5th CCI-CMUG Meeting

GHG-CCI: Current and planned applications of data products

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Dominik Brunner & the GHG-CCI team

The Inversion Lab

Outline

- **Data, documentation, achievements versus user requirements**
- **Selected research activities**
- **Living Planet CCI Fellowships related to GHG-CCI**
- **Items to be addressed according to CMUG**

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

SCIAMACHY/ENVISAT

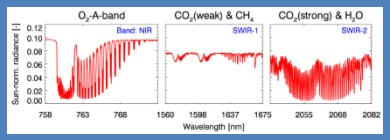
TANSO/GOSAT

Comparisons etc.: OCO-2

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

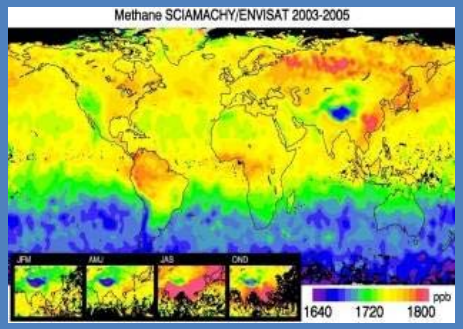
Calibration (L 0-1)

Calibrated radiances



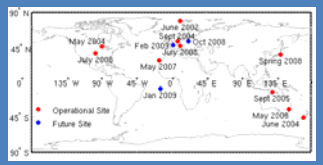
Retrieval (L 1-2)

Atmospheric GHG distributions

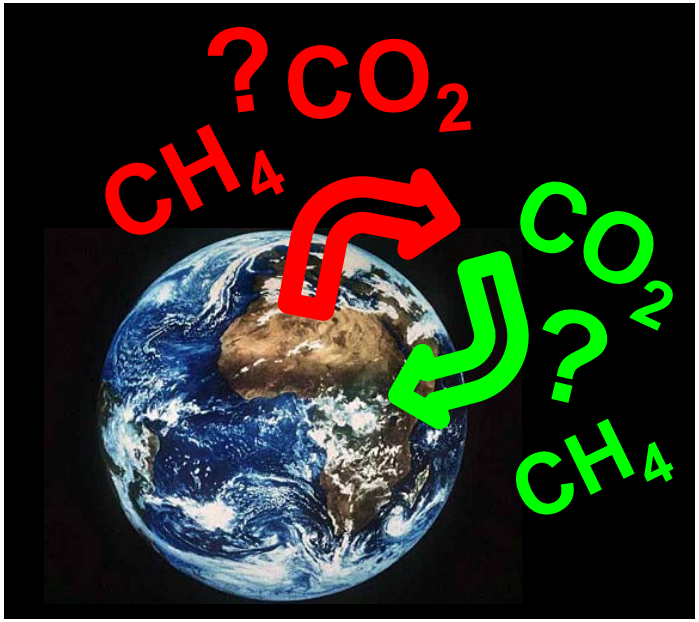


Validation

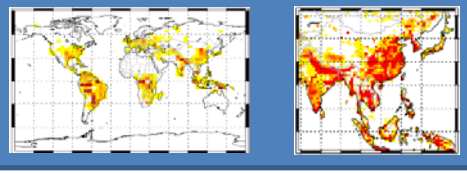
Reference observations



Global observations



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

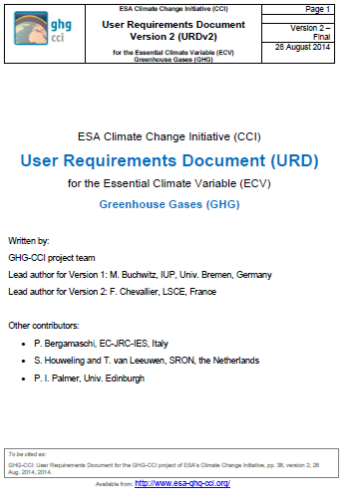
ECA Algorithms for column-averaged dry air mole fractions:

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: Documents

User Requirements URDv2


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

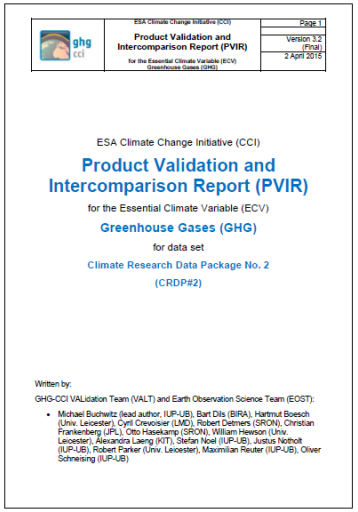
Other contributors:

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

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

CRDP#2 (released April 2015):

Product Validation PVIRv3.2


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

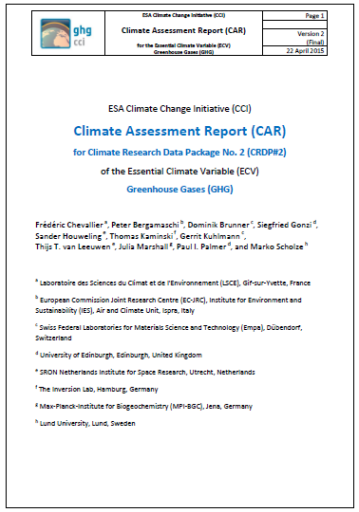
(CRDP#2)

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

of the Essential Climate Variable (ECV)

Greenhouse Gases (GHG)

… 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. 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. Note: GCOS requirements are target (maximum) requirements but URD requirements listed here are threshold (minumum) requirements.	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		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 (§§)
		(#) 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):

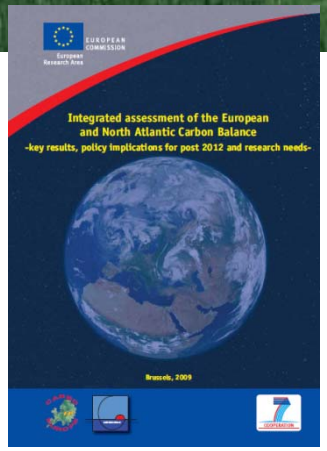
- **GCOS-154:** „SYSTEMATIC OBSERVATION REQUIREMENTS FOR SATELLITE-BASED DATA PRODUCTS FOR CLIMATE"
- **URD:** "GHG-CCI User Requirements Document", v2.0

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

Terrestrial carbon sink

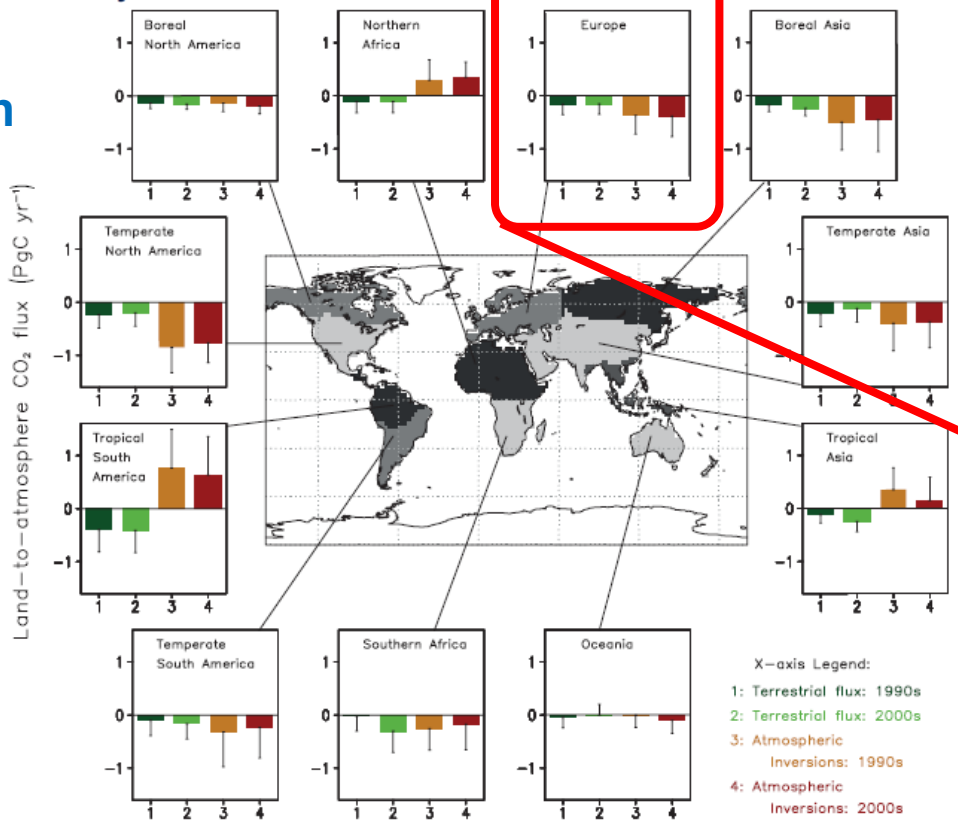


Regional terrestrial carbon fluxes

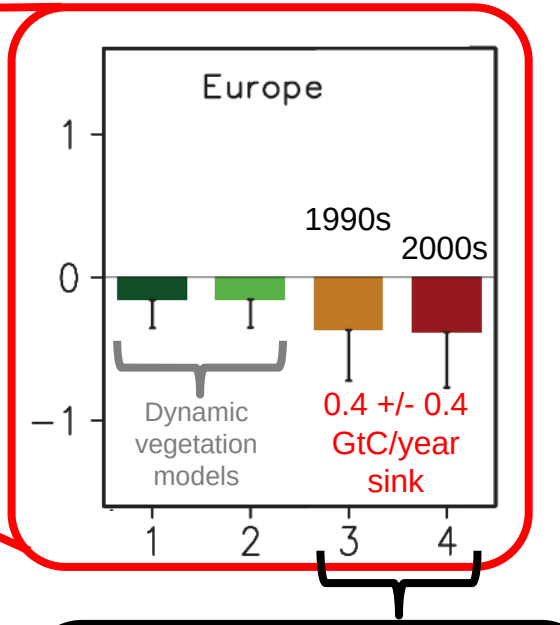
IPCC 2013, WG1

Carbon and Other Biogeochemical Cycles

Based on **Peylin et al., 2013**



Continental (TransCom) Europe



Decadal fluxes via atmospheric inversions

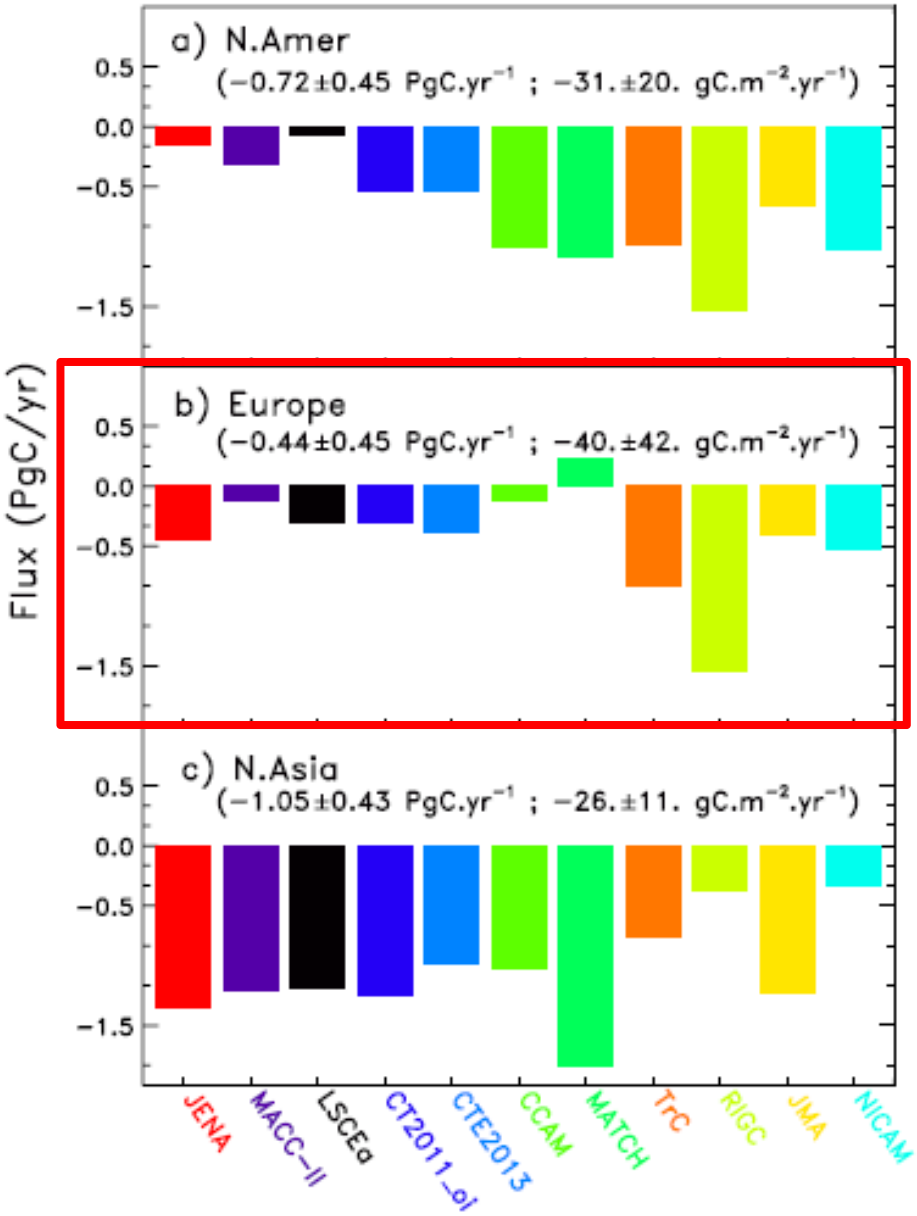
- mostly CO_2 flask measurements (very accurate but sparse) (Peylin et al., 2013)
- without satellite CO_2

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

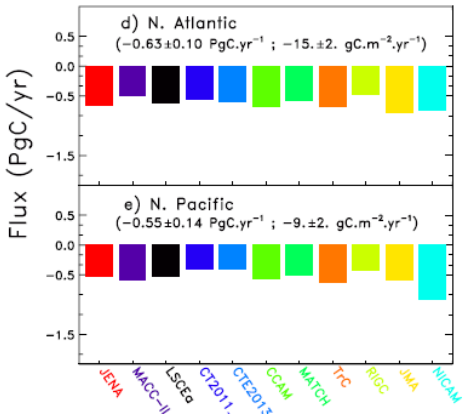
Can we do better using satellite XCO_2 ?

Regional carbon fluxes (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)

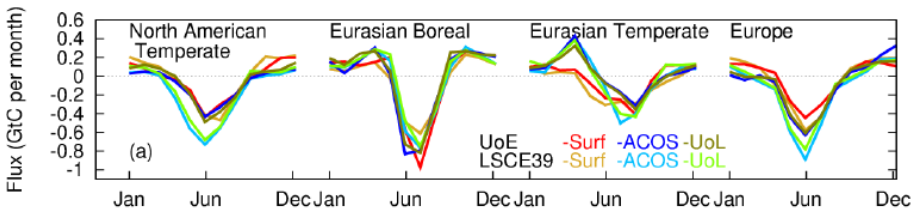
No satellite XCO_2 data used

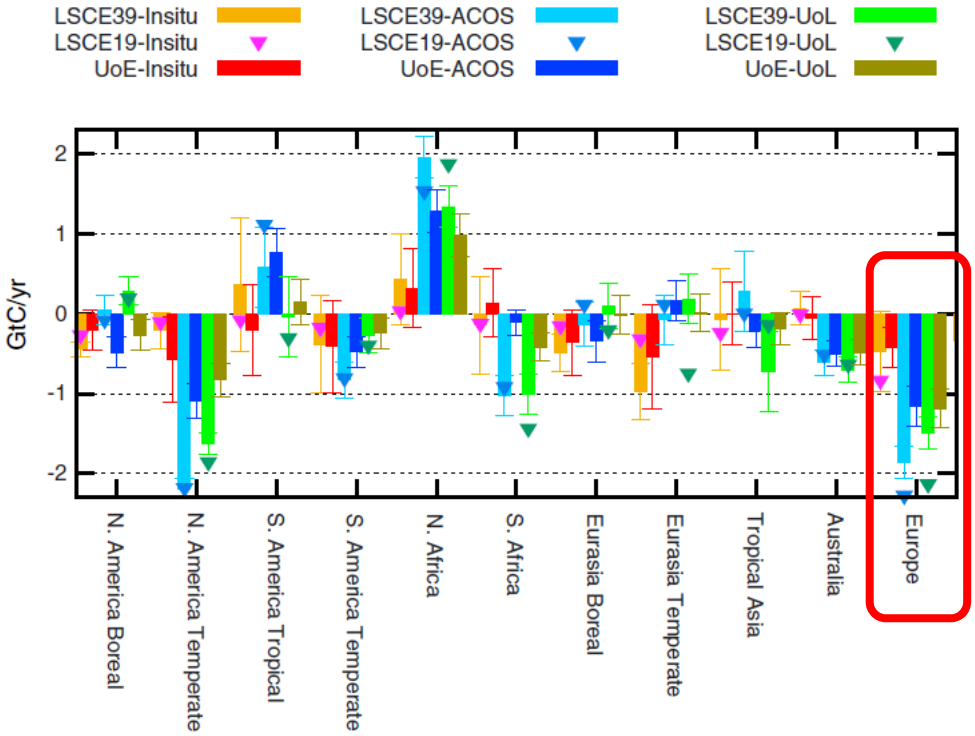
CO_2 flux inversions using different GOSAT XCO_2 products and models

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)

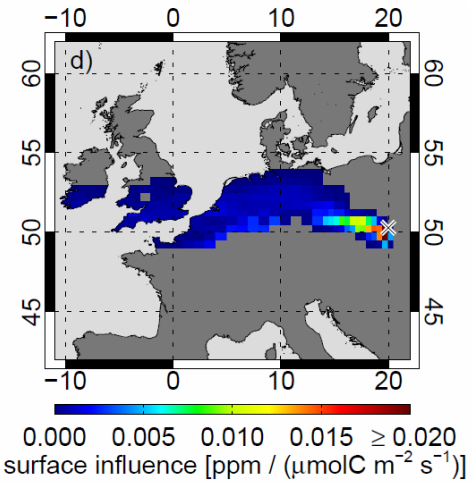
European terrestrial carbon fluxes from SCIAMACHY and GOSAT - I

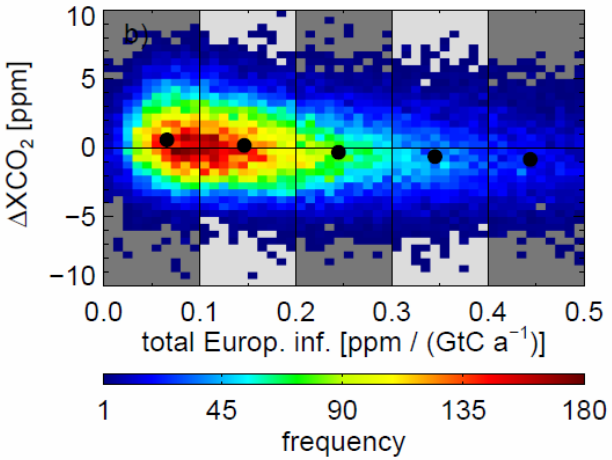
Goal: Get information on European terrestrial carbon fluxes using satellite data and a method which is not or much less sensitive to potential error sources as discussed in the literature such as

- 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., ACP, 2014



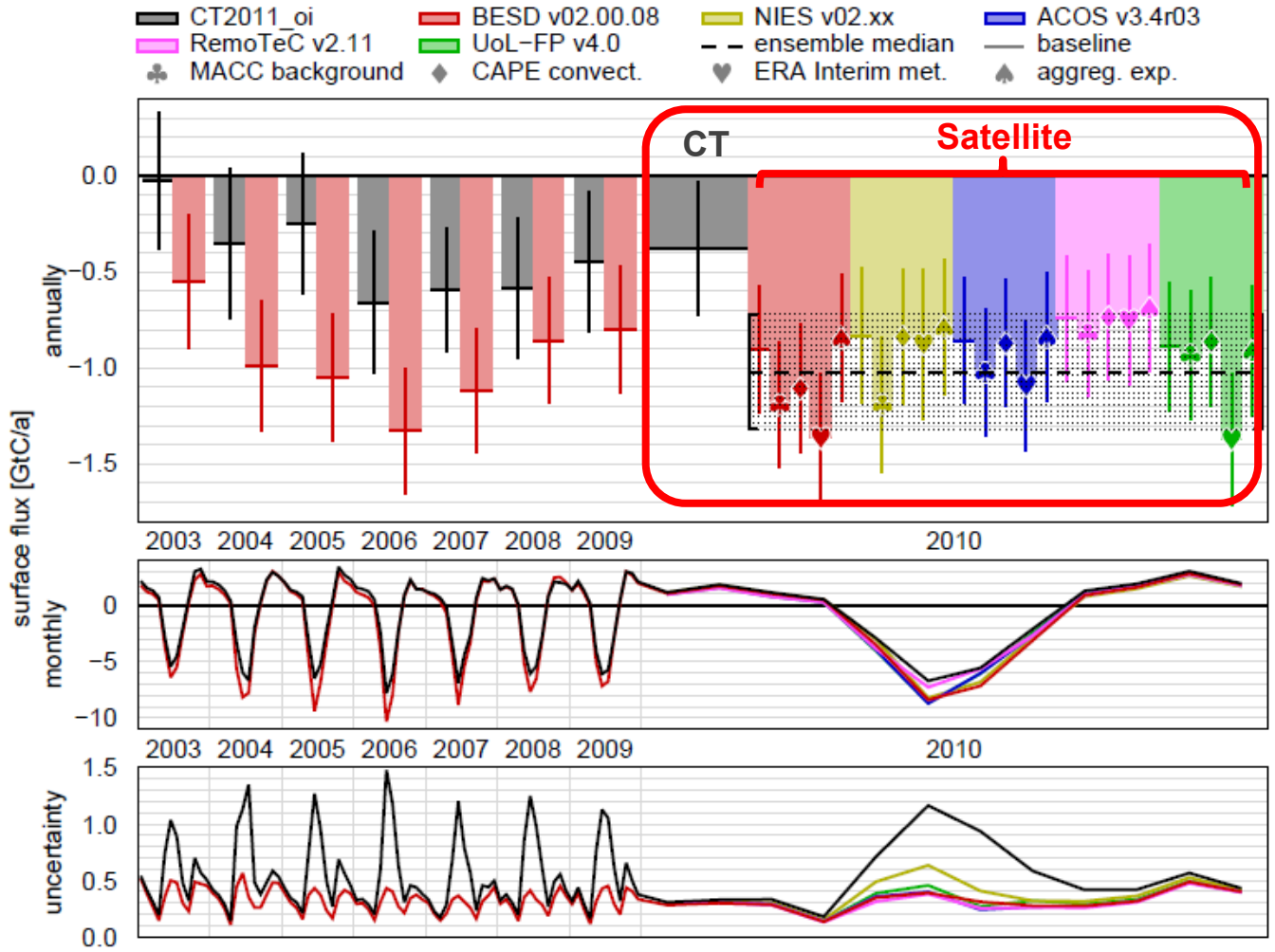


- The satellite minus model (CT2011_oi) difference **ΔXCO_2** shows a **negative correlation** with the integrated **European surface influence**.
- Interpretation: CarbonTracker's **European carbon sink is too weak**.
- Quantitative analysis using the **optimal estimation** framework (1D-Var) to get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

European terrestrial carbon fluxes from SCIAMACHY and GOSAT - II

„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



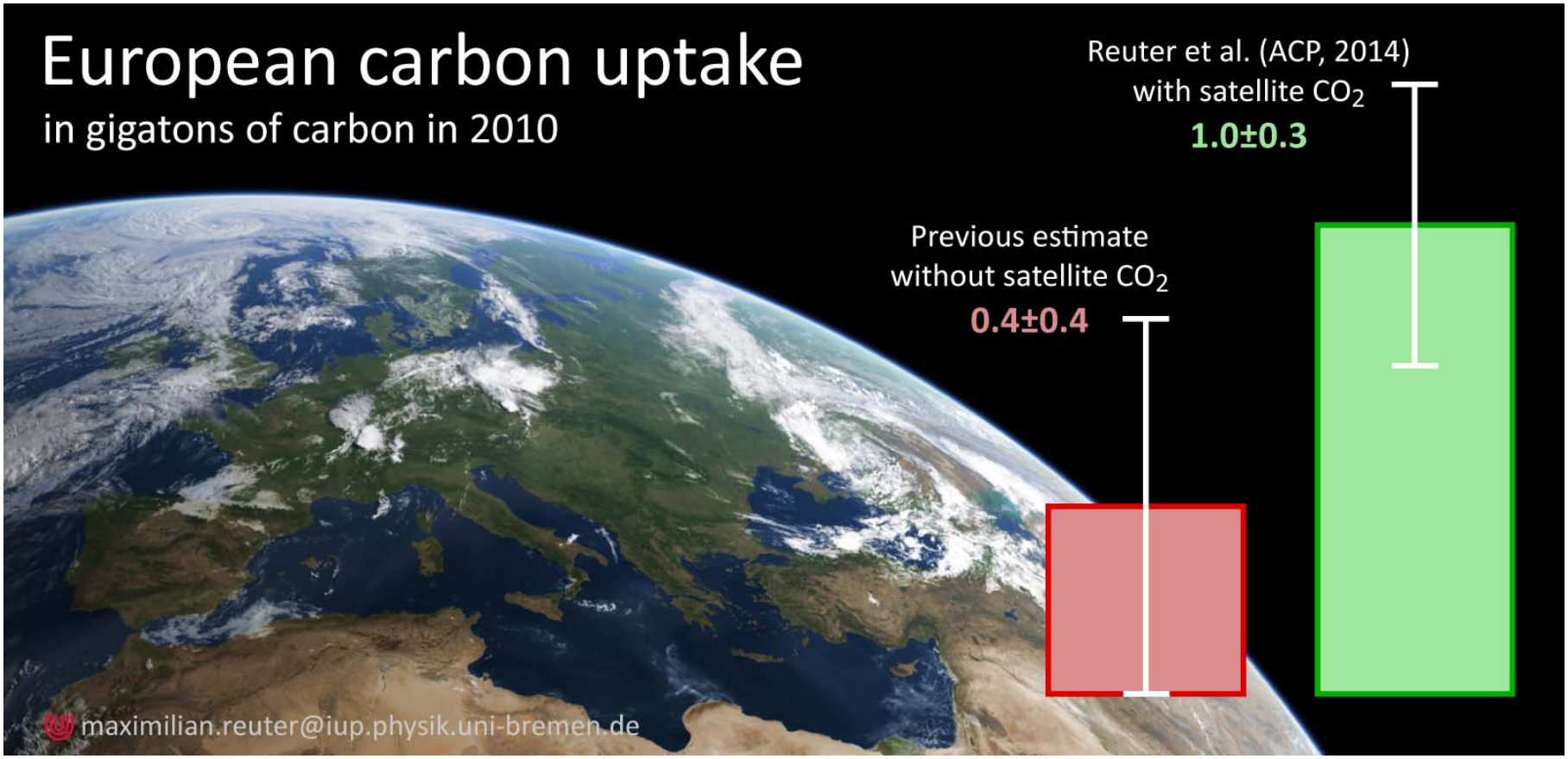
- 2 satellites
- 5 retrieval algorithms / products
- New flux inversion method insensitive to observations outside Europe, large-range transport & other errors
- Various sensitivity studies

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 - III

Summary for continental (TransCom) Europe:

Reuter et al., ACP, 2014



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

Regional carbon fluxes: Ongoing activities

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

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

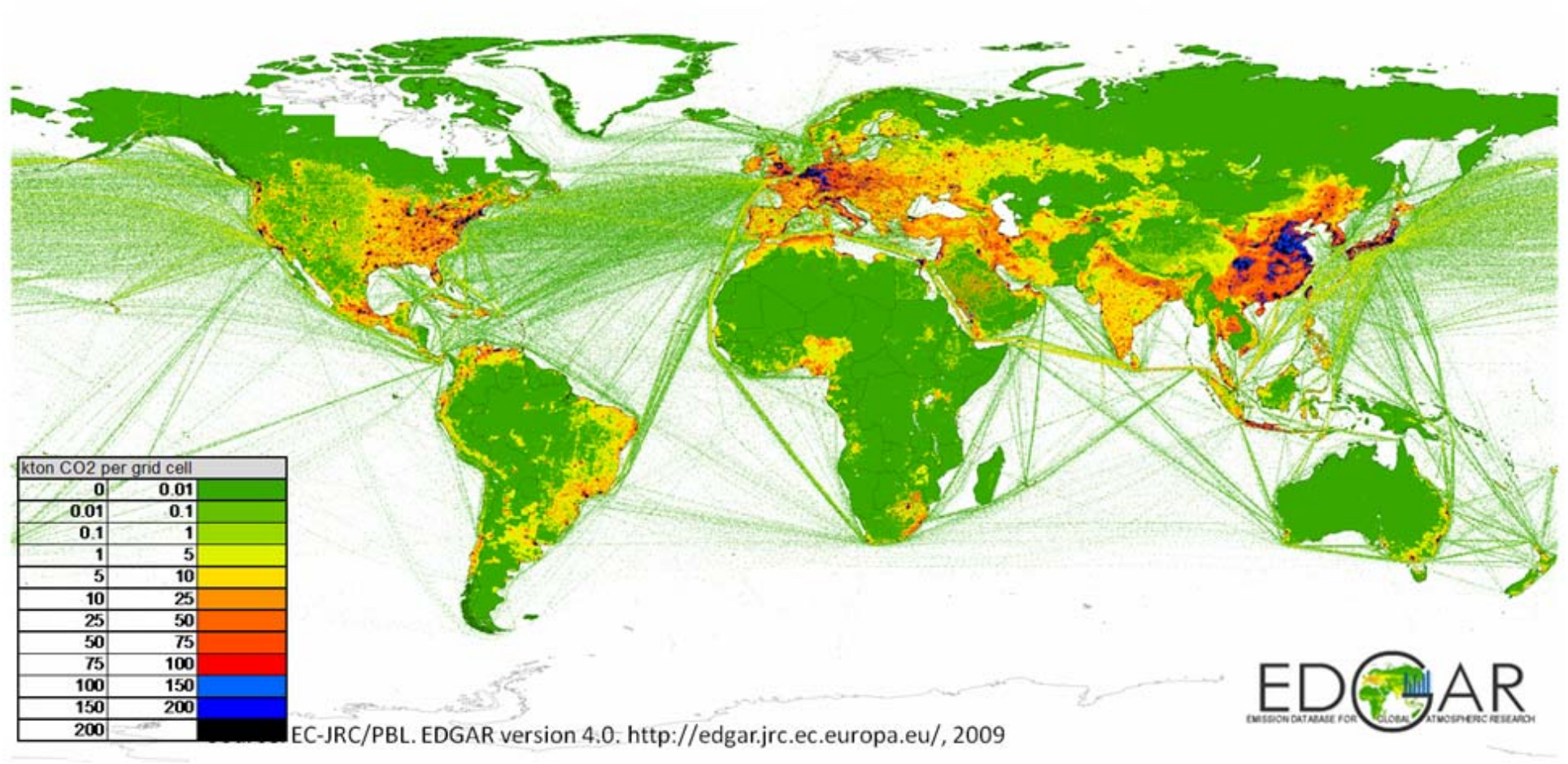
L. Feng[1],
I. Morino[7]

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

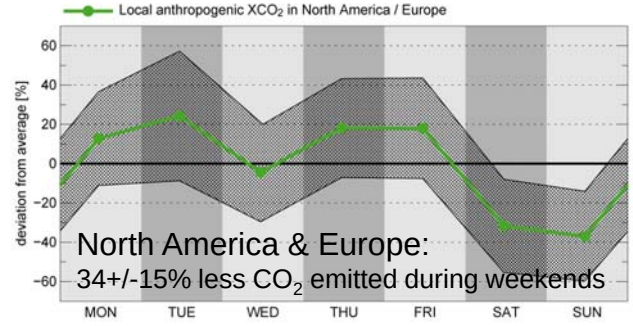


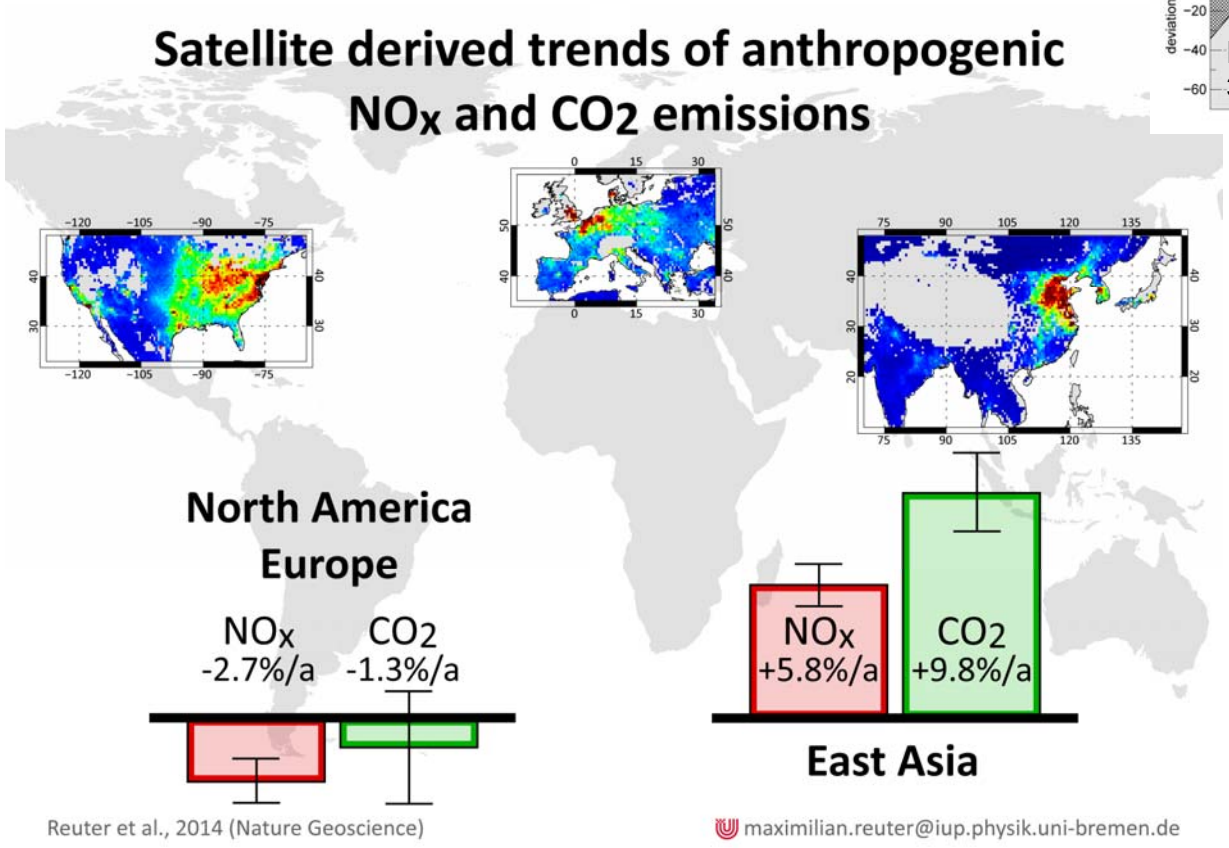
Bottom-up estimate
Currently not possible to verify this using satellite data !?
-> We hope for CarbonSat !

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“





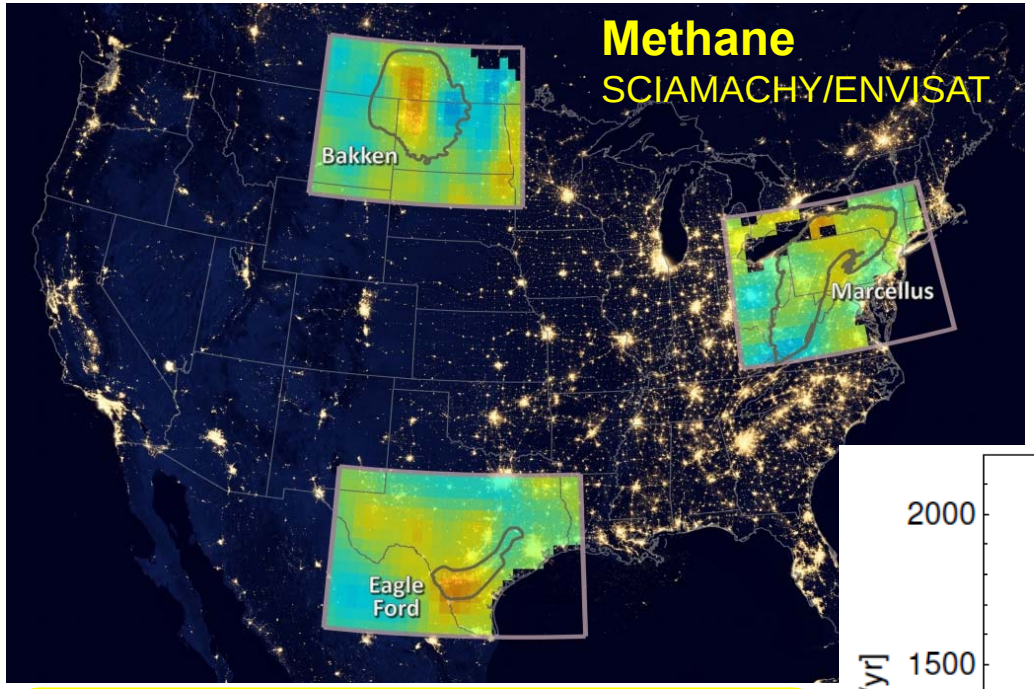
- Anthropogenic CO_2 emission signal from localized sources isolated via simultaneous SCIAMACHY XCO_2 and NO_2 observations & new spatial filtering method
- **North America & Europe: Decreasing emissions (but uncertain for CO_2)**
- **East Asia: Increasing emissions but less NOx per CO_2: Trend towards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

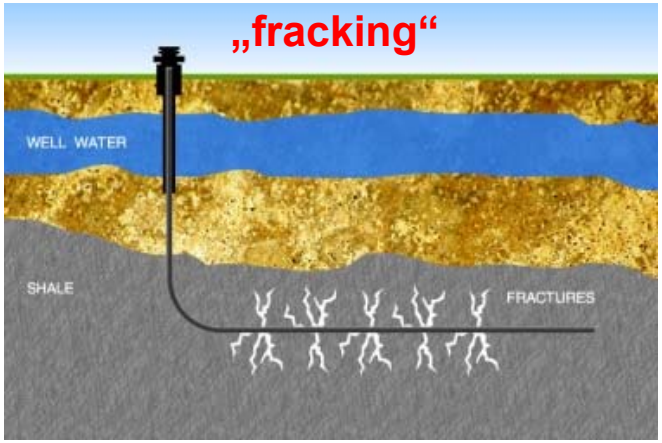
SCIAMACHY methane:

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**

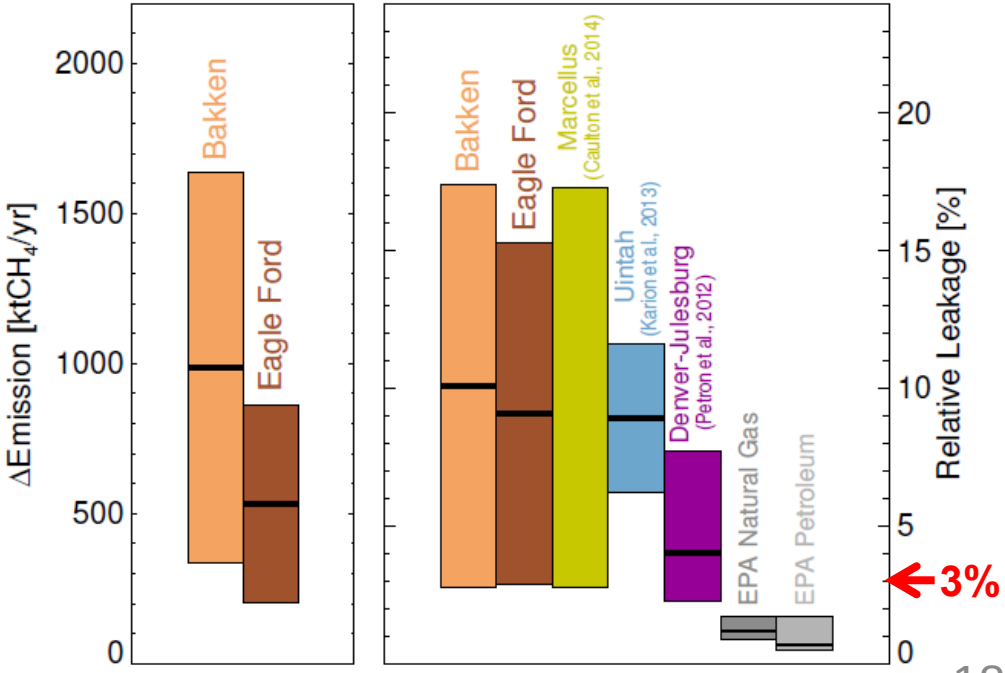
Emission estimates correspond to **leakages** of

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

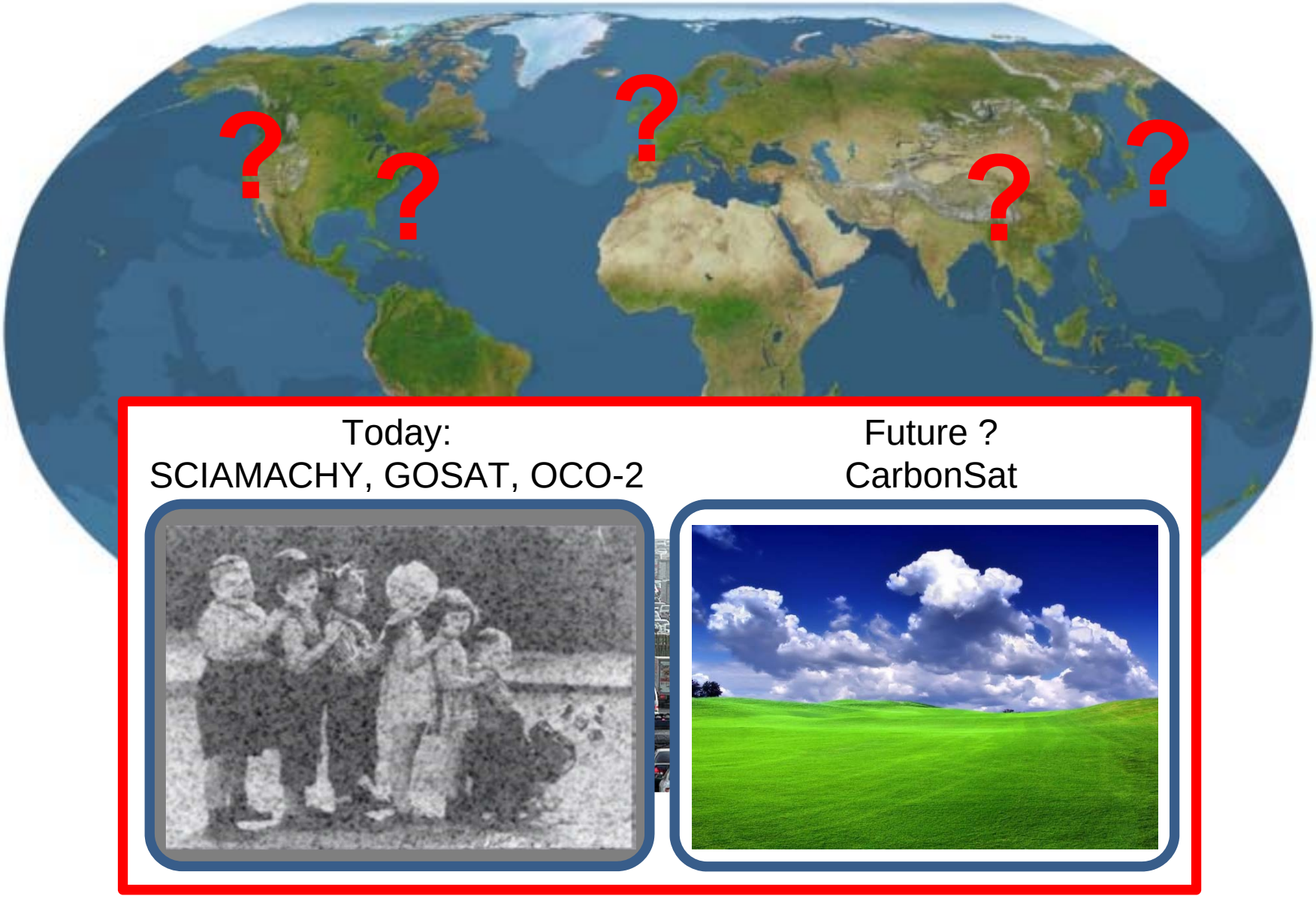
in terms of energy content.

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

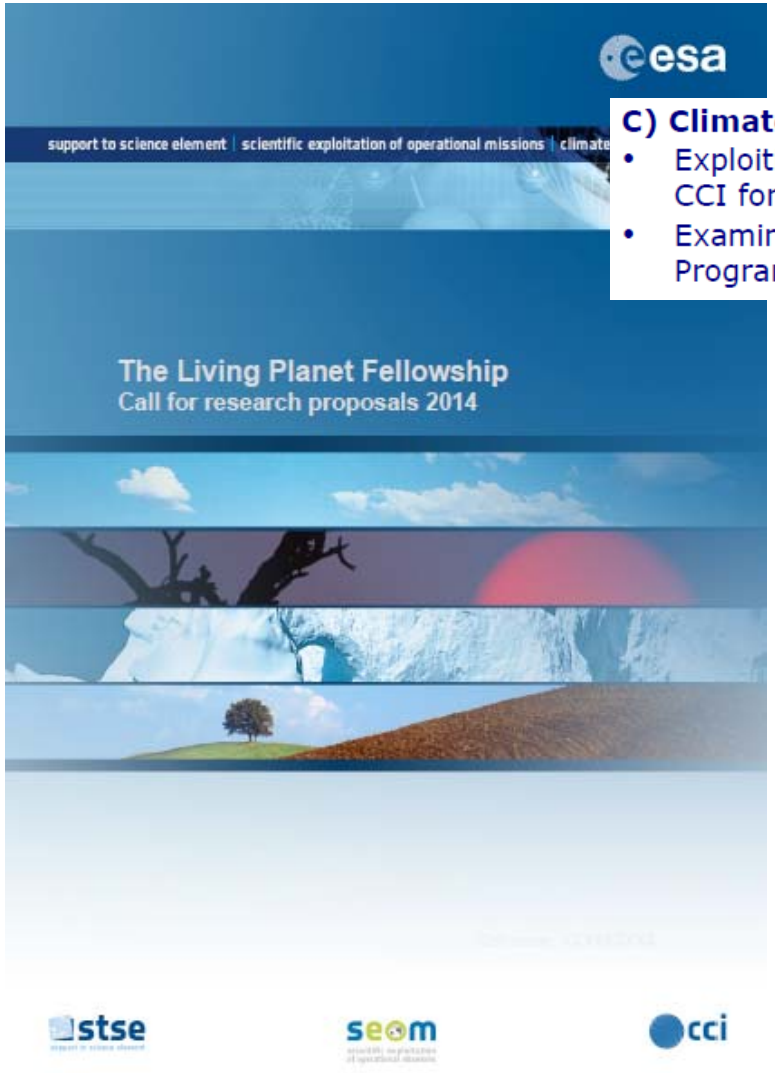
Likely **underestimated in inventories**.



Anthropogenic CO_2 and CH_4 emissions from space



Living Planet / CCI Fellowships



Programmatic Areas:

C) Climate Change Initiative (see [URL5] and Annex B for more details):

- Exploiting Essential Climate Variable (ECV) products generated by the ESA's CCI for improved understanding of the climate system.
- Examining Cross-ECV consistency and multiple ECV use (those under the CCI Programme in particular).

2 GHG-CCI PostDocs selected (both started 1st March 2015):

- Dr Robert Parker, UoL
  - ELEGANCE-GHG: ExpLoring thE Global cArboN CyclE through atmospheric GreenHouse Gas variability
- Dr Jens Heymann, IUP-UB
  - CARBOFIRES: CARBOn dioxide emissions from FIRES

Items to be addressed - I

1. Description of available data

- **Specification:**
  - Level 2 generated from SCIAMACHY & GOSAT
  - Column-averaged mole fractions XCO_2 [ppm] and XCH_4 [ppb] incl. uncertainty estimates, averaging kernels, quality flag etc. for each single ground pixel
- **Validation & uncertainties:**
  - Validation via TCCON ground-based XCO_2 and XCH_4
  - Random errors & stability (in the sense of long-term drifts) requirements met (but some „jumps“ for SCIAMACHY due to (detector) degradation issues)
  - Systematic error requirements: At least threshold req. met for XCH_4; not (yet) for XCO_2 (use for CO_2 source/sink applications requires care; usefulness demonstrated for several applications (see publications); further improvements ongoing and needed)
- **Improvement of current state-of-the-art:**
  - We are the state-of-the-art and aim at further pushing it

Items to be addressed - II

2. Current and planned application of the data products

- **Current:**
  - To improve our knowledge on the natural and anthropogenic sources and sinks of the greenhouse gases CO_2 and CH_4
  - To improve carbon / climate / chemistry models
- **Future:**
  - See above
- **Projects:**
  - Several unfunded activities: GOSAT, OCO-2, …
  - Currently funded: CCI-1, other ESA (2 CCI Fellowships, projects related to future satellites (S-5P, CarbonSat, …)), MACC-III
  - Future (potentially): CAMS (ITT expected soon), CCI-2 ???, other ESA or national (S-5P, CarbonSat, other) ???, H2020 ???, C3S ???, other ???

Items to be addressed - III

3. Plans for products, delivery and engaging with climate researchers

- **Products incl. delivery:**
  - Focus on time series extension and improved quality
  - Updates once per year (CRDP#2 released in April 2015, CRDP#3 will be released in April 2016, …)
- **Engagements with researchers:**
  - Via common projects, publications, …

4. Common issues between ECVs

- **???**


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