GHG-cci

Living Planet Symposium, Bergen, Norway, 2010

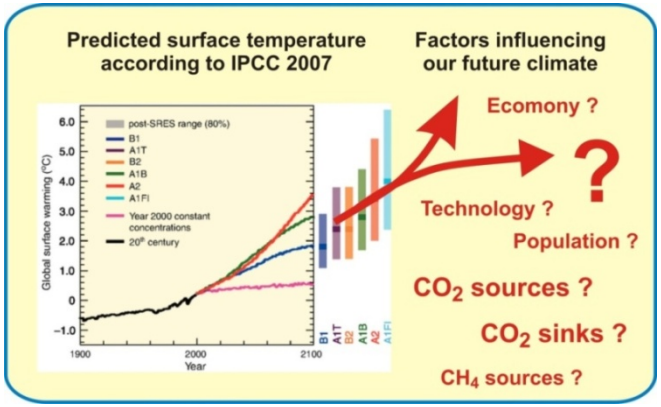
Essential Climate Variable (ECV)
Greenhouse Gases (GHG)

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

and the GHG-cci team

ECV GHG ?

CO_2 and CH_4 are the two most important anthropogenic greenhouse gases and increasing concentrations result in global warming.



Reliable climate prediction requires a good understanding of the natural and anthropogenic (surface) **sources and sinks of CO_2 and CH_4**.

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:

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

Ingredients needed to achieve this

Global satellite observations

Global information on near-surface CO_2 & CH_4

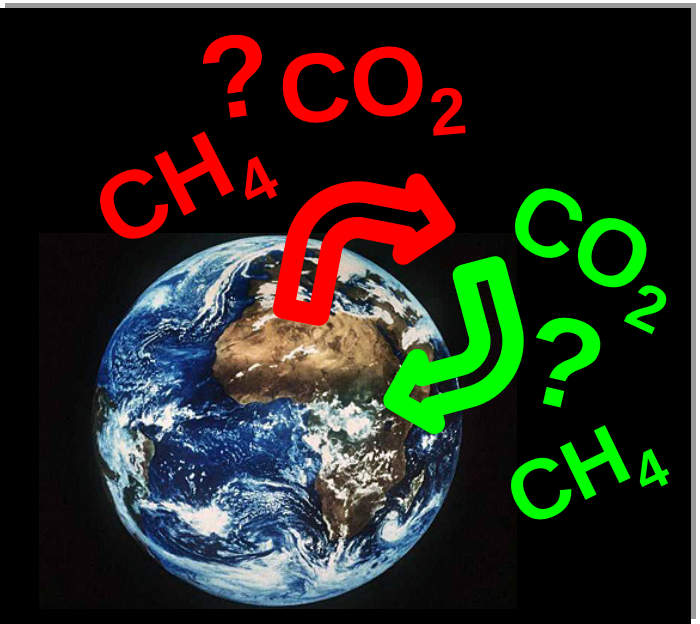
SCIAMACHY/ENVISAT

TANSO/GOSAT

Upper layer CO_2 & CH_4

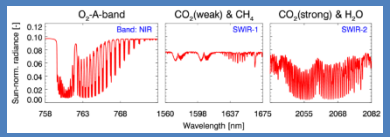
AIRS,
IASI,
TES,
MIPAS,
SCIA/occ,
ACE-FTS,
...

Global observations



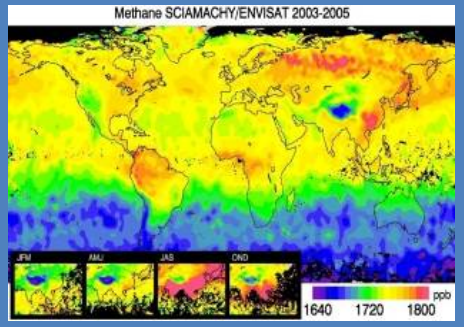
Calibration (L 0-1)

Calibrated radiances



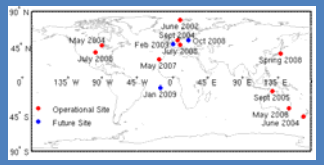
Retrieval
(L 1-2)

Atmospheric GHG distributions



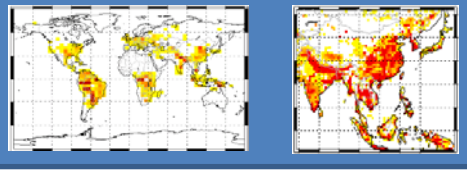
Validation

Reference observations



Inverse modelling, CCDAS

Improved information on GHG sources & sinks



Already demonstrated for SCIAMACHY CH_4

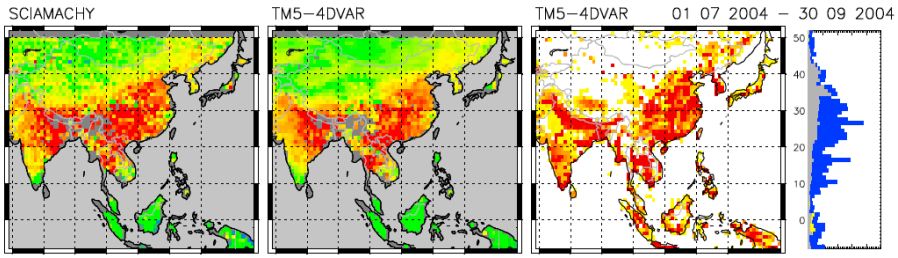
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, D22301, doi:10.1029/2009JD012287, 2009

Click Here for Full Article

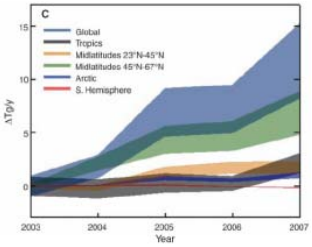
Bergamaschi et al., JGR, 2009

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.



Bloom et al., Science, 2010



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]

SCIAMACHY CH_4, groundwater depth, skin T

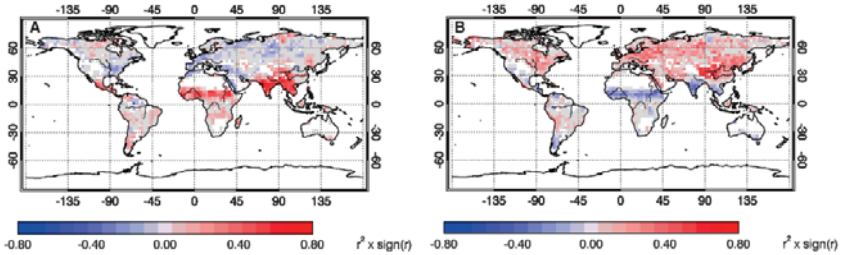


Fig. 1. Correlations (r^2) between cloud-free SCIAMACHY CH_4 column volume mixing ratios (VMRs) (in parts per million) and (A) equivalent groundwater depth (in meters), determined from gravity anomaly measurements from the GRACE satellites (18) and (B) NCEP/NCAR surface skin temperatures (in kelvin), 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.

Two main application areas:

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

➡ **Better climate prediction, …**

However, ...

… so far approach only demonstrated for SCIAMACHY CH_4 2003 – 2005.

Remaining challenges:

- SCIAMACHY CH_4 after 2005: Degradation issues
- SCIAMACHY CO_2: Bias issues, e.g., thin cirrus
- GOSAT CO_2 & CH_4: New in space
- SCIAMACHY – GOSAT CO_2 & CH_4: Consistency ?
- …

GHG-cci: User Requirements

SCIAMACHY

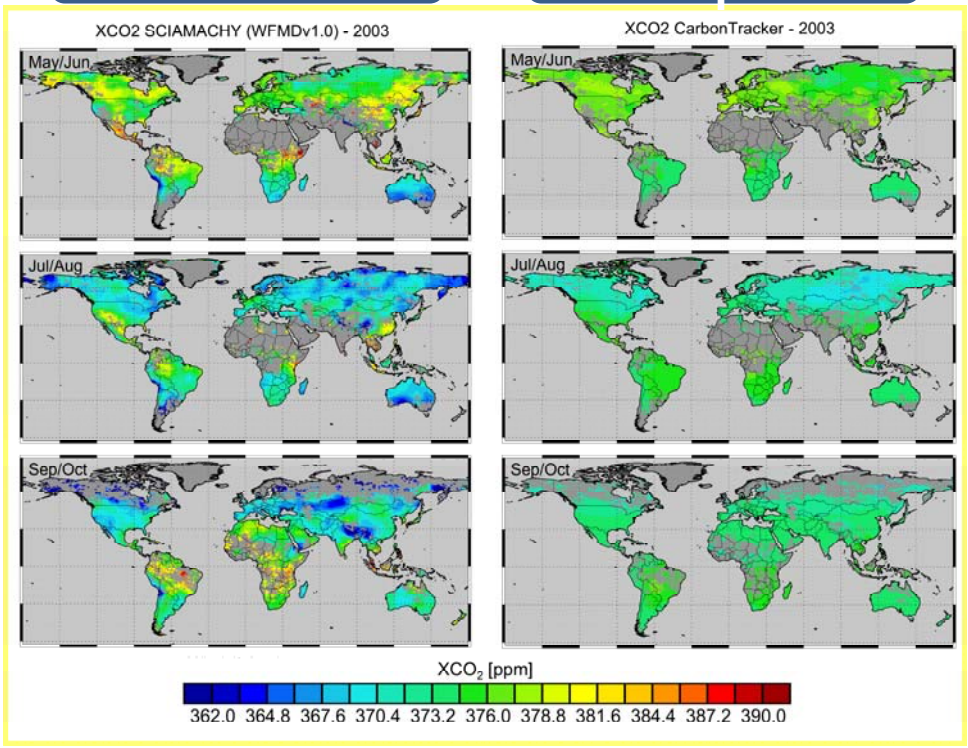
CarbonTracker

Challenging !

Inverse modelling:

Observation – Model differences interpreted as model surface flux errors.

Model transport errors !?
Biases satellite data !?



Key requirement:

Avoid systematic biases !

Required relative accuracy *):

- XCO_2: < 0.3% (1 ppm) (e.g., Chevallier et al., JGR, 2007)
- XCH_4: < 0.6% (10 ppb) (e.g., Meirink et al., ACP, 2006)

*) for spatio-temporal averages, e.g., monthly, few deg x few deg

GCOS (accuracy RMS): CO_2 column: < 1%, CH_4 column: < 2%

GHG-cci Project Team

Science Leader
M. Buchwitz (IUP)

Management Team
M. Buchwitz (IUP, Science Leader)
H. Bösch (Univ.Leicester, Project Manager)
M. Reuter (IUP, Deputy PM)
O. Hasekamp (SRON)
J. Notholt (IUP-V, Validation Lead)
F. Chevallier (LSCE, CRG Lead)

Project Manager
H. Bösch (Univ.Leicester)
Deputy: M. Reuter (IUP)

EO Science Team (EOST)

EOST1: SCIAMACHY & GOSAT
Lead: M. Buchwitz, IUP
IUP, Univ.Leicester, SRON, DLR

EOST2: TIR (IASI, MIPAS, …)
Lead: C. Crevoisier, LMD
LMD, KIT-M, IUP

VALT: Validation
Lead: J. Notholt, IUP-V
IUP-V, KIT-V, BIRA, EMPA

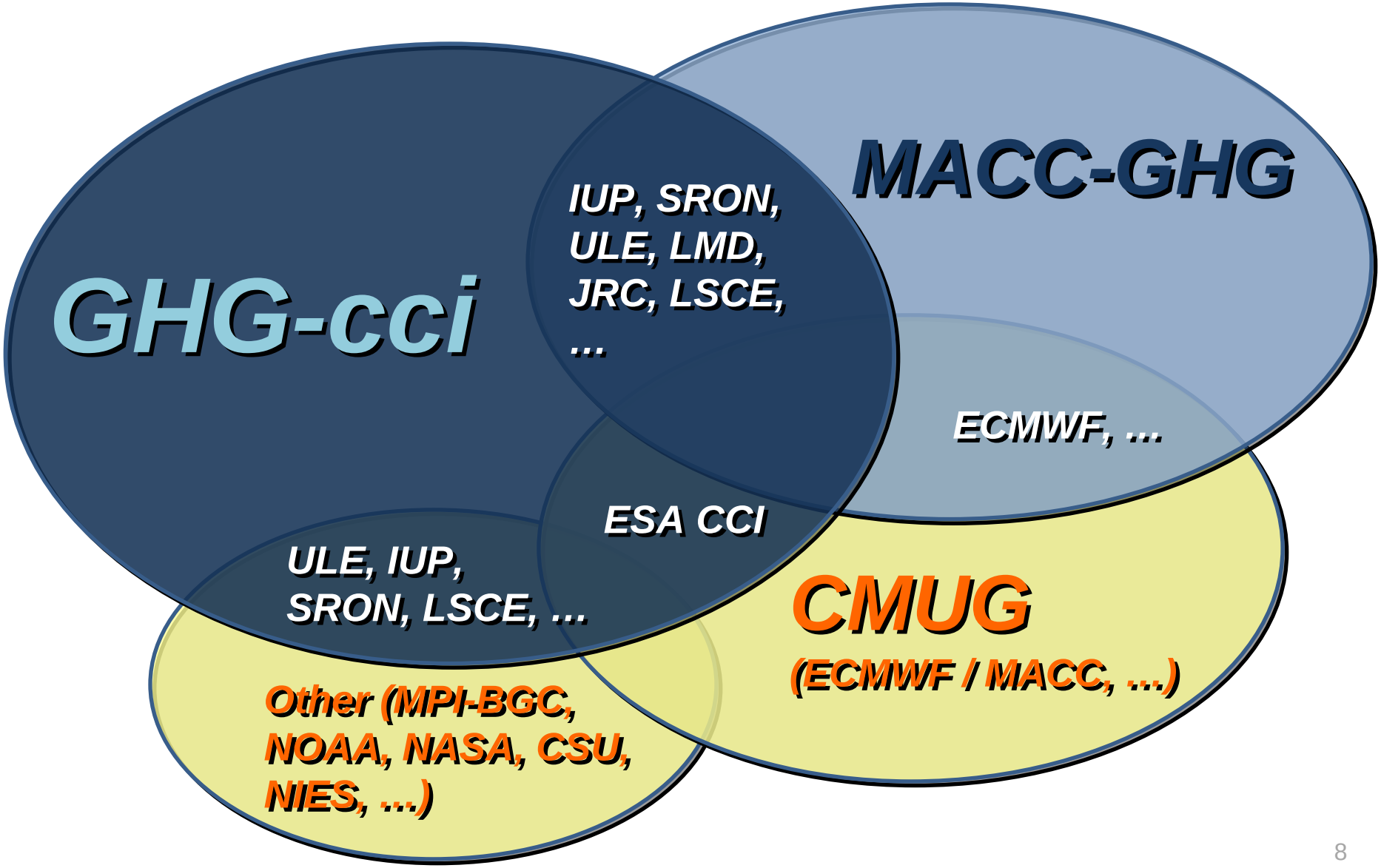
Climate Research Group (CRG)
Lead: F. Chevallier, LSCE

LSCE, JRC

System Engineering Team (SET)
Lead:
G. Lichtenberg, DLR

DLR

GHG-cci: Links with User Groups



GHG-cci: Overall Schedule

Task	Year 1	Year 2	Year 3
	Aug 2010 – Jul 2011	Aug 2011 – Jul 2012	Aug 2012 – Jul 2013
	Kick-Off		
1	Task 1		
Requirements Analysis & Product Specification			
2	Task 2		
Algorithm Development, Round Robin	Algorithm „Improvement Processing Comparison“ Cycles		ECV generation
3		Task 3	
Validation Data & ECV Production			
4			Task 4
ECV Validation & Final User Assessment		Validation & User Assessment	
6 Management	Task 6		

CMUG Coloc. Review Progress Meet. (not shown)

Algorithms & Data Products

Core Products	GHG-cci Core Algorithms							
	IUP		Univ. Leicester		SRON		NIES	NASA
	BESD	WFMD	OCO-FP	FSI-WFMD	IMAP (CO_2 PROXY)	SRON-FP	Operational GOSAT	ACOS
SCIA XCO_2	ECV	ECV						
SCIA XCH_4		ECV		ECV	ECV			
GOSAT XCO_2			ECV			ECV	cmp	cmp
GOSAT XCH_4			ECV		ECV	ECV	cmp	

ECV: baseline; **ECV**: alternative; **cmp**: comparison only

Algorithms & data products for additional constraints and comparison:

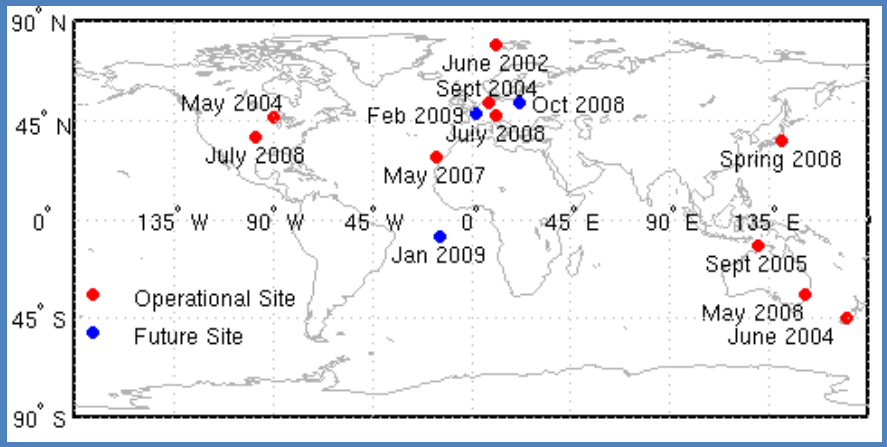
LMD: AIRS CO_2, IASI CO_2&CH_4, ACE-FTS CO_2, …,

KIT: MIPAS CH_4, IUP: SCIA-occultation CH_4, …

FCDR: DLR: SCIA L1 improvements (GHG-cci specific; in coop. with SQWG), …

GHG-cci: Validation

TCCON FTS sites



NDACC FTS XCH_4 via BIRA

aeronomie.be

In-situ CO_2 and CH_4: All quasi-continuous GAW and AGAGE Stations via EMPA

EMPA

Surface CO_2 and CH_4 observations also used via model comparisons (e.g., NOAA's CarbonTracker & JRC's TM5)

Validation lead:
Prof Dr J Notholt, IUP,
European TCCON lead

iup

TCCON

IUP FTS sites: Bremen (G), Bialystok (P), Orleans (F), Ny Alesund (N), *Paramaribo (Suriname)*

KIT Karlsruhe Institute of Technology

KIT FTS sites:
Garmisch (G), *Zugspitze (G)*, Karlsruhe (G), Izana (Tenerife)

Non-European TCCON sites:
- Park Falls, Lamont (USA, PI: P. Wennberg)
- Wollongong, Darwin (Australia, PI: D. Griffith),
- Lauder (New Zealand, PI: V. Sherlock)

GHG-cci: Data Access

User

Internet

GHG-cci Project ECV Database

GHG-cci

Links using official access

Internal provider

SCIA & GOSAT L2/3 Scientific XCO_2 & XCH_4

IUP

ULE

SRON

Other L2/3 products

Other

External provider

GOSAT Op. L1

JAXA

GOSAT Op. L2/3

NIES

Other products

Other

Intern/extern

SCIA Op. L1

DLR / ESA

SCIA Op. L2

DLR

Status & Goals: XCO_2

CCI Phase 1

Status

XCO2		2003-2005	2006-2008	2009-2011	2012-2014
SCIA	Processed				PROXY
	Published		Schneising et al., 2008		
	Sources & sinks				
GOSAT	Processed				FP
	Published				
	Sources & sinks				

GHG-cci Phase 1 Goal

Processing

XCO2		2003-2005	2006-2008	2009-2011	2012-2014
SCIA	Processed				PROXY, FP
	Published				
	Sources & sinks				
GOSAT	Processed		FP SCIA: 9 yrs goal 1 yr threshold		FP
	Published		FP GOSAT: 3 yrs g 1 yr t		
	Sources & sinks				

Status & Goals: XCH_4

CCI Phase 1

Status

XCH4		2003-2005	2006-2008	2009-2011	2012-2014
SCIA	Processed				**PROXY**
	Published		Frankenberg et al., 2005, 2008; Schneising et al., 2009		
	Sources & sinks		Bergamaschi et al., 2007, 2009		
GOSAT	Processed				**FP, PROXY**
	Published				
	Sources & sinks				

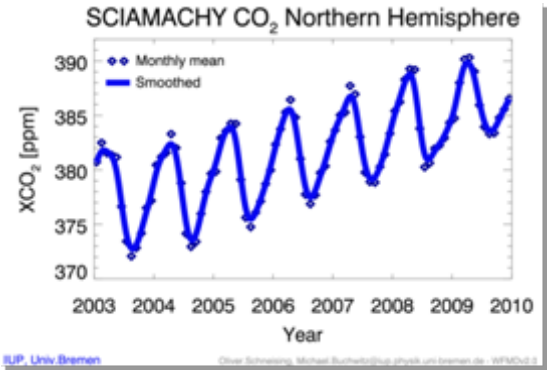
GHG-cci Phase 1 Goal

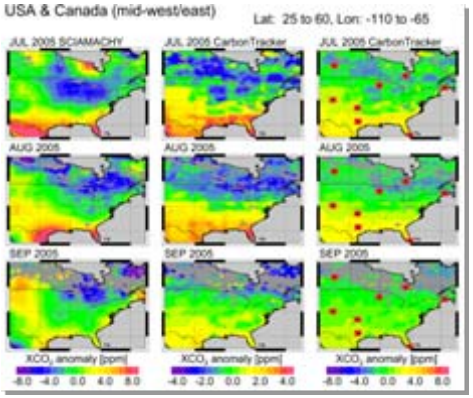
Processing

XCH4		2003-2005	2006-2008	2009-2011	2012-2014
SCIA	Processed				**PROXY**
	Published				
	Sources & sinks				
GOSAT	Processed				**PROXY, FP**
	Published		**FP GOSAT:**		
	Sources & sinks		**3 yrs goal** **1 yr threshold**		

GHG-cci: SCIAMACHY XCO_2

Retrieval algorithm: WFM-DOAS





Latest peer-reviewed publication: Schneising et al., ACP, 2008

Known issues: E.g., non-negligible errors due to thin cirrus & aerosols

Feedback from MACC on WFMDv1.0: Improve accuracy & error characterization

New retrieval algorithm: BESD

Atmos. Meas. Tech., 3, 209–232, 2010
www.atmos-meas-tech.net/3/209/2010/

Atmospheric Measurement Techniques

Reuter et al., AMT, 2010

A method for improved SCIAMACHY CO_2 retrieval in the presence of optically thin clouds

M. Reuter, M. Buchwitz, O. Schneising, J. Heymann, H. Bovensmann, and J. P. Burrows
University of Bremen, Institute of Environmental Physics, P.O. Box 330440,
28334 Bremen, Germany

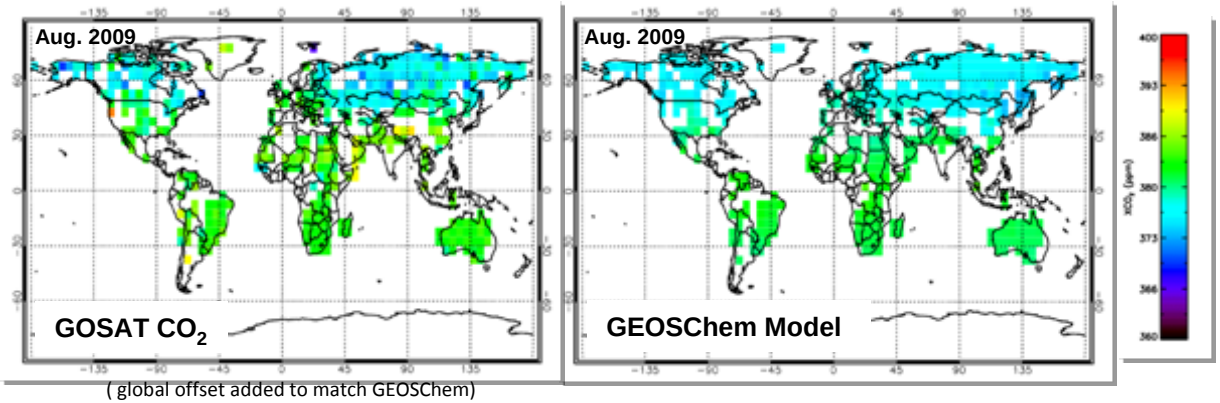
Received: 28 August 2009 – Published in Atmos. Meas. Tech. Discuss.: 8 October 2009
Revised: 15 January 2010 – Accepted: 9 February 2010 – Published: 12 February 2010

GHG-cci approach:

Further development of BESD (current GHG-cci SCIA XCO_2 baseline algorithm) by extended error analysis (e.g., SCORE-MIP), application to real SCIAMACHY data, analysis of the results by comparison with global models and ground-based FTS observations, SCIA WFM-DOAS XCO_2 (improved in parallel), iterative improvements.

GHG-cci: GOSAT XCO_2

Retrieval algorithm: OCO Full Physics (FP)



(global offset added to match GEOSChem)

Latest peer-reviewed publication: Baker D., Bösch H, et al., ACP, 2010

Known issues: Treatment of cirrus clouds & aerosols needs to be further improved; potential issues with current instrument calibration and available spectroscopy

Retrieval algorithm description:

Space-based near-infrared CO_2 measurements: Testing the Orbiting Carbon Observatory retrieval algorithm and validation concept using SCIAMACHY observations over Park Falls, Wisconsin — Bösch et al., JGR, 2006

H. Bösch,[1] G. C. Toon,[1] B. Sen,[1] R. A. Washenfelder,[2] P. O. Wennberg,[2] M. Buchwitz,[3] R. de Beek,[3] J. P. Burrows,[3] D. Crisp,[1] M. Christi,[4] B. J. Connor,[5] V. Natraj,[2] and Y. L. Yung[2]

Orbiting Carbon Observatory: Inverse method and prospective error analysis — Connor et al., JGR, 2008

Brian J. Connor,[1] Hartmut Boesch,[2] Geoffrey Toon,[2] Bhaswar Sen,[2] Charles Miller,[2] and David Crisp[2]

GHG-cci approach:

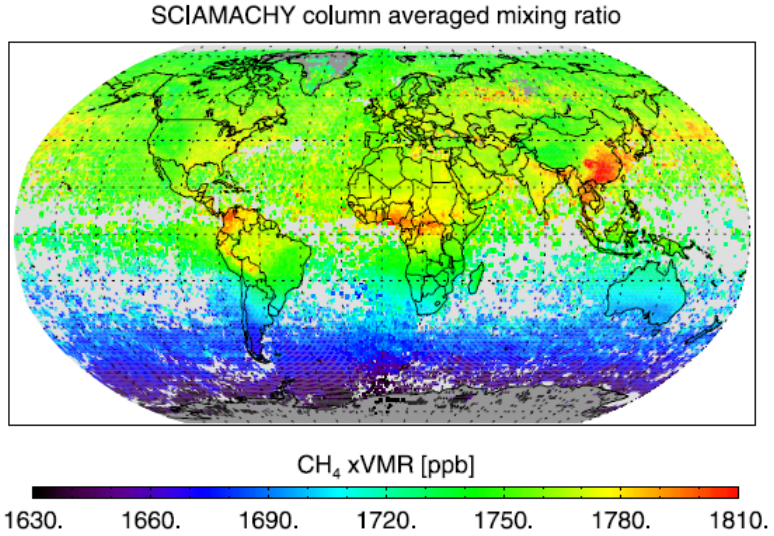
University of Leicester

Further optimization of OCO-FP (current GHG-cci GOSAT XCO_2 baseline algorithm) and its aerosol approach by continued synthetic studies and intercomparison studies (SCORE-MIP) and by detailed analysis and validation of GOSAT retrievals. Continued collaboration with NASA team on algorithm improvements.

GHG-cci: SCIAMACHY XCH_4

Retrieval algorithm: IMAP-DOAS

Latest peer-reviewed publications: Frankenberg et al., Science, 2005; Frankenberg et al., ACP, 2008; Frankenberg et al., GRL, 2008; Bergamaschi et al., JGR, 2009; Bloom et al., Science, 2010

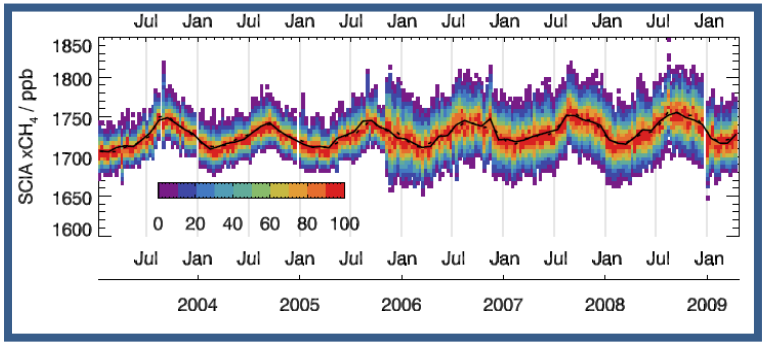


Known issues: Degraded quality after November 2005 due to radiation damaged detector pixels. 2003-2005: Statistical error on single measurement ~1-2%. After November 2005 about x 1.5-2 higher.

GHG-cci approach:

SRON Netherlands Institute for Space Research

Use the IMAP-DOAS algorithm to produce the SCIAMACHY methane ECV product. Sufficiently developed for this task.

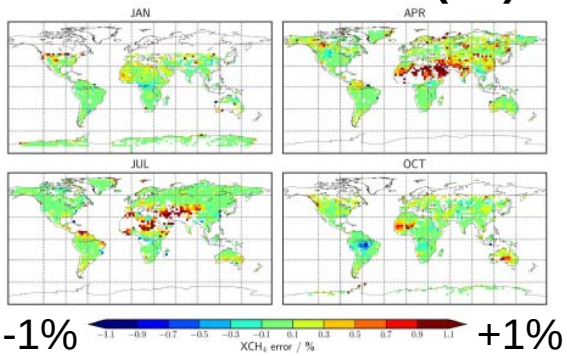


Frankenberg et al., in prep.

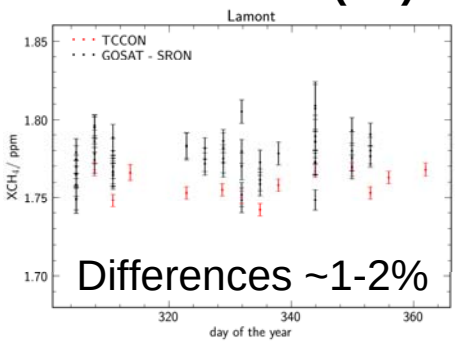
GHG-cci: GOSAT XCH_4

Retrieval algorithms: SRON-FP & „CO_2 PROXY“

GOSAT simulation (FP)



GOSAT real (FP)



Latest peer-reviewed publication: Butz, et al., Appl. Opt., 2009

Known issues: So far mainly applied to simulations. Only first prelimin. results for real data.

Retrieval algorithm description:

Retrievals of atmospheric CO_2 from simulated space-borne measurements of backscattered near-infrared sunlight: accounting for aerosol effects

Butz et al., AO, 2009

André Butz,* Otto P. Hasekamp, Christian Frankenberg, and Ilse Aben

SRON Netherlands Institute for Space Research, Sorbonnelaan 2, 3584 CA Utrecht, The Netherlands

*Corresponding author: a.butz@sron.nl

Methane SCIA & GOSAT: FP vs PROXY:
Butz et al., JGR, submitted

GHG-cci approach:

SRON Netherlands Institute for Space Research

Further development of SRON-FP and „CO_2 PROXY“ (IMAP-DOAS) algorithms.
Comparison with FTS & other reference data.
Iterative improvements.
Trade-off FP versus PROXY algorithms (accuracy, speed, …).

Ongoing international cooperation

On-going international involvement in GOSAT and OCO/ACOS projects

International network TCCON for satellite validation

International retrieval algorithms intercomparison project on best effort basis (SCORE-MIP)

Whished/needed international cooperation

Close collaboration needed with other projects generating climate variables (NOAA, NASA ...)

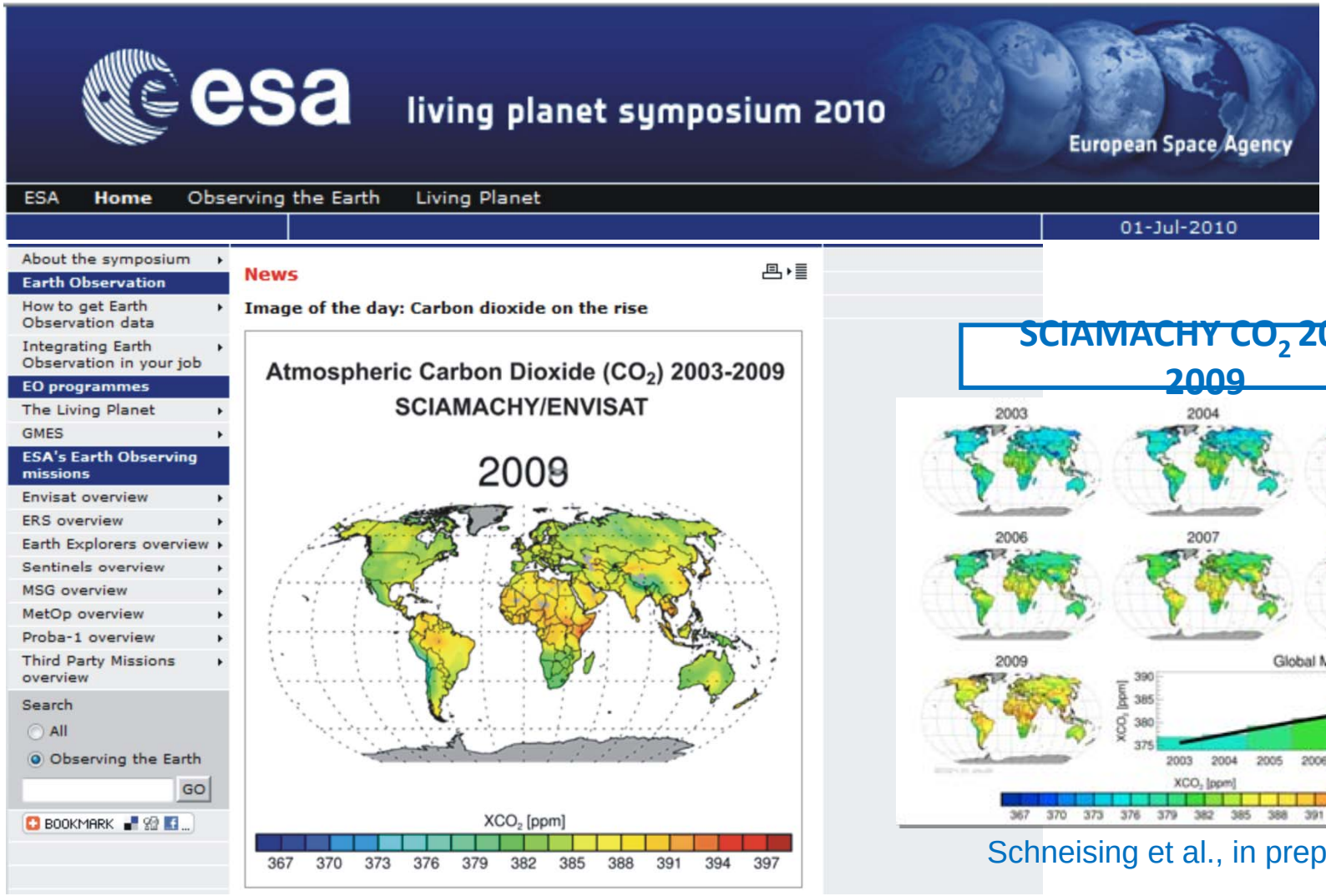
Future GHG missions

- to develop a strategy for long-term, continuous, cross-calibrated data records
- to move towards consistent data formats and documentation
- to achieve a consistent way of documenting and assessing data quality
- to facilitate constellations of satellites or joint missions to increase the science return

One-stop-shop for GHG satellite datasets and relevant sub-orbital data (ground-based, aircraft)

International cooperation to guarantee the continued support for ground-based networks and to influence future site selection to increase the benefit for satellite validation

Thank you very much for your attention !



SCIAMACHY CO_2 2003-2009

Schneising et al., in preparation

Backup

GHG-cci Project Team (2)

IUP, Univ. Bremen, Germany: Project lead, Retrieval (focus SCIA XCO_2), Validation lead (TCCON FTS);

„IUP“ (AG Prof Burrows): M. Buchwitz (Science Leader), M. Reuter, O. Schneising, …

„IUP-V“(alidation) (AG Prof Notholt): J. Notholt, T. Warneke, …

Univ. Leicester, UK: Retrieval (focus GOSAT XCO_2);

H. Bösch (Project Manager), P. Monks, …

SRON, Netherlands: Retrieval (focus SCIA&GOSAT XCH_4);

O. Hasekamp, I. Aben, A. Gloudemans, …

DLR, O‘hofen, Germany: SCIA L0-1, System engineering;

G. Lichtenberg, B. Aberle, S. Slijkhuis, …

LMD, France: Retrieval (AIRS, IASI, ACE-FTS);

C. Crevoisier, A. Chédin, …

KIT, Germany: Retrieval (MIPAS CH_4), Validation (FTS);

„KIT-M“(ipas): G. Stiller, J. Orphal, …

„KIT-V“(alidation): T. Blumenstock, F. Hase, R. Sussmann, M. Rettinger, …

BIRA, Belgium: Validation (NDACC FTS);

M. De Mazière, B. Dils, …

EMPA, Switzerland: Validation (in-situ WMO & AGAGE);

D. Brunner, B. Buchmann, …

LSCE, France: User lead (MACC interface), Modelling (CO_2);

F. Chevallier, F.-M. Bréon, P. Peylin, …

JRC, Italy: User aspects, Modelling (CH_4);

P. Bergamaschi, …

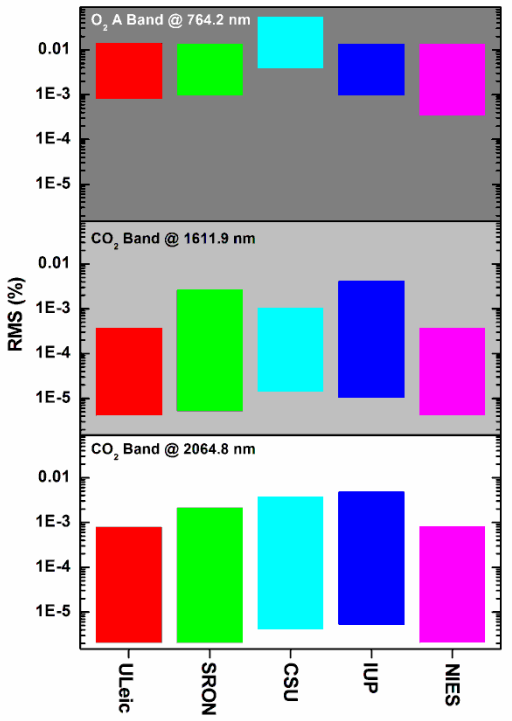
Round Robin & SCORE-MIP

SWIR Carbon Observation Retrieval Model Inter-comparison Project (SCORE-MIP)

(lead: Dr. H. Bösch, ULE):

- Initiated as a voluntary, non-funded activity at IWGGMS-6 in Kyoto, 2010
- Main objectives: (i) intercompare retrieval methods and diagnose their differences, (ii) provide guidance for algorithm improvement and estimate algorithm-specific uncertainties
- Currently participating institutions are IUP Bremen; Univ. Leicester; SRON; NIES/GOSAT; NASA-ACOS
- First meeting at EGU 2010

SCORE-MIP activities focusing on GOSAT XCO_2 will be part of GHG-cci Round Robin for ULE, SRON, IUP

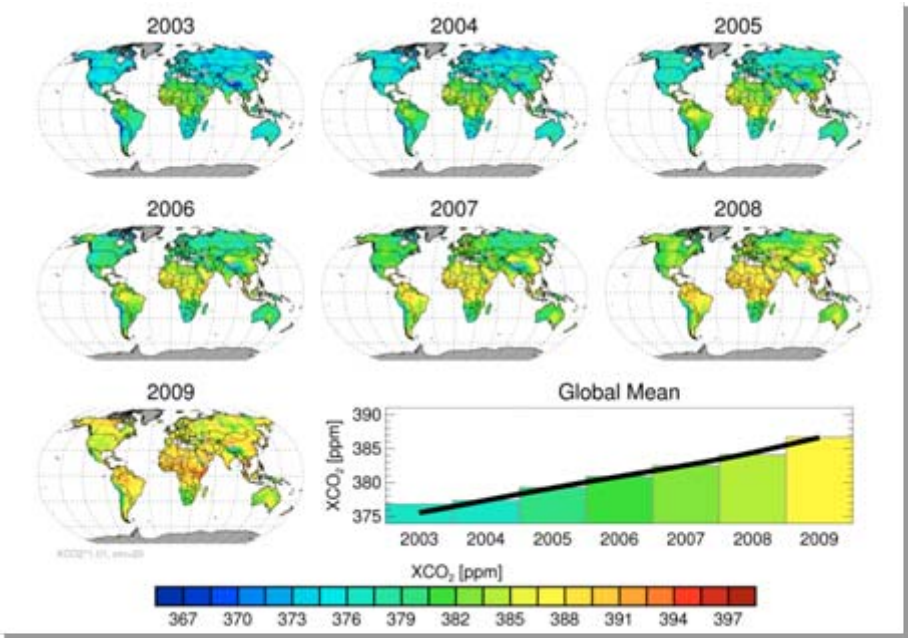


Comparison of radiative transfer codes. Bars give range of root-mean square (RMS) deviation from mean of calculations (several scenarios) by all five groups.

GOSAT Newsletter #6
http://sites.google.com/site/scoremip

SCIAMACHY GHG: WFM-DOAS

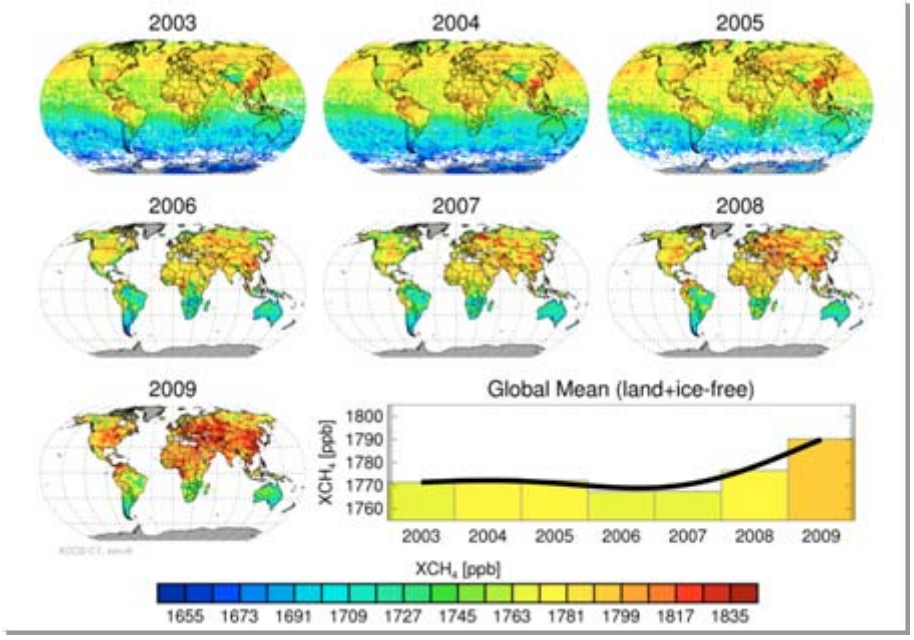
SCIAMACHY CO_2 2003-2009



Schneising et al., in preparation

SCIAMACHY

SCIAMACHY CH_4 2003-2009



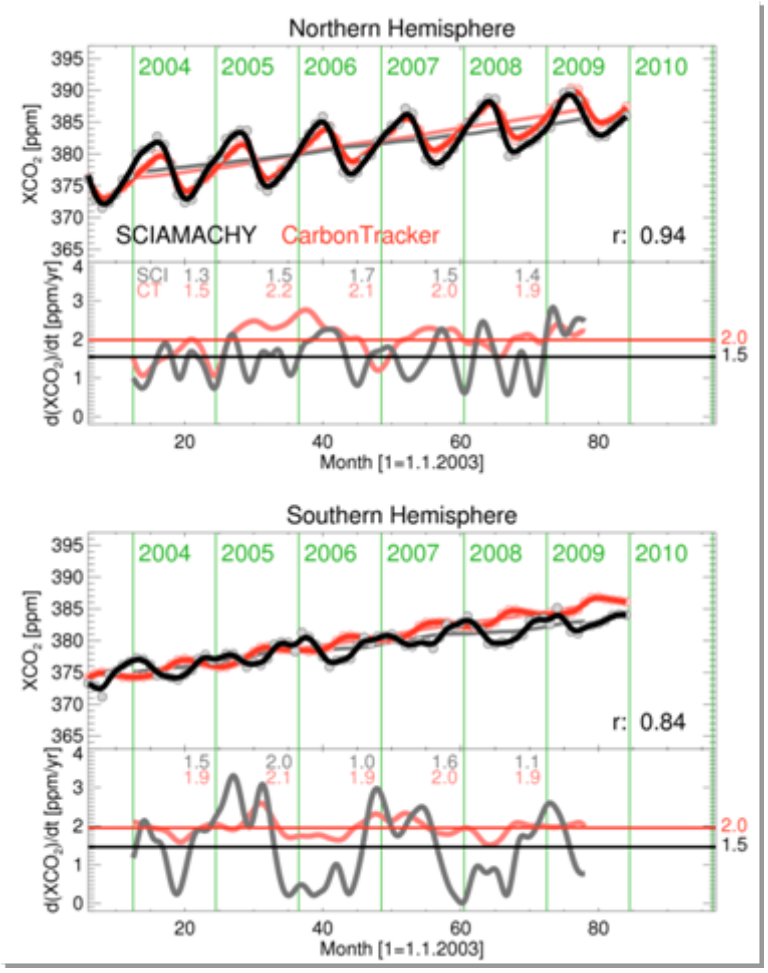
Algorithm: WFM-DOAS v2.0

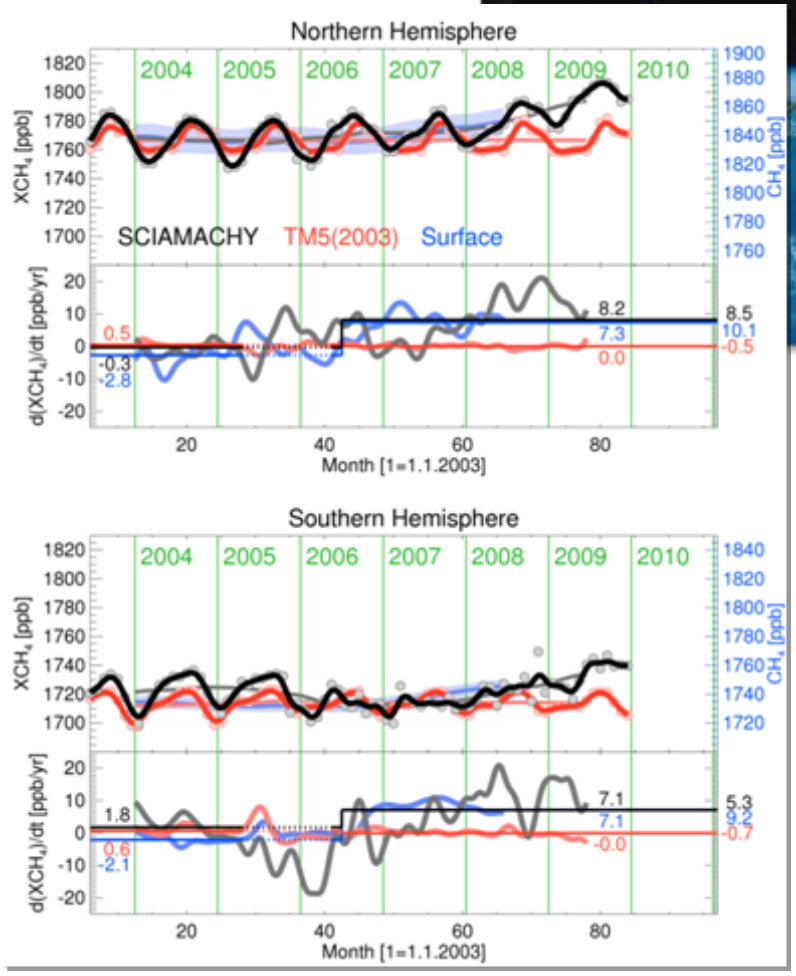
See talk Schneising et al., 1 July, Room 2, 16:40

SCIAMACHY GHG: WFM-DOAS

SCIAMACHY CO_2 vs CarbonTracker (NOAA)

SCIAMACHY CH_4 vs TM5(2003) (JRC)





Algorithm: WFM-DOAS v2.0

See talk Schneising et al., 1 July, Room 2, 16:40

SCIAMACHY XCO_2: BESD

Atmos. Meas. Tech., 3, 209–232, 2010
www.atmos-meas-tech.net/3/209/2010/

Atmospheric Measurement Techniques

Reuter et al., AMT, 2010

A method for improved SCIAMACHY CO_2 retrieval in the presence of optically thin clouds

M. Reuter, M. Buchwitz, O. Schneising, J. Heymann, H. Bovensmann, and J. P. Burrows

University of Bremen, Institute of Environmental Physics, P.O. Box 330440,
28334 Bremen, Germany

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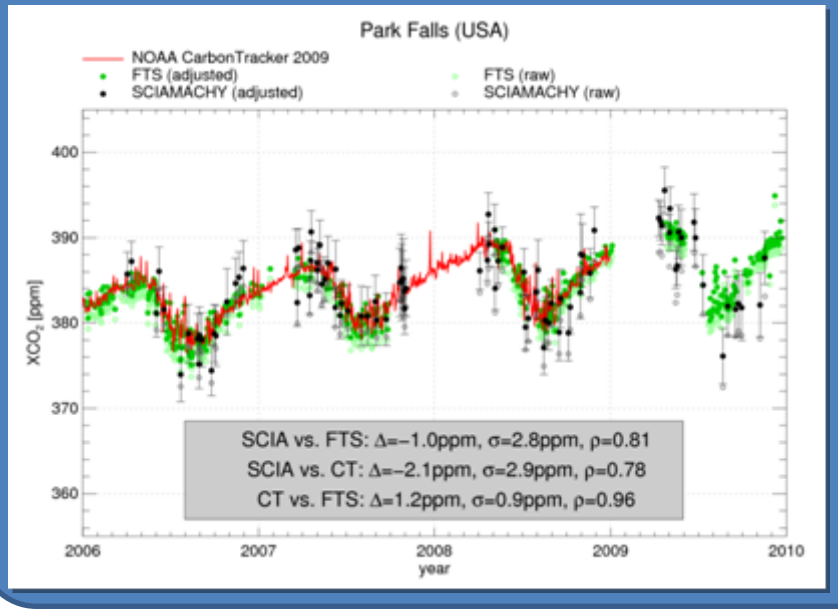
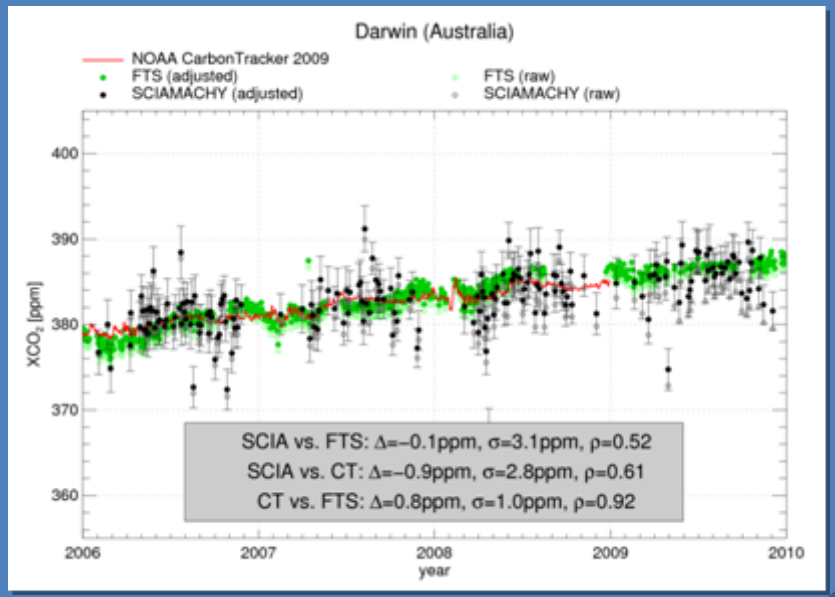
Revised: 15 January 2010 – Accepted: 9 February 2010 – Published: 12 February 2010

First application of BESD to real SCIAMACHY data





Algorithm: BESD

See talk Reuter et al., 1 July, Room 6, 11:20

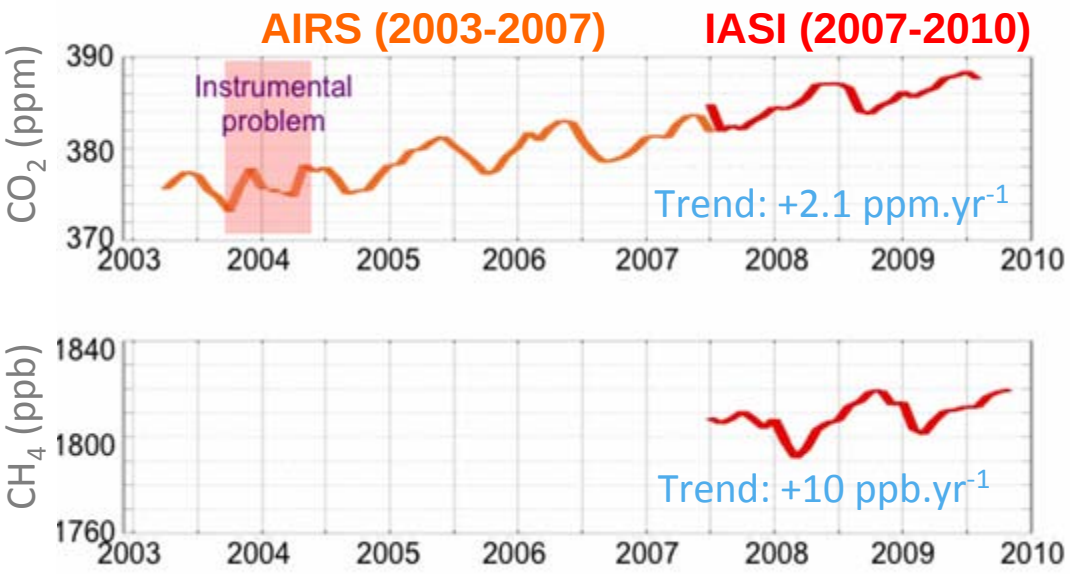
GHG-cci: AIRS, IASI, ACE-FTS

Mid-tropospheric integrated columns from AIRS and IASI

First retrieval of CO_2 from space: Chédin et al. 2003 using TOVS instruments.

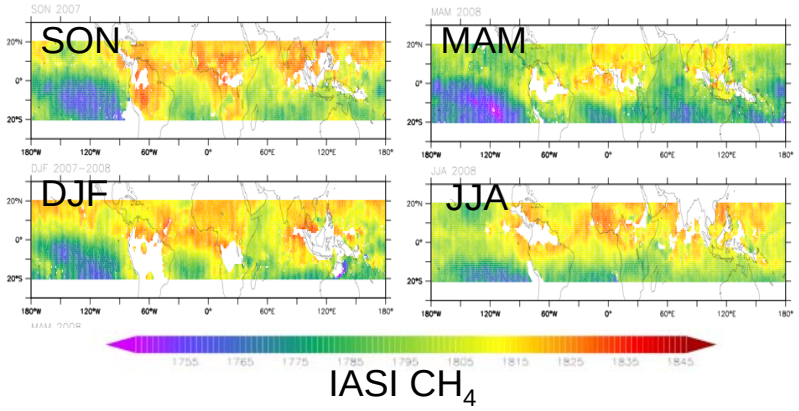
Characteristics: mid-tropospheric columns of CH_4 and CO_2 from nadir-viewing IR sounders (TOVS, AIRS, IASI) using a non-linear inference scheme based on neural networks.

Study of long-time series:



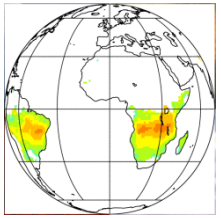
(Crevoisier et al. GRL 2004, ACP 2009a, 2009b)

Study of geographic distribution:



Study of CO_2 diurnal cycle:

Proxy for CO_2 emissions from tropical fires (Chédin et al., 2005, 2008)

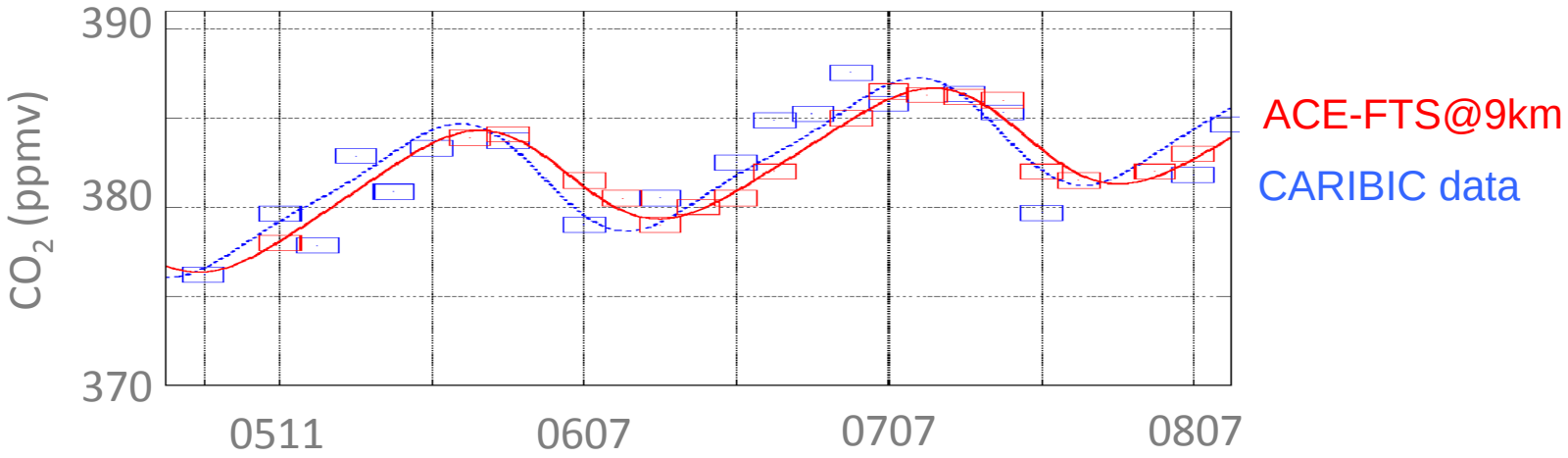


With 3 successive IASI, more than 20 years of GHG retrievals will be available.

GHG-cci: AIRS, IASI, ACE-FTS (2)

CO_2 vertical profiles from ACE-FTS

Characteristics: retrieval of CO_2 vertical profiles from about 5 km to 25 km with a precision of ~2 ppmv and a resolution of 2 km from the limb viewing instrument ACE-FTS, working in solar occultation mode, flying on board the Canadian satellite SCISAT (Foucher et al. ACP 2009, 2010 in prep.).

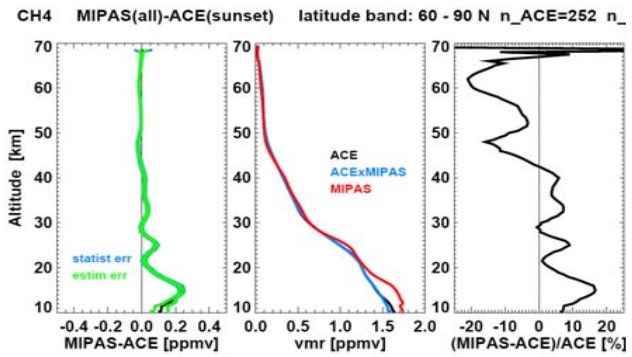


GHG-cci approach:

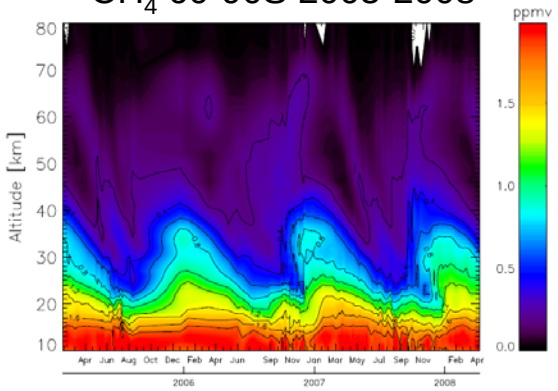
Reinterpretation of AIRS and IASI data in terms of CO_2 and CH_4 columns in the new context of the availability of the ACE-FTS CO_2 profiles, improvement of the retrieval by using new spectral ranges to constrain temperature, comparison with other satellite data (e.g. TES, MIPAS), additional constraint on the surface flux inverse modelling.

GHG-cci: MIPAS CH_4 Profiles

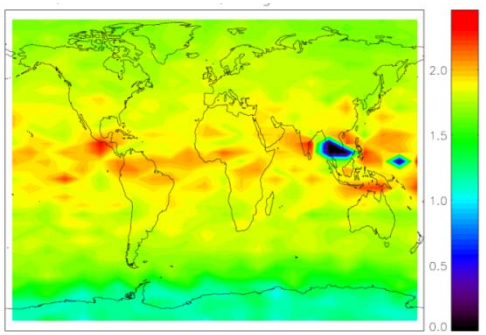
Algorithm: KOPRA/RCP (KIT IMK)



CH_4 60-90S 2005-2008



CH_4@16 km ASON 2003



Precision: 5% (@ 15 km) to 14% (@ 50 km); Vert. res.: 2 km (@ 20 km) to 3.7 km (@ 50 km);
Hor. res.: 198 km (@ 10 km) to 468 km (@ 40 km) (von Clarmann et al., AMT, 2009)

Known issues: High bias (approx. 0.2 ppmv = 10%) below 25 km

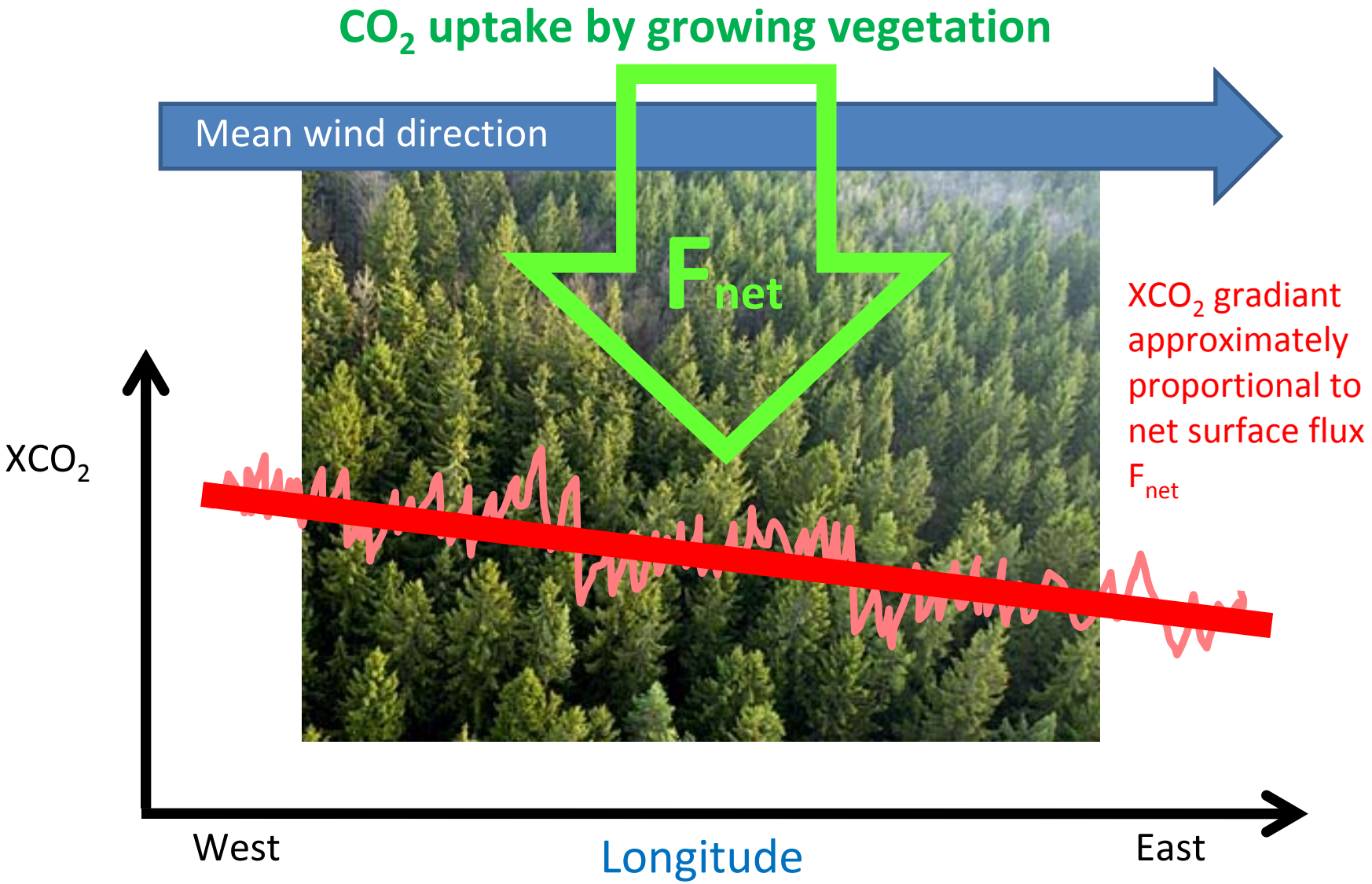
Publications / applications:

- CH_4 used as a tracer for mixing across the polar vortex boundary (Glatthor et al., JAS, 2005; Mengistu Tsidu et al., JGR 2005) and for polar winter subsidence (Funke et al., JGR, 2005; Konopka et al., JGR 2007; Funke et al., ACP, 2008)
- Variation of $H_2O+2*CH_4$ studied for analysis of stratospheric hydrogen budget (Wrotny et al., JGR, 2010)

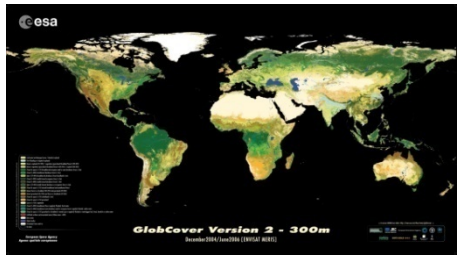
GHG-cci approach:

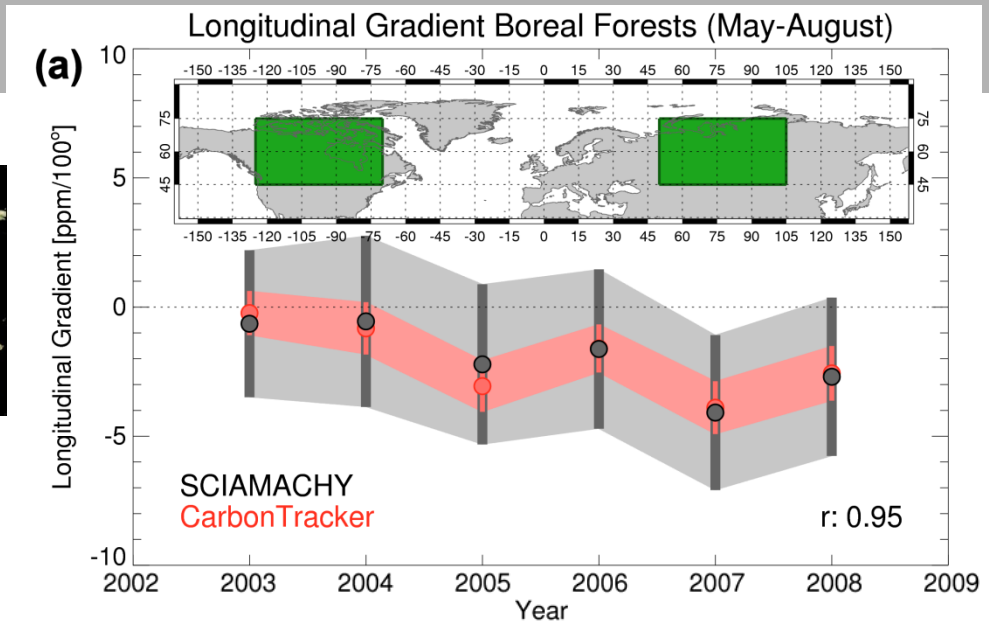
- De-bias MIPAS CH_4 profiles (by comparison to other observations providing profile info)
- Validate XCH_4 and partial columns from SCIAMACHY and GOSAT by comparing to de-biased MIPAS profiles and partial colums
- Validate spatial (horizontal) and temporal variations and patterns from SCIA and GOSAT CH_4 by comparing to MIPAS

SCIA & Boreal Forest CO_2 uptake: Idea

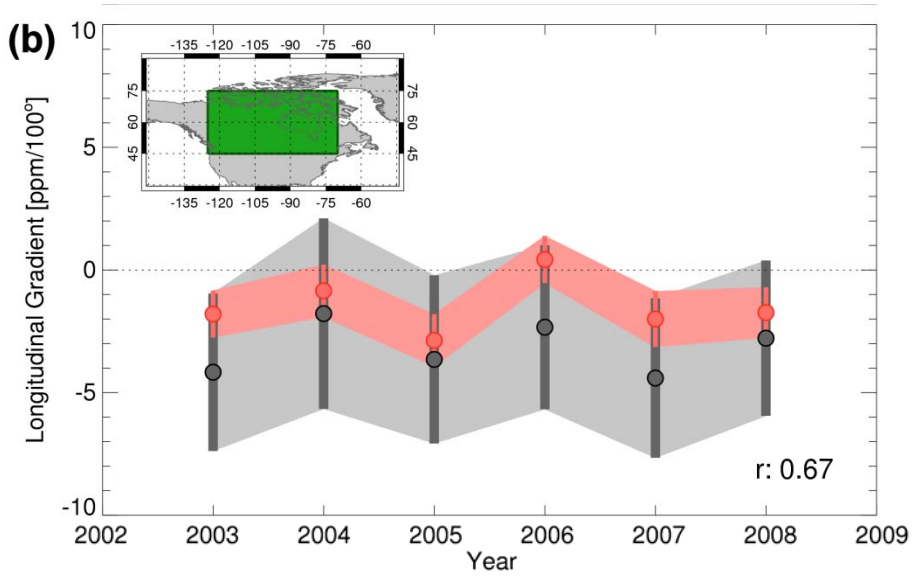


SCIA & Boreal Forest CO_2 uptake: First Results

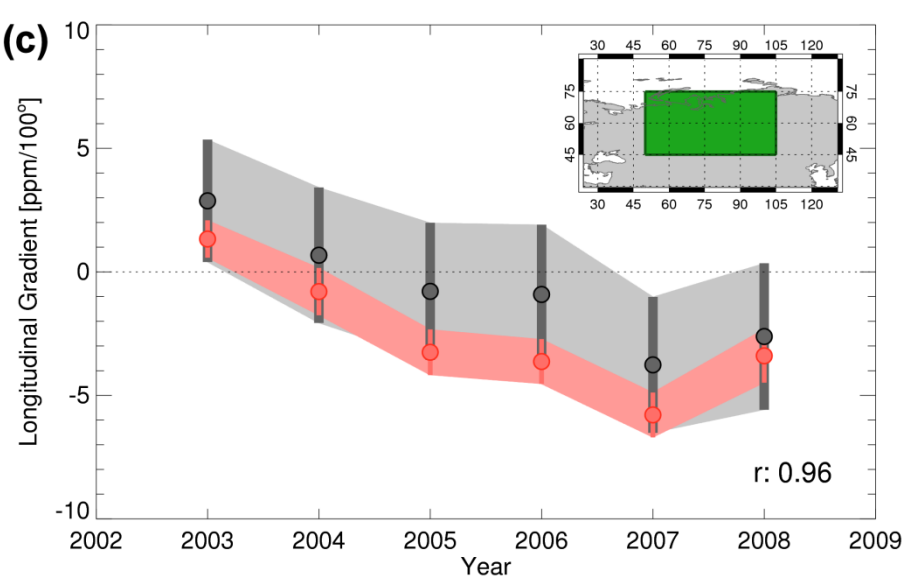




Overall very good agreement

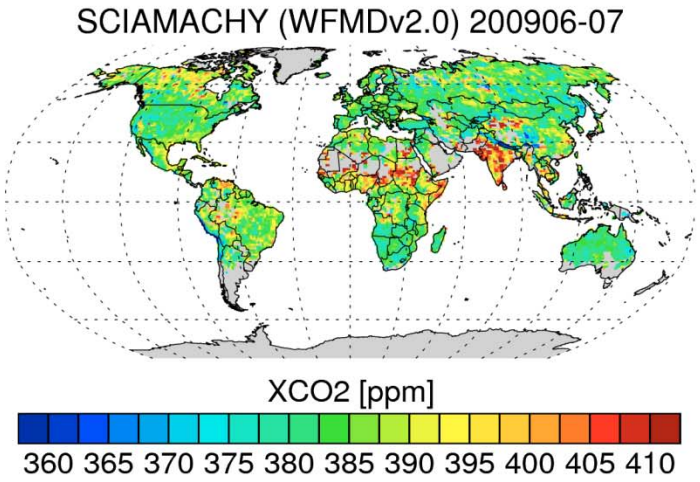


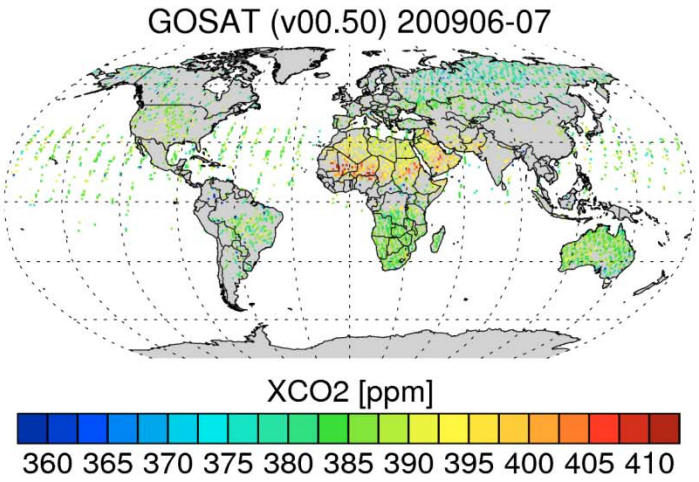
Canada: Stronger CO_2 uptake ?

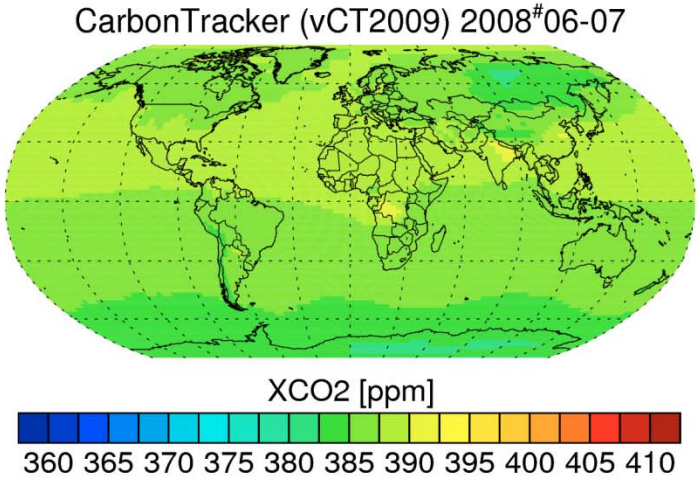


Russia: Weaker CO_2 uptake ?

SCIA – GOSAT comparison: XCO_2 - all

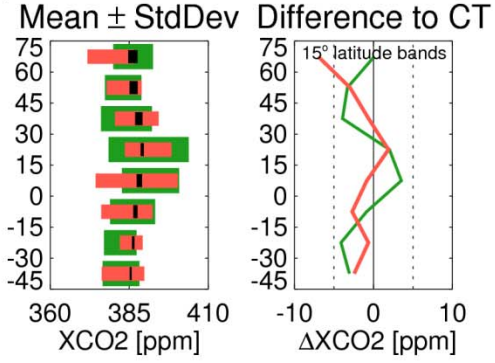




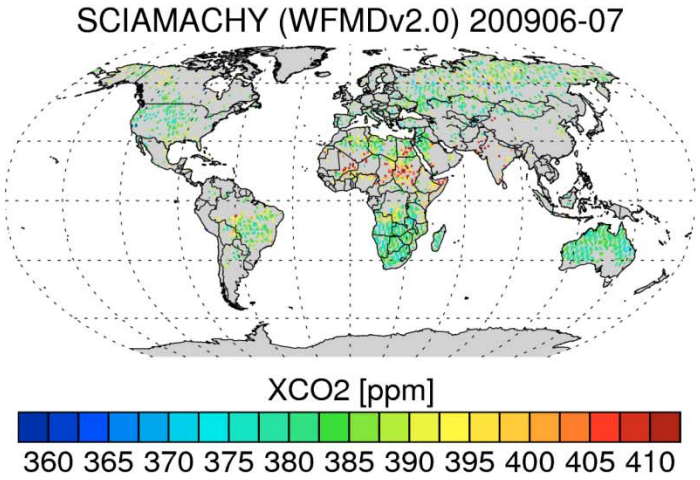


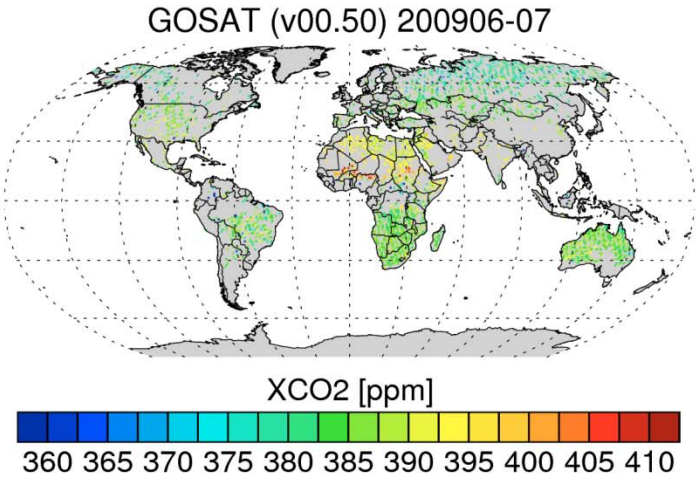
	StdDev [ppm]	Mean [ppm]	Scale
SCIAMACHY:	8.2	385.7	1.01
GOSAT:	8.3	385.9	1.02
CarbonTracker: (2008 values + 2ppm)	1.9	386.4	1.00

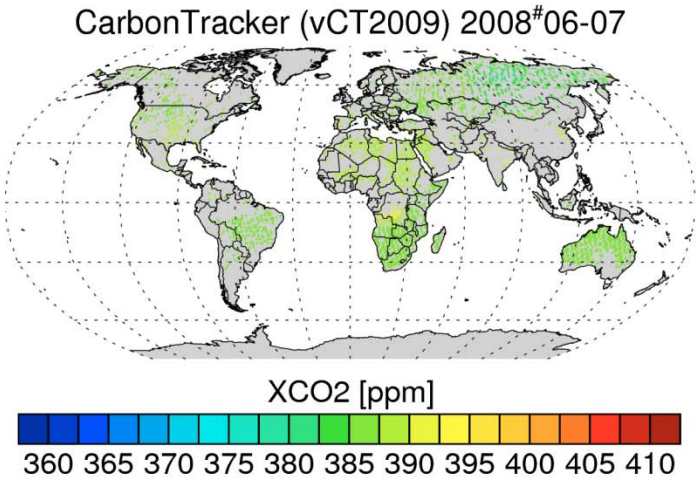
R(S,G): 0.51
R(S,C): 0.78
R(G,C): 0.85



SCIA – GOSAT comparison: XCO_2 – co-located







	StdDev [ppm]	Mean [ppm]	Scale
SCIAMACHY:	7.9	385.4	1.01
GOSAT:	7.6	385.2	1.02
CarbonTracker: (2008 values + 2ppm)	1.7	386.7	1.00

R(S,G): 0.20
R(S,C): 0.31
R(G,C): 0.42

R(S,G): 0.52
R(S,C): 0.62
R(G,C): 0.93