Key findings from 10 years of CO_2 and CH_4 satellite observations

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iup

Overview Talks 1 & 2

Greenhouse gas observations from space

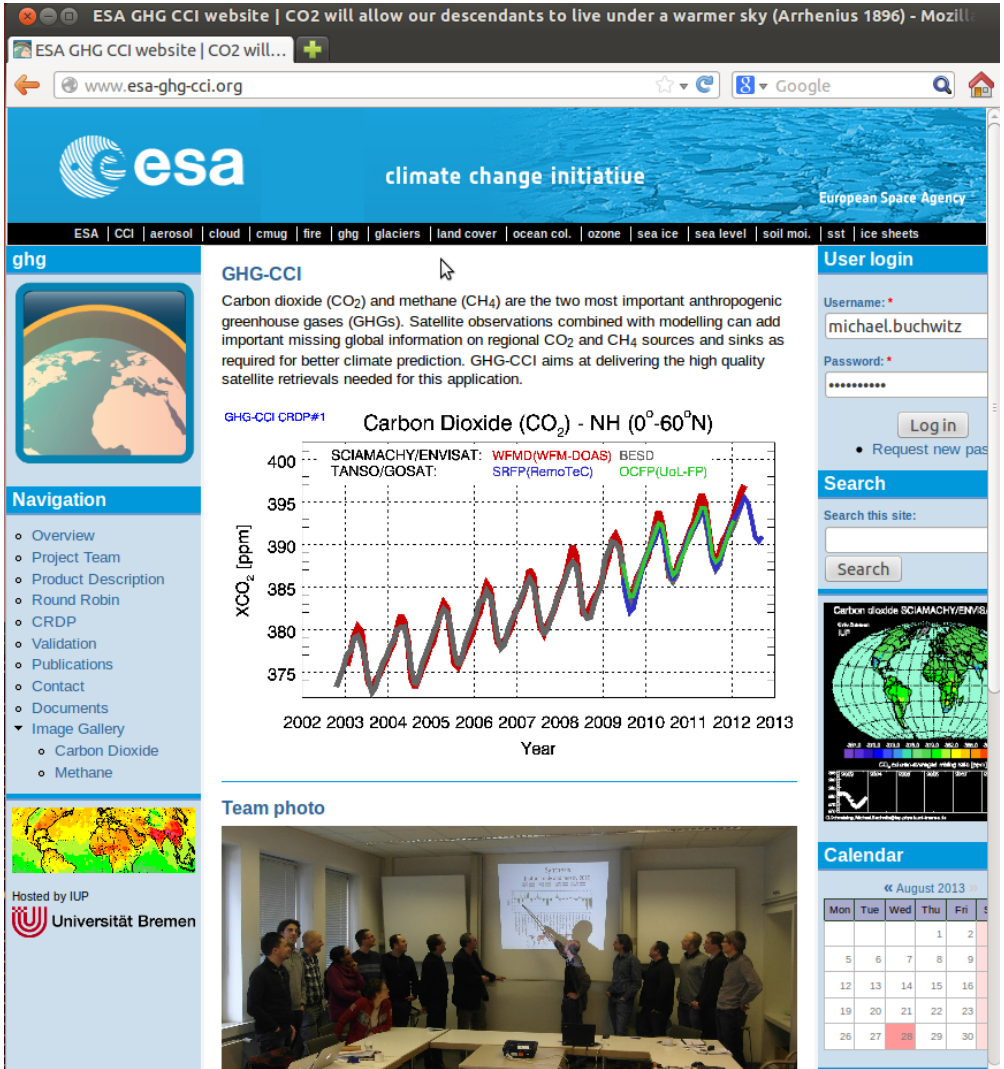
1. Why and how ?

2. Key findings from 10 years of CO_2 and CH_4 satellite observations (focus: results from ESA GHG-CCI project)

ESA Climate Change Initiative (CCI)

to generate Essential Climate Variables (ECVs)

www.esa-ghg-cci.org/



ESA programme

led by Mark Doherty, ESA/ESRIN

Currently 13 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

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

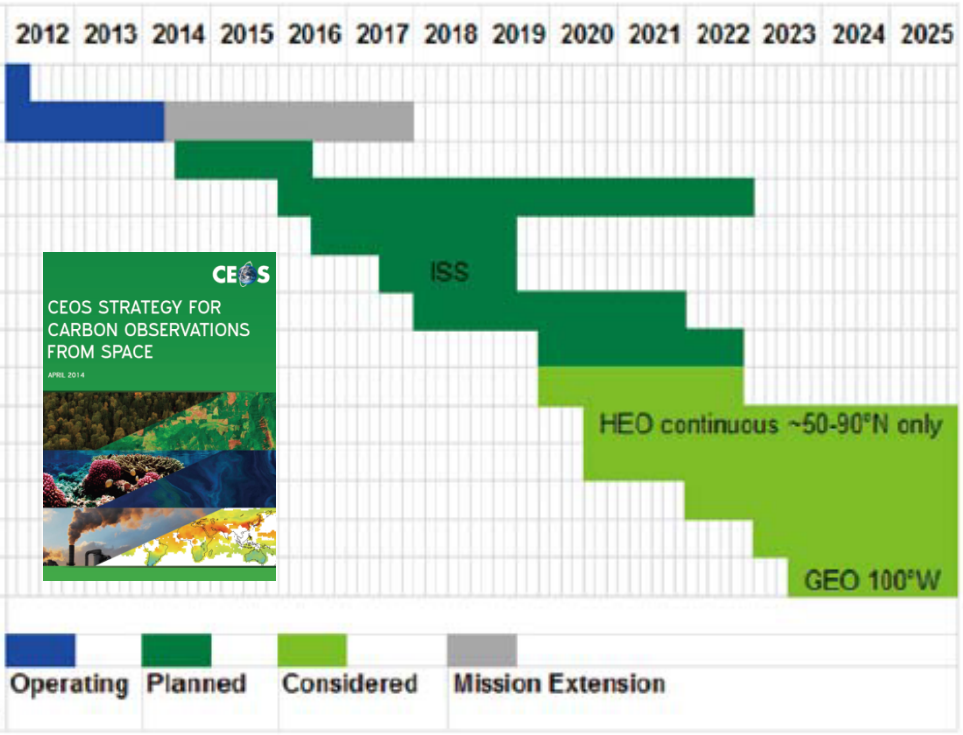
- Lead: Roger Saunders (Met Office Hadley Centre)
- Met Office Hadley Centre, ECMWF, MPI-Meteorology, Météo France

Existing and planed GHG (*) satellite missions

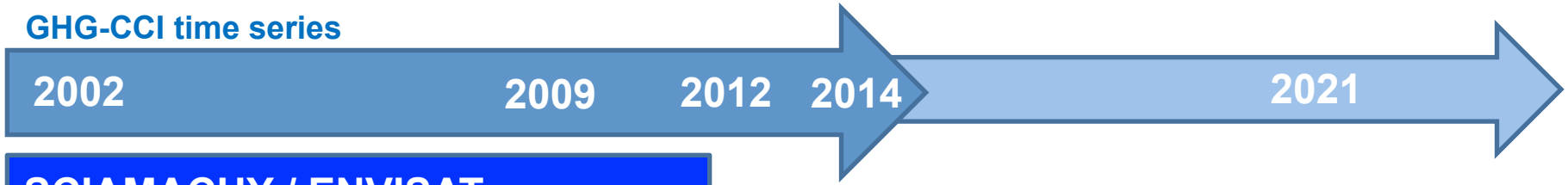
Satellite, Instrument (Agencies)	CO_2	CH_4	FOV
ENVISAT SCIAMACHY (ESA)	●	●	30x60 km²
GOSAT TANSO-FTS (JAXA-NIES-MOE)	●	●	10.5 km (d)
OCO-2 (NASA)	●		1.29x2.25 km²
Sentinel-5P TROPOMI (ESA)		●	7x7 km²
TanSat (CAS-MOST-CMA)	●		1x2 km²
OCO-3 (NASA)	●		~4 km²
GOSAT-2 TANSO-FTS (JAXA-NIES-MOE)	●	●	10.5 km (d)
MERLIN (DLR-CNES)		●	0.135 km (w)
MicroCarb (CNES)	●		25 km²
PCW-PHEOS-FTS (CSA)	?	●	10x10 km²
MetOpSG Sentinel-5 (ESA-EUMETSAT)		●	7x7 km²
CarbonSat (ESA)	●	●	2x3 km²
ASCENDS (NASA)	●		0.100 km (w)
GEO-CAPE (NASA)		●	4x4 km²

Based on information from various sources

d = diameter
w = width of a narrow strip along orbit track



GHG-CCI time series



SCIAMACHY / ENVISAT

ESA / G(DLR)/NL/B
PI: Univ. Bremen

GOSAT

JAXA /
NIES / MOE

OCO-2

NASA

. . .

ESA / Univ. Bremen

CarbonSat

(*) Near-surface-sensitive CO_2 and/or CH_4 missions

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

Global satellite observations

Global information on near-surface CO_2 & CH_4

SCIAMACHY/ENVISAT

TANSO/GOSAT

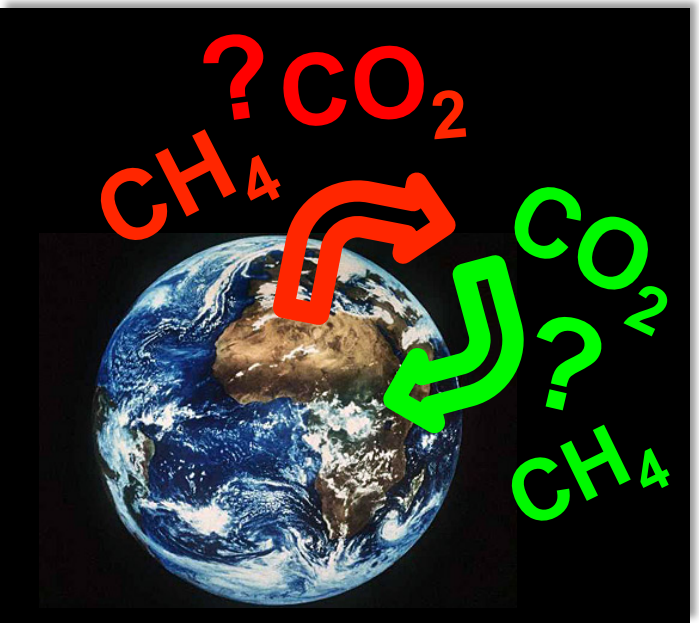
GOSAT

Preparing for: OCO-2

Upper layer CO_2 & CH_4

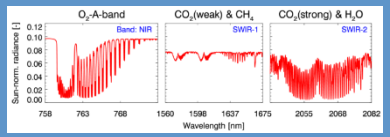
IASI, MIPAS, SCIA/occ, AIRS, ACE-FTS, …

Global observations



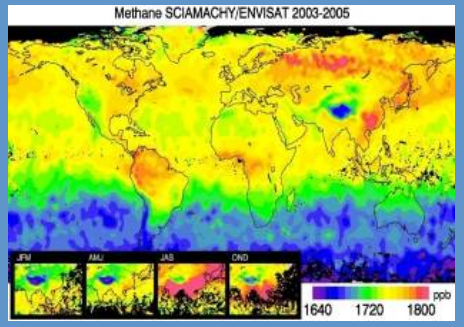
Calibration (L 0-1)

Calibrated radiances



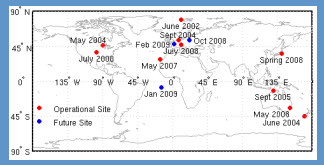
Retrieval (L 1-2)

Atmospheric GHG distributions



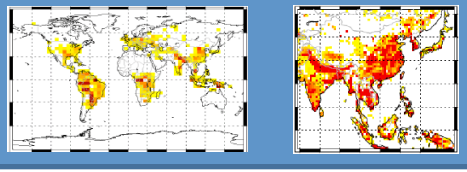
Validation

Reference observations



Inverse modelling (L 2-4)

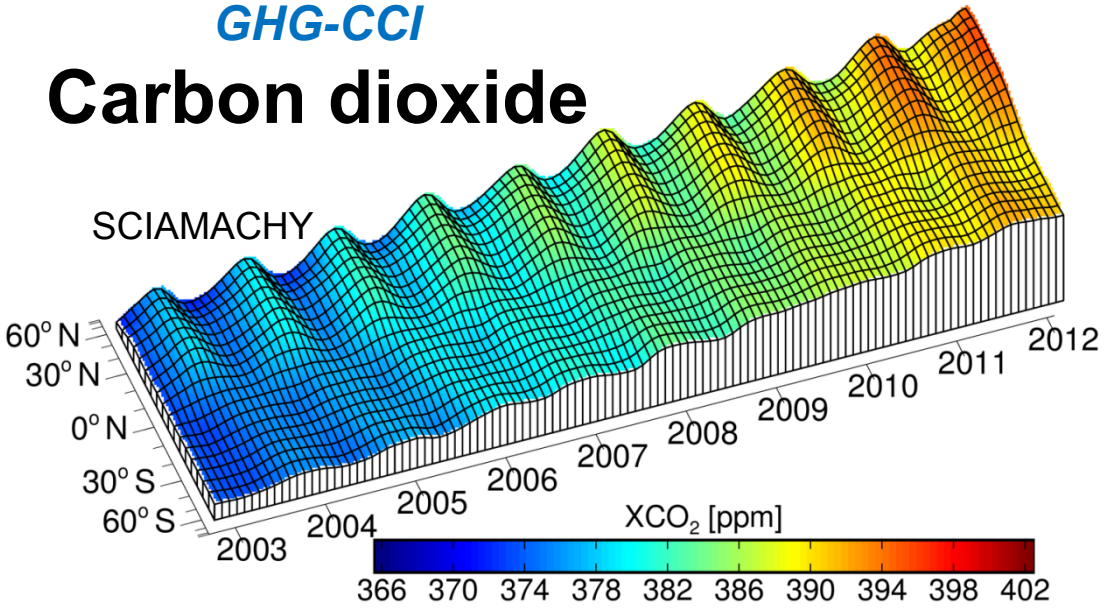
Improved information on GHG sources & sinks

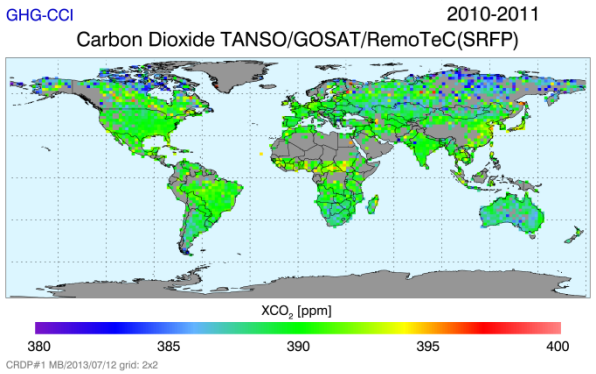


GHG-CCI: GHG data sets

GHG-CCI

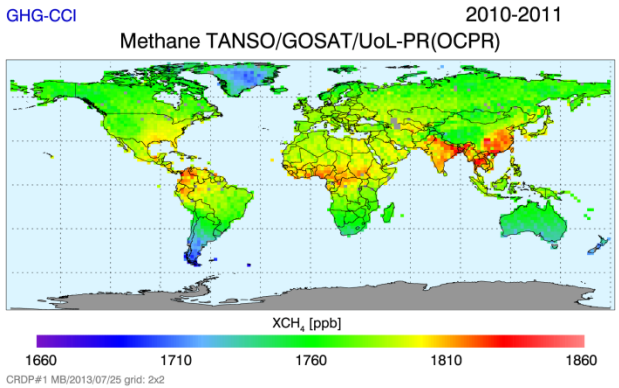
Carbon dioxide

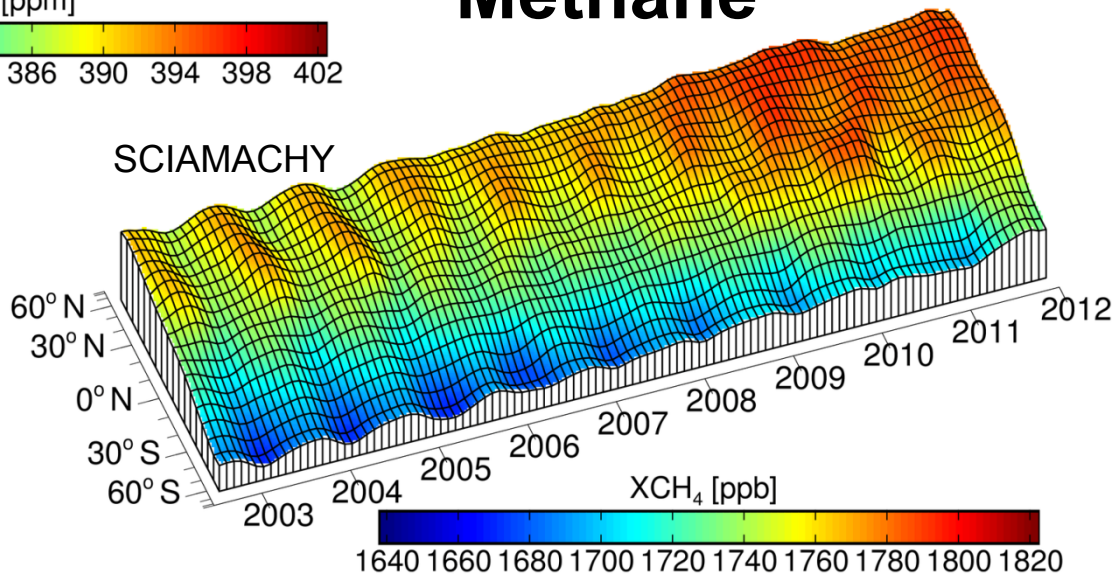




GHG-CCI

Methane



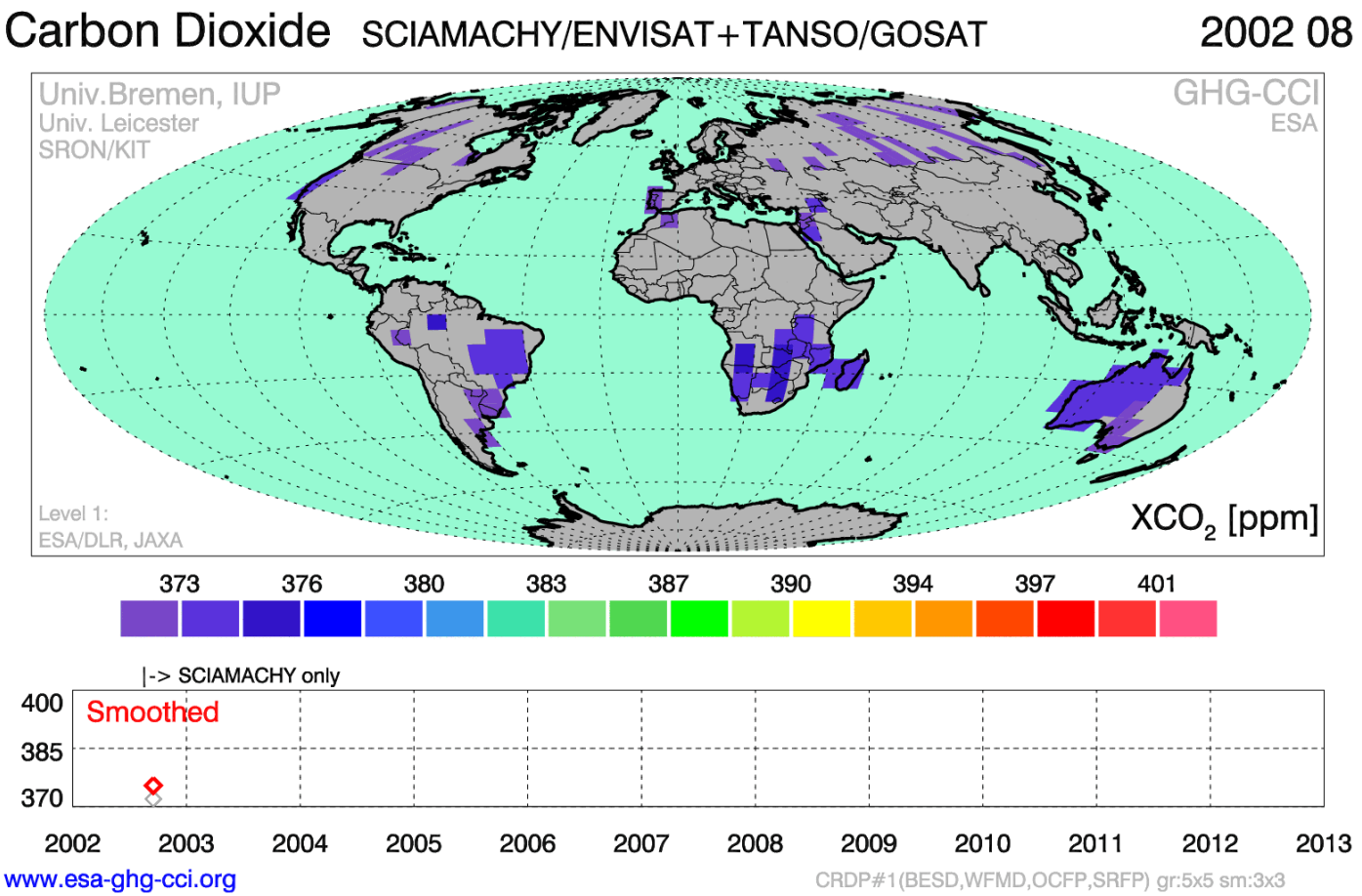


GHG-CCI: XCO_2 Animation

Level 2:
IUP, Univ. Bremen
Univ. Leicester
SRON / KIT

Level 1:
ESA/DLR
JAXA

GHG-CCI Phase 1 (2010-2013): CRDP#1



SCIAMACHY/ENVISAT

TANSO/GOSAT

Animation:
http://www.esa-ghg-cci.org/sites/default/files/documents/public/images/co2scigos_crdp1_ani_v2sm.gif

Results

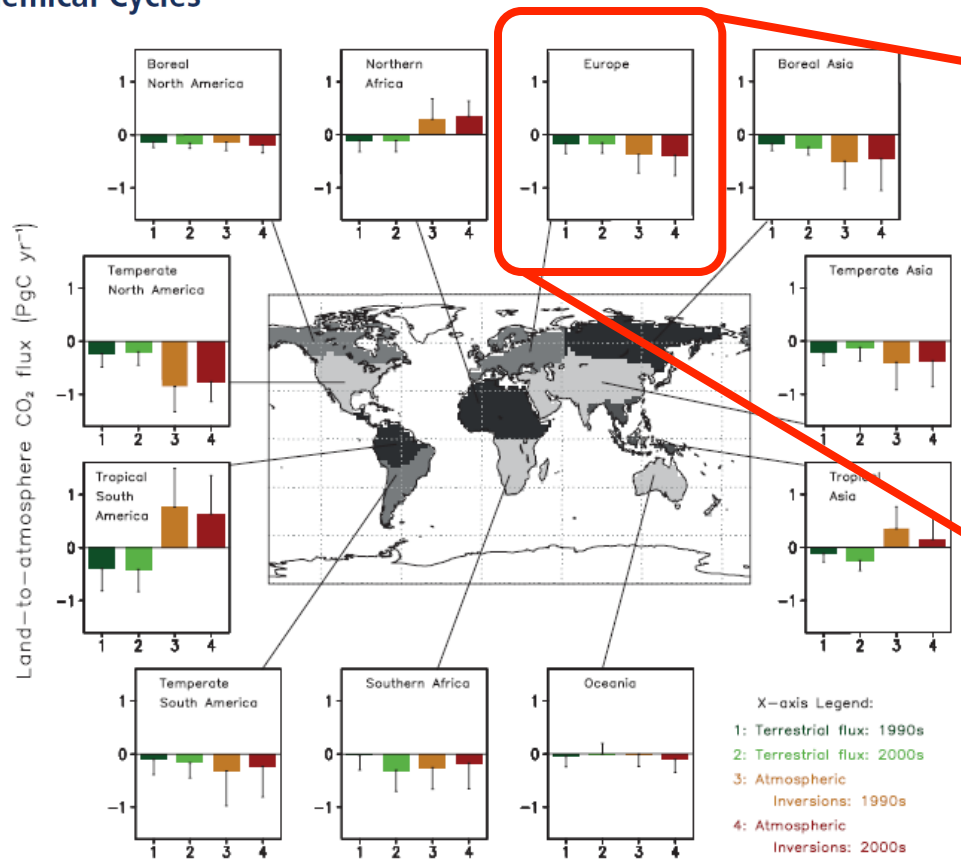
Focus:
Satellite-derived
GHG source/sink-related results:

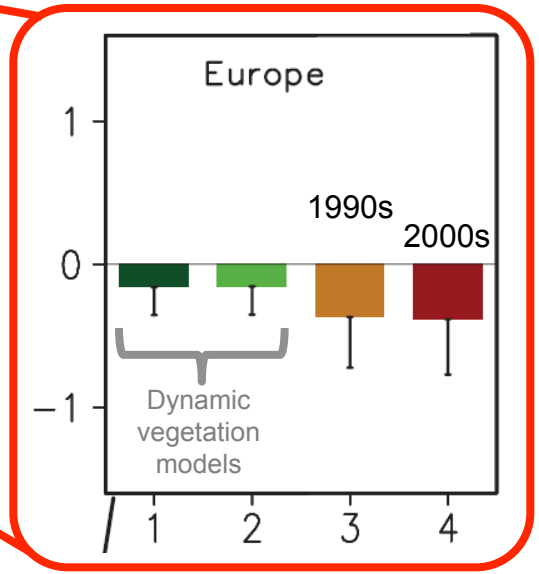
Carbon dioxide

Terrestrial C sources and sinks: Adding real satellite data ?

Regional terrestrial CO_2 fluxes

IPCC 2013, WG1
Carbon and Other
Biogeochemical Cycles



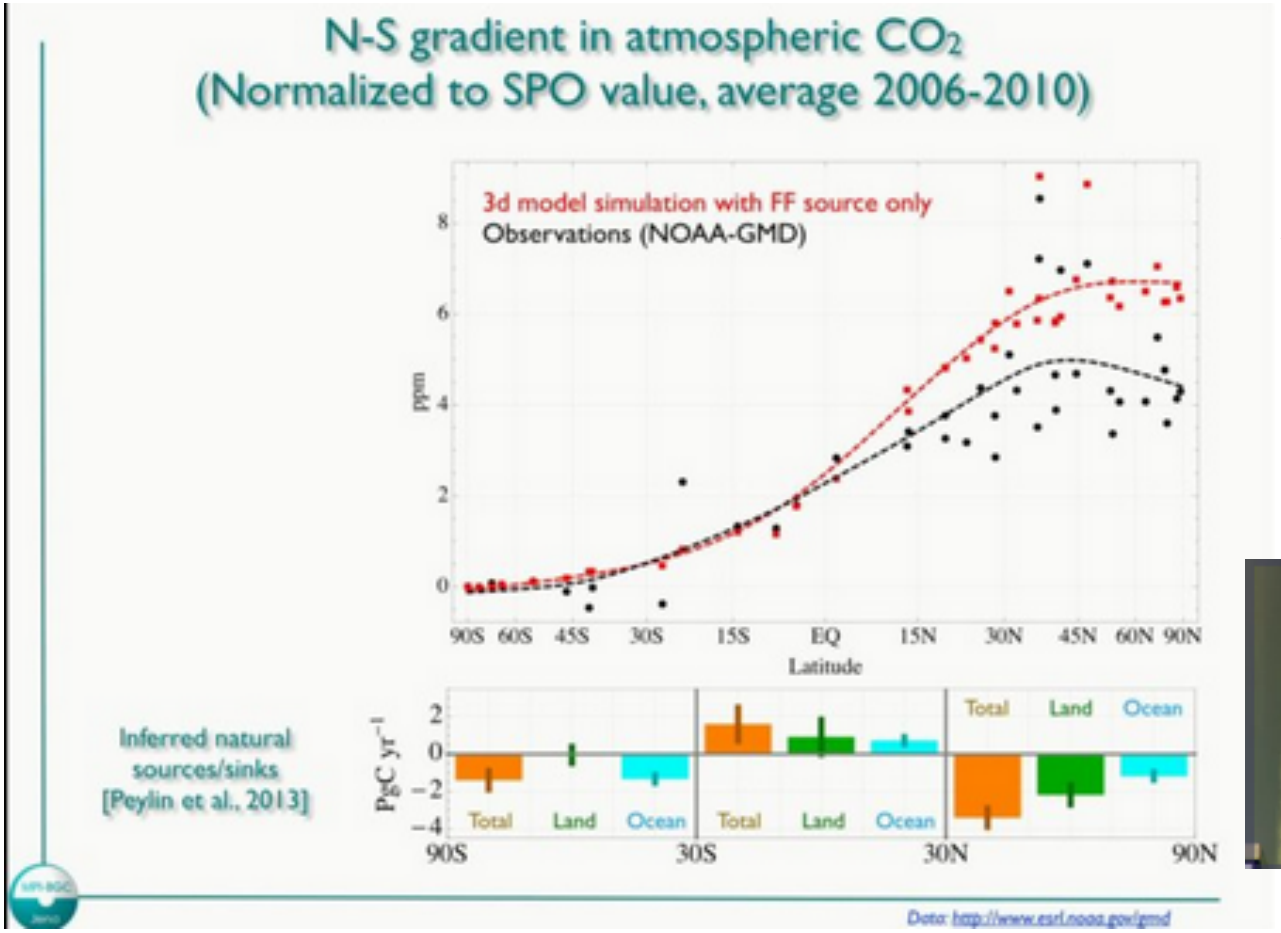


Decadal fluxes via atmospheric inversions

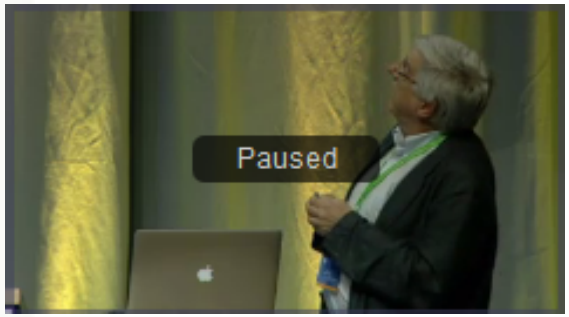
- mostly CO_2 flask measurements (very accurate but sparse)
- without satellite CO_2

Large discrepancies models vs atmospheric inversions esp. in tropics and northern Africa & large uncertainties (~100%) !

Satellite CO_2 observations have potential to improve our knowledge



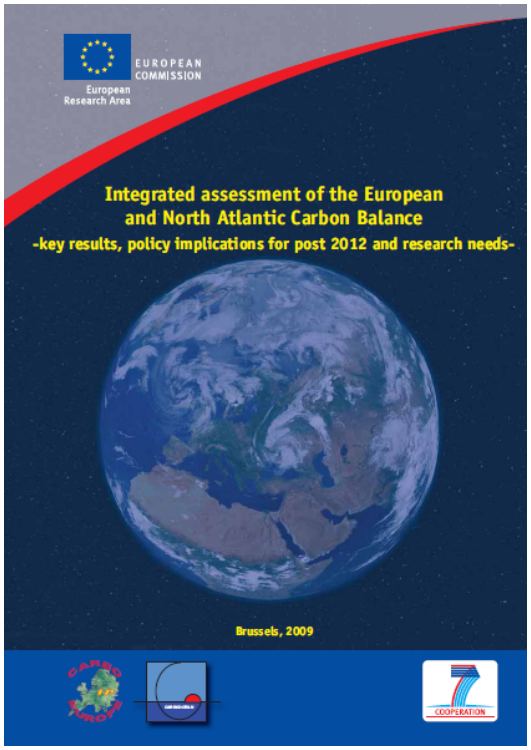
„Robust finding: Strong carbon sink in northern extra-tropics.“



Martin Heimann
@ Climate Symposium 2014

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

CarboEurope findings (2009)

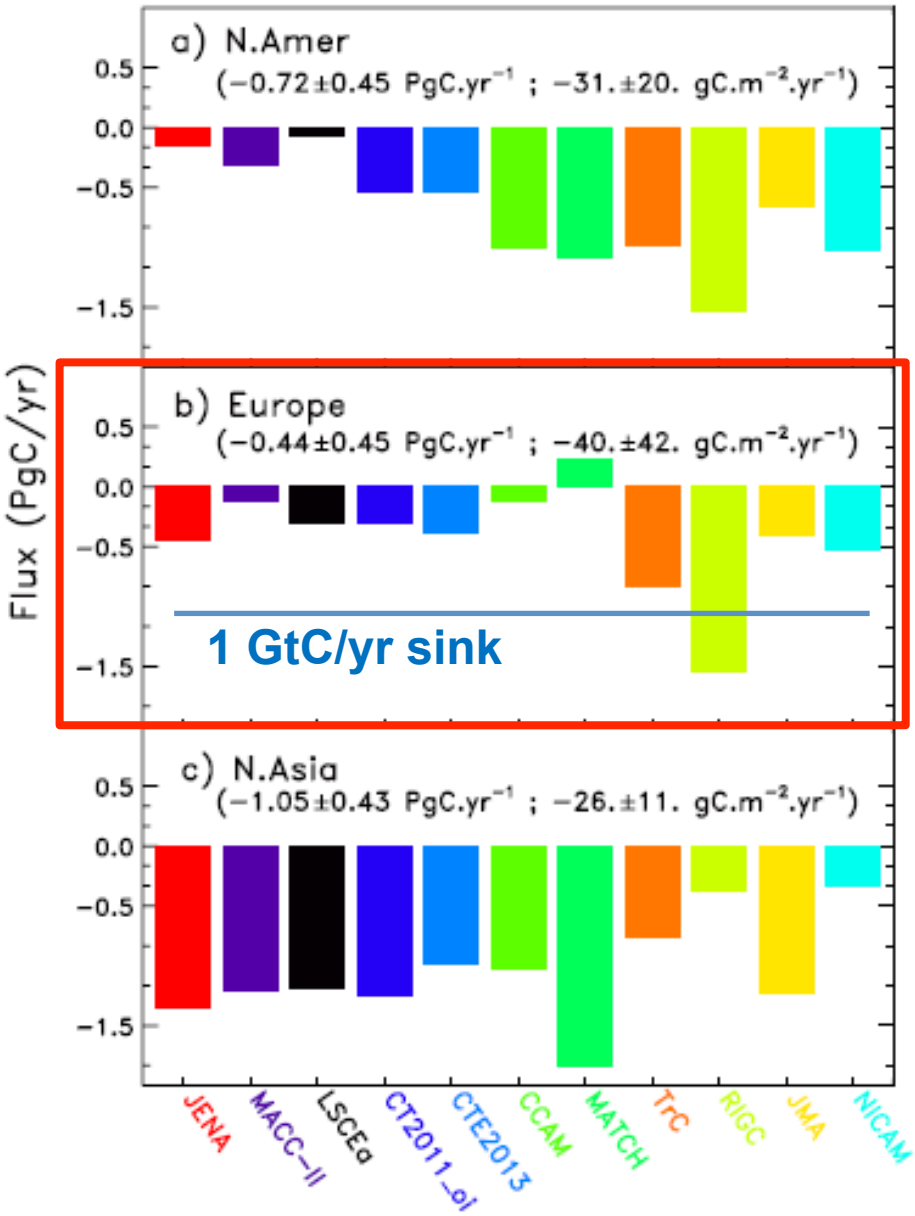


Executive Summary of the terrestrial carbon balance (CarboEurope-IP)

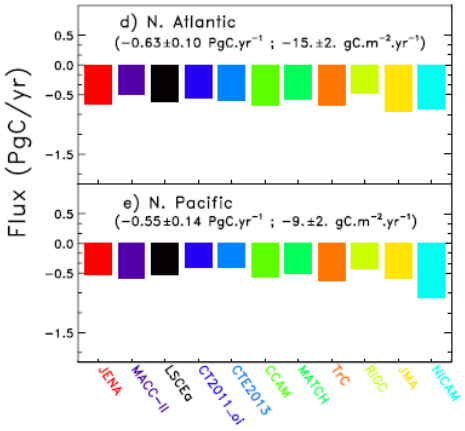
- The **land surface of continental Europe** (the geographic region between the Atlantic coast and the Ural Mountains) is a **carbon sink for CO_2 of 300 Tg C/yr** (**0.3 GtC/yr**) (as indicated by atmospheric and ground-based measurements). The **estimated sink has almost doubled since 2003, mainly due to additional processes understanding**.
- …
- **Almost 60%** of the continental CO2 sink is located outside the EU-25 in **eastern Europe, mainly European Russia**. …
- …
- **The uncertainty in the magnitude of the terrestrial sink remains high.** This is a consequence of the heterogenous landscape of Europe, and the diversity of management practices at small scale.
- …

Global atmospheric carbon budget: Peylin et al., 2013

Land



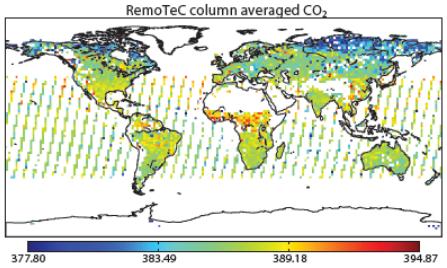
Oceans



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)

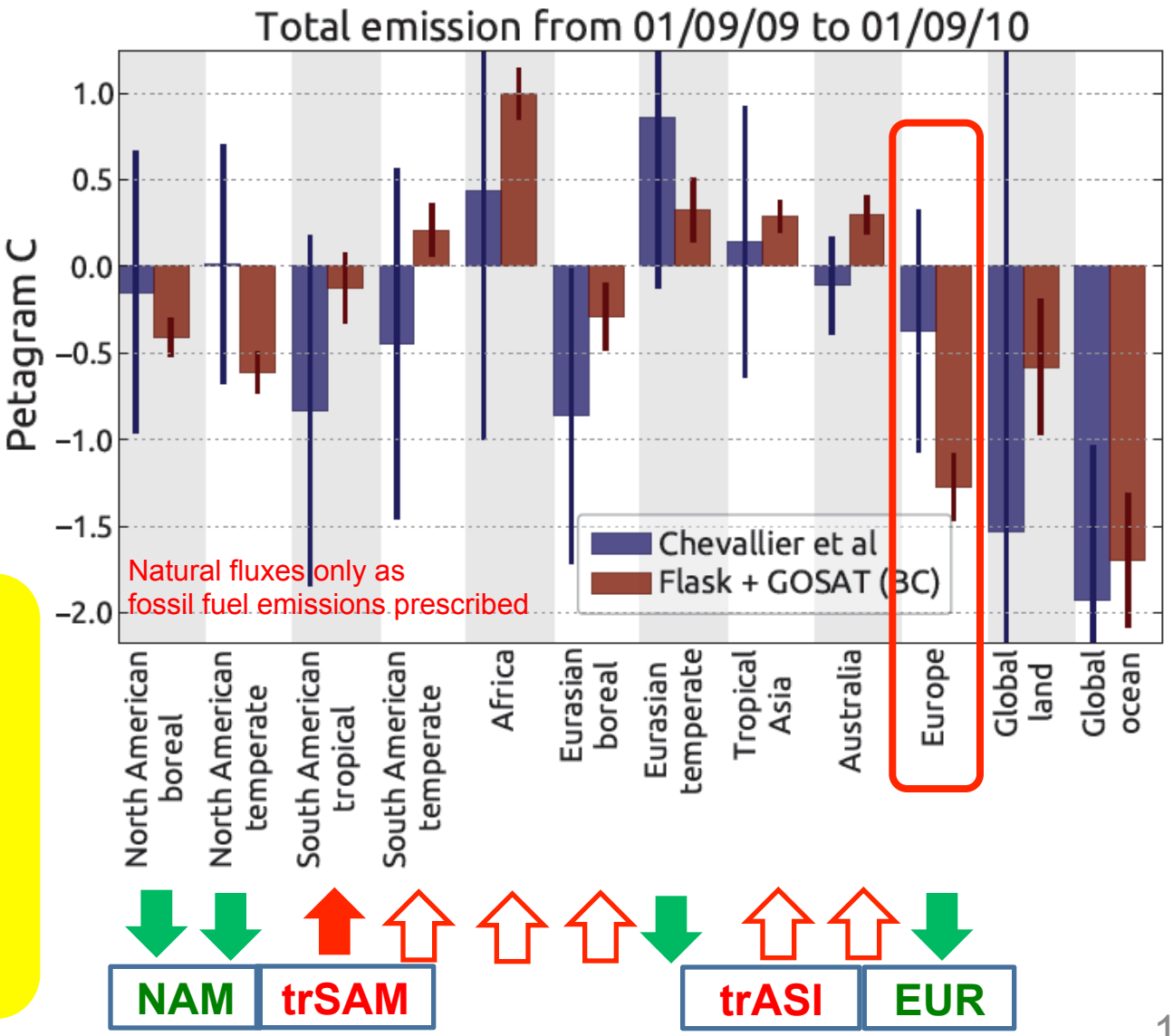
No satellite XCO_2 data used

First global regional-scale CO_2 surface fluxes from GOSAT/RemoTeC



Basu et al., ACP, 2013

Chevallier et al., GRL, 2011:
- TCCON-only inversion
- Consistent with flask-only but larger uncertainties



Adding GOSAT:

Shift of terrestrial net carbon uptake from tropics to (northern) extra tropics

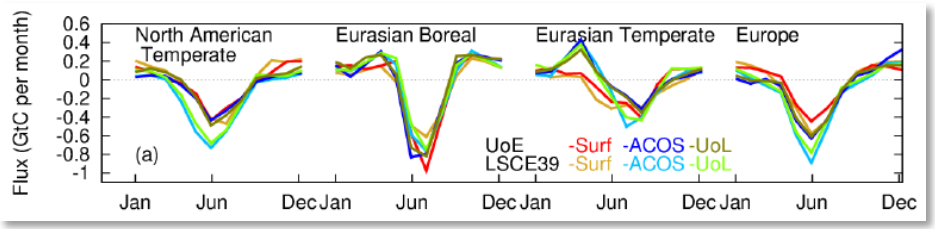
But: 1 year only, still bias issues (e.g., land/ocean), …

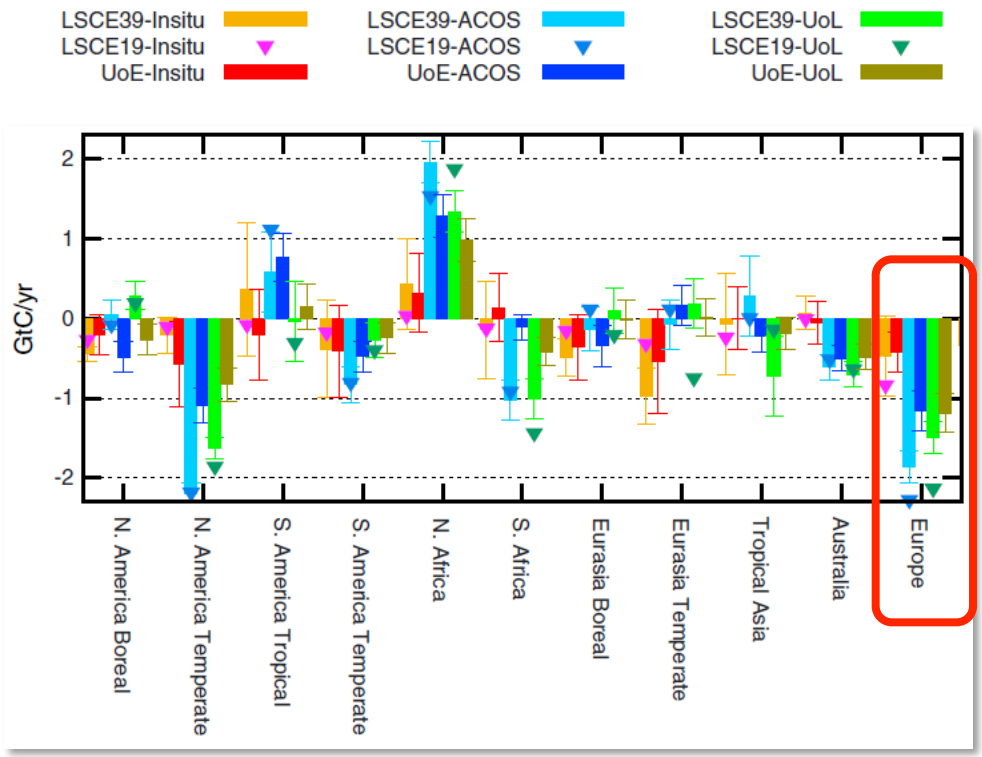
CO_2 flux inversions using different GOSAT XCO_2 products and models

Toward robust and consistent regional CO_2 flux estimates from in situ and spaceborne measurements of atmospheric CO_2

Frédéric Chevallier[1], Paul I. Palmer[2], Liang Feng[2], Hartmut Boesch[3], Chri
and Philippe Bousquet[1]

Chevallier et al., GRL , 2014





Regional natural CO_2 fluxes for 2010

Method:

- 3 inversion methods (2x LSCE (LMDZ 19&39), 1x Univ. Edinburgh (UoE))
- CO_2 surface observations and x2 GOSAT satellite XCO_2 products:
  - **GHG-CCI UoL (OCFP) v4**
  - NASA ACOS v3.3

Conclusions:

Regional flux time series:

- Good agreement for phase but NOT amplitude

Annual regional fluxes:

- Not considered realistic for all regions, e.g., Europe: inferred sink „significantly too large“

Possible issues / to be improved: Inversion method incl. prior fluxes and transport models, satellite data (biases to be further reduced)

European terrestrial carbon fluxes from SCIAMACHY and GOSAT - I

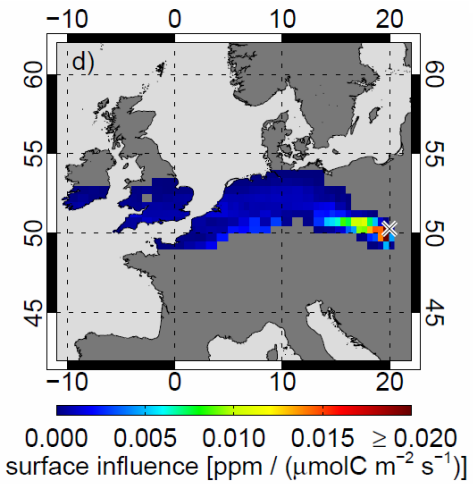
Goal: Get information on European terrestrial carbon fluxes using satellite data and a method which is not or much less sensitive to potential error sources as discussed in the literature such as

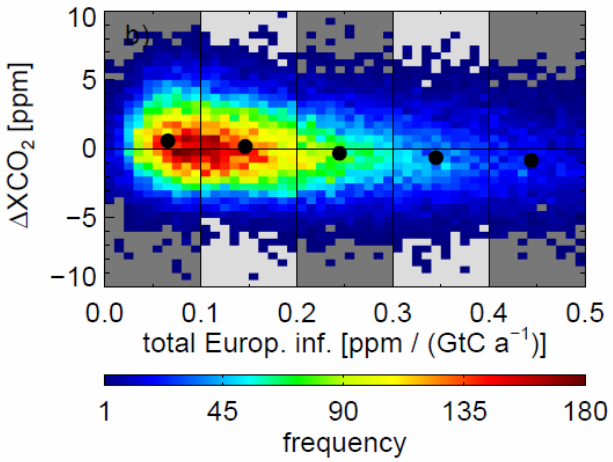
- Potential adverse impact of satellite XCO_2 biases outside of target region (e.g., XCO_2 biases over Africa due to desert dust storm aerosols)
- Potential problems related to long-range transport modelling
- Potential problems related to the used satellite

Approach:

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

Reuter et al., ACPD



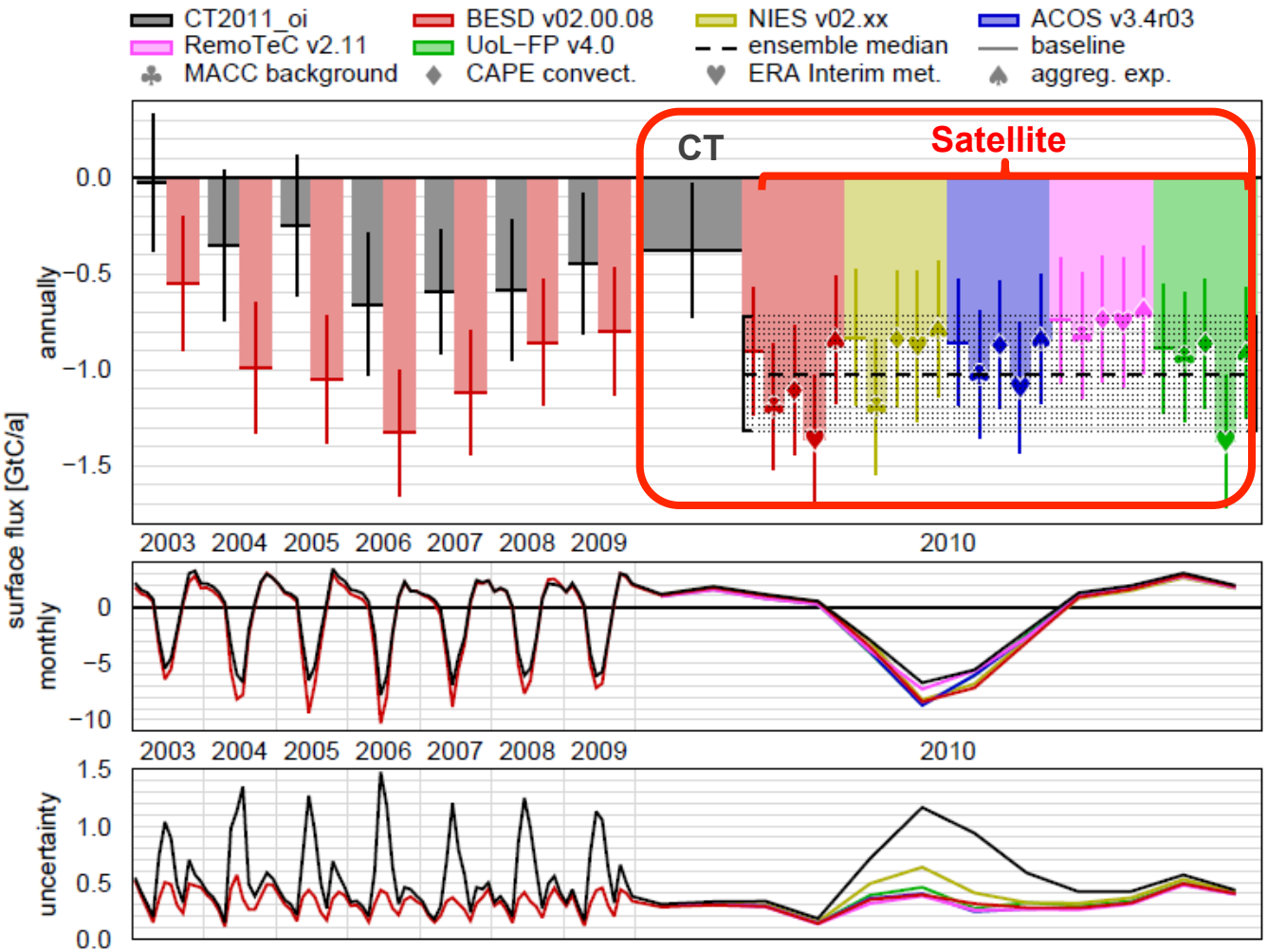


- The satellite minus model (CT2011_oi) difference **ΔXCO_2** shows a **negative correlation** with the integrated **European surface influence**.
- Interpretation: the model's **European carbon sink is too weak**.
- Quantitative analysis using the **optimal estimation** framework (1D-Var) results in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

European terrestrial carbon fluxes from SCIAMACHY and GOSAT - II

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

Reuter et al., ACPD



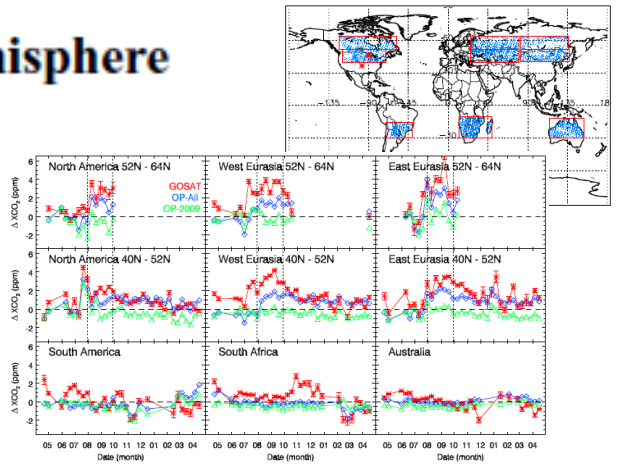
- 2 satellites
- 5 retrieval algorithms / products
- New flux inversion method insensitive to observations outside Europe, large-range transport & other errors
- Various sensitivity studies

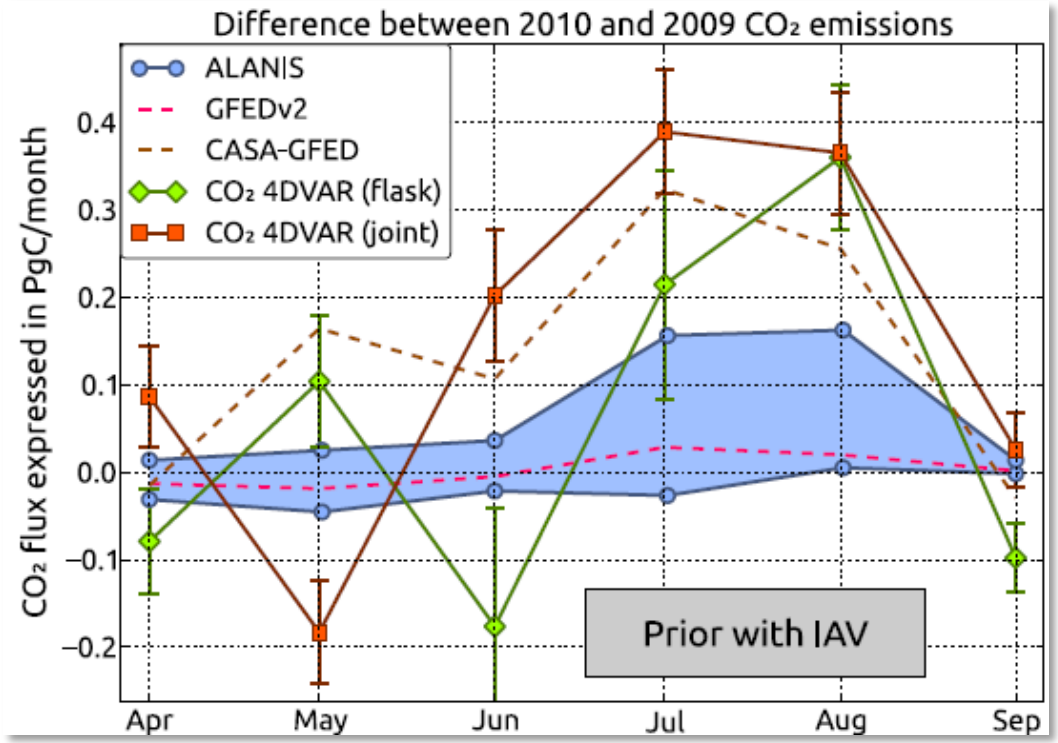
Satellite data suggest a (TransCom region) European C sink of 1.02 +/- 0.3 GtC/yr (for 2010)

GOSAT/RemoTeC CO_2:
Northern hemisphere summer 2010 carbon fluxes

Reduced carbon uptake during the 2010 Northern Hemisphere summer from GOSAT Guerlet et al., GRL, 2013

S. Guerlet,[1,2] S. Basu,[1,3] A. Butz,[4] M. Krol,[1,3,5] P. Hahne,[4] S. Houweling,[1,3] O. P. Hasekamp,[1] and I. Aben[1]



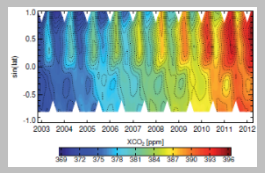


Reduced carbon uptake in the summer of 2010 most likely due to **Eurasian heat wave** driving biospheric fluxes and fire emissions.

Joint inversion GOSAT & flasks:

Biospheric & fire CO_2 emission anomaly April–September 2010:

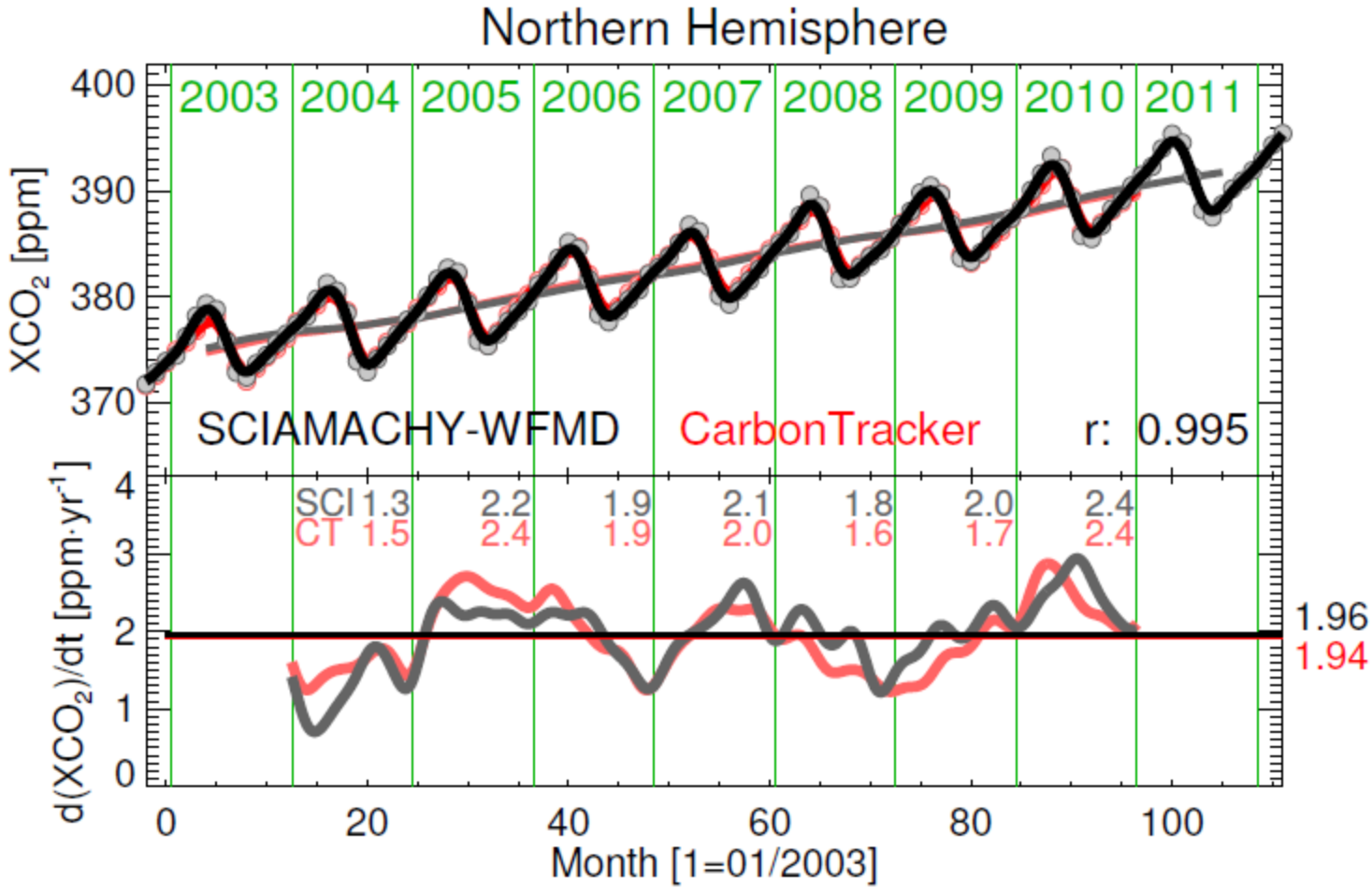
0.89±0.20 PgC over Eurasia

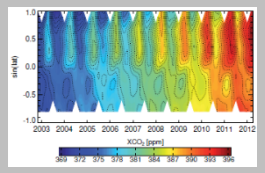


CO_2 seasonal cycle and growth rate

Terrestrial carbon sink observed from space: Variation of growth rates and seasonal cycle amplitudes in response to interannual surface temperature variability Schneising et al., ACP, 2014

O. Schneising[1], M. Reuter[1], M. Buchwitz[1], J. Heymann[1], H. Bovensmann[1], and J. P. Burrows[1]
[1]Institute of Envi



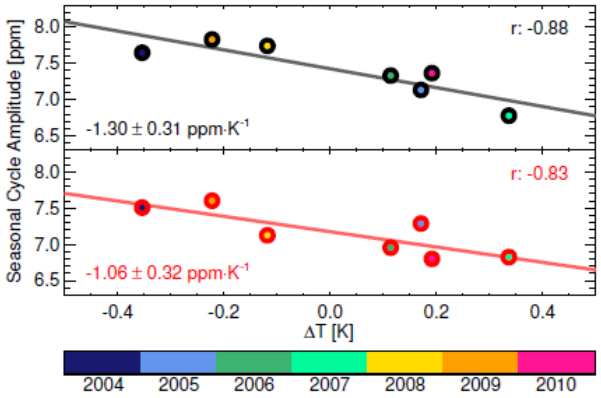


SCIA WFMD&BESD CO_2: Terrestrial carbon sink

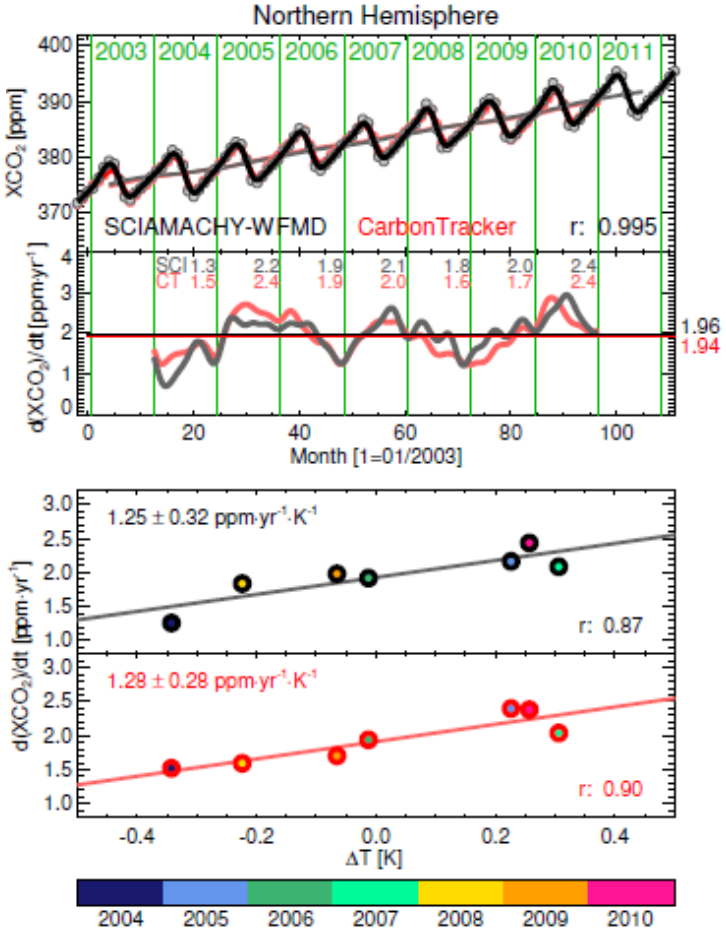
Terrestrial carbon sink observed from space: Variation of growth rates and seasonal cycle amplitudes in response to interannual surface temperature variability Schneising et al., ACP, 2014

O. Schneising[1], M. Reuter[1], M. Buchwitz[1], J. Heymann[1], H. Bovensmann[1], and J. P. Burrows[1]
[1]Institute of Environmental Physics (IUP), University of Bremen FB1, Bremen, Germany

Inter-annual variability of CO_2 seasonal cycle amplitude vs Temperature



Inter-annual variability of CO_2 growth rate vs Temperature



Terrestrial carbon uptake variability correlated with / driven by near-surface temperature changes:

SCIAMACHY:

- **1.25 +/ 0.32 ppm /yr /K**
- **-> approx. 2.7 +/- 0.7 GtC /yr /K**

CarbonTracker vs. SCIAMACHY: Good agreement

Less carbon uptake (= higher atmospheric growth rate) **in warmer years**

GHG-CCI CAR: CCDAS

Carbon Cycle Data Assimilation System (CCDAS)

CAR, v1.1: Initial assessment by FastOpt (T. Kaminski and M. Scholze) using the reported (reliable) uncertainties as given in the CRDP#1 SCIAMACHY BESD (SCIAMACHY) and EMMA (SCIAMACHY and GOSAT merged) XCO_2 products

Approach:

- Optimization of biosphere model parameters

Advantage w.r.t. direct flux inversion:

- May lead to improved biosphere models -> Better climate prediction

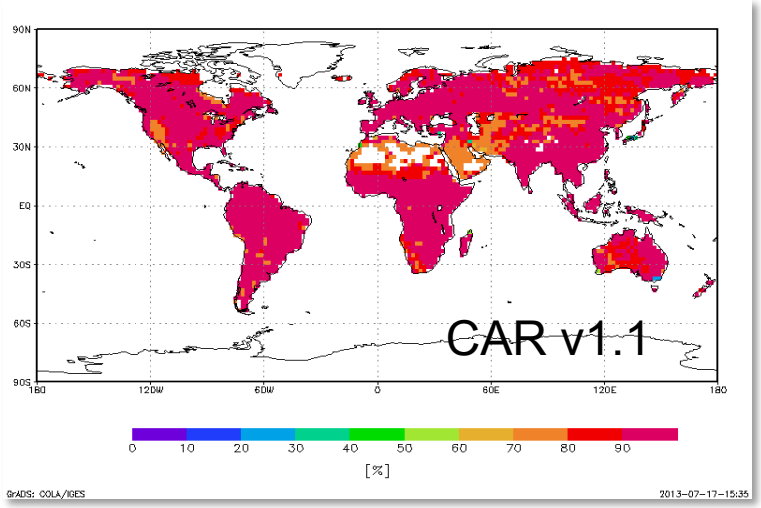
Assessed target quantities:

- regional Net Primary Production (NPP)
- regional heterotrophic RESpiration (RES)
- regional Net Ecosystem Production (NEP)

Findings:

- **Very high uncertainty reduction:**
  - **> 50% at model grid scale**
  - **> 70% for aggregated regions**
- To be assessed: impact of biases

Potential for high uncertainty reduction of NEP even when using only 1 year of SCIAMACHY XCO_2

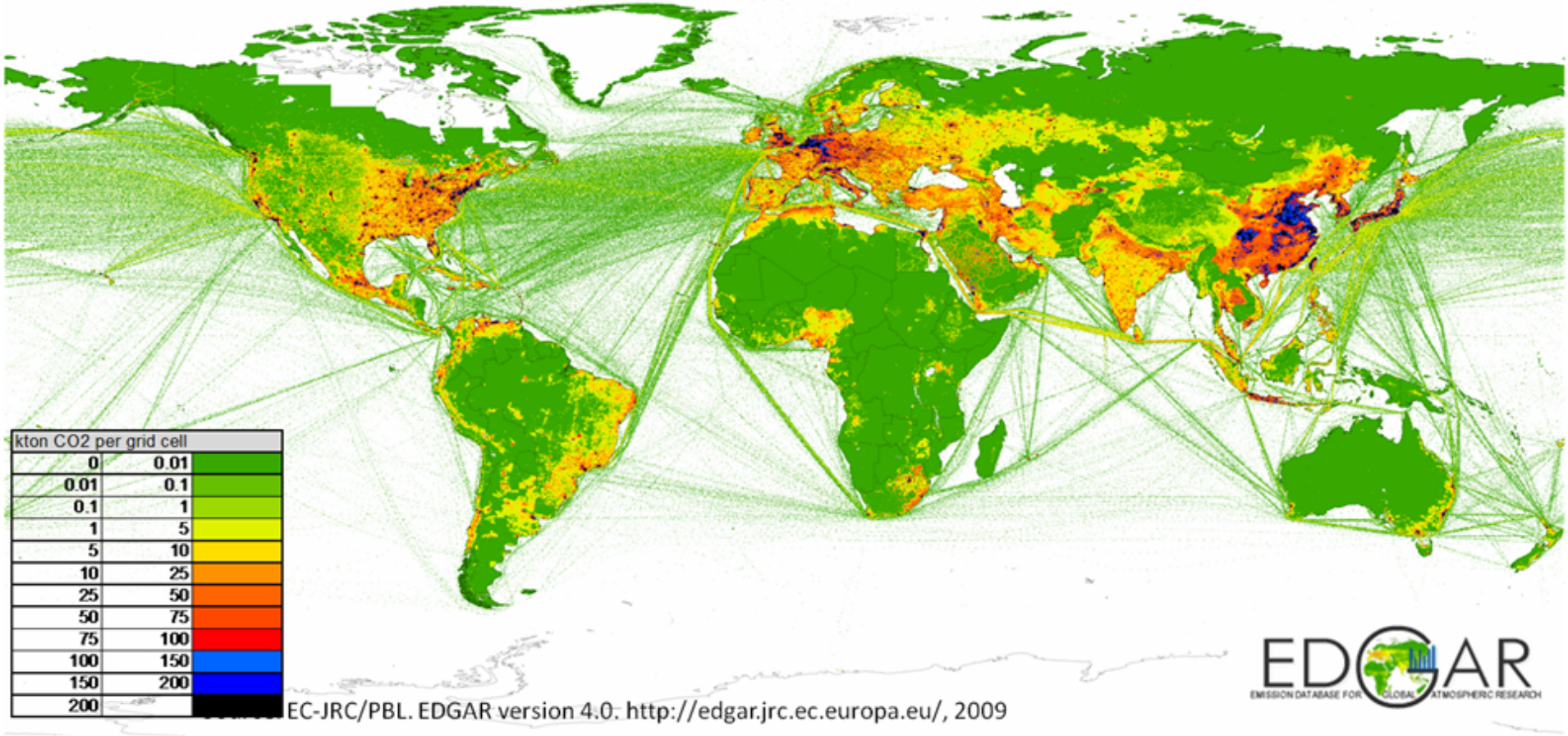


0% **50%** **100%**

Prior: Scholze et al., 2007
Model: BETHY-TM3

Anthropogenic CO_2

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

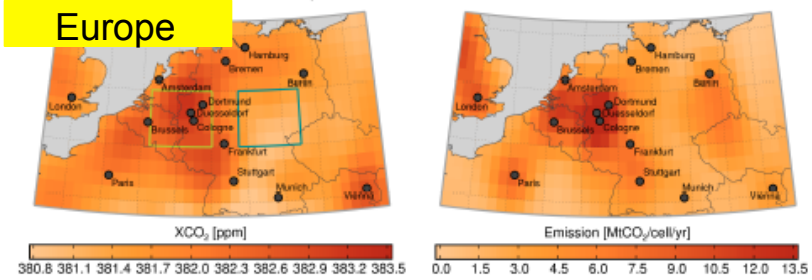
SCIAMACHY XCO_2

WFMDv2.3 (2003-2009)

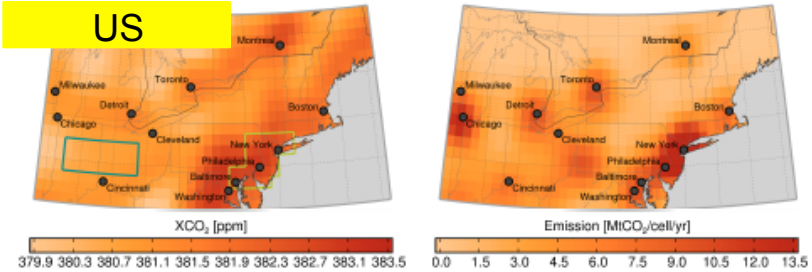
EDGAR CO_2 emissions

EDGAR v4.2

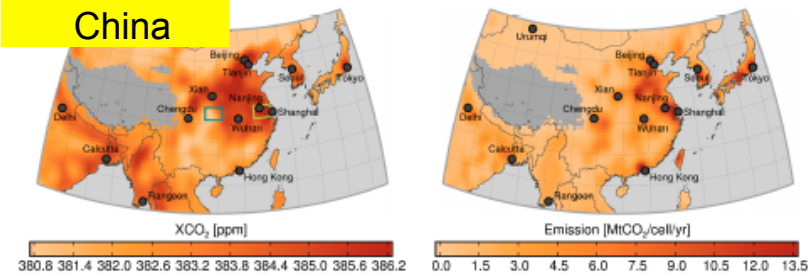
Europe

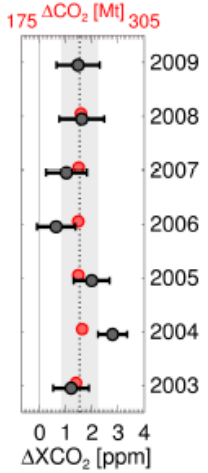


US



China

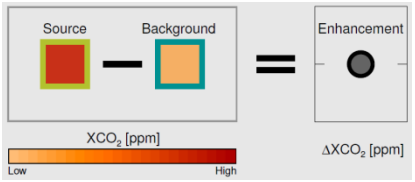


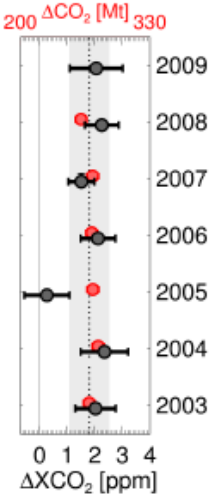


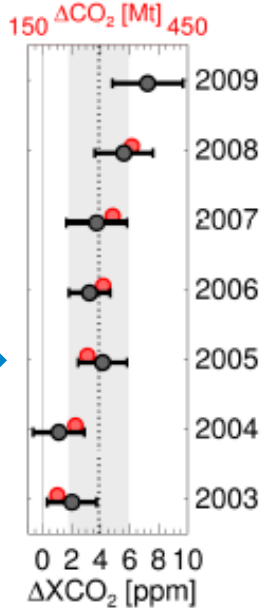
Schneising et al., 2013

SCIAMACHY
EDGAR

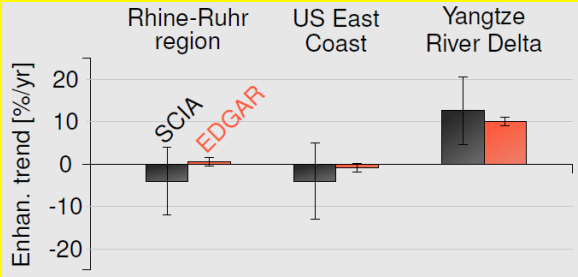
Regional enhancement =
Source - Background







Trend [%CO_2/yr]

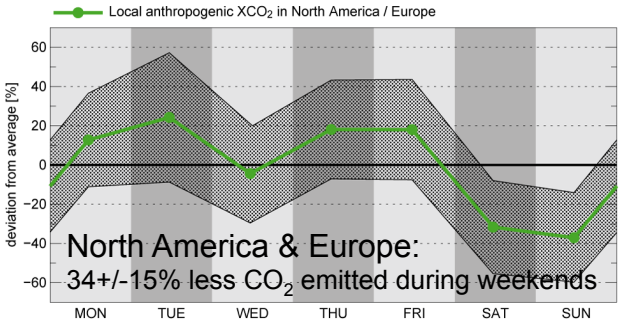


EDGAR emissions consistent with SCIAMACHY

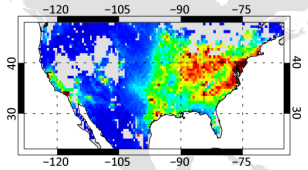
Anthropogenic emissions: Good and bad news

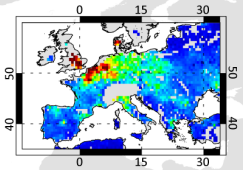
Reuter et al., Nature Geoscience, 2014

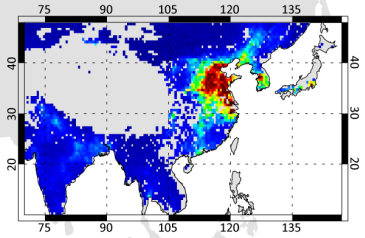
„Decreasing NO_x relative to CO_2 emissions in East Asia inferred from satellite observations“

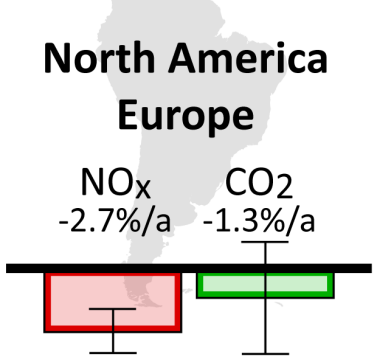


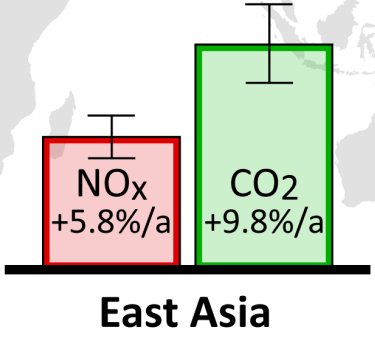
Satellite derived trends of anthropogenic NO_x and CO_2 emissions











- 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**

Reuter et al., 2014 (Nature Geoscience)

maximilian.reuter@iup.physik.uni-bremen.de

Anthropogenic CO_2 emissions: Individual cities ?

GEOPHYSICAL RESEARCH LETTERS, VOL. 39, L17806, doi:10.1029/2012GL052738, 2012

Kort et al., GRL, 2012

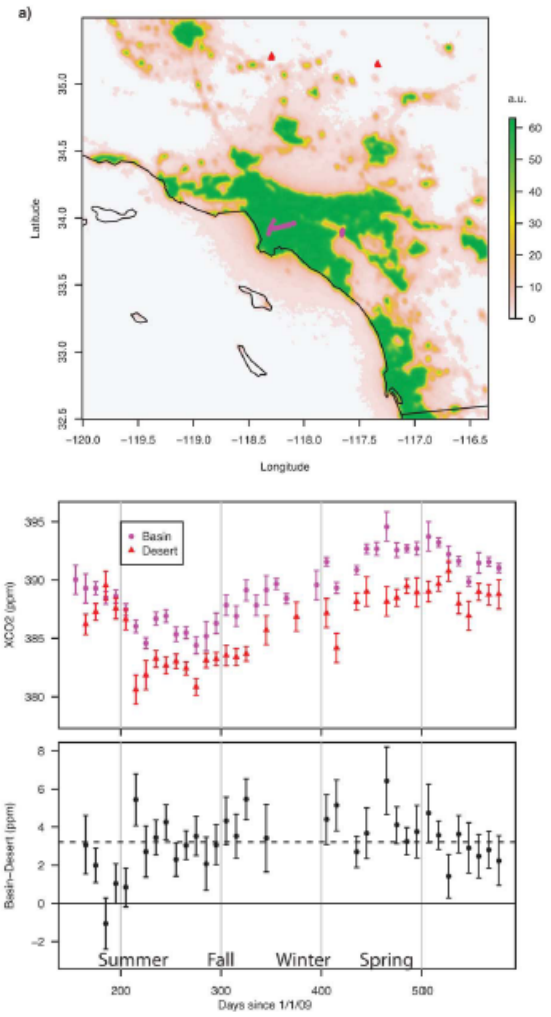
Space-based observations of megacity carbon dioxide

Eric A. Kort,[1,2] Christian Frankenberg,[2] Charles E. Miller,[2] and Tom Oda[3,4]

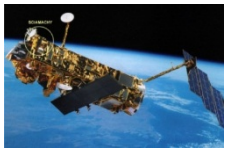
Differencing **GOSAT** observations over megacities with those in nearby background:

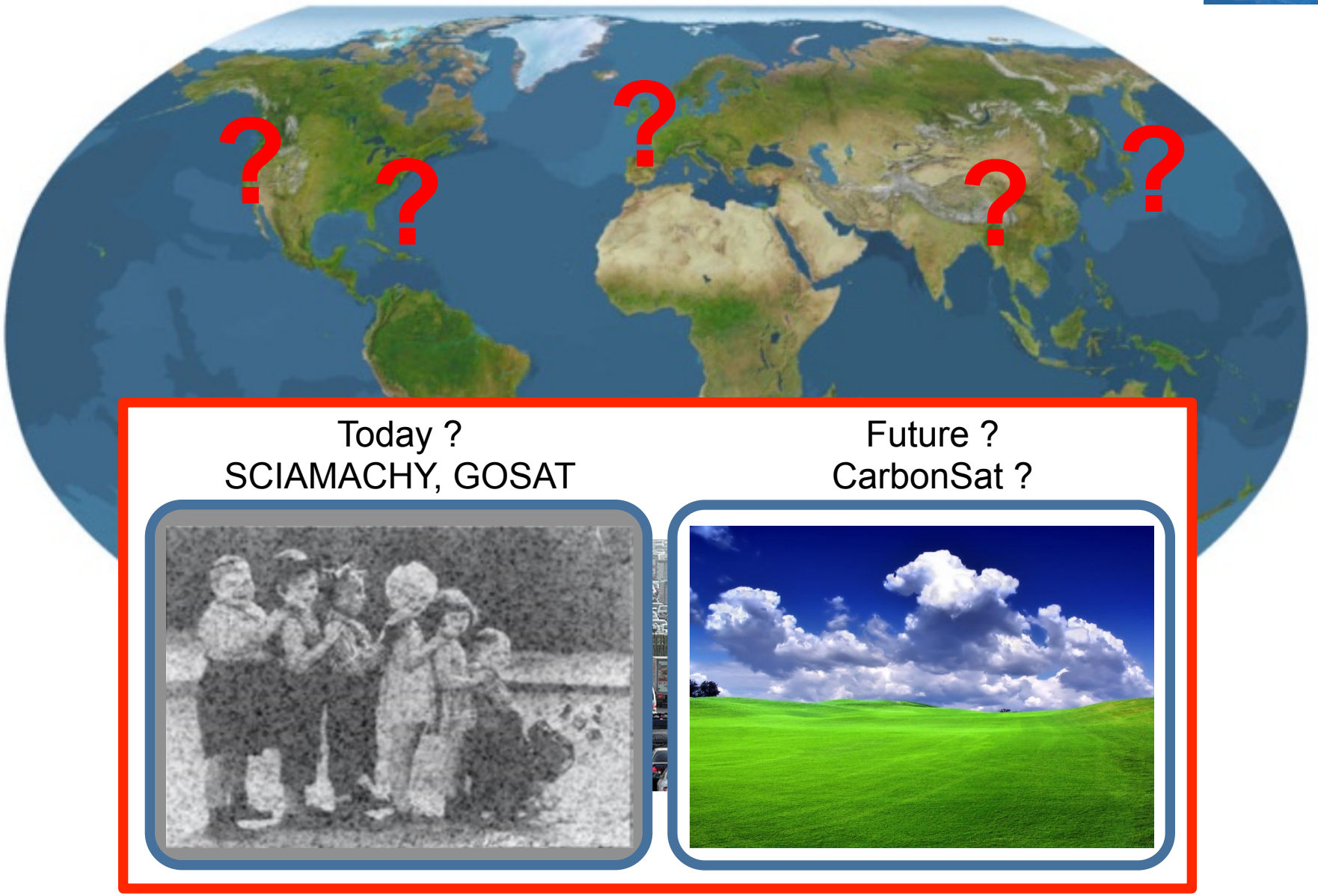
- **Los Angeles:**
  - XCO_2 enhancement: **3.2+/-1.5 ppm**
  - XCO_2 changes of 0.7 ppm, corresponding to a 22% change in emissions, detectable with GOSAT at the 95% confidence level.
- **Mumbai:**
  - XCO_2 enhancement: **2.4+/-1.2 ppm**

Observed XCO_2 urban dome of Los Angeles June 2009 to August 2010



Anthropogenic CO_2 emissions from space ?





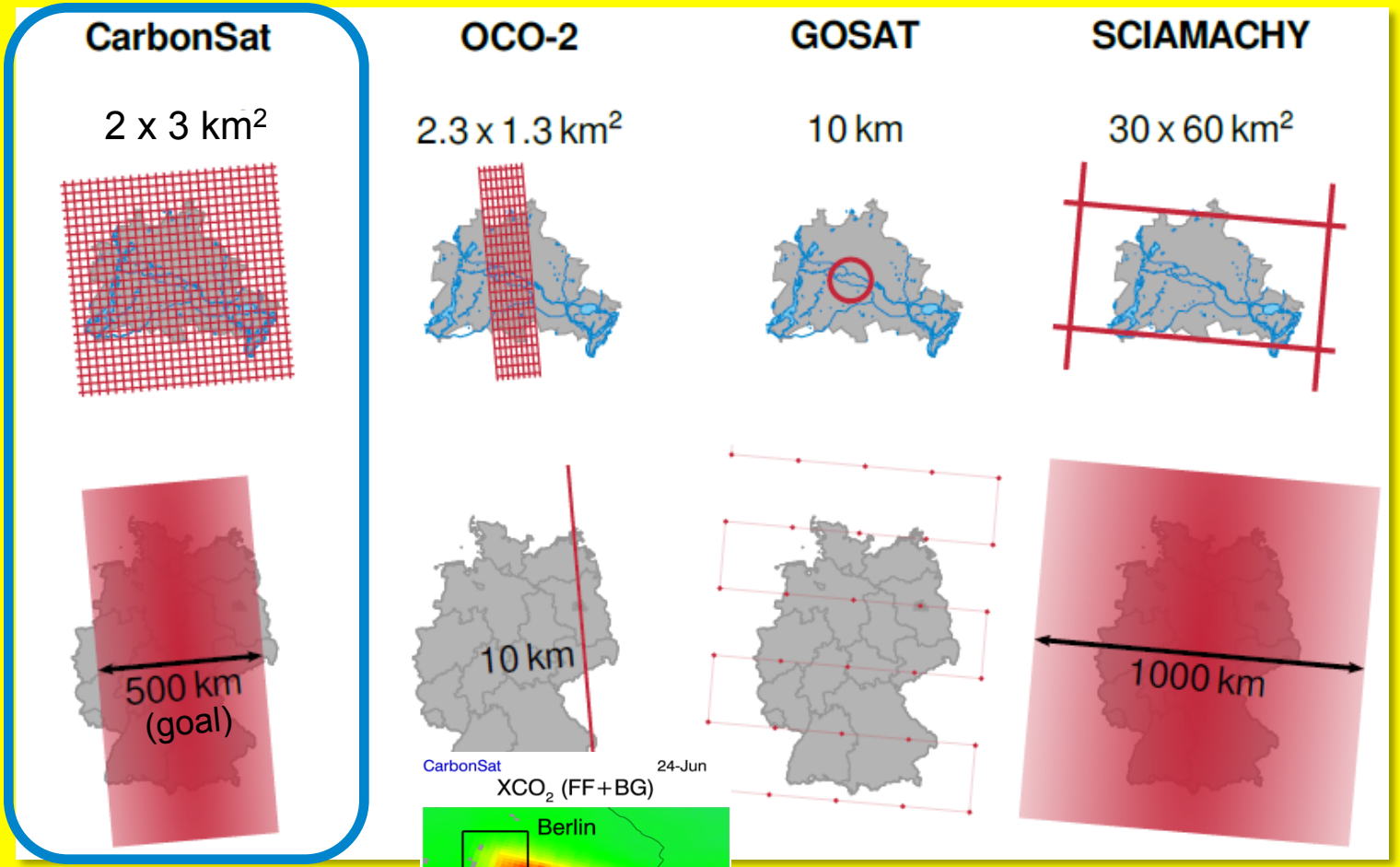
Today ?
SCIAMACHY, GOSAT

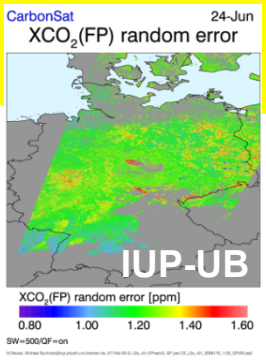
Future ?
CarbonSat ?

From SCIAMACHY to CarbonSat

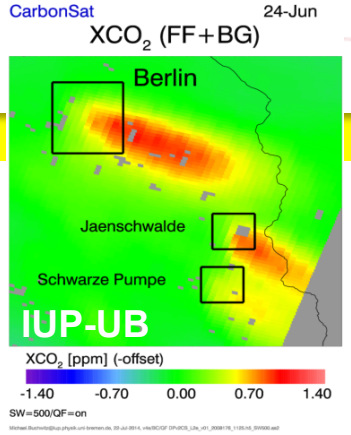
Berlin

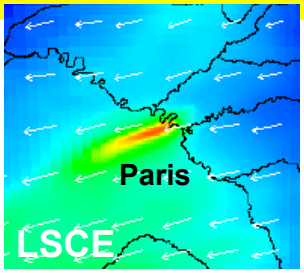
Germany

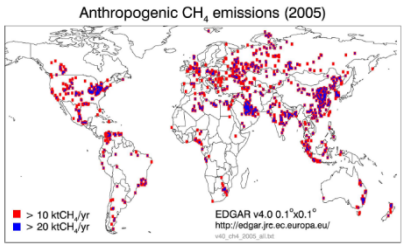




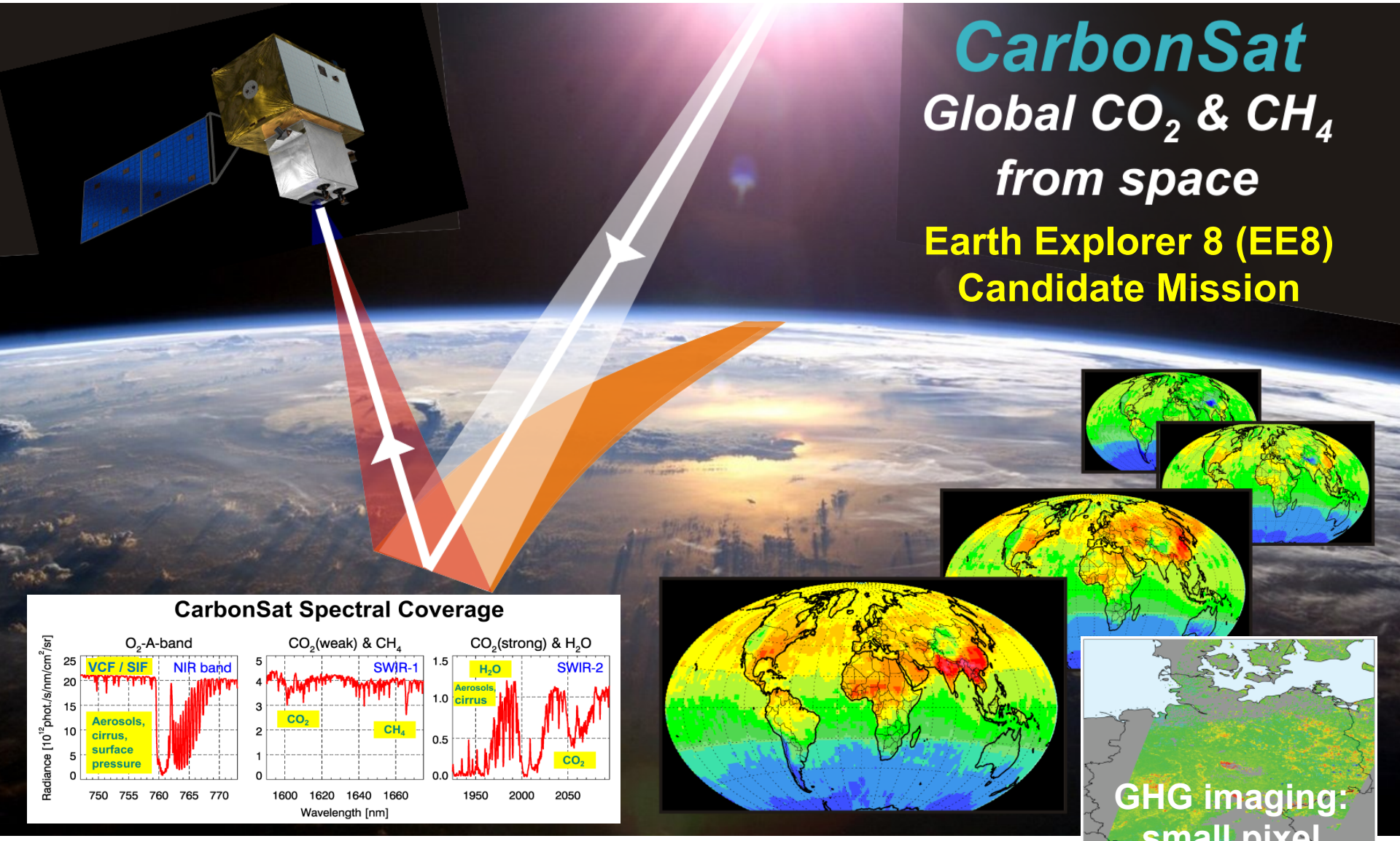
New capabilities:
Cities, power plants, oil & gas fields, geological „point“ sources, …







Carbon Monitoring Satellite (CarbonSat)



www.iup.uni-bremen.de/carbonsat

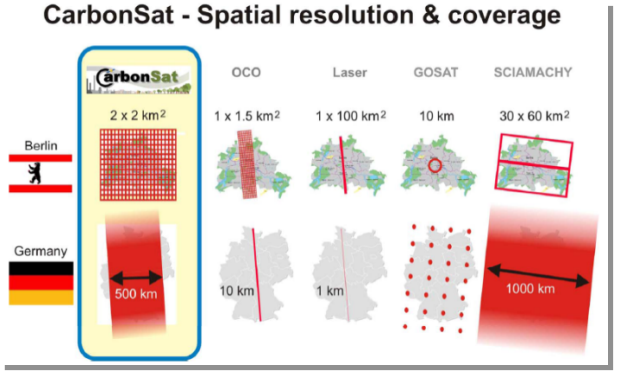
CarbonSat: Mission Goals

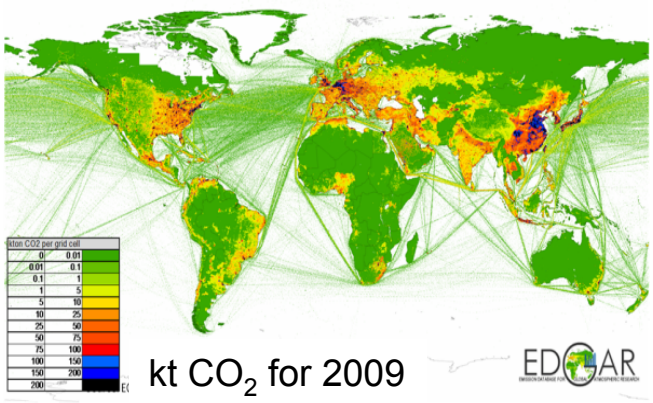
CarbonSat aims at better separating natural and anthropogenic carbon fluxes via **high spatial resolution** (~2x3 km^2) & **good coverage** (swath: ~200 km (TBC); goal: 500 km) atmospheric **XCO_2 and XCH_4 observations** (secondary products: vegetation Solar Induced Fluorescence (SIF, …) with **"GHG imaging"** of strong localized CO_2 and CH_4 emission sources.

In combination with **inverse modeling** and robust **validation (TCCON)** this will provide:

Better top-down CO_2 & CH_4 constraints on

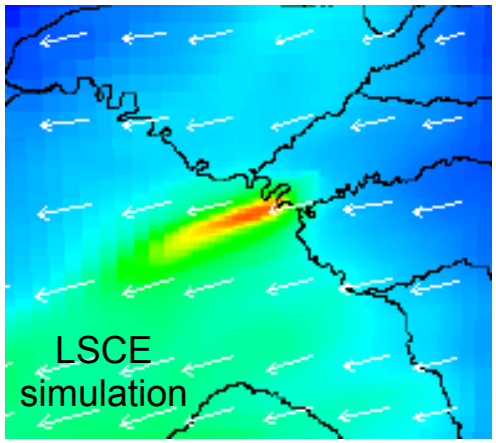
- **regional / country scale (mainly natural) fluxes** (sources and sinks) (e.g., SCIAMACHY, GOSAT, OCO-2, …)
- **city scale emissions** (e.g., Buchwitz et al., AMTD, 2013)
- **point source emissions** (e.g., Bovensmann et al., AMT, 2010)



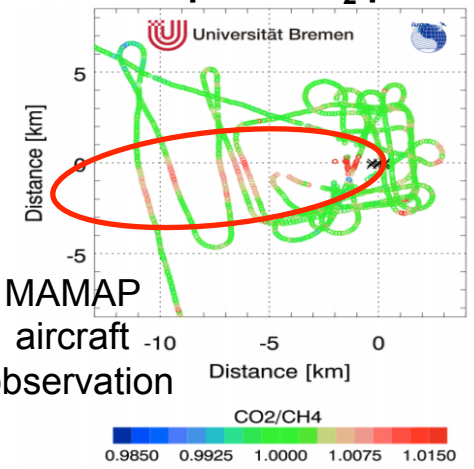


kt CO_2 for 2009

Paris city CO_2 plume



Power plant CO_2 plume



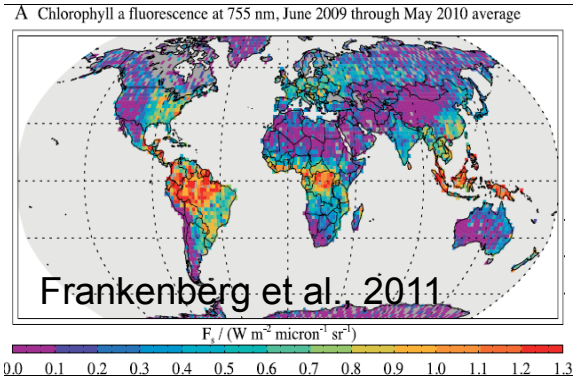
CarbonSat: Vegetation Chlorophyll Fluorescence

- **Vegetation Chlorophyll / Solar Induced Fluorescence (VCF / SIF)** provides observational constraints on carbon Gross Primary Productivity (GPP) (e.g., Guanter et al., 2014)

- O_2-A band „disturbed“ by sun induced plant fluorescence -> correction needed for accurate XCO_2 retrieval
- Analysis of GOSAT, SCIAMACHY and GOME-2 data demonstrated that VCF/SIF can be well retrieved using clear solar Fraunhofer lines (Joiner et al, Frankenberg et al., Guanter et al., etc.) -> same approach planned for OCO-2 (Frankenberg et al., 2014) and CarbonSat (Buchwitz et al., 2013)

- **CarbonSat will provide high-quality SIF @ 755 nm to better constrain GPP**

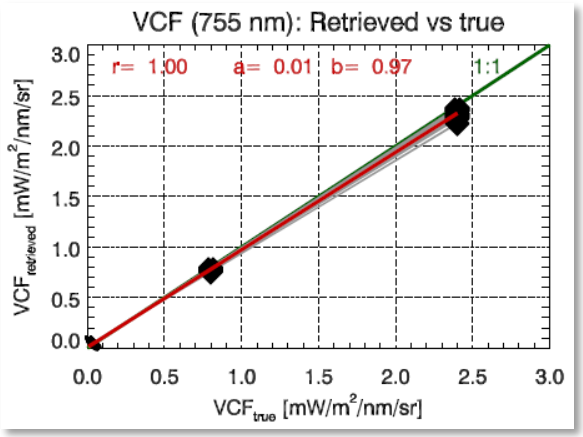
Space-borne demonstration:
GOSAT:
SIF @ 755 nm



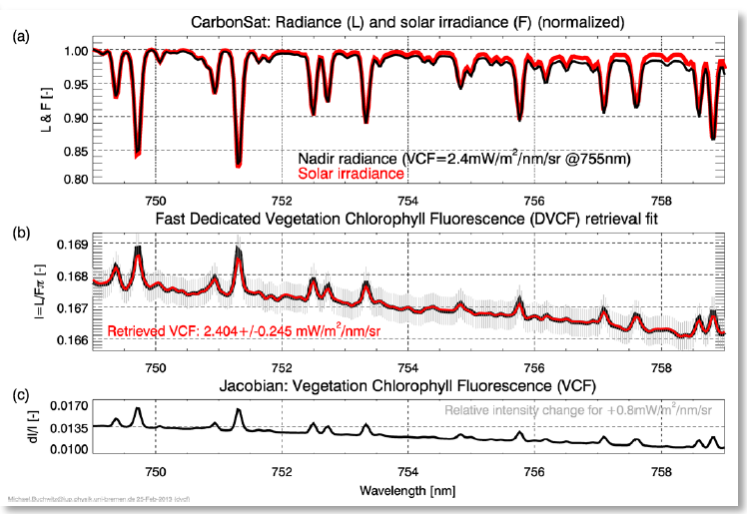
CarbonSat SIF @ 755 nm:

Single measurement precision (1-sigma):
~0.3 mW/m²/nm/sr

Low bias due to use of clear Fraunhofer lines



Buchwitz et al., AMT, 2013



CarbonSat: Similar quality expected as for OCO-2 but with much better coverage

Results

Satellite-derived GHG source/sink-related results:

Methane

Methane


Natural gas


Coal mining


Wetlands


Rice

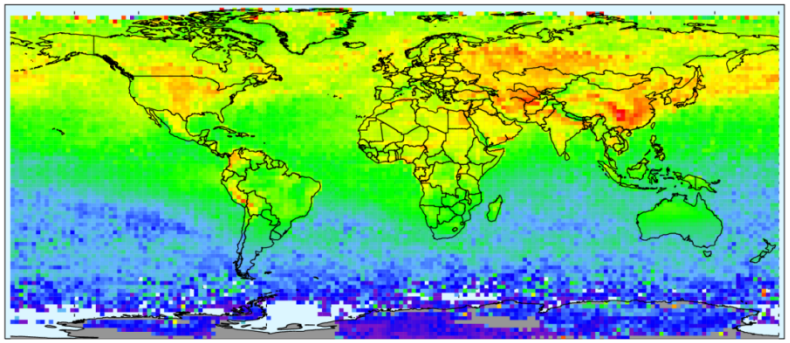


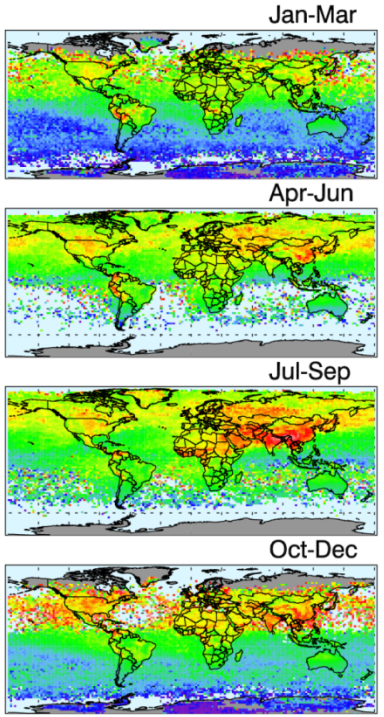
Ruminants


Wastewater

GHG-CCI 2002-2011

Methane SCIAMACHY/WFMD

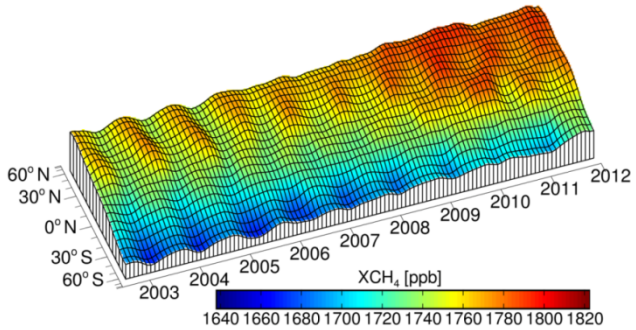


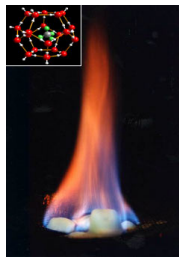



Landfills


Energy


Termites




Hydrates

Global regional-scale CH_4 emissions via SCIAMACHY

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

Click Here for Full Article

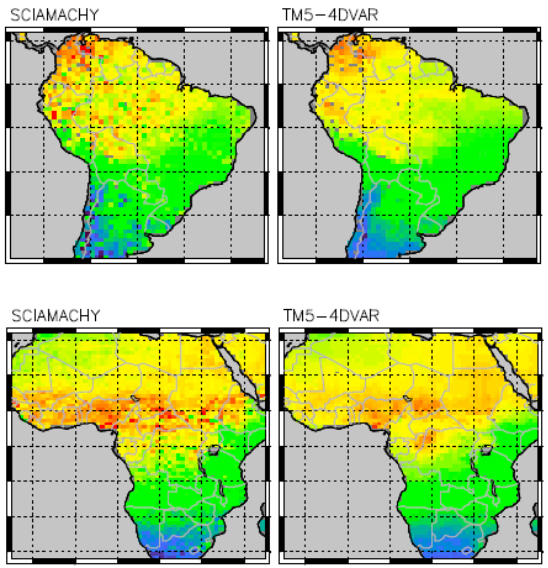
Bergamaschi et al., 2009

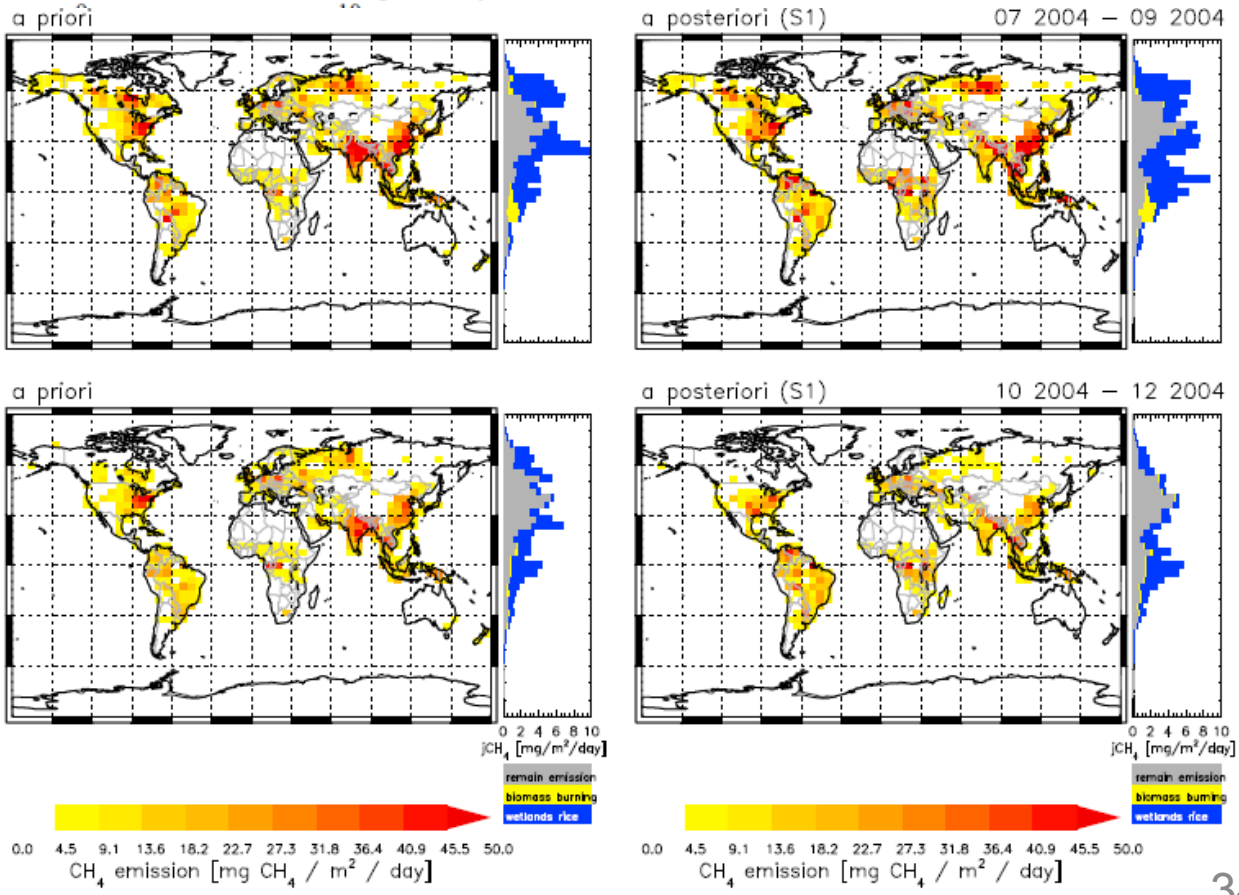
Methane retrievals from SCIAMACHY provide important information on atmospheric CH_4 sources, particularly in tropical regions which are poorly monitored by in situ surface observations.

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

Peter Bergamaschi,[1] Christian Frankenberg,[2] Jan Fokke Meirink,[3] Maarten Krol,[2,4,5] M. Gabriella Villani,[1] Sander Houweling,[2,5] Frank Dentener,[1] Edward J. Dlugokencky,[6] John B. Miller,[6,7] Luciana V. Gatti,[8] Andreas

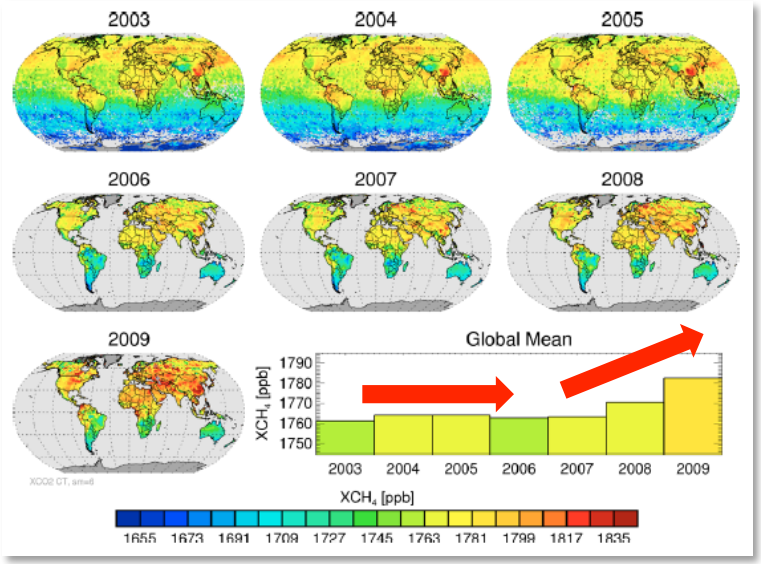
Received 20 April 2009; revised 23 June 2009; accepted 18 A





SCIAMACHY: Renewed methane growth

Schneising et al., 2011



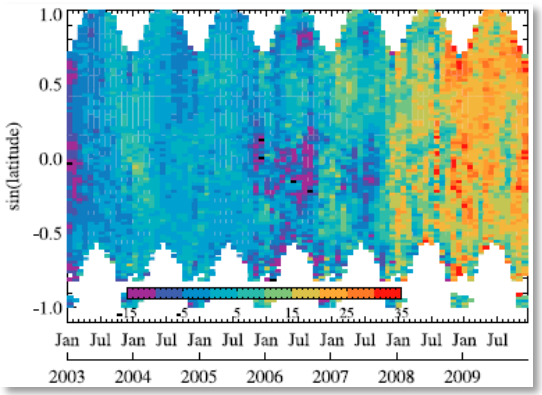
Latitude band	Mean amplitude seasonal cycle [ppb]		Anomaly since 2007 [ppb yr^{-1}]	
	SCIA	TM5(2003)	SCIA	TM5(2003)
Global	13.4±4.0	9.8±2.9	7.4	−0.4
NH	13.7±2.6	9.3±0.3	8.2	−0.5
SH	8.5±5.3	8.5±1.7	5.4	−0.6
30° N–90° N	12.4±8.0	11.2±0.8	6.6	−0.6
30° S–30° N	7.3±3.7	5.1±0.9	8.2	−0.2
30° S–90° S	10.6±1.2	8.5±3.1	4.4	0.0
0° N–30° N	17.2±1.9	10.8±1.0	9.1	−0.4
0° S–30° S	6.1±2.7	5.2±0.3	5.8	−0.5

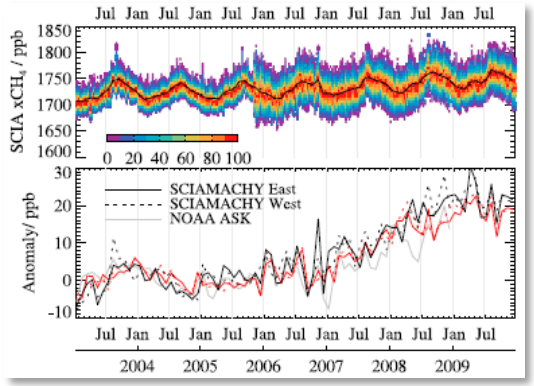
NH (~0- 60°)

Tropics

NH Tropics

Frankenberg et al., 2011





Findings:

- **Increase ~7-9 ppb/yr** (0.4-0.5%/yr) (2007-2009 relative to 2003-2006)
- **Mainly tropics & NH mid latitudes**
- No "local / regional hot spot" found
- Analysis complicated by detector degradation

SCIAMACHY & NOAA/flasks: Renewed methane growth

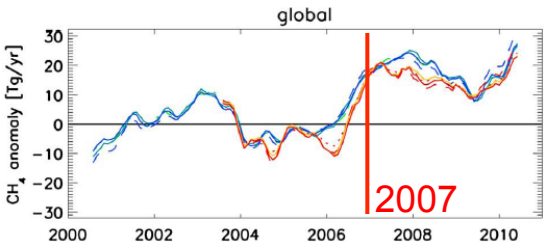
Atmospheric CH_4 in the first decade of the 21st century: Inverse modeling analysis using SCIAMACHY satellite retrievals and NOAA surface measurements Bergamaschi et al., 2013

P. Bergamaschi,[1] S. Houweling,[2,3] A. Segers,[1,4] M. Krol,[2,3,5] C. Frankenberg,[6] R. A. Scheepmaker,[2] E. Dlugokencky,[7] S. C. Wofsy,[8] E. A. Kort,[6] C. Sweeney,[7,9] T. Schuck,[10] C. Brenninkmeijer,[10] H. Chen,[7,9,11] V. Beck,[12] and C. Gerbig[12]

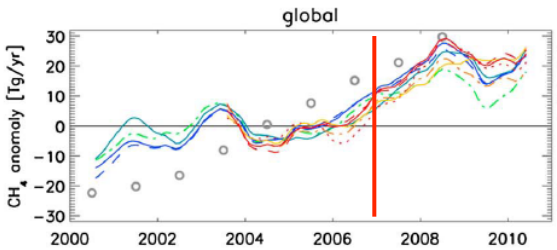
S1–SCIA
S2–SCIA (WHyMe)
S3–SCIA (no a priori IAV)
S4–SCIA (SP OH)
S5–SCIA (smooth bias)
S1–NOAA
S2–NOAA (WHyMe)
S3–NOAA (no a priori IAV)
S4–NOAA (SP OH)

reference year: 2003–2005
running mean: 12 months

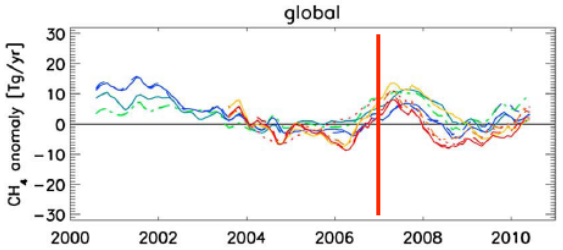
Total emissions



Anthropogenic



Wetlands



Findings:

- **Methane emissions 2007-2010: +16-20 $TgCH_4$/yr** higher compared to 2003-2005
- **Atmospheric increase 2007-2010: on average ~6+/-1 ppb/yr** (0.3-0.4%/yr) (relative to 2003-2006; update of global means from Dlugokencky et al., 2009)
- **Where?: Mainly tropics & NH mid latitudes**, no significant trend for arctic latitudes
- **Reason for increase: Mainly increasing anthropogenic emissions**
- **Interannual variations: Mainly wetlands & biomass burning**

SCIAMACHY & NOAA/flasks: Renewed methane growth

Atmos. Chem. Phys., 14, 3991–4012, 2014
www.atmos-chem-phys.net/14/3991/2014/
doi:10.5194/acp-14-3991-2014

Atmospheric Chemistry and Physics Open Access

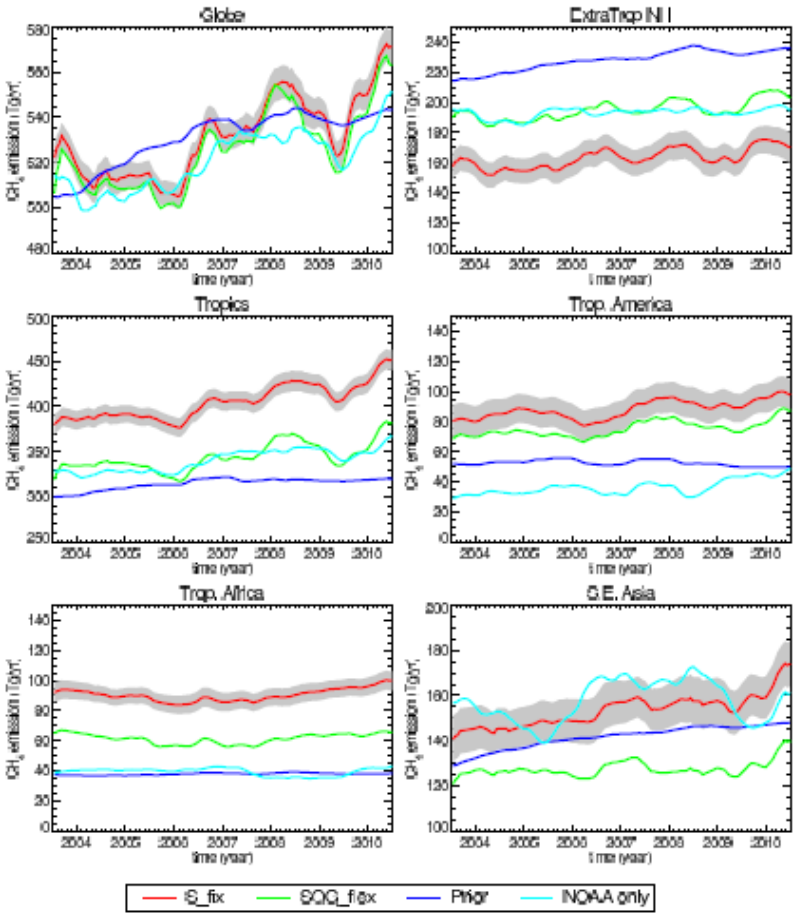
Houweling et al., ACP, 2014

A multi-year methane inversion using SCIAMACHY, accounting for systematic errors using TCCON measurements

S. Houweling[1,2], M. Krol[1,2,3], P. Bergamaschi[4], C. Frankenberg[5], E. J. Dlugokencky[6], I. Morino[7], J. Notholt[8], V. Sherlock[9], D. Wunch[10], V. Beck[11], C. Gerbig[11], H. Chen[12,13], E. A. Kort[14], T. Röckmann[2], and I. Aben[1]

Addresses which region contributed most to the CH_4 increase since 2007:

- Two 2-year periods before and after July 2006 analyzed
- Global difference varies between **27 and 35 Tg/yr** most of which is attributed to the **tropics** with the **northern hemispheric part** of this zone contributing most
- Splitting the tropics: largest portion **south-east Asia (9+/-13 Tg/yr)** consistent with growing demand for energy and food and rapidly growing economies (but large uncertainty)



Renewed methane growth: Anthropogenic or wetlands ?

Kirschke, Bousquet, Ciais, et al., 2013

Global Methane Budget

2013

Three Decades of Global Methane Sources and Sinks

Three decades of global methane sources and sinks

Results of the Scenario Analysis

Stabilisation period (1999-2006):

→ Decreasing to stable fossil fuel emissions and stable to increasing microbial emissions are more likely

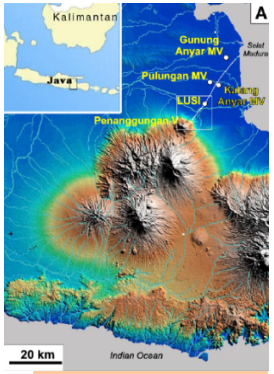
Resumed atmospheric increase (>2006) :

→ Mix of fossil fuel and wetland emissions increase, but relative magnitude remains uncertain

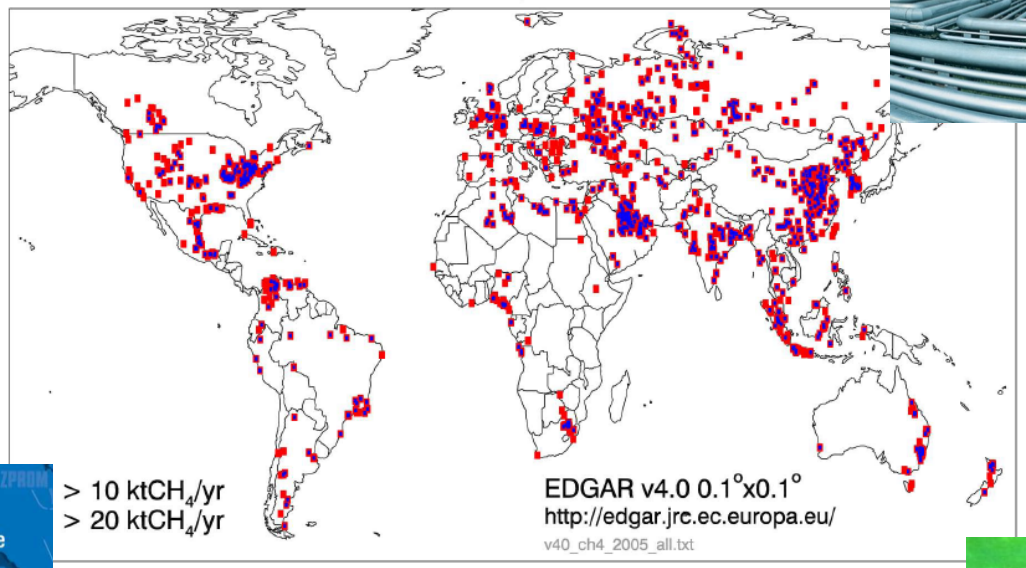
Methane Hot Spots

CarbonSat XCH_4 single observation retrieval precision: 9 ppb (0.5%)
Target must produce a detectable methane column enhancement at 2 x 3 km^2 resolution
→ Single overpass detection limit / uncertainty: 4 - 8 $ktCH_4$/year (e.g., depending on wind speed)

Mud volcanoes



Anthropogenic CH_4 emissions (2005)



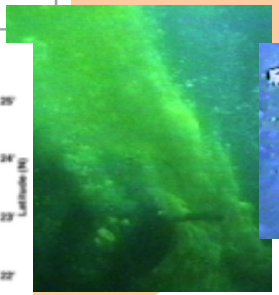
Pipelines incl. compressor stations

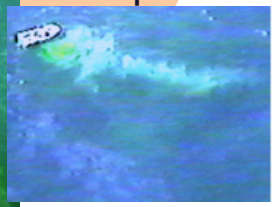
Landfills / Waste

Oil and gas fields

Bovensmann et al. AMT, 2010

Seeps



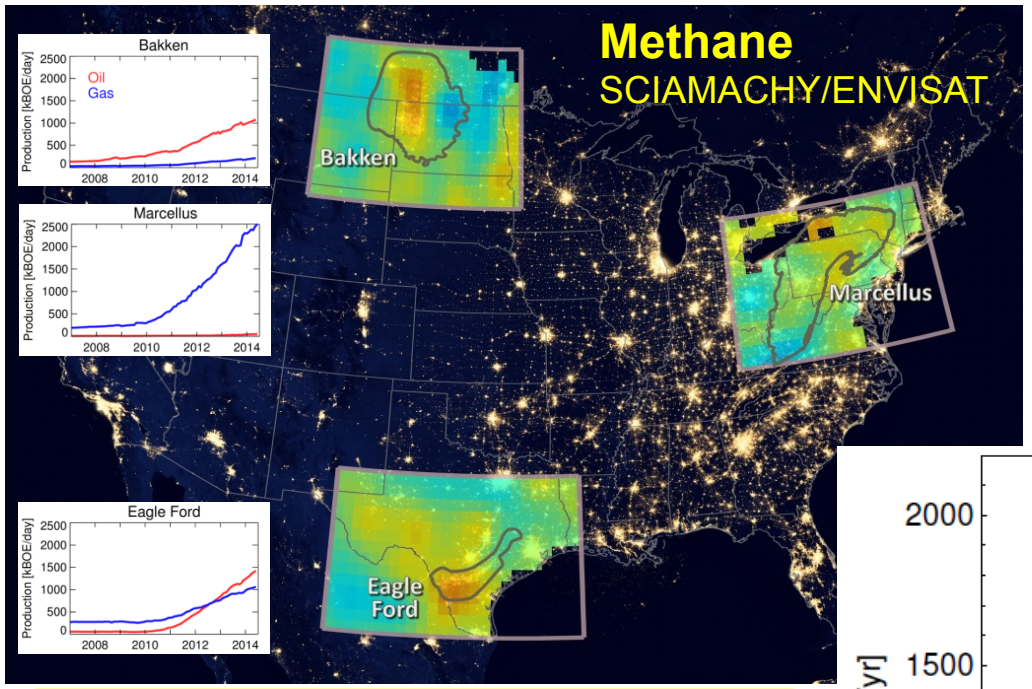


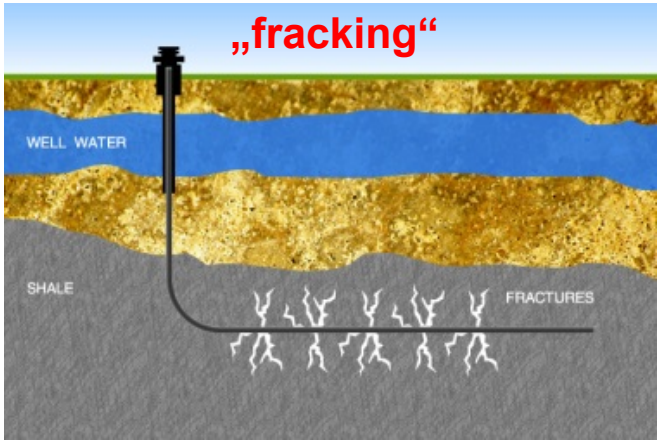
SCIAMACHY methane:

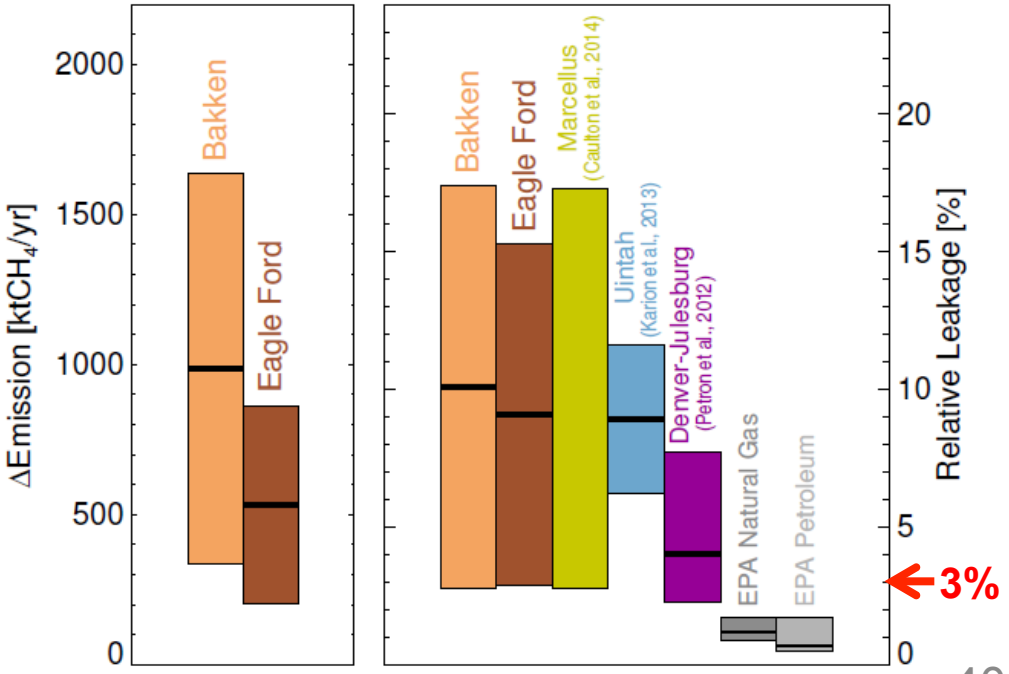
Remote sensing of fugitive methane emissions from oil and gas production in North American tight geologic formations

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

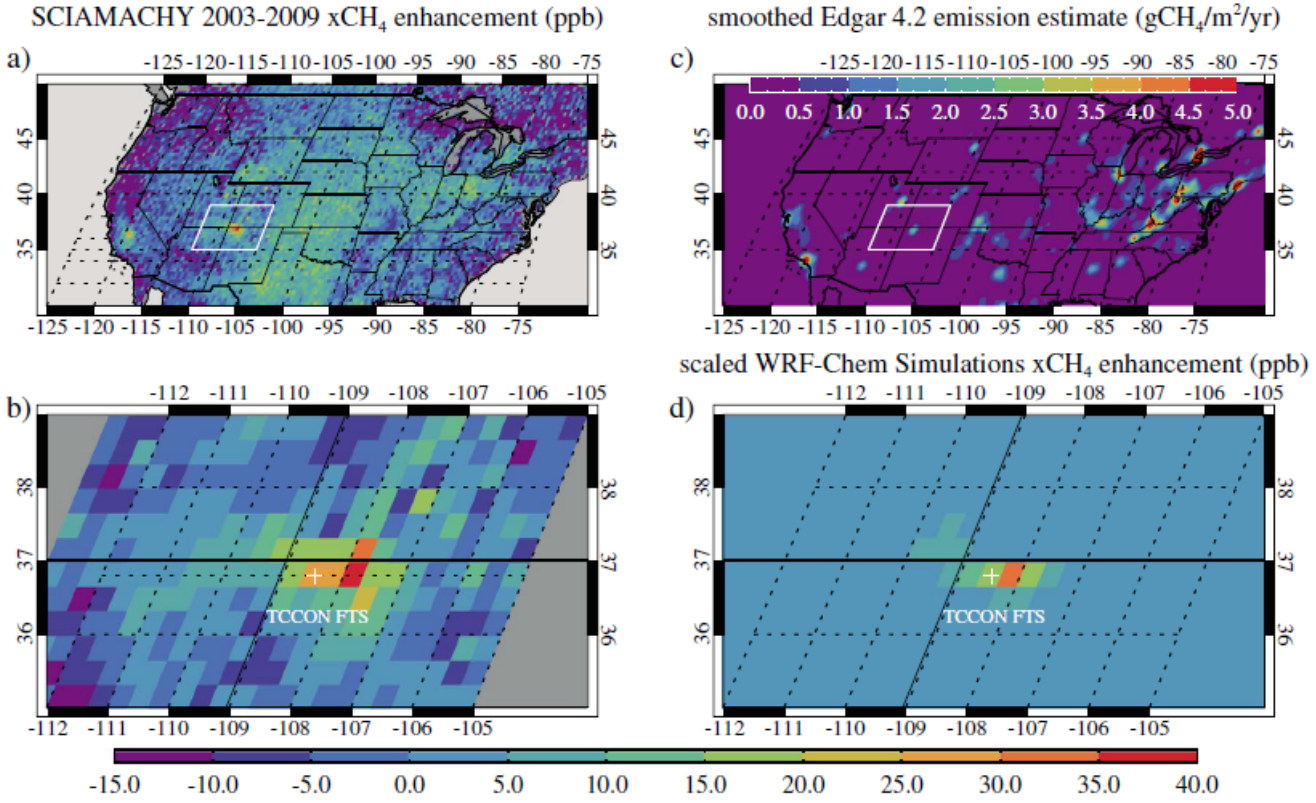
Likely **underestimated in inventories**.

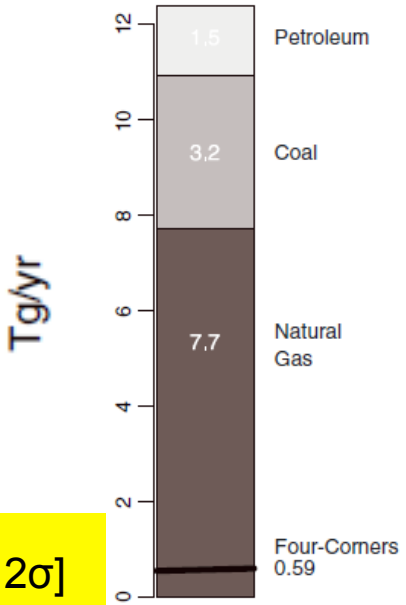
SCIAMACHY & TCCON methane:

Four corners: The largest US methane anomaly viewed from space

Kort et al., GRL, 2014

Eric A. Kort[1], Christian Frankenberg[2], Keeley R. Costigan[3], Rodica Lindenmaier[3,4], Manvendra K. Dubey[3], and Debra Wunch[5]





Estimated emission Four Corners region: **0.59 Tg CH_4/yr** [0.50–0.67; 2σ]

This **underestimated source (3.5 x EDGARv4.2)** approaches **10% of the EPA estimate of total U.S. CH_4 emissions from natural gas.**

Assessement of Climate-Chemistry Model using SCIAMACHY methane - I

Atmos. Chem. Phys., 13, 2653–2689, 2013
www.atmos-chem-phys.net/13/2653/2013/
doi:10.5194/acp-13-2653-2013

Atmospheric Chemistry and Physics Open Access

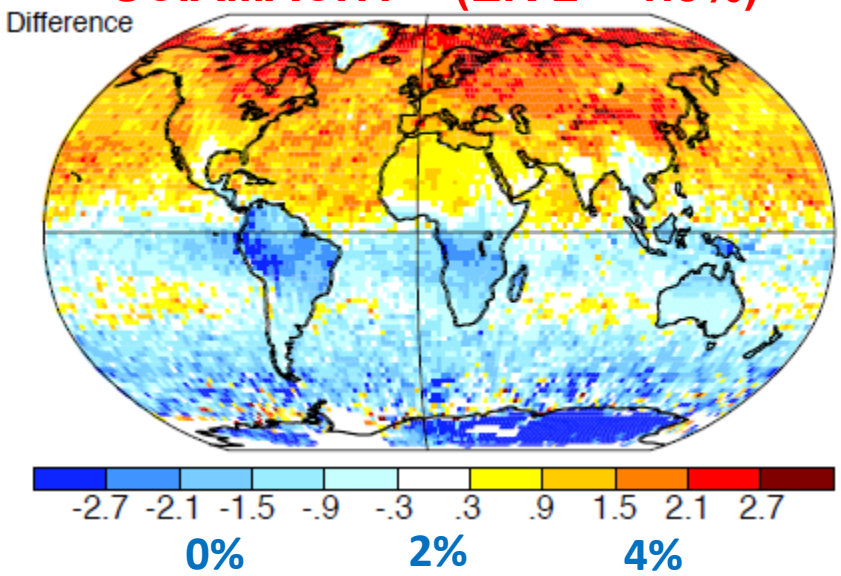
Shindell et al., 2013

Interactive ozone and methane chemistry in GISS-E2 historical and future climate simulations

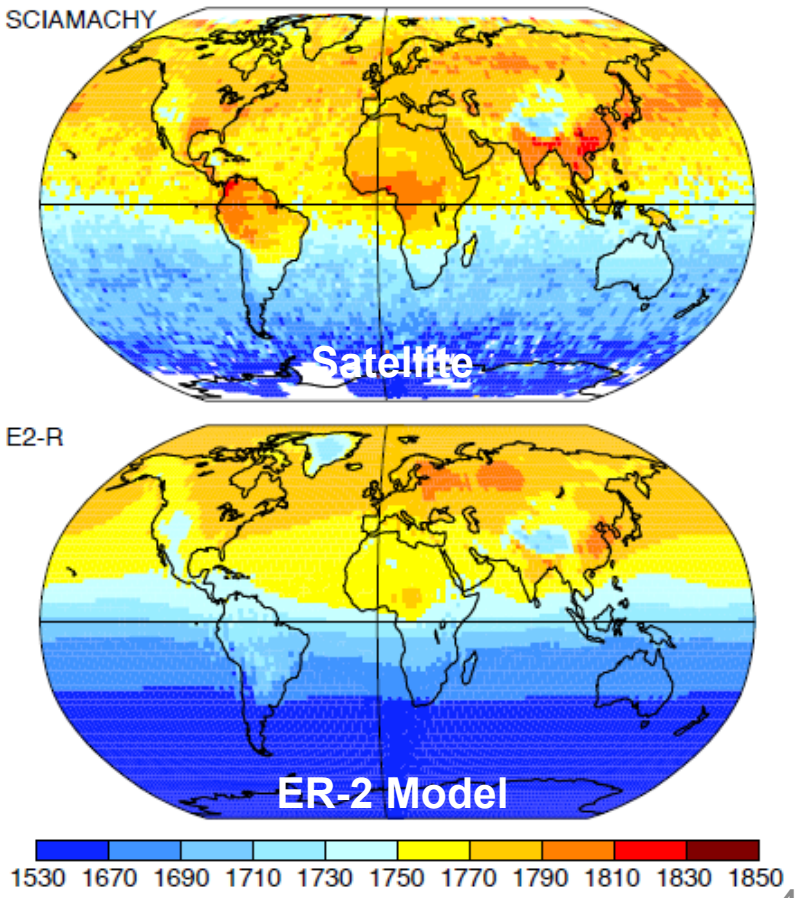
D. T. Shindell[1], O. Pechony[1], A. Voulgarakis[1,*], G. Faluvegi[1], L. Nazarenko[1], J.-F. Lamarque[2], K. Bowman[3], G. Milly[1], B. Kovari[1], R. Ruedy[1], and G. A. Schmidt[1]

[1]NASA Goddard Institute for Space Studies and Columbia Earth Institute, New York, NY USA
[2]National Center for Atmospheric Research, Boulder, CO USA
[3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA USA
[*]now at: Department of Physics, Imperial College London, London, UK

SCIAMACHY – (ER-2 + 1.8%)



SCIAMACHY WFMD 2003-2005
(Schneising et al., 2011)
versus ER-2
(new generation GISS climate model)



Assessement of Climate-Chemistry Model using SCIAMACHY methane - II

Hayman et al., 2014

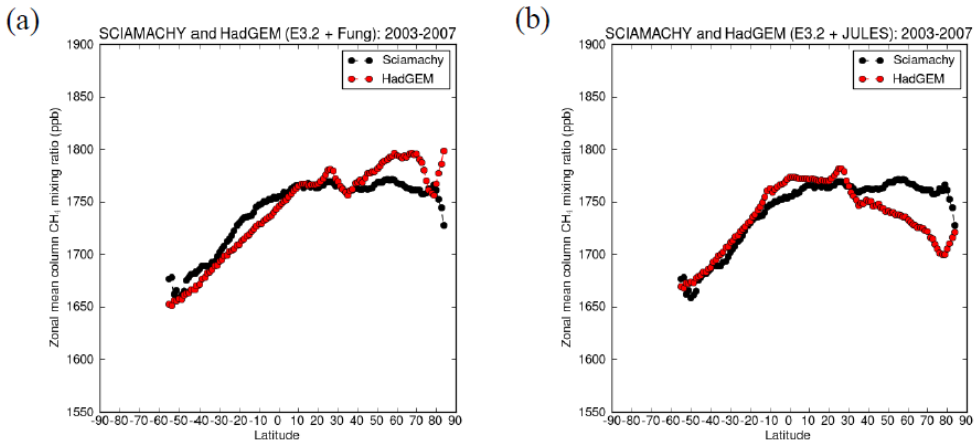
Atmos. Chem. Phys. Discuss., 14, 12967–13020, 2014
www.atmos-chem-phys-discuss.net/14/12967/2014/
doi:10.5194/acpd-14-12967-2014

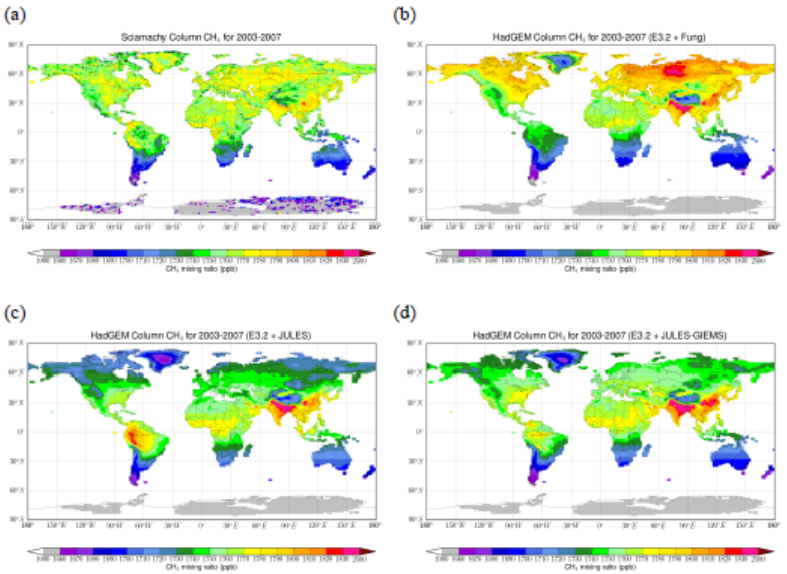
Atmospheric Chemistry and Physics Discussions

Comparison of the HadGEM2 climate-chemistry model against in-situ and SCIAMACHY atmospheric methane data

G. D. Hayman[1], F. M. O'Connor[2], M. Dalvi[2], D. B. Clark[1], N. Gedney[3], C. Huntingford[1], C. Prigent[4], M. Buchwitz[5], O. Schneising[5], J. P. Burrows[5], C. Wilson[6], N. Richards[6], and M. Chipperfield[6]

We found that the annual cycles observed in the SCIAMACHY measurements and at many of the surface sites influenced by non-wetland sources **could not be reproduced in these HadGEM2 runs**. This suggests that the emissions over certain regions (e.g., India and China) are possibly too high and/or the monthly emission patterns for specific sectors are incorrect.



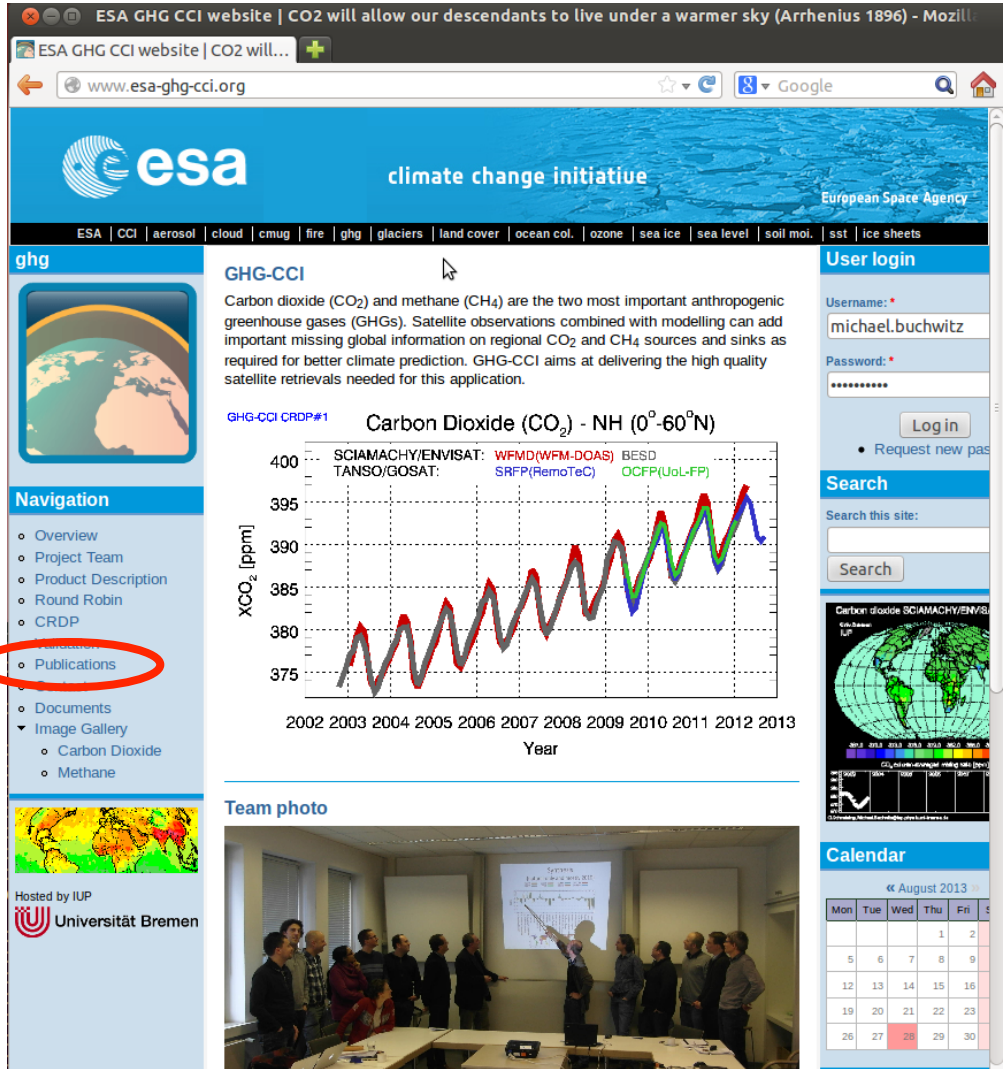


GHG-CCI: Publications

Interested in more results?

- **Publications**

www.esa-ghg-cci.org/




The End
of talk 2