ENVISAT, launched on 1 March 2002. SCIAMACHY observes absorption spectra of molecules from the UV (214 nm) to the short-wave infrared wavelength range (2386 nm) and derives the atmospheric composition – trace gases, aerosols, clouds – from these measurements. Having meanwhile successfully monitored and explored the Earth's atmosphere for more than 8 years, new and exciting insights into the Earth-atmosphere system are obtained. The provided global data sets do not only cover greenhouse gases and pollutants in the troposphere or the ozone chemistry in the stratosphere but even reach up to the mesosphere and lower thermosphere. They contribute significantly to atmospheric physics and chemistry as well as climate change research.

SCIAMACHY is one of the major current Earth Observation undertakings of Germany, The Netherlands and Belgium, accomplished in cooperation with the European Space Agency (ESA). Many scientific groups at various institutes in Europe and abroad were and are actively involved in the analysis of the data.

This book is a comprehensive summary describing the entire SCIAMACHY mission – from the very first ideas to the current results. It illustrates how the measurements are performed, how the trace gas concentrations are derived from the measured spectra and how the unique data sets are used to improve our understanding of the changing Earth's atmosphere. The targeted readership is not only the existing and potentially new SCIAMACHY data users from undergraduate student level up to researchers new in the fields of atmospheric chemistry and remote sensing, but anyone who is keen to learn about SCIAMACHY's efforts to study the atmosphere and its responses to both, natural phenomena and anthropogenic effects.

Earth Sciences

ISBN 978-90-481-9895-5

▸ springer.com

Gottwald · Bovensmann *Eds.*

SCIAMACHY – Exploring the Changing Earth's Atmosphere

Manfred Gottwald
Heinrich Bovensmann
*Editors*

SCIAMACHY

Exploring the Changing Earth's Atmosphere

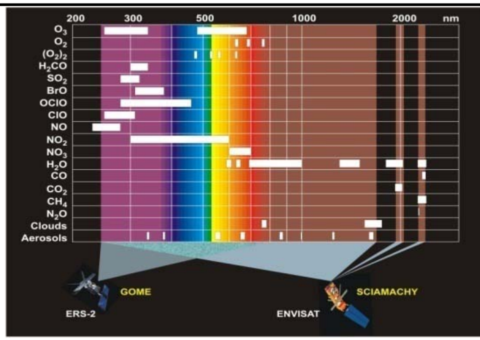
Springer

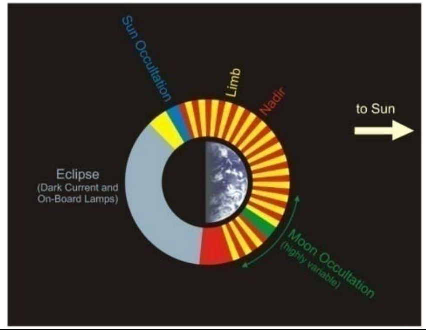
Universität Bremen

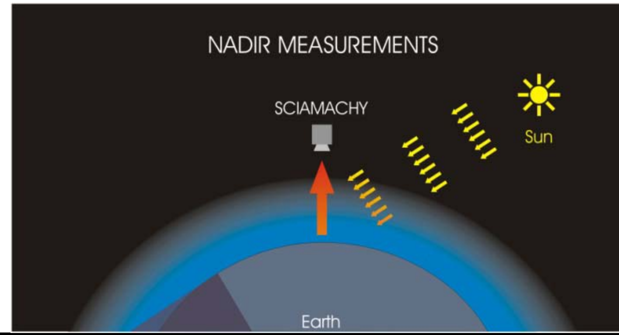
**SCIAMACHY - Exploring the Changing Earth's Atmosphere**

Gottwald, Manfred; Bovensmann, Heinrich (Eds.) 1st Edition., 2011, 240 p. 50 illus. in color., Hardcover, ISBN: 978-90-481-9895-5

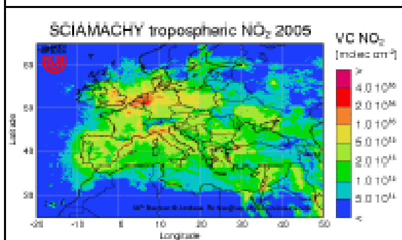
# SCIAMACHY tropospheric data products



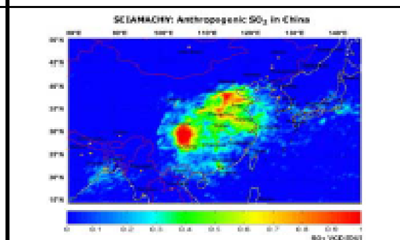



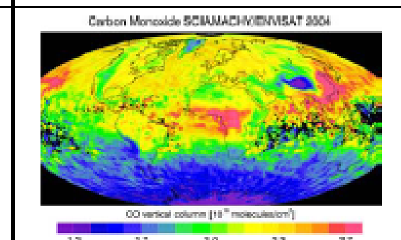

## NO2



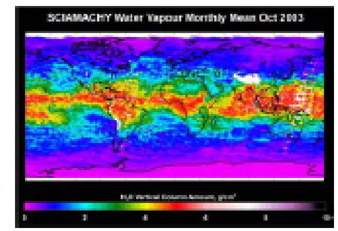

## SO2



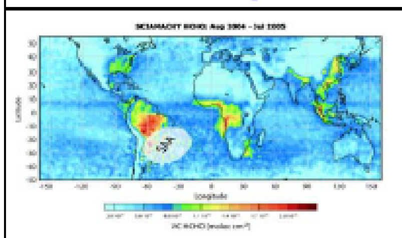

## CO



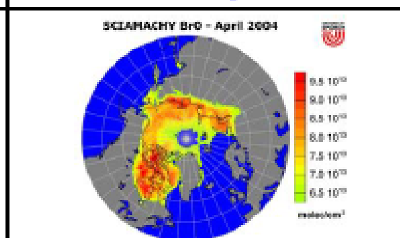

## H2O



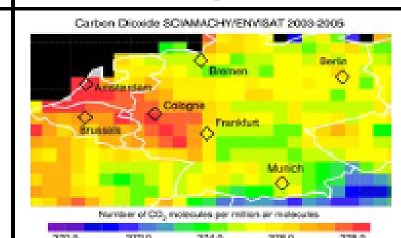

## HCHO



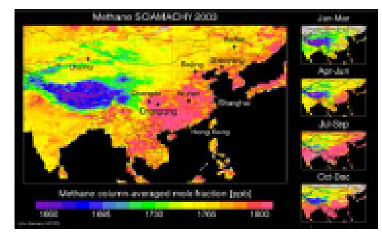
## BrO



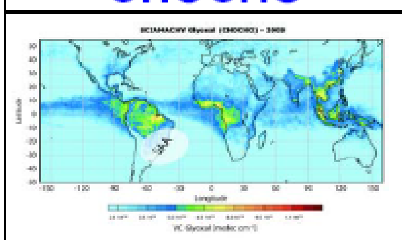

## CO2



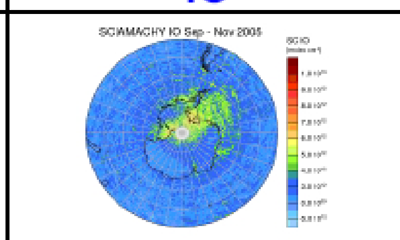

## CH4



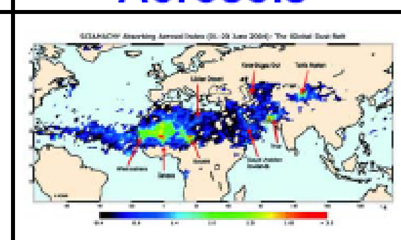

## CHOCHO



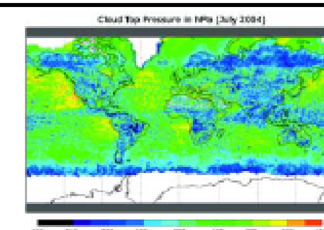
## IO




## Aerosols



## Clouds

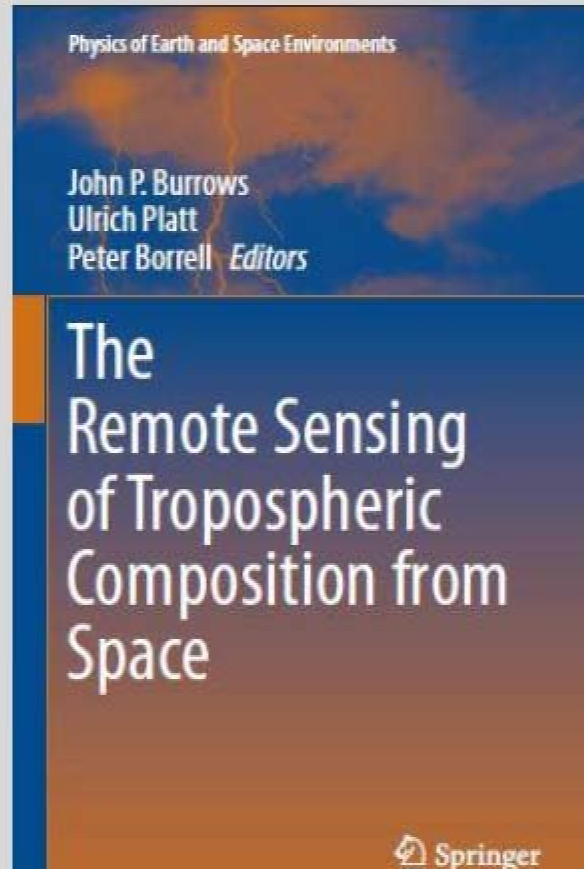



**... and more.**

# The Remote Sensing of Tropospheric Composition from Space

Editors:

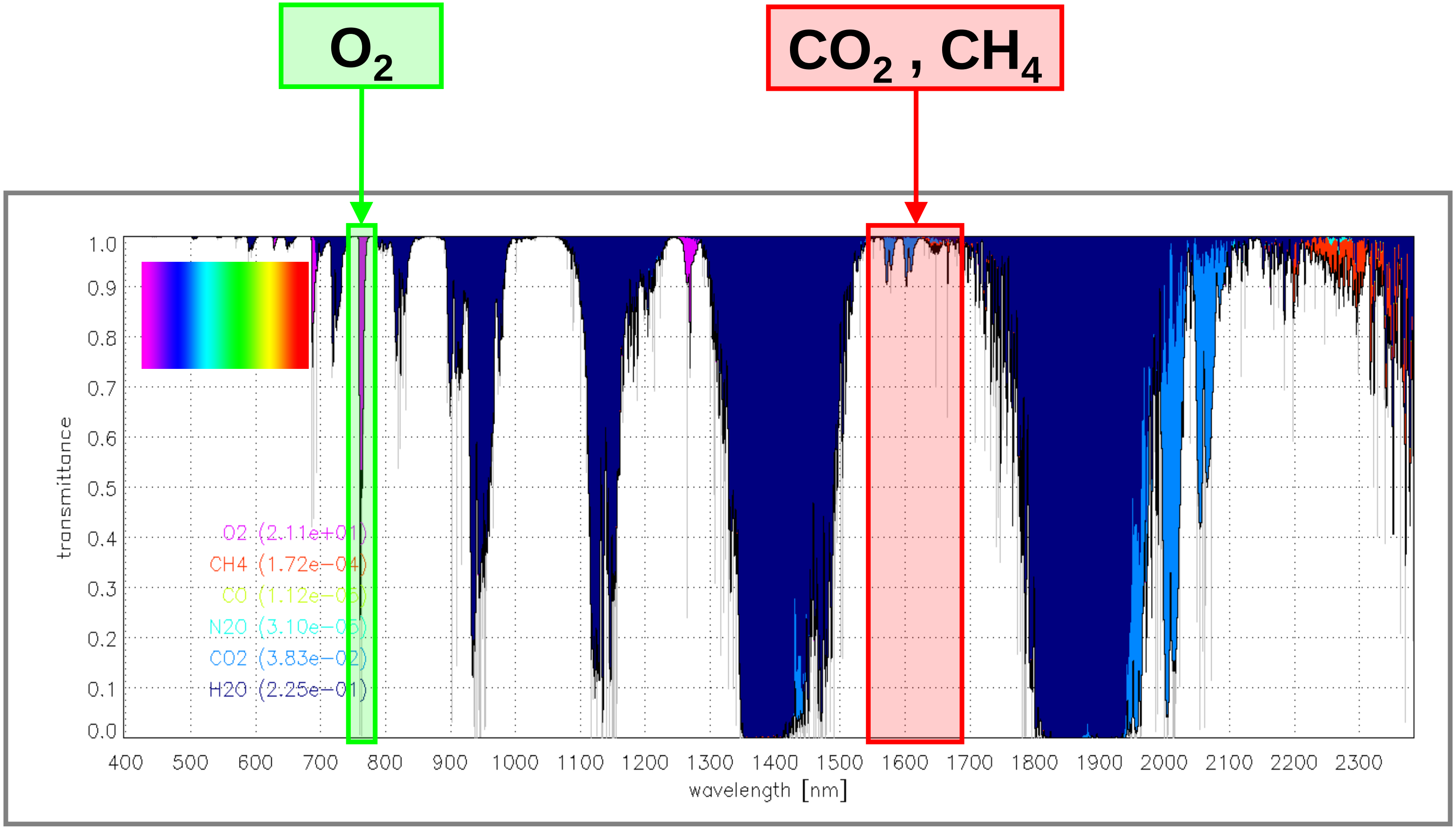
John P. Burrows
Ulrich Platt
Peter Borrell




DOI 10.1007/978-3-642-14791-3

Springer Heidelberg Dordrecht London New York, 2011

# SCIAMACHY GHG Fit Windows

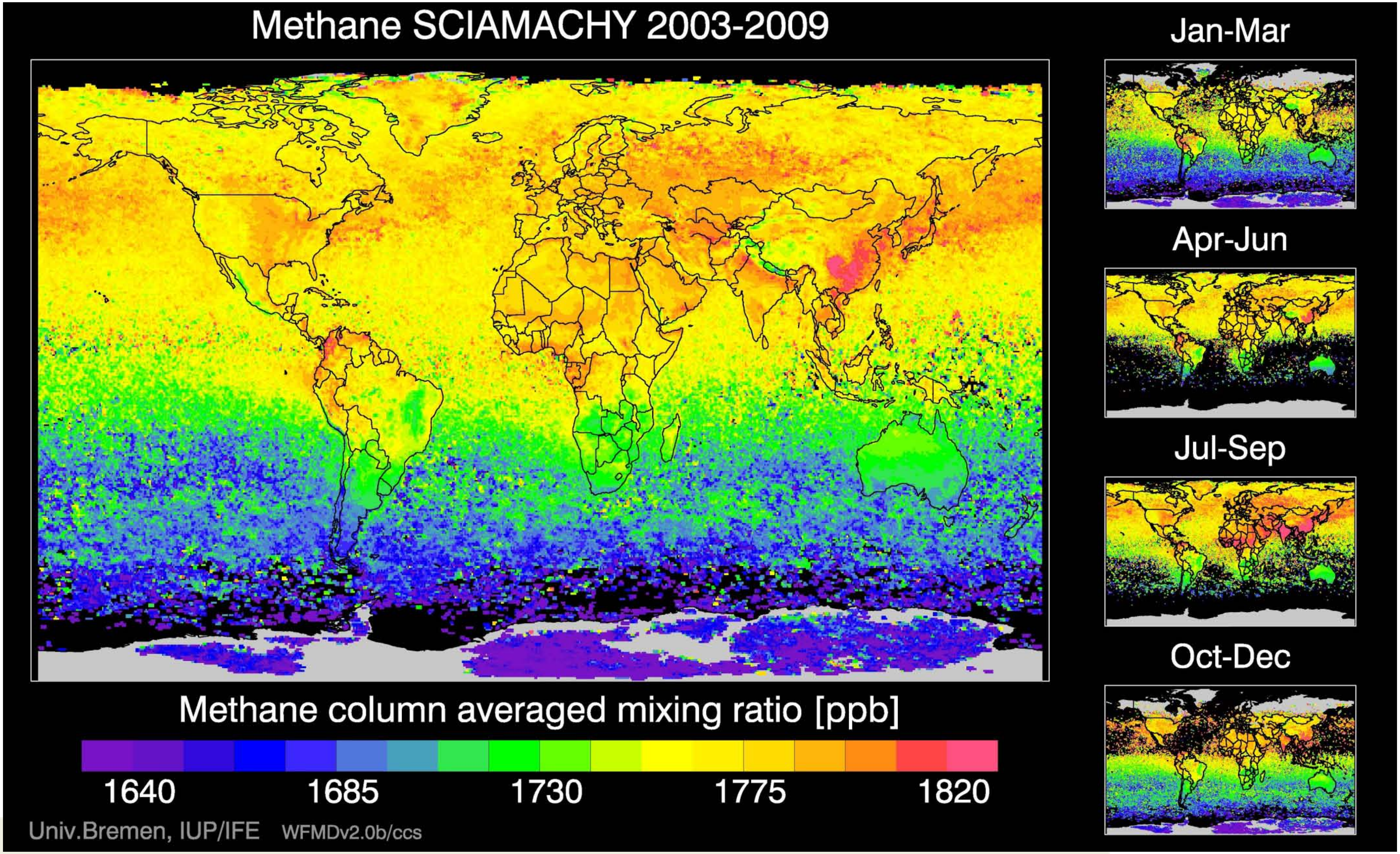



**2 µm (strong CO2) not usable due to ice and external straylight**

# XCO2: BESD vs WFMD

| | BESD ($XCO_2$) | WFMD ($XCO_2$, $XCH_4$) |
|---|---|---|
| Inversion Algorithm: | Optimal Estimation;<br>CO2 profile (10 para.) | Least-squares;<br>CO2 profile shift (1 para.) |
| A-priori constraints: | Yes<br><u>Constant:</u> CO2(p), aerosol, cirrus, ...<br><u>Per pixel:</u> P, T, H2O, ... | No<br>(constant atmosphere as linearization point for RT) |
| Atmosphere: | ECMWF | US Standard (sev. H2O) |
| Aerosols: | State vector (APS) | Constant; AAI filter (CO2 only) |
| Clouds: | State vector (CWP, CTH);<br>Filtering: MERIS 1x1 $km^2$ | RT cloud free;<br>Filtering: O2 & PMD (CO2 only) |
| Fit windows: | Merged fit windows | Independent fit windows |
| Radiative Transfer: | SCIATRAN on-line | SCIATRAN LUT |
| Speed: | Slow (~15 min./pixel) | Fast (~2 min./orbit) |
| Optimized for: | Accuracy | Compromise accuracy/speed |

# SCIAMACHY Methane 2003 - 2009

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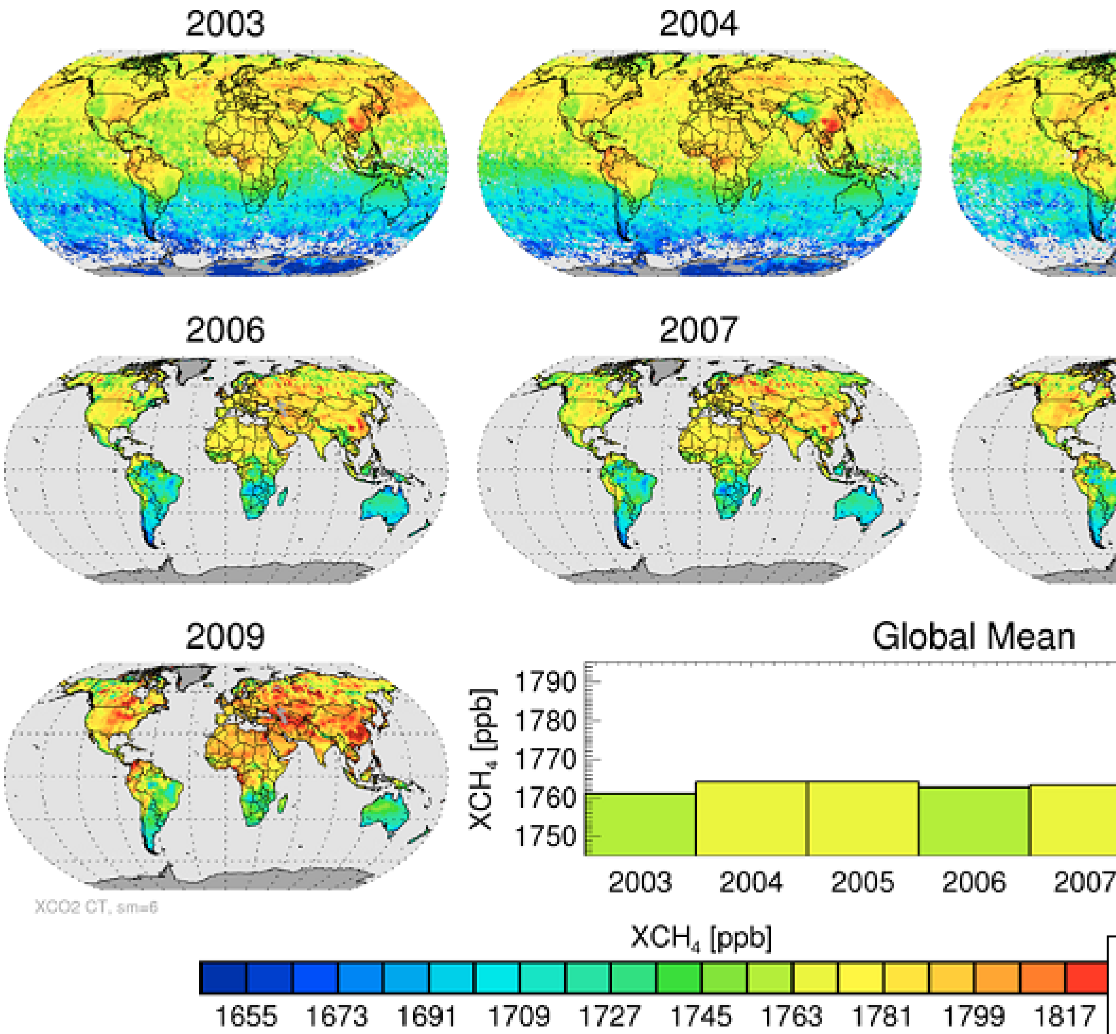
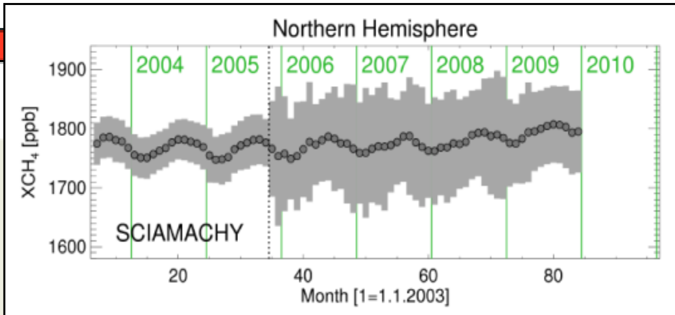
Schneising et al., ACP, 2011

# SCIAMACHY Methane 2003 – 2009

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Schneising et al., ACP, 2011

# SCIAMACHY CH4 & CH4 emissions

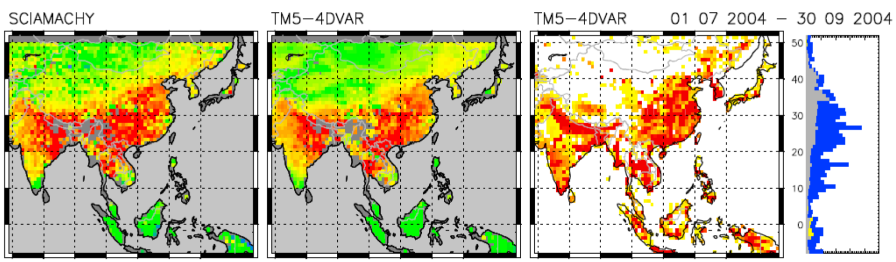
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, D22301, doi:10.1029/2009JD012287, 2009

Click Here for Full Article

Bergamaschi et al., JGR, 2009

Inverse modeling of global and regional $CH_4$ emissions using SCIAMACHY satellite retrievals

… the **SCIAMACHY data put strong constraints on the smaller-scale spatial distribution of emissions**, while remote surface measurements mainly constrain the emissions of larger regions.




Two main applications:

- Improved emission inventories
  - (for different categories, e.g., wetlands, rice, …)
- Improved process understanding
  - (e.g., land biosphere & related emissions)

➡ **Better climate prediction, …**

## Large-Scale Controls of Methanogenesis Inferred from Methane and Gravity Spaceborne Data

A. Anthony Bloom,[1] Paul I. Palmer,[1]* Annemarie Fraser,[1] David S. Reay,[1] Christian Frankenberg[2]

Bloom et al., Science, 2010

SCIAMACHY $CH_4$, groundwater depth, skin T

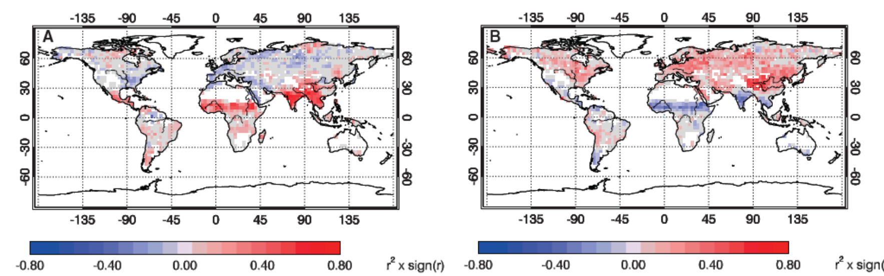
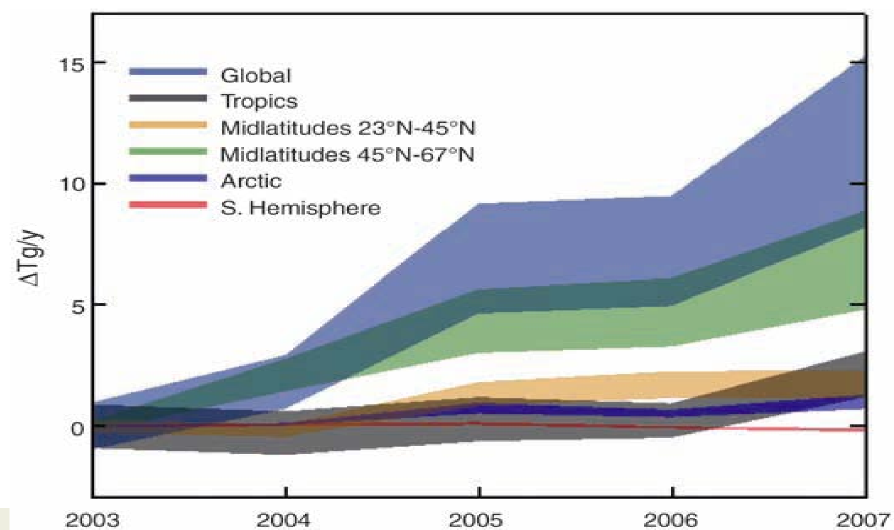
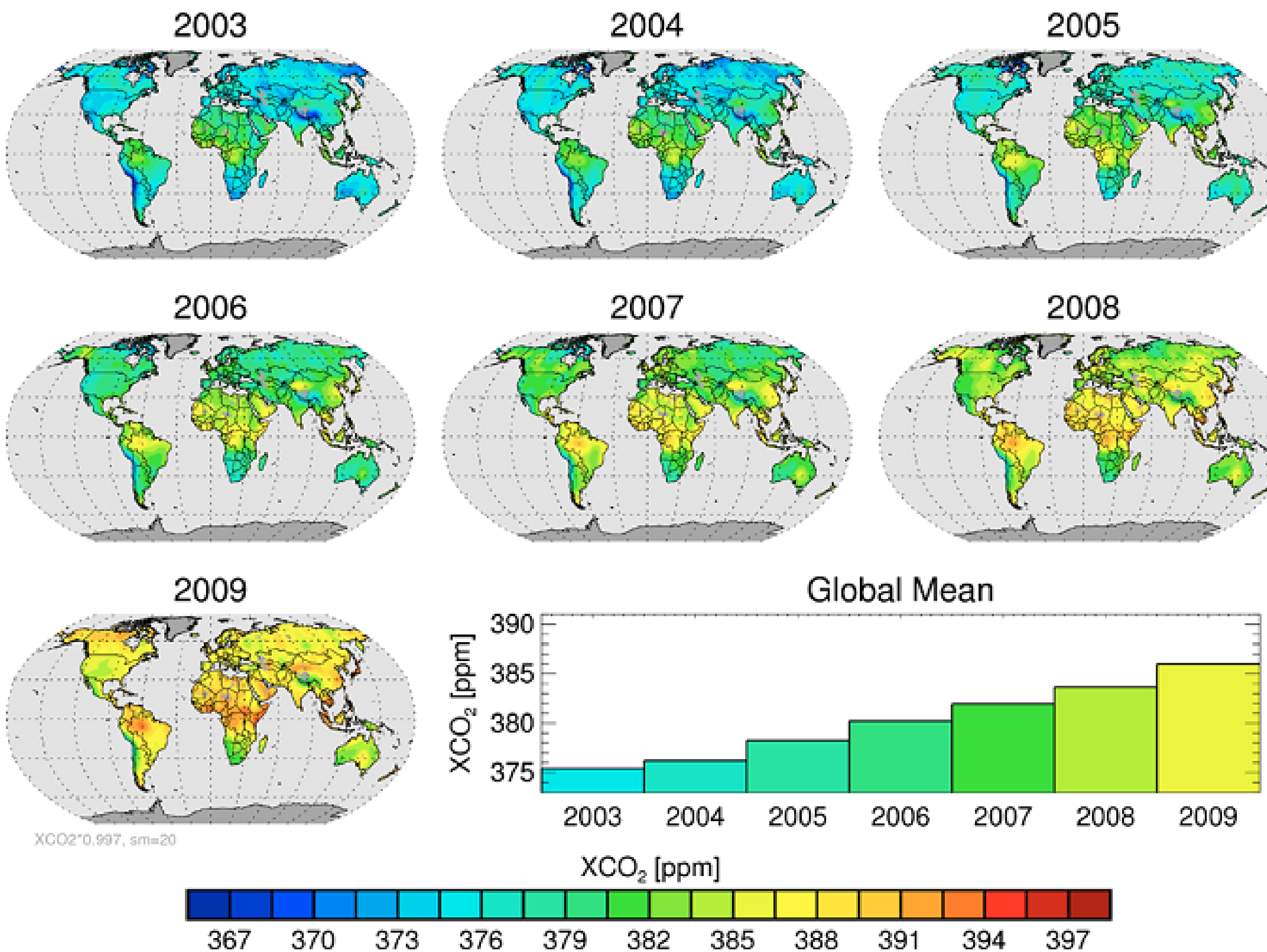



**Fig. 1.** Correlations ($r^2$) between cloud-free SCIAMACHY $CH_4$ column volume mixing ratios (VMRs) (in parts per million) and **(A)** equivalent groundwater depth (in meters), determined from gravity anomaly measurements from the GRACE satellites (*18*) and **(B)** NCEP/NCAR surface skin temperatures (in kelvin), calculated on a 3° × 3° horizontal grid over 2003–2005. The correlation at a given point is determined by at least 15 and typically 60 $CH_4$, groundwater, and temperature measurements. See SOM for a description of individual data sets.



# $CO_2$ from SCIAMACHY 2003 – 2009

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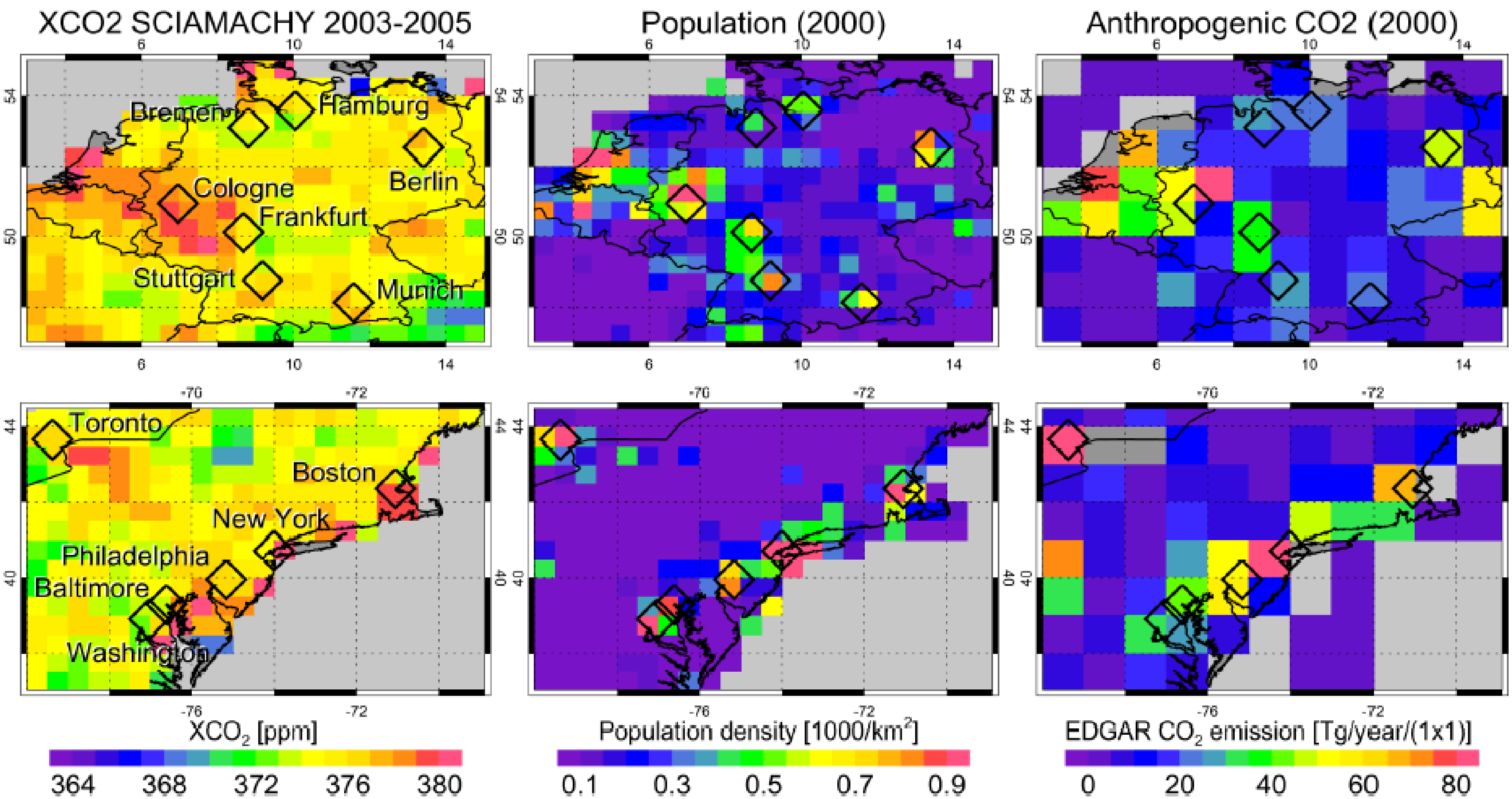
Schneising et al., ACP, 2011

# Anthropogenic signatures in SCIAMACHY $CO_2$

## SCIAMACHY $CO_2$ | Population | Emissions

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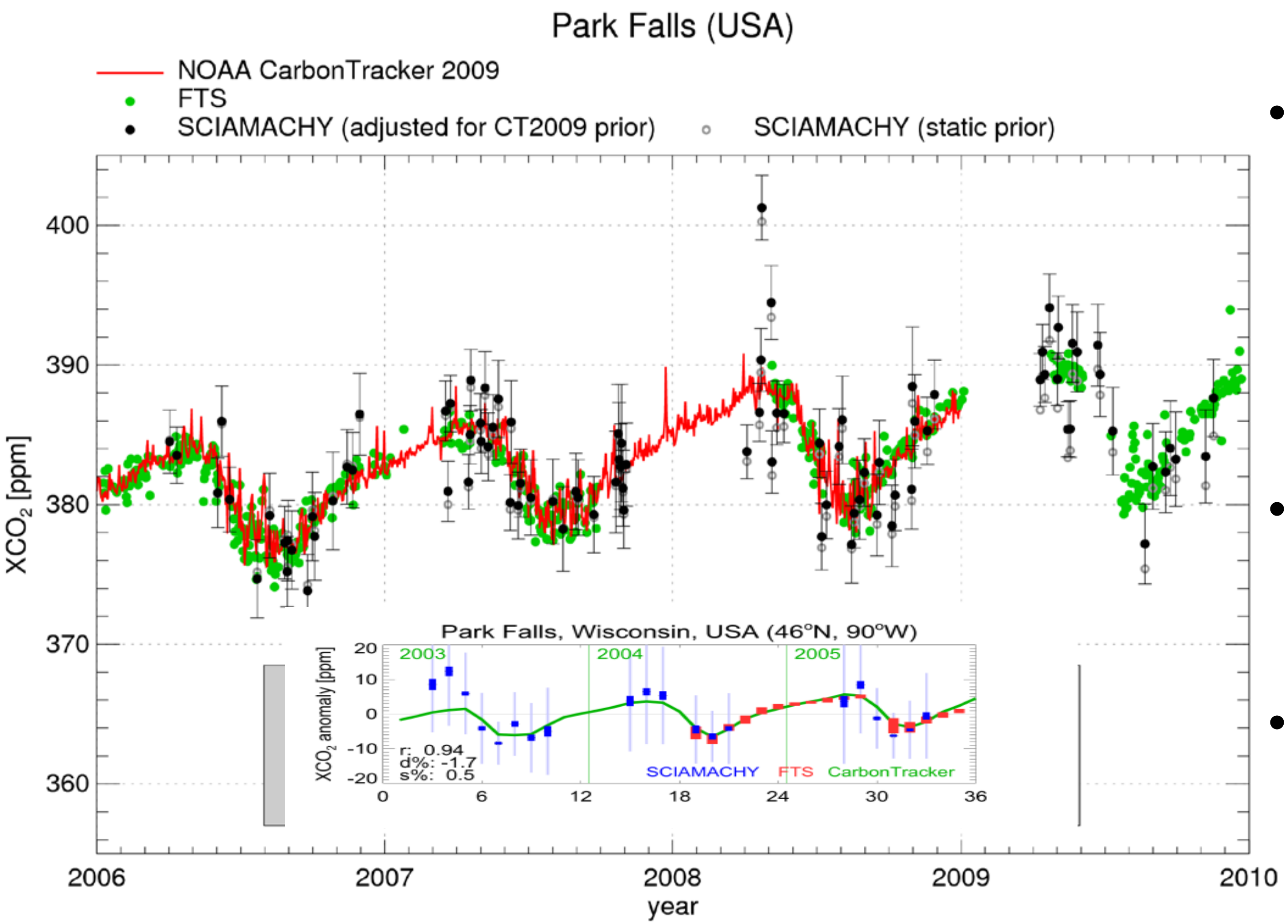
Schneising et al., ACP, 2008

# Recent Improvements SCIA $XCO_2$




- New algorithm explicitly takes into account atm. scattering using $O_2$ A Band (Reuter et al. AMT 2010)
- Biases reduced from 4 - 6 ppm to 0.2 – 0.8 ppm (also in tropics)
- precision of 2.5 (before 4-8 ppm) ppm now at sensor noise level

**Algorithm will be part of ESA CCI-GHG project**

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**Reuter et al. JGR 2011**

# XCO2 (BESD) Statistics

No statistical significant regional biases

Single measurement precision ~2.5ppm

**Table 1.** Regional biases … co-located measurements shown in Fig. 2. The column "global" corresponds to a merged data set enclosing the data of all four sites. As des… correction is applied. Therefore, all biases are … definition in this case.

| Location | SCIAMACHY vs. FTS | | | SCIAMACHY vs. CT2009 | | | CT2009 vs. FTS | | |
|---|---|---|---|---|---|---|---|---|---|
| | Δ [ppm] | σ [ppm] | ρ | Δ [ppm] | σ [ppm] | ρ | Δ [ppm] | σ [ppm] | ρ |
| Park Falls (USA) | −0.2 ± 0.4 | 2.5 | 0.83 | −0.2 ± 0.3 | 3.0 | 0.77 | 0.1 ± 0.1 | 0.8 | 0.97 |
| Darwin (Australia) | 0.3 ± 0.2 | 2.4 | 0.69 | 0.4 ± 0.2 | 2.3 | 0.74 | 0.0 ± 0.1 | 0.9 | 0.93 |
| Bremen (Germany) | −1.2 ± 0.6 | 2.6 | 0.61 | −1.1 ± 0.6 | 2.5 | 0.73 | 0.1 ± 0.2 | 1.3 | 0.95 |
| Lauder (New Zealand) | 0.5 ± 0.8 | 2.5 | 0.47 | 0.5 ± 0.8 | 2.9 | 0.64 | 0.0 ± 0.4 | 0.9 | 0.86 |
| global | 0.0 ± 0.2 | 2.5 | 0.72 | 0.0 ± 0.2 | 2.7 | 0.74 | 0.0 ± 0.1 | 0.9 | 0.94 |

Good agreement of year-to-year increase and seasonal cycle

**Table 2.** Year-to-year increase as well as average peak-to-peak amplitude of the seasonal cycle calculate…

| Location | Year-to-year increase [ppm/year] | | | Peak-to-peak amplitude [ppm] | | |
|---|---|---|---|---|---|---|
| | SCIAMACHY | FTS | CT2009 | SCIAMACHY | FTS | CT2009 |
| Park Falls (USA) | 1.88 ± 0.44 | 2.01 ± 0.05 | 1.96 ± 0.03 | 7.92 ± 0.95 | 7.41 ± 0.13 | 6.94 ± 0.08 |
| Darwin (Australia) | 2.27 ± 0.20 | 2.30 ± 0.03 | 1.99 ± 0.01 | 2.48 ± 0.42 | 1.91 ± 0.05 | 1.18 ± 0.02 |

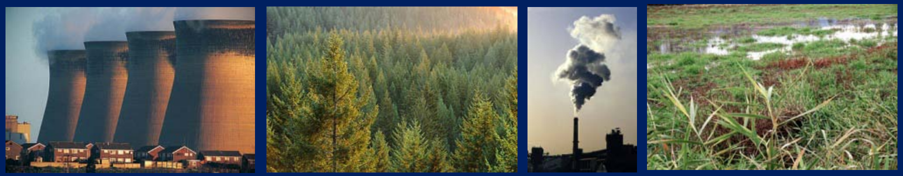
# Towards a Long Term GHG data sets (GCOS ECV‘s)

**ECV GHG:**

**Global distribution of atmospheric Greenhouse Gases, as Methane and Carbon Dioxide, of sufficient quality to estimate regional sources and sinks.**

# GHG-cci

## Essential Climate Variable (ECV)
## Greenhouse Gases (GHG)




Michael Buchwitz,
Institute of Environmental Physics (IUP),
University of Bremen, Bremen, Germany

*and the GHG-cci team*

# Ingredients needed to achieve this

## Global satellite observations

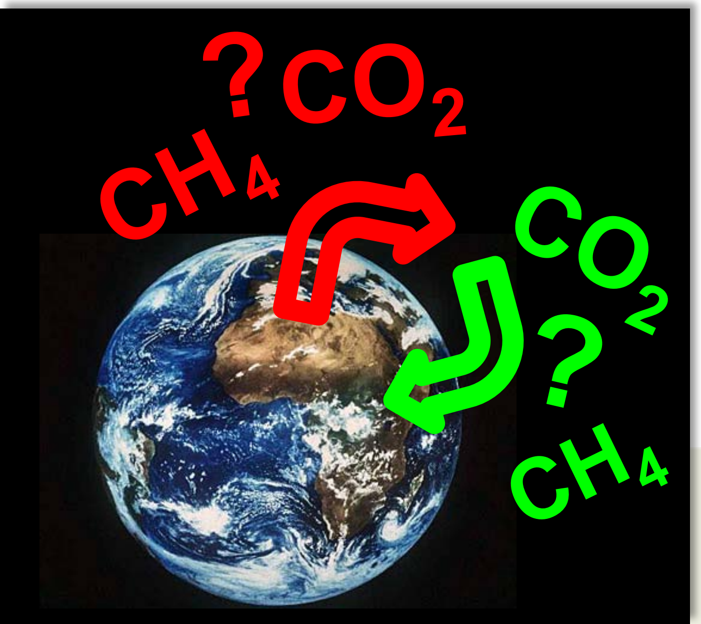
Global information on near-surface $CO_2$ & $CH_4$

Upper layer $CO_2$ & $CH_4$



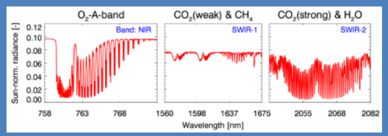
AIRS, IASI, TES, MIPAS, SCIA/occ, ACE-FTS, …

Global observations



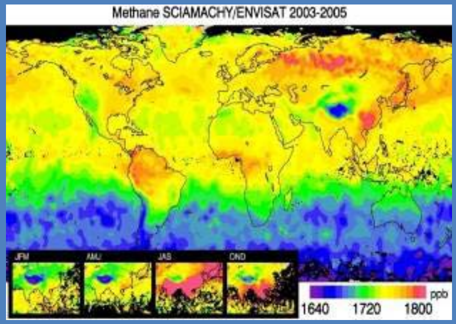

Calibration (L 0-1)

**Calibrated radiances**

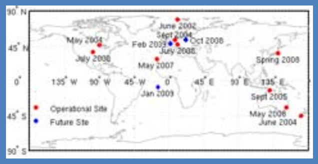



**Retrieval** (L 1-2)

**Atmospheric GHG distributions**



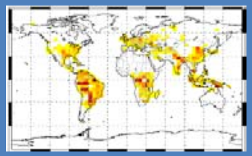

**Reference observations**

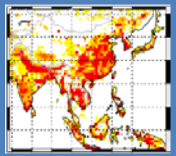



Validation

**Inverse modelling, CCDAS**

**Improved information on GHG sources & sinks**





# GHG CCI User Requirements

| ESA Climate Change Initiative (CCI) | Page 1 |
|---|---|
| User Requirements Document Version 1 (URDv1) | Version1 – Final |
| for the Essential Climate Variable (ECV) Greenhouse Gases (GHG) | 3 Feb 2011 |

ESA Climate Change Initiative (CCI)

**User Requirements Document (URD)**

for the Essential Climate Variable (ECV)

**Greenhouse Gases (GHG)**

Written by:

GHG-CCI project team

Lead author: M. Buchwitz, IUP, Univ. Bremen, Germany

Approved by:

GHG-CCI Climate Research Group (CRG), represented by

- F. Chevallier, LSCE, France
- P. Bergamaschi, EC-JRC-IES, Italy

*To be cited as:*

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.

Available from: http://www.esa-ghg-cci.org/

**Requirements for regional $CO_2$ and $CH_4$ source/sink determination using SCIAMACHY/ENVISAT and TANSO/GOSAT**

| Parameter | Req. type | Random error ("Precision") | | Systematic error ("Accuracy") | Stability |
|---|---|---|---|---|---|
| | | Single obs. | $1000^2$ km$^2$ monthly | | |
| $XCO_2$ | G | < 1 ppm | < 0.3 ppm | < 0.2 ppm (absolute) | As systematic error but per year |
| | B | < 3 ppm | < 1.0 ppm | < 0.3 ppm (relative §)) | -"- |
| | T | < 8 ppm | < 1.3 ppm | < 0.5 ppm (relative #)) | -"- |
| $XCH_4$ | G | < 9 ppb | < 3 ppb | < 1 ppb (absolute) | As systematic error but per year |
| | B | < 17 ppb | < 5 ppb | < 5 ppb (relative §)) | -"- |
| | T | < 34 ppb | < 11 ppb | < 10 ppb (relative #)) | -"- |

**Table 1:** GHG-CCI $XCO_2$ and $XCH_4$ random ("precision") and systematic ("accuracy") retrieval error requirements for measurements over land. Abbreviations: G=Goal, B=Breakthrough, T=Threshold requirement. §) Required systematic error after bias correction, where only the application of a constant offset / scaling factor independent of time and location is permitted for bias correction. #) Required systematic error after bias correction, where bias correction is not limited to the application of a constant offset / scaling factor.

| | |
|---|---|
| **REQ-GHGCCI-ERR-2** | The $XCO_2$ and $XCH_4$ ECV data products over land shall meet the systematic error (accuracy) requirements given in Table 1.<br>*The required thresholds refer to global long-term statistics (i.e., they refer to the ensemble of data products, i.e., individual retrievals). Locally in space and time larger values may be acceptable.* |

**Demanding relative accuracy req., esp. for $XCO_2$ !**

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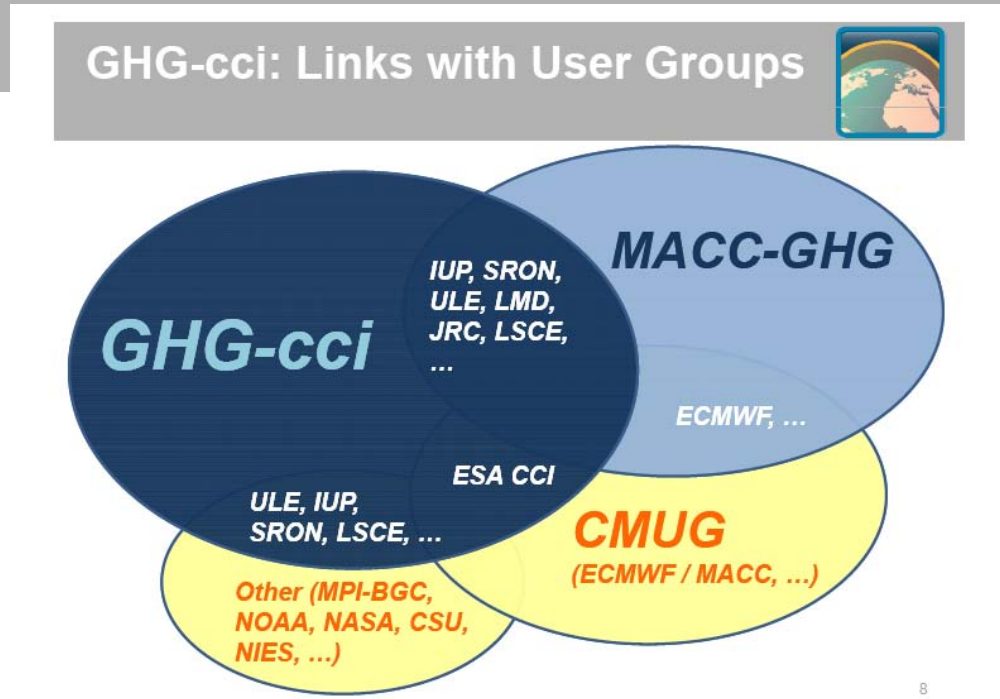
# GHG-CCI (EO data) <-> MACC (modelling)




**SCIAMACHY $XCO_2$ & $XCH_4$ retrievals**

ghg cci

macc Monitoring atmospheric composition & climate

Feedback on data quality

Universität Bremen

# Summary (most recent paper)

**$XCO_2$ BESD,** (Reuter et al. 2010, 2011)

- Successful validation against TCCON FTS measurements:
  - No statistical significant regional biases
  - Single measurement precision of ~2.5ppm
  - Good agreement of year-to-year increase and seasonal amplitude

**$XCO_2$ WFMDv2.1** (Schneising et al 2011)

- Uptake of $CO_2$ observed over boreal forests
- Results suggest that modeled CO2 uptake is too low in Canada and too large in Russia

**$XCH_4$** (Bergamaschi et al. 2009, Frankenberg et al. 2011, Schneising et al. 2011)

- Renewed increase observed from SCIAMACHY consistent with flask measurements despite enhanced scatter due to more dead pixels
- improved global emission patterns and fluxes
- Pre-operational use in MACC-GHG system

# The End