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→ ATMOS 2015

Advances in Atmospheric Science and Applications

The greenhouse gas project of ESA's Climate Change Initiative (GHG-CCI): Phase 2 achievements & future plans

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& the GHG-CCI team

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University of Leicester
SRON Netherlands Institute for Space Research
DLR
LMD
Max-Planck-Institut für Biogeochemie
EMPA
KIT Karlsruhe Institute of Technology
The University of Edinburgh
European Commission
LSCE
aeronomie.be
The Inversion Lab

8–12 June 2015 | University of Crete | Heraklion, Greece

European Space Agency

GHG-CCI project team

www.esa-ghg-cci.org/

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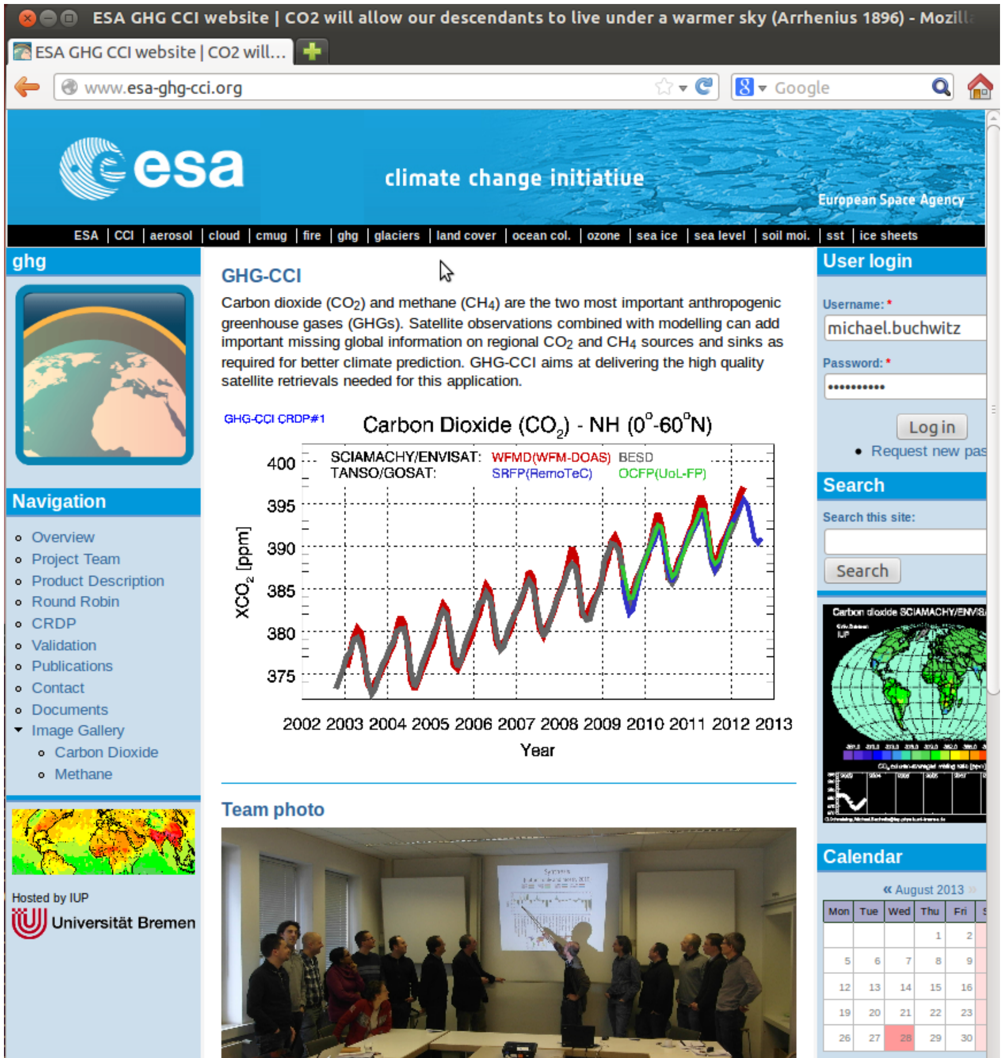
Outline

- **Overview** ESA Climate Change Initiative (CCI) & GHG-CCI project
- **Selected results from SCIAMACHY and GOSAT:**
  - **Terrestrial vegetation CO_2 sink:**
    - European terrestrial carbon sink from SCIAMACHY and GOSAT (Reuter et al., ACP, 2014)
  - **Anthropogenic CO_2 emissions from SCIAMACHY:**
    - Schneising et al., ACP, 2013
    - Reuter et al., Nature Geoscience, 2014
  - **Anthropogenic CH_4 emissions from SCIAMACHY:**
    - First results from major US „fracking“ areas (Schneising et al., Earth‘s Future, 2014)
- **Future aspects**

ESA Climate Change Initiative (CCI)

to generate Essential Climate Variables (ECVs)

www.esa-ghg-cci.org/



ESA programme

led by Mark Doherty, ESA/ESRIN

ECV projects:

- Aerosol-CCI
- Cloud-CCI
- Fire-CCI
- **GHG-CCI - CO_2 & CH_4**
- Glaciers-CCI
- LandCover-CCI
- OceanColour-CCI
- Ozone-CCI
- SeaLevel-CCI
- SST-CCI
- SoilMoisture-CCI
- SeaIce-CCI
- IceSheets-CCI (Greenland, Antarctica)

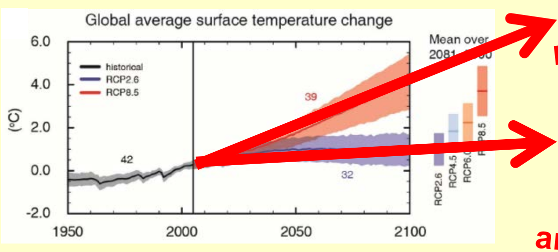
+ **CMUG** (Climate Modelling User Group)

- Lead: Roger Saunders (Met Office Hadley Centre)
- Met Office Hadley Centre, ECMWF, MPI-Meteorology, Météo France, IPSL, SMHI, DLR

ECV Greenhouse Gases

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

Observed and predicted temperature change (AR5)



Future?

Ecomomy?

Population?

Technology?

GHG sources and sinks?

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 / Product A.8.1 (GCOS-154*)):

"Retrievals of greenhouse gases, such as CO_2 and CH_4, of sufficient quality to estimate regional sources and sinks."

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

GHG-CCI project www.esa-ghg-cci.org

Global satellite observations

Global information on near-surface CO_2 & CH_4

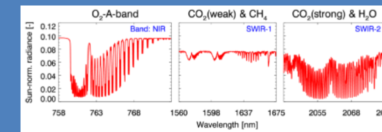
Upper layer CO_2 & CH_4

Comparisons etc.: OCO-2

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

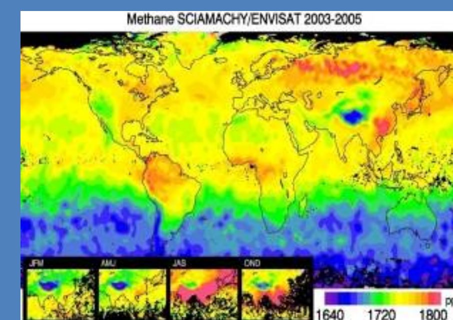
Calibration (L 0-1)

Calibrated radiances

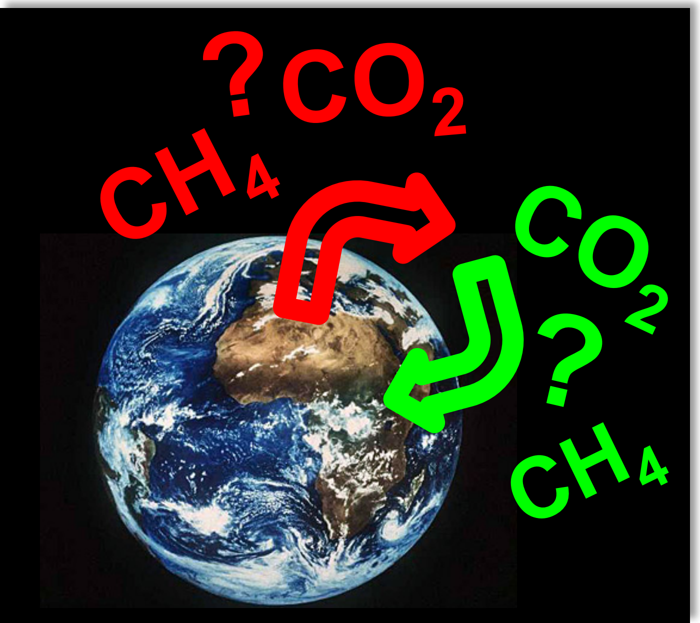


Retrieval (L 1-2)

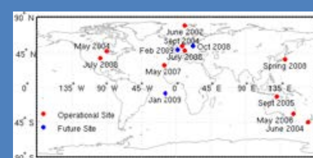
Atmospheric GHG distributions



Global observations

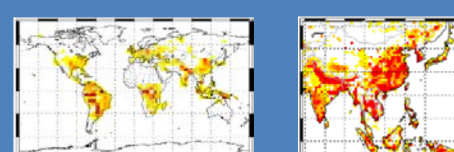


Reference observations



Validation

Improved information on GHG sources & sinks



Inverse modelling (L 2-4)

GHG-CCI: Data sets

GHG-CCI Climate Research Data Package (CRDP#2)															
Product ID	Product (Level 2, mole fractions)	Years processed													
		2002	03	04	05	06	07	08	09	10	11	12	13	14	15
GHG-CCI Core Products: ECV Core Algorithm (ECA) Products															
XCO2_SCIA	XCO_2														
XCH4_SCIA	XCH_4														
XCO2_GOSAT	XCO_2														
XCH4_GOSAT	XCH_4														
XCO2_EMMA	XCO_2														
Additional Constraints Algorithm (ACA) Products															
CO2_IASI	CO_2 (1)														
CH4_IASI	CH_4 (1)														
CH4_SCIAOCC	CH_4 (2)														
CO2_SCIAOCC	CO_2 (2)														
CO2_ACEFTS	CO_2 (2)														
CH4_MIPAS	CH_4 (2)														
CO2_AIRS	CO_2 (1)														

Comments:

ACA products:
(1) Mid / upper tropospheric column
(2) Upper tropospheric / stratospheric profile

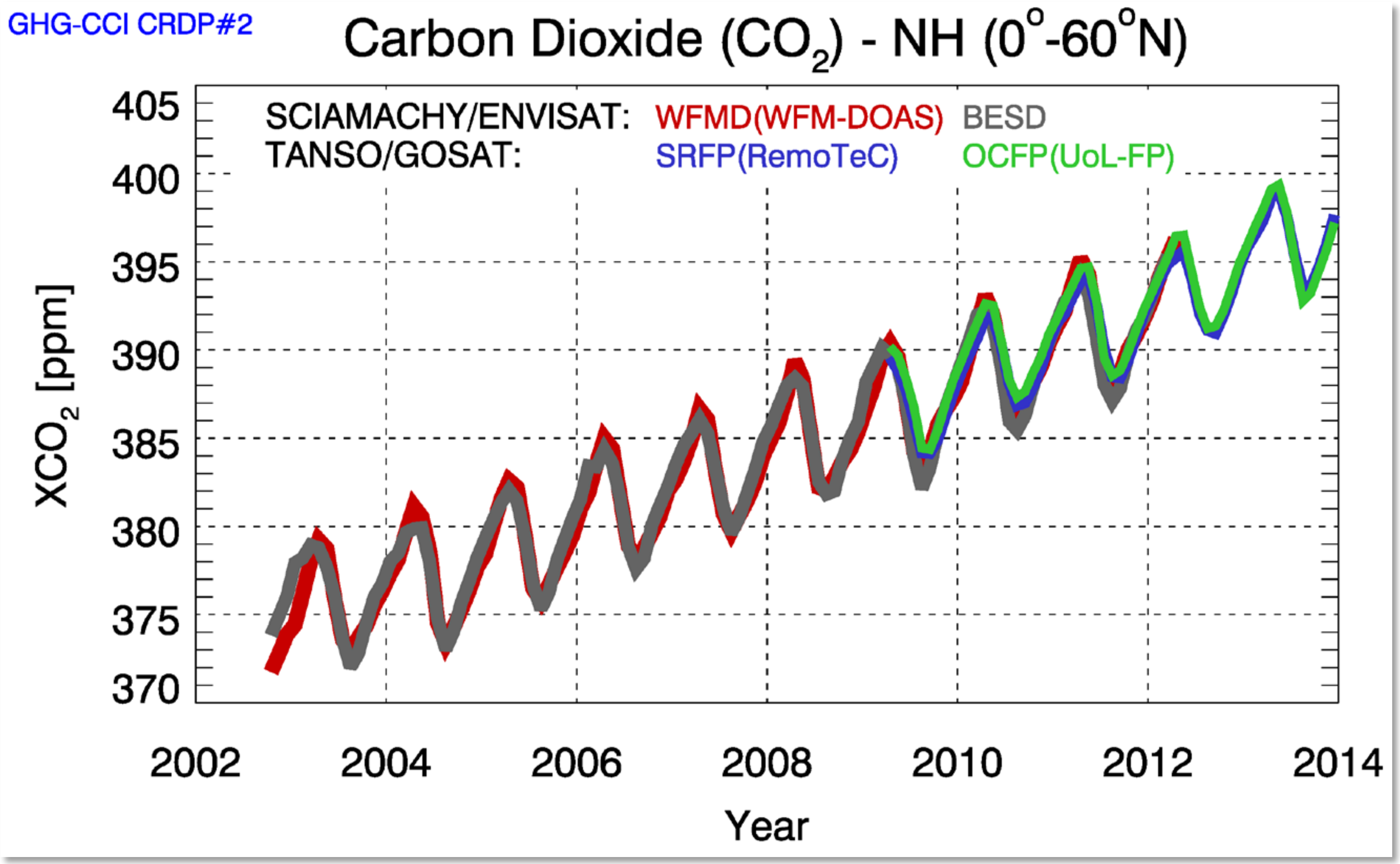
CRDP#2
Also available

ECA Algorithms for column-averaged dry air mole fractions:

XCO2_SCIA: BESD, WFMD
XCH4_SCIA: WFMD, IMAP
XCO2_GOSAT: SRFP (RemoTeC), OCFP (UoL-FP)
XCH4_GOSAT: SRFP & SRPR (RemoTeC), OCPR (UoL-PR)
XCO2_EMMA: Various (SCIA & GOSAT merged)

Details please see: www.esa-ghg-cci.org -> CRDP (Data)

GHG-CCI: XCO_2 time series



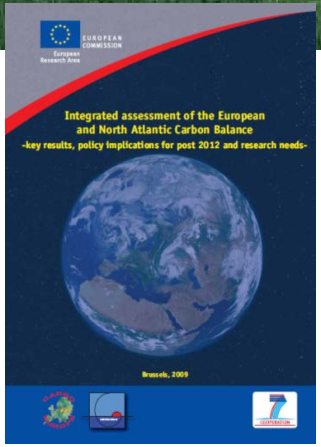
Ensemble: Key to success

- **Multiple satellite algorithms / products**

http://www.northpacificmusic.com/ensemble.east.west.jpg

- **Multiple models / inverse models**

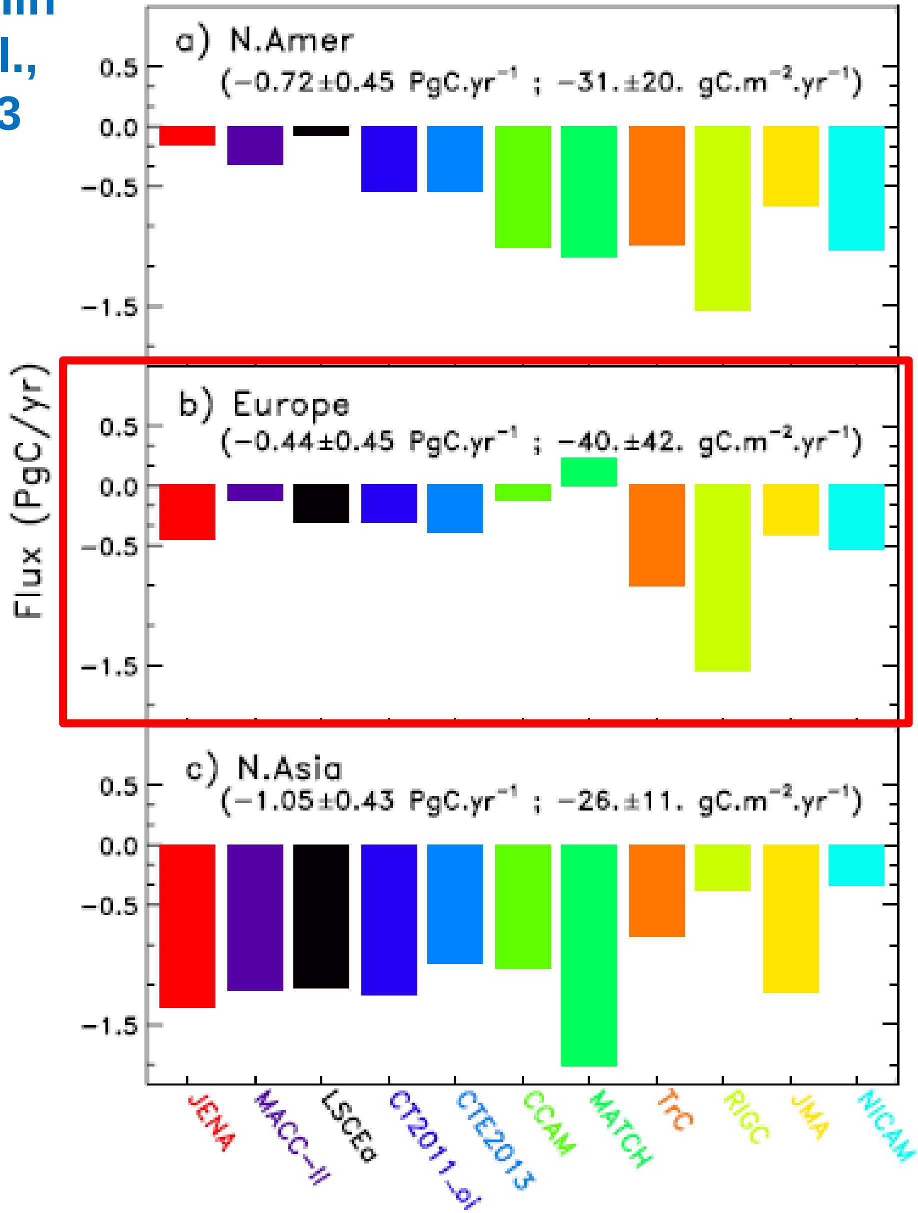
Terrestrial carbon sink



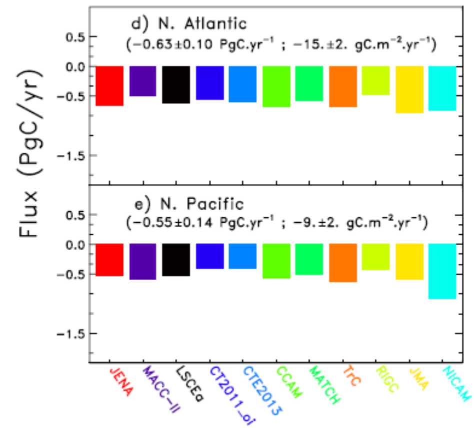
Regional carbon budgets

Peylin et al., 2013

Land



Oceans



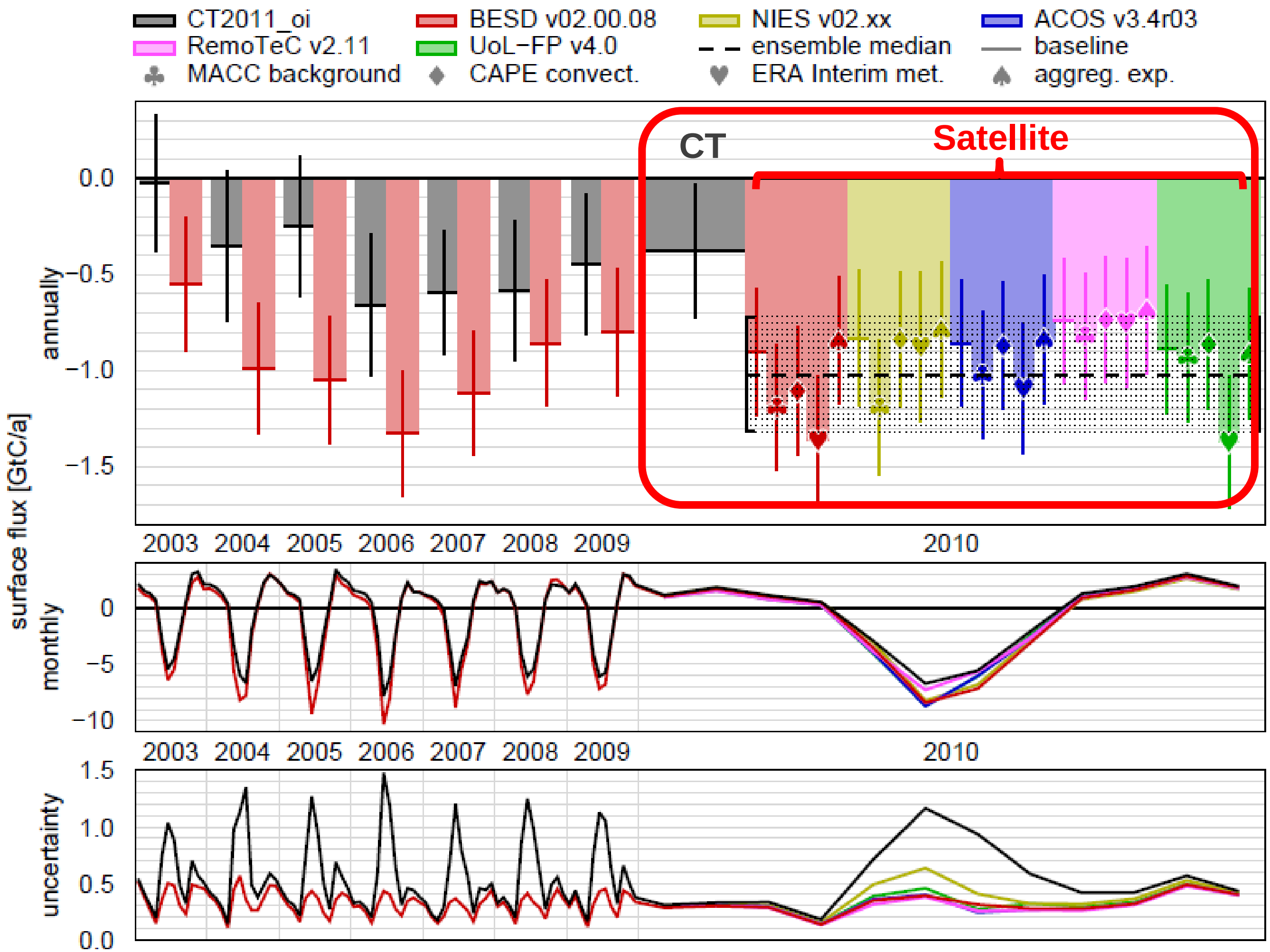
Acronym	Reference
LSCEa	Piao et al. (2009)
MACC-II	Chevallier et alal. (2010)
CCAM	Rayner et al. (2008)
MATCH	Rayner et al. (2008)
CT2011_oi	Peters et al. (2007)
CTE2013	Peters et al. (2010)
JENA (s96, v3.5)	Rödenbeck (2005)
RIGC (TDI-64)	Patra et al. (2005a)
JMA	Maki et al. (2010)
TrC	Gurney et al. (2008)
NICAM	Niwa et al. (2012)

No satellite XCO_2 data used

European terrestrial carbon fluxes from SCIAMACHY and GOSAT

„Continental Europe only“ inversion using STILT-based short range (days) particle dispersion modelling using an ensemble of satellite XCO_2 retrievals:

Reuter et al., ACP, 2014



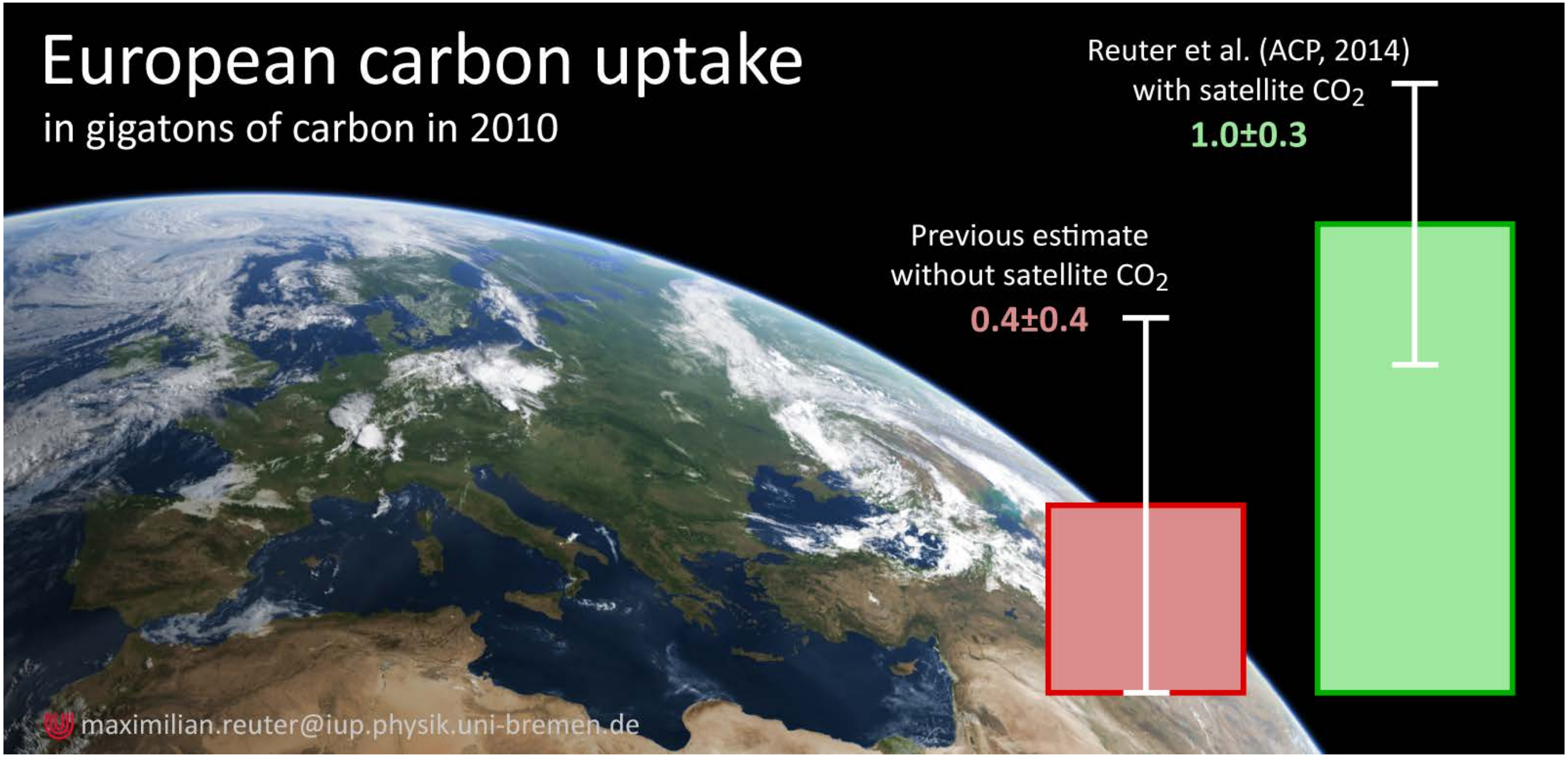
- 2 satellites
- 5 retrieval algorithms / products
- New flux inversion method insensitive to observations outside Europe, large-range transport & other errors
- Various sensitivity studies

Satellite data suggest a continental (TransCom) **European C sink of 1.02 +/- 0.3 GtC/yr (for 2010)**

European terrestrial carbon fluxes from SCIAMACHY and GOSAT

Reuter et al., ACP, 2014

Summary for continental (TransCom) Europe:



Related ESA webstory: Is Europe an underestimated sink for carbon dioxide ?
http://www.esa.int/Our_Activities/Observing_the_Earth/Is_Europe_an_underestimated_sink_for_carbon_dioxide

European carbon sink: Ongoing research ...

Atmos. Chem. Phys. Discuss., 15, 1989–2011, 2015
www.atmos-chem-phys-discuss.net/15/1989/2015/
doi:10.5194/acpd-15-1989-2015

Atmospheric Chemistry and Physics Discussions
Open Access

This discussion paper is/has been under review for the journal Atmospheric Chemistry and Physics (ACP). Please refer to the corresponding final paper in ACP if available.

Elevated uptake of CO_2 over Europe inferred from GOSAT X_{CO_2} retrievals: a rea
analy

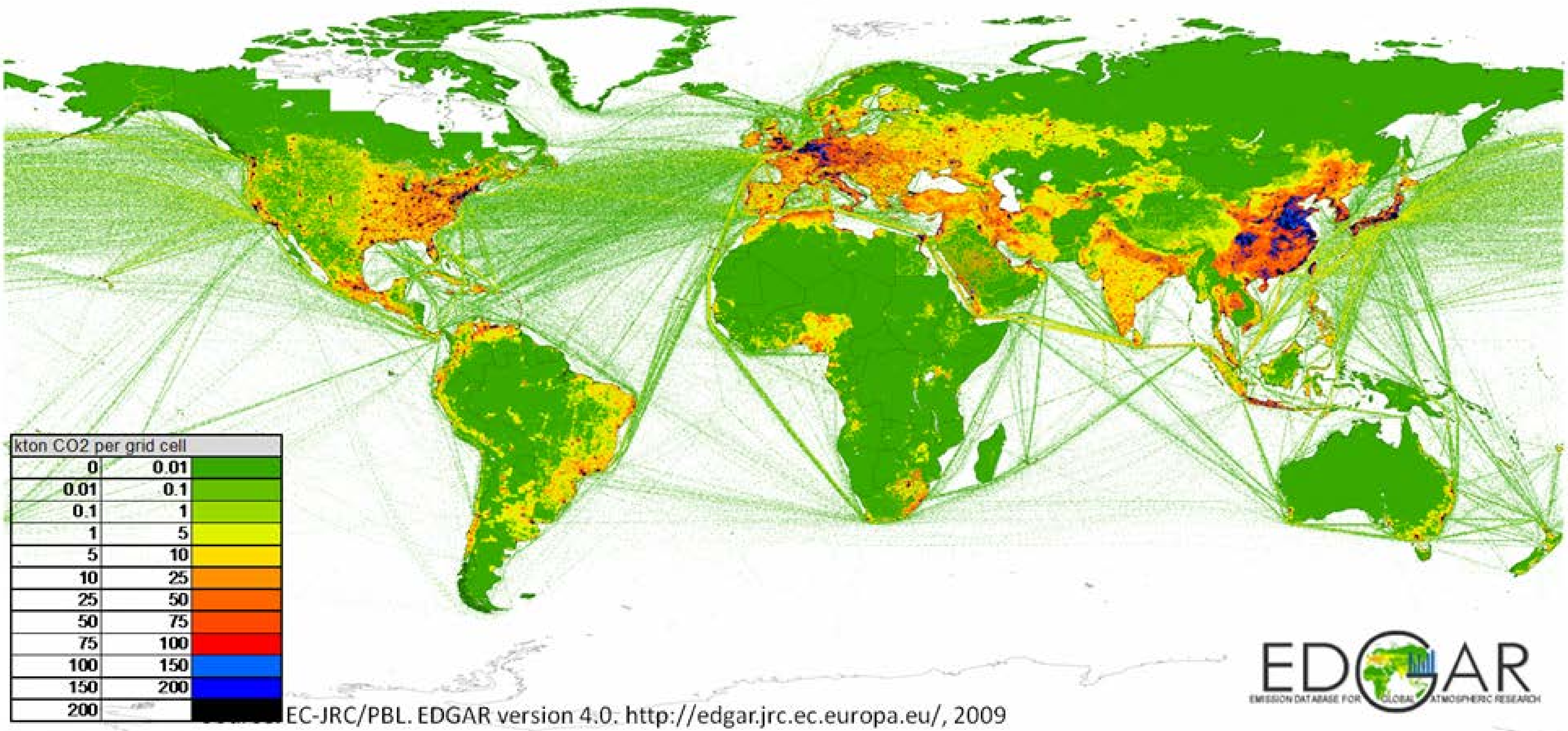
L. Feng[1],
I. Morino[7]

An inter-comparison of inverse models for estimating sources and sinks of CO_2 using GOSAT measurements

S. Houweling,[1,2] D. Baker,[3] S. Basu,[4] H. Boesch,[12] A. Butz,[13] F. Chevallier,[5] F. Deng,[6] E. J. Dlugokencky,[7] L. Feng,[8] A. Ganshin,[9] O. Hasekamp,[1] D. Jones,[6] S. Maksyutov,[10] J. Marshall,[12] T. Oda,[4,16,17] C. W. O'Dell,[15] S. Oshchepkov,[10] P. I. Palmer,[8] P. Peylin,[5] Z. Poussi,[11] F. Reum,[12] H. Takagi,[10] Y. Yoshida,[10] R. Zhuravlev[9]

Anthropogenic emissions

Anthropogenic CO_2



Bottom-up estimate
Currently not possible to verify this using satellite data !?
-> We hope for CarbonSat !

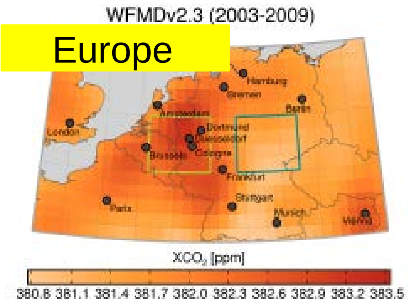
SCIAMACHY CO_2 over anthropogenic source regions

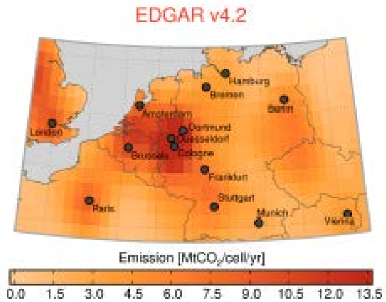
SCIAMACHY XCO_2

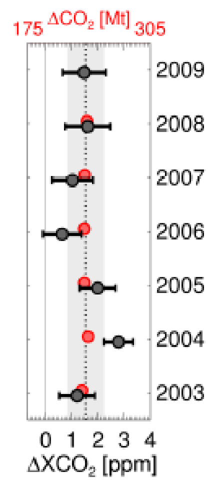
EDGAR CO_2 emissions

Schneising et al., ACP, 2013

Europe



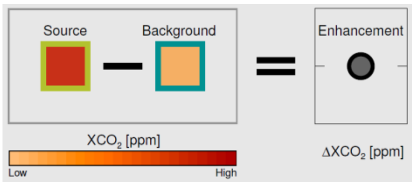




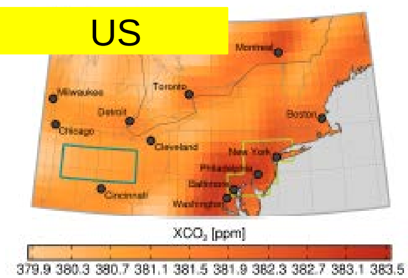
SCIAMACHY

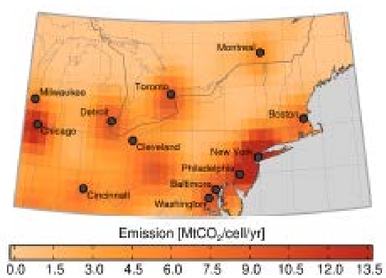
EDGAR

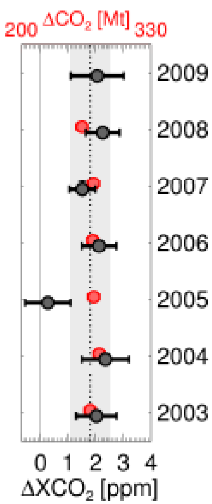
Regional enhancement =
Source - Background



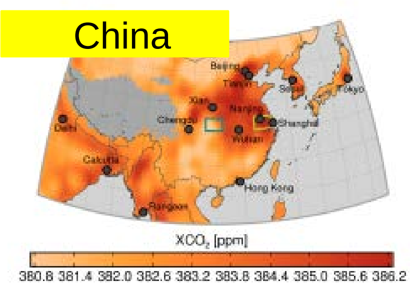
US

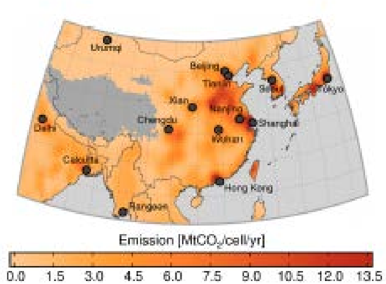


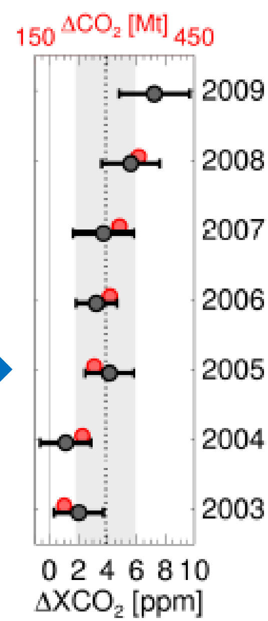




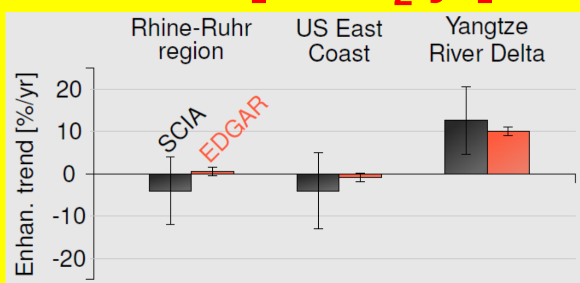
China







Trend [$\%CO_2$/yr]

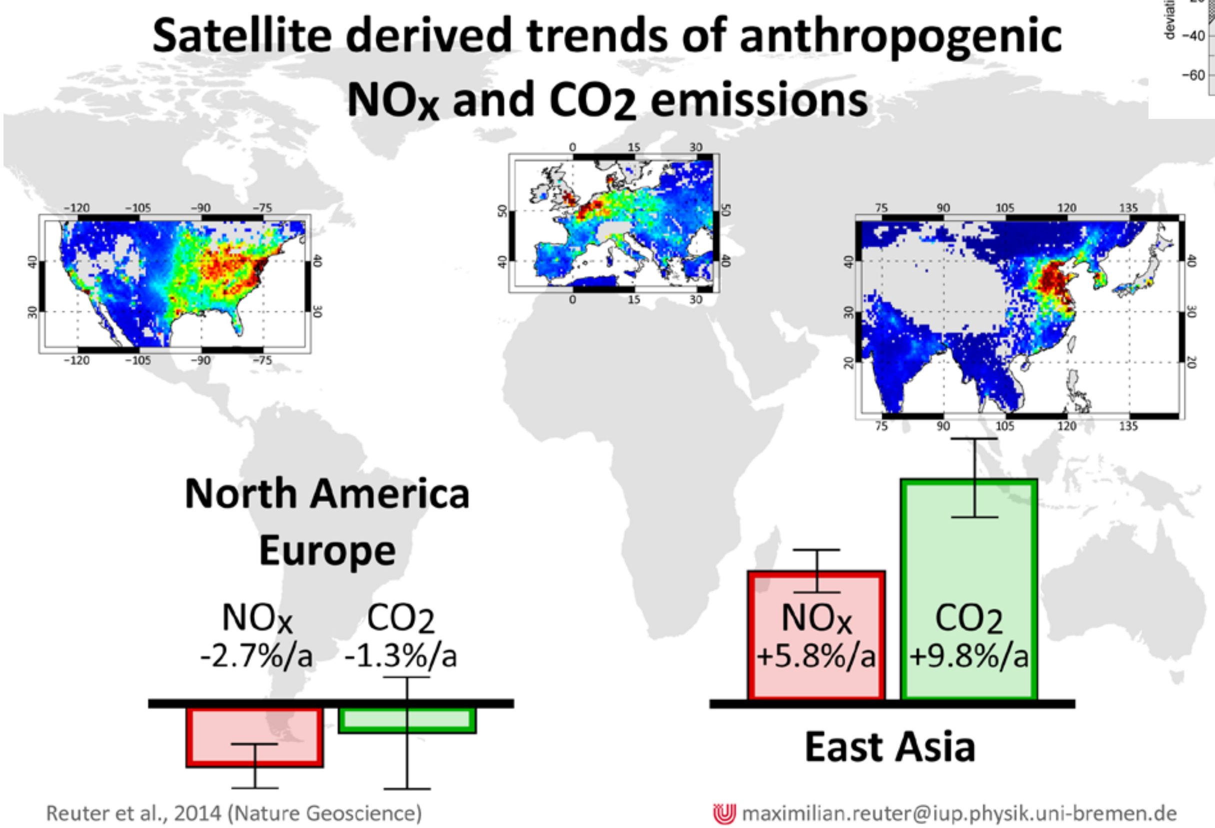


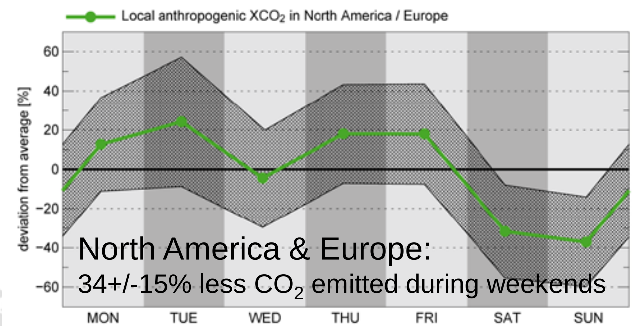
EDGAR emissions consistent with SCIAMACHY

Anthropogenic emissions: Good and bad news

Reuter et al., Nature Geoscience, 2014

„Decreasing NO_x relative to CO_2 emissions in East Asia inferred from satellite observations"





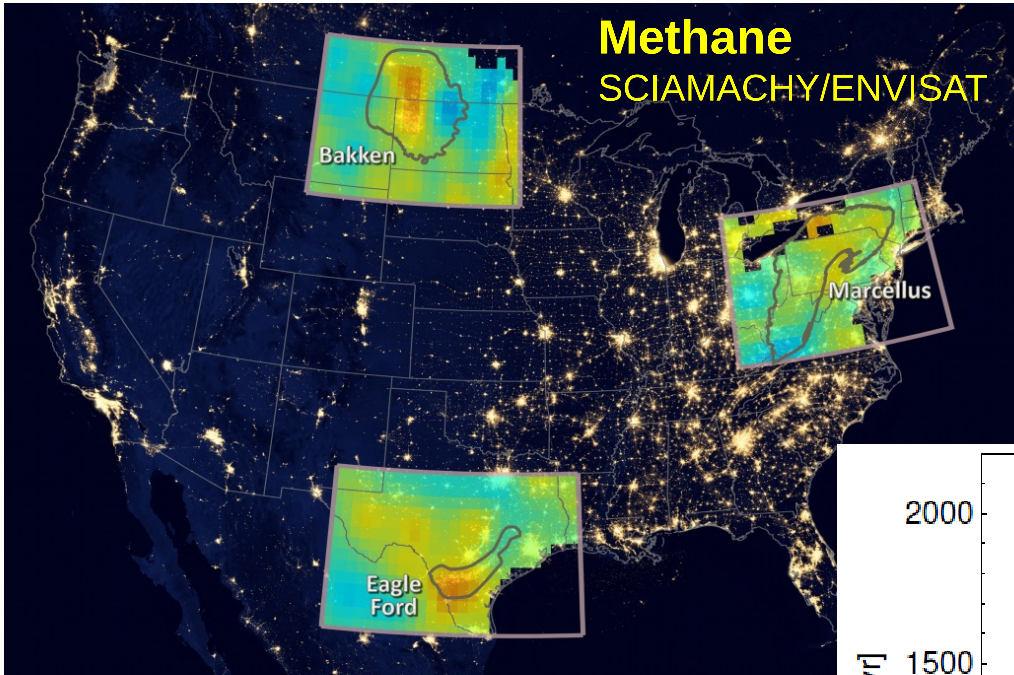
- Anthropogenic CO_2 emission signal from localized sources isolated via simultaneous SCIAMACHY XCO_2 and NO_2 observations & new spatial filtering method
- **North America & Europe: Decreasing emissions (but uncertain for CO_2)**
- **East Asia: Increasing emissions but less NOx per CO_2: Trend towards cleaner technology in East Asia**

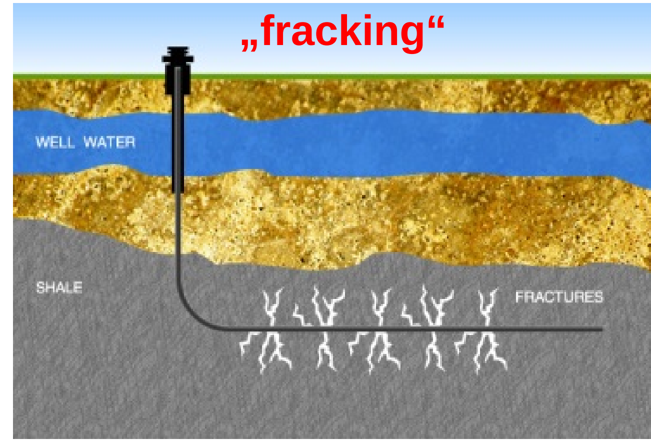
SCIAMACHY methane:

Remote sensing of fugitive methane emissions from oil and gas production in North American tight geologic formations

Oliver Schneising[1], John P. Burrows[1,2,3], Russell R. Dickerson[2], Michael Buchwitz[1], Maximilian Reuter[1], and Heinrich Bovensmann[1]

Schneising et al., Earth's Future, 2014





Estimated emission increase 2009-2011 relative to 2006-2008:

- **Bakken: 990±650 $ktCH_4/yr$**
- **Eagle Ford: 530±330 $ktCH_4/yr$**

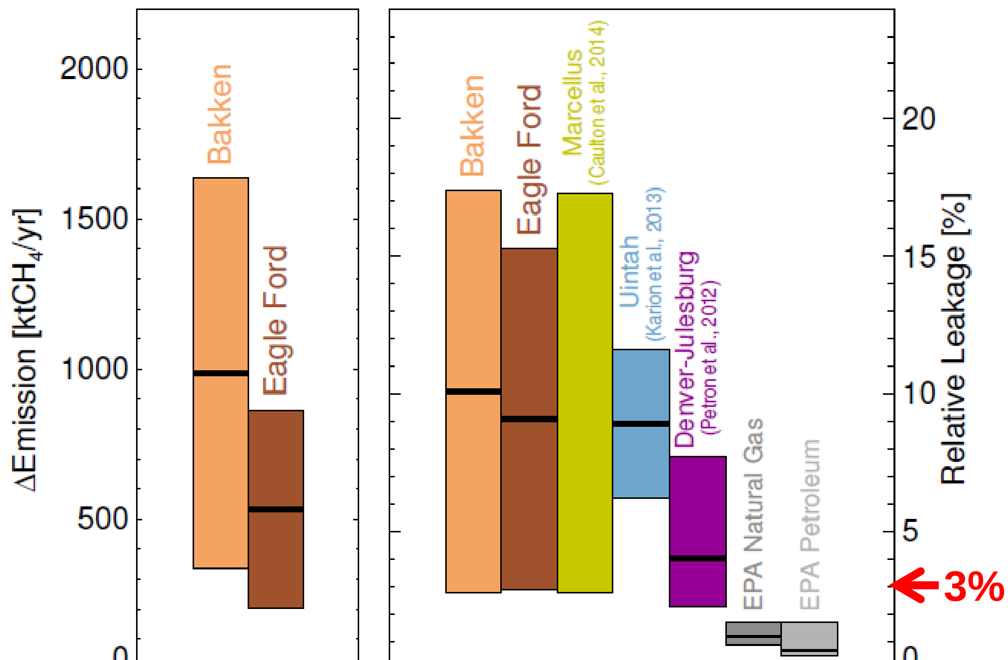
Emission estimates correspond to **leakages** of

- Bakken: 10.1±7.3% and
- Eagle Ford: 9.1±6.2%

in terms of energy content.

Exceeds 3.2% "climate benefit" threshold (Alvarez et al., 2012) for switching from coal to natural gas

Likely **underestimated in inventories**.



Anthropogenic CO_2 and CH_4 emissions from space

Today:
SCIAMACHY, GOSAT, OCO-2

Future ?
CarbonSat

GHG-CCI: Future

We aim at „More & better“ via

- **Extension of existing „Carbon from Space“ time series** (updates are planned once per year)
- **Quality improvements** (algorithms, error characterization, documentation, …)
- **Enhanced data exploitation:** Extracting as much information on CO_2 and CH_4 sources & sinks as possible (inverse modelling, CCDAS, other)

Achieving our long-term climate-relevant goals requires

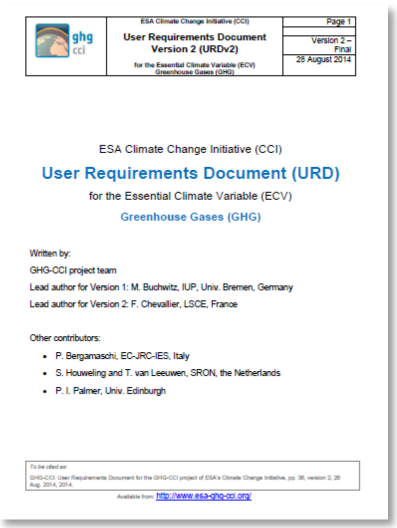
- **Continuity e.g. in terms of funding** (e.g., „CCI+“) not only for „operations“ but also for the mandatory „research“ (to push the state-of-the-art & to make sure that products are state-of-the-art)
- **New sensors** (e.g., CarbonSat, …)


Thank you very much for your attention !
The GHG-CCI team

Backup

GHG-CCI: Documents

User Requirements
URDv2



ESA Climate Change Initiative (CCI) — User Requirements Document Version 2 (URDv2) for the Essential Climate Variable (ECV) Greenhouse Gases (GHG) — Page 1 — Version 2 – Final — 28 August 2014

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 for Version 1: M. Buchwitz, IUP, Univ. Bremen, Germany

Lead author for Version 2: F. Chevallier, LSCE, France

Other contributors:

- P. Bergamaschi, EC-JRC-IES, Italy
- S. Houweling and T. van Leeuwen, SRON, the Netherlands
- P. I. Palmer, Univ. Edinburgh

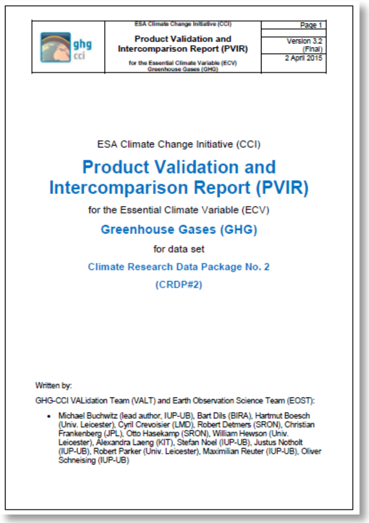
To be cited as:

GHG-CCI: User Requirements Document for the GHG-CCI project of ESA's Climate Change Initiative, pp. 38, version 2, 28 Aug. 2014, 2014.

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

- **Processing system** **DARD SSD SVR**
- **Algorithm descriptions ATBDs**
- **Quality assessments CECRs**
- **Product Specification and User Guides PSD PUGs**
- **Other**

Product Validation
PVIRv3.2



ESA Climate Change Initiative (CCI) — Product Validation and Intercomparison Report (PVIR) for the Essential Climate Variable (ECV) Greenhouse Gases (GHG) — Page 1 — Version 3.2 (Final) — 2 April 2015

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. 2

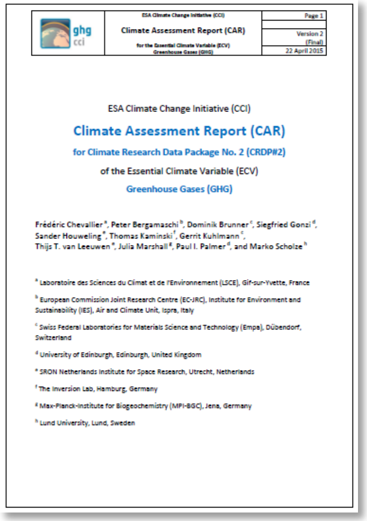
(CRDP#2)

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), Cyril Crevoisier (LMD), Robert Detmers (SRON), Christian Frankenberg (JPL), Otto Hasekamp (SRON), William Hewson (Univ. Leicester), Alexandra Laeng (KIT), Stefan Noel (IUP-UB), Justus Notholt (IUP-UB), Robert Parker (Univ. Leicester), Maximilian Reuter (IUP-UB), Oliver Schneising (IUP-UB)

User Assessments
CARv2



ESA Climate Change Initiative (CCI) — Climate Assessment Report (CAR) for the Essential Climate Variable (ECV) Greenhouse Gases (GHG) — Page 1 — Version 2 (Final) — 22 April 2015

ESA Climate Change Initiative (CCI)

Climate Assessment Report (CAR)

for Climate Research Data Package No. 2 (CRDP#2)

of the Essential Climate Variable (ECV)

Greenhouse Gases (GHG)

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… and many more …

All publicly available on www.esa-ghg-cci.org -> Documents
and / or www.esa-ghg-cci.org -> CRDP (Data)

GHG-CCI CRDP#2: Comparison with GCOS Requirements

Variable(*)	Resolution	Accuracy	Stability (§§)
XCO_2	Temporal: GCOS: 4 hours Achieved: Days No existing nor any planned mission meets the GCOS temporal resolution requirement.	GCOS: < 1 ppm URD(#): < 0.5 ppm Achieved(#): 0.4-0.9 ppm(?) (?) Depending on sensor, time period and assessment method	GCOS: < 0.2 ppm/yr URD: < 0.5 ppm/yr Achieved: << 0.5 ppm/yr(+) (+) Derived trends not significant
XCH_4	Spatial: GCOS: 5-10 km Achieved($): 10 km ($) for GOSAT. SCIAMACHY: 30x60 km^2. URD: SCIAMACHY and GOSAT are useful to generate the ECV GHG.	GCOS: < 10 ppb URD(#): < 10 ppb Achieved(#): 3-8 ppb(§) (§) for GOSAT; for SCIAMACHY 8-15 ppb depending on time period (degradation after Oct. 2005)	GCOS: < 2 ppb/yr URD: < 10 ppb/yr Achieved: < 4 ppb/yr(!) (§§) (!) Derived trends mostly not significant but note (§§)
	Note: GCOS requirements are target (maximum) requirements but URD requirements listed here are threshold (minumum) requirements.	(#) Relative accuracy (i.e., excluding a possible constant global offset) (§§) Stability as used here quantifies only long-term drift and therefore does not capture certain "jumps" due to detector issues as observed when analyzing the global SCIAMACHY XCH_4 (e.g., IMAP product mid 2010) **Estimated by comparison with TCCON ground-based observations; TCCON accuracy (1-sigma): 0.4 ppm for XCO_2 and 3.5 ppb for XCH_4**	

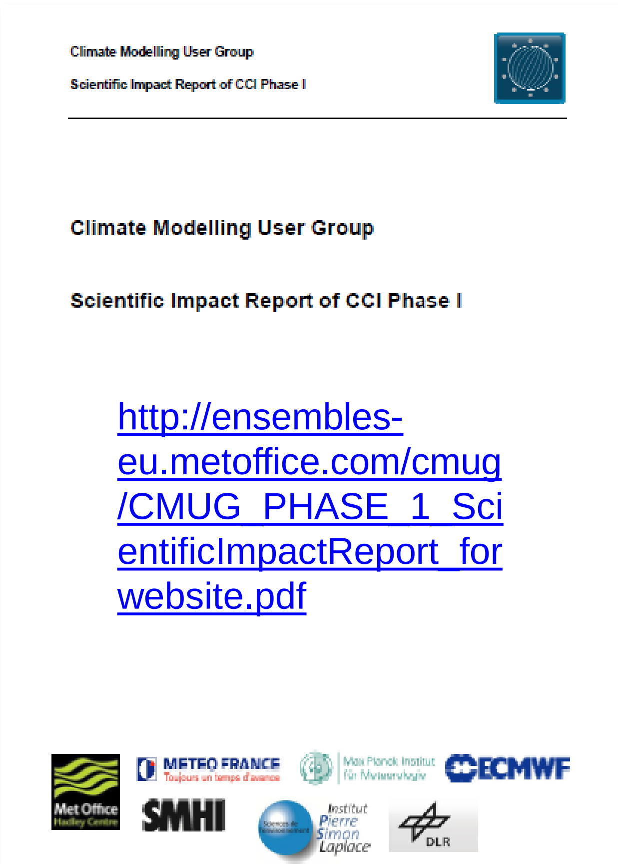
(*) Requirements for column-averaged mole fractions (= air column normalized vertical GHG columns) as required by URD; it is assumed here that this corresponds to GCOS variables „Tropospheric CO_2 column“ and „Tropospheric CH_4 column“

References: Requirements for ECV Greenhouse Gases (GHG):
- **GCOS-154:** „SYSTEMATIC OBSERVATION REQUIREMENTS FOR SATELLITE-BASED DATA PRODUCTS FOR CLIMATE“
- **URD:** "GHG-CCI User Requirements Document", v2.0

Definition: ECV GHG (GCOS-154):
- Product A.8.1: Retrievals of CO_2 and CH_4 of sufficient quality to estimate regional sources and sinks

PVIRv3.2

GHG-CCI: Publications


Climate Modelling User Group

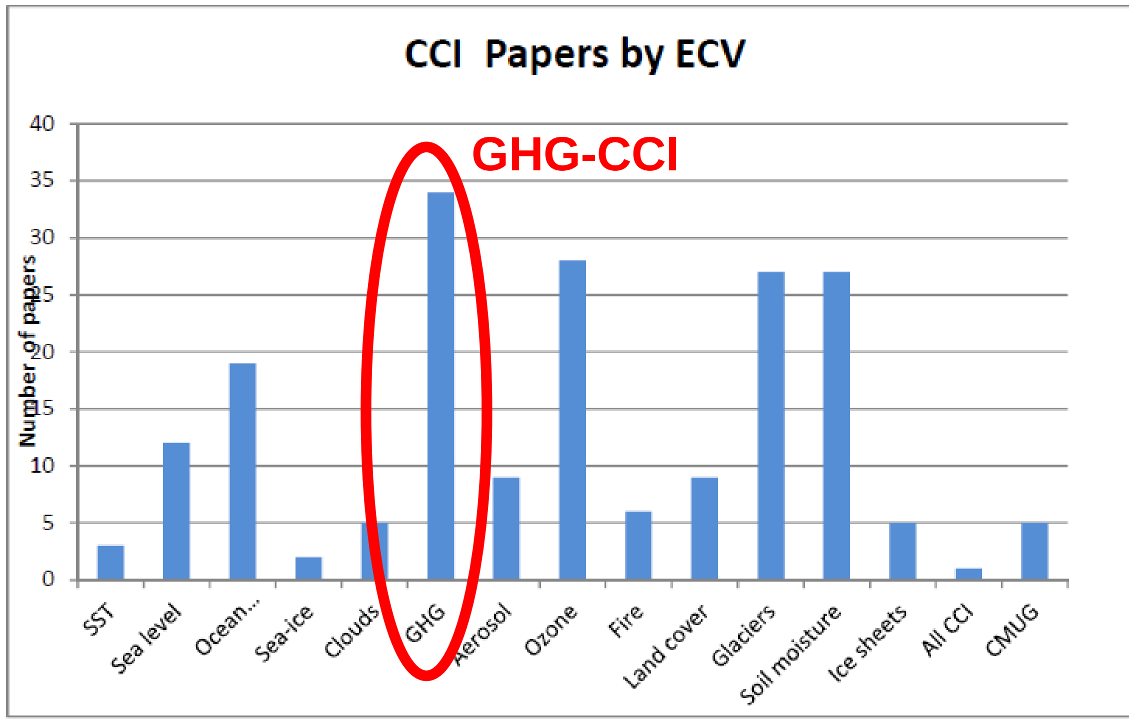
Scientific Impact Report of CCI Phase I

Climate Modelling User Group

Scientific Impact Report of CCI Phase I

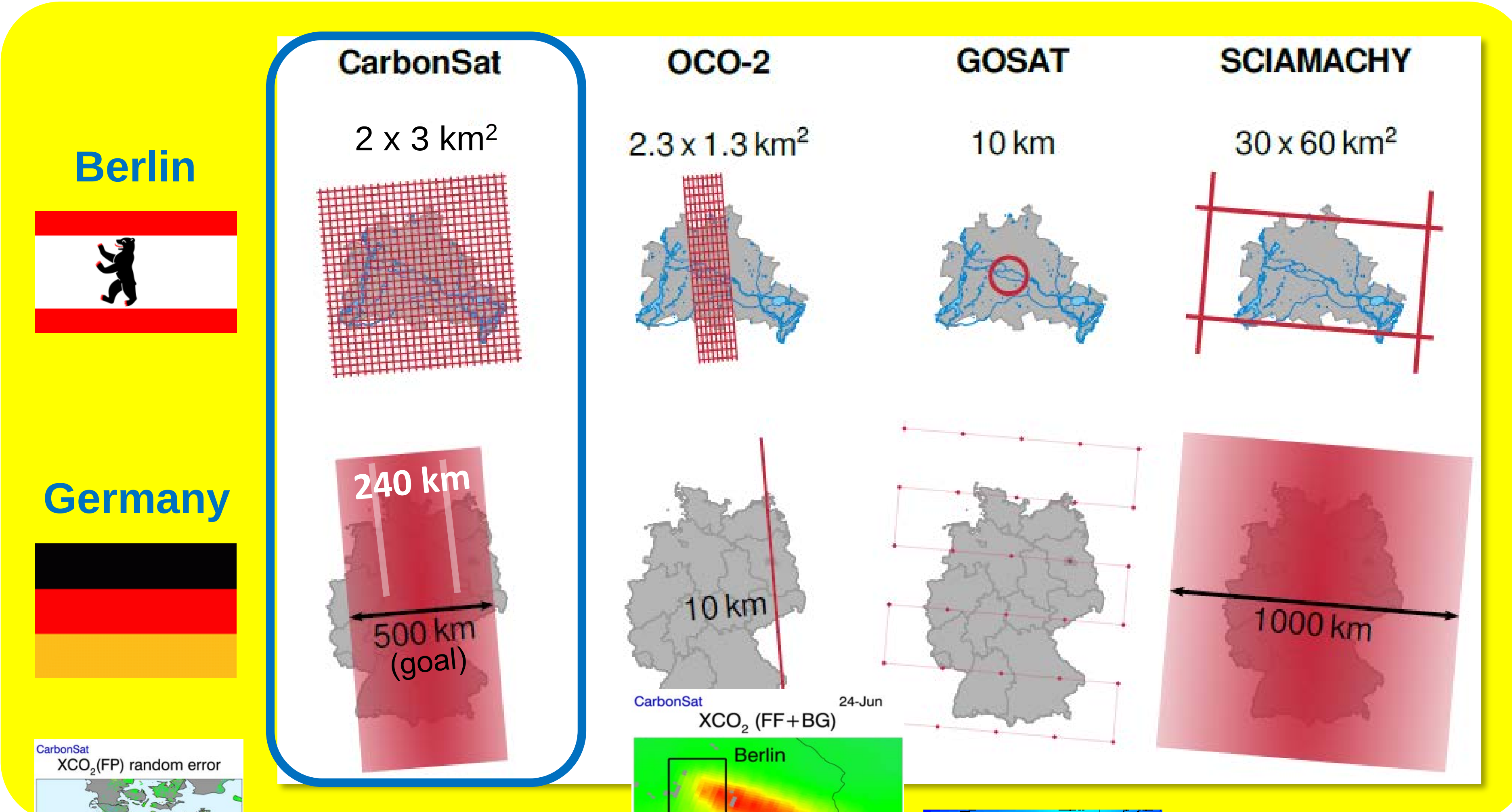
[http://ensembles-eu.metoffice.com/cmug/CMUG_PHASE_1_ScientificImpactReport_for website.pdf](http://ensembles-eu.metoffice.com/cmug/CMUG_PHASE_1_ScientificImpactReport_forwebsite.pdf)

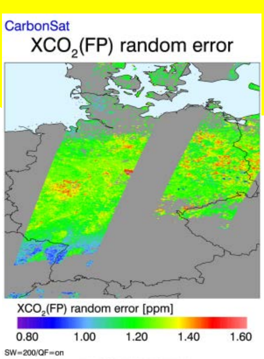
Number of peer-reviewed publications



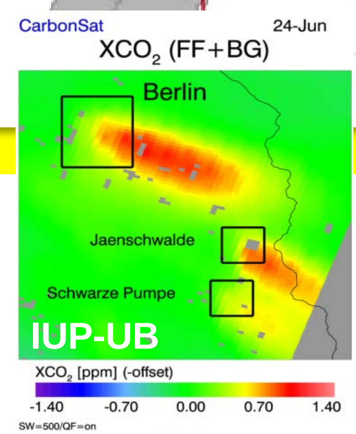
Details please see: www.esa-ghg-cci.org -> Publications

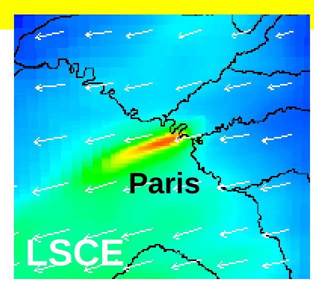
From SCIAMACHY to CarbonSat

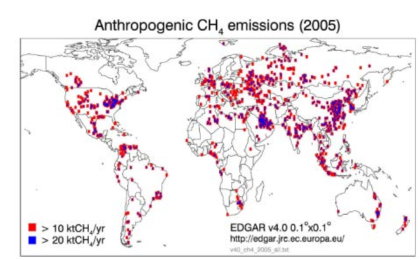




New capabilities:
Cities, power plants, oil & gas fields, geological „point“ sources, …

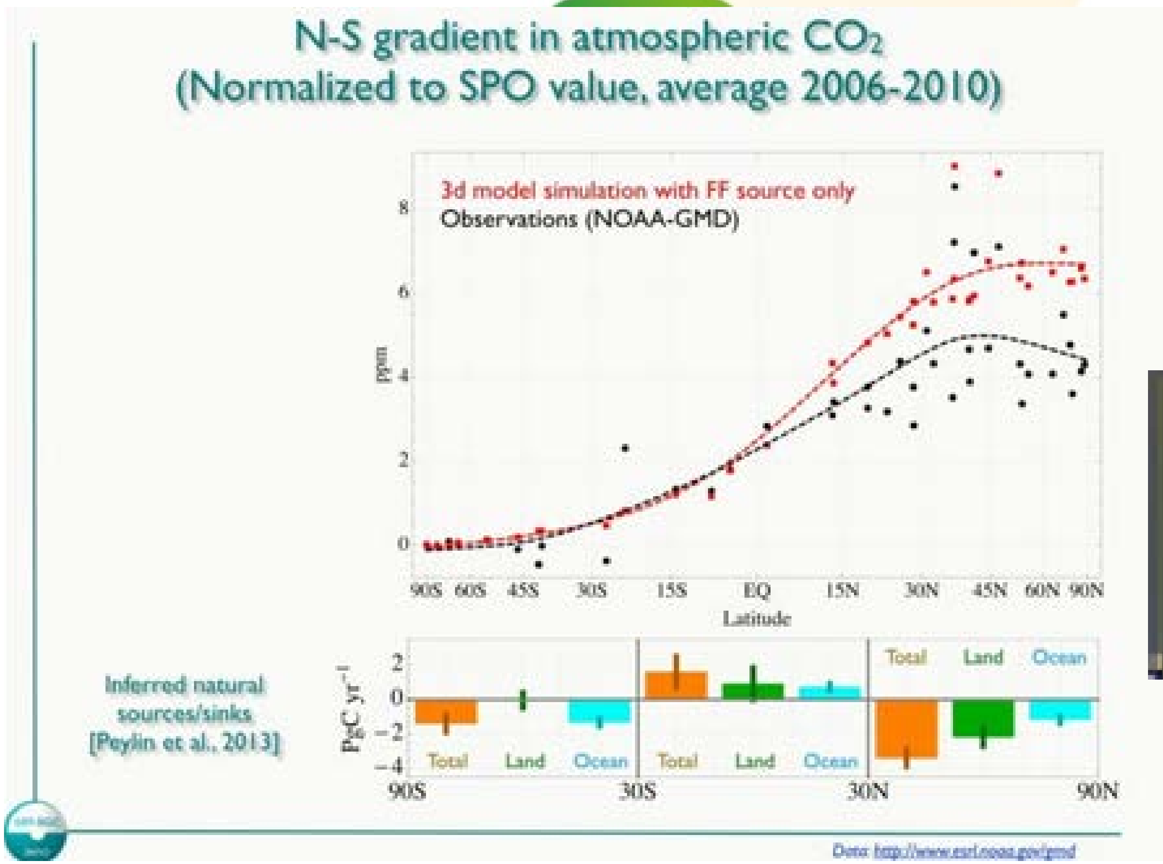




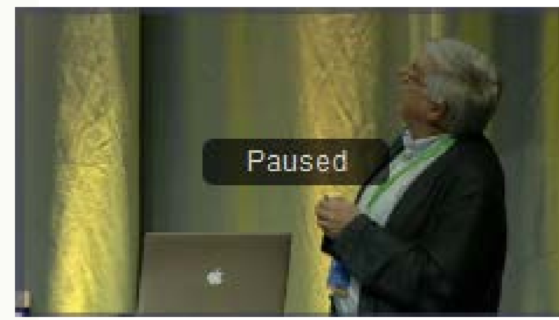


THE CLIMATE SYMPOSIUM 2014

Climate Research and Earth Observations from Space | Climate Information for Decision Making



„Strong carbon sink in northern extra-tropics.“



Martin Heimann @ Climate Symposium 2014

But where exactly is it ???

Watch video @ http://www.theclimatesymposium2014.com
Session: Monday 13th 14:00-15:30 - Setting the scene: Science perspective

European terrestrial carbon fluxes from SCIAMACHY and GOSAT - I

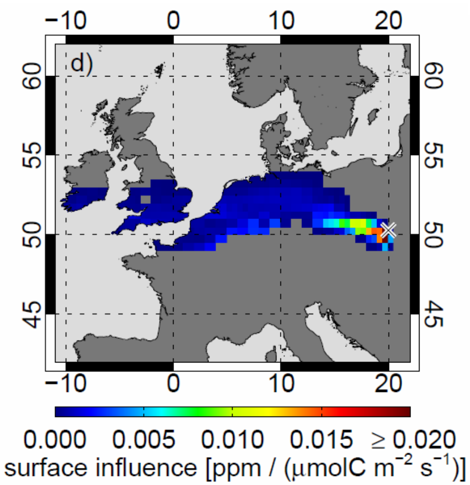
Goal: Get information on European terrestrial carbon fluxes using satellite data and a method which is not or much less sensitive to potential error sources as discussed in the literature such as

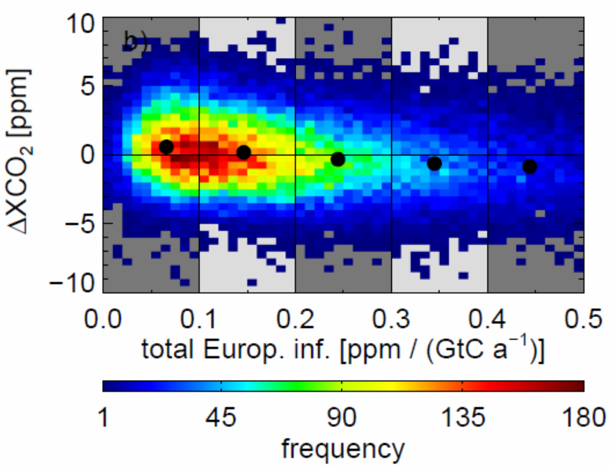
- Potential adverse impact of satellite XCO_2 biases outside of target region (e.g., XCO_2 biases over Africa due to desert dust storm aerosols)
- Potential problems related to long-range transport modelling
- Potential problems related to the used satellite

Reuter et al., ACP, 2014

Approach:

„Europe only“ inversion using STILT-based short range (days) particle dispersion modelling using an ensemble of satellite XCO_2 retrievals





- The satellite minus model (CT2011_oi) difference **ΔXCO_2** shows a **negative correlation** with the integrated **European surface influence**.
- Interpretation: CarbonTracker's **European carbon sink is too weak**.
- Quantitative analysis using the **optimal estimation** framework (1D-Var) to get optimized European surface fluxes considering satellite XCO_2 retrievals.