The Earth Explorer 8 Candidate Mission

Towards Disentangling Natural and Anthropogenic GHG Fluxes from Space

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Contributions from **Science Study consortia**

Contributions from **Campaign consortia**

Contributions from **Mission Advisory Group**

Contributers: CarbonSat - II

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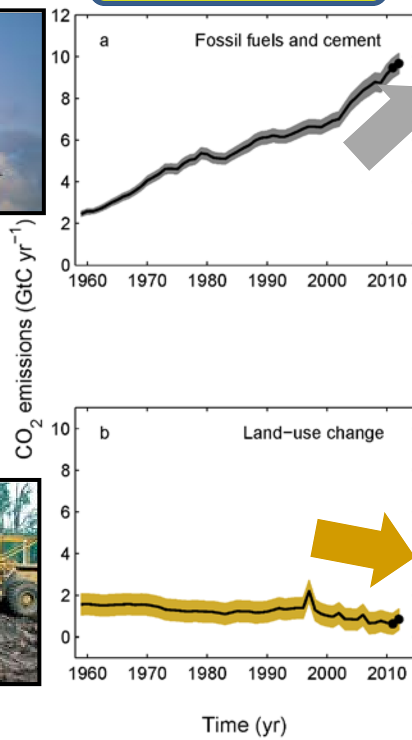
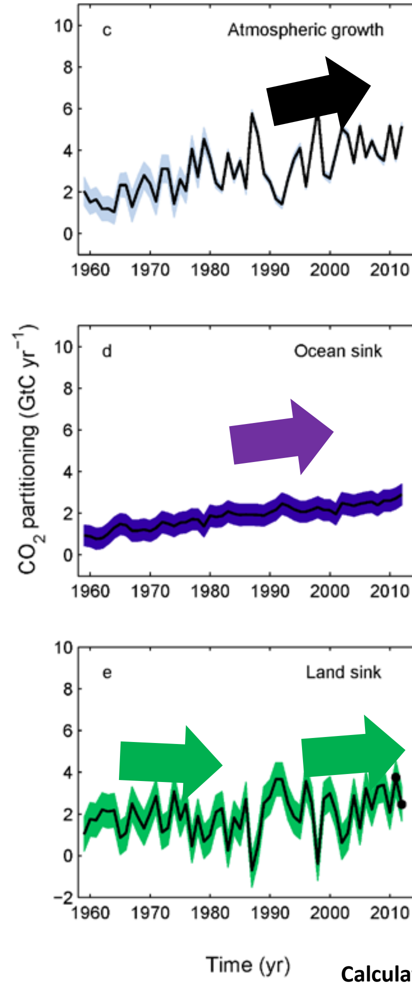
Changes in the Carbon Budget over Time

Fossil Fuel emissions still going strong!

Luckily, the sinks have continued to grow with increasing emissions. Will that continue for ever?

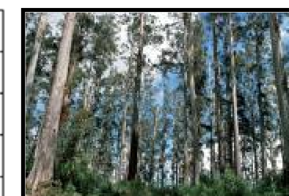
Emissions





Atmospheric growth

Ocean Sink



Land Sink

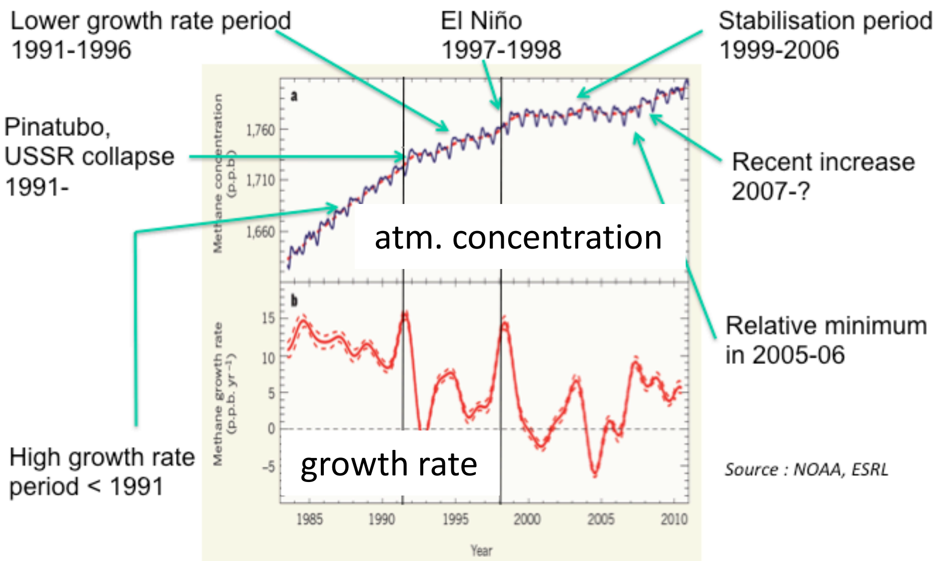
Calculated as the residual of all other flux components

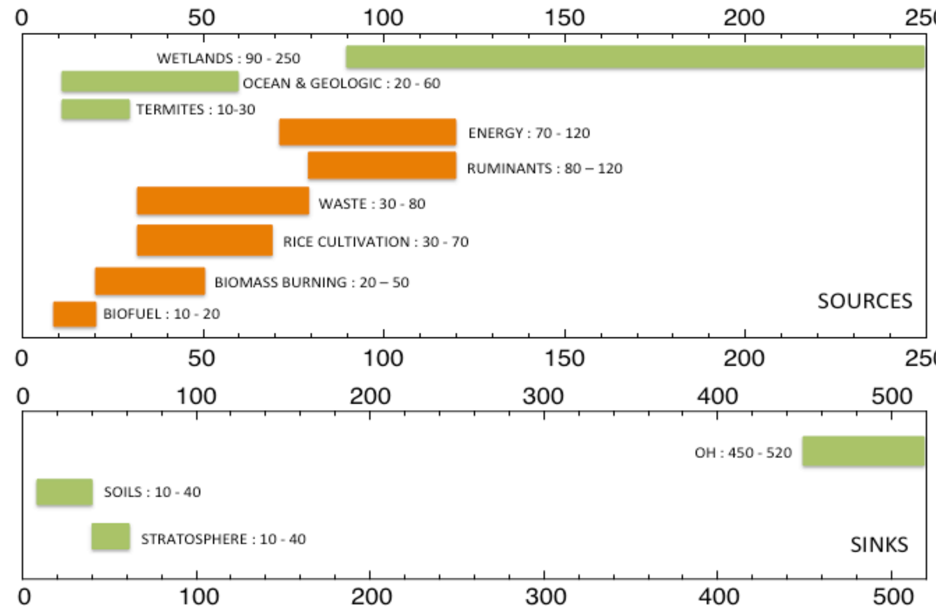
Terrestrial sink is estimated as residual from other sources and sinks → large errors & large variability (droughts etc.):

- How will they change in a changing climate?
- **Will ocean and land biosphere continue to absorb CO_2 as in the past?**

Source: Le Quéré et al 2013; CDIAC Data; NOAA/ESRL Data; Global Carbon Project 2013

Sources and Sinks of CH_4





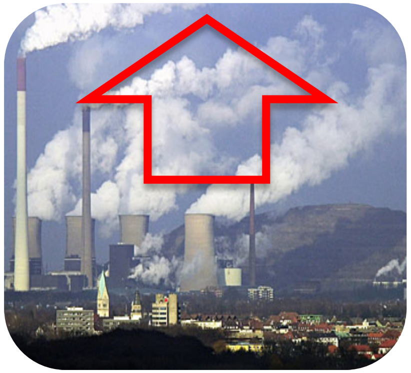
Range of bottom-up estimates of CH4 sources and sinks (in $TgCH_4$/yr). After *Kirsche et al.,* 2013.

- CH_4 increased in the 1980's, then nearly stabilized in the 1990s, and increased again since 2006
- Recent changes in the atmospheric CH_4 budget (Kirschke et al. 2013) are controlled by a diverse array of natural (wetlands) and human sources (livestock, fossil fuel, landfills etc.), and natural sinks, that are **less well understood (esp. sources)** than those for CO_2

How strong are the various CO_2 and CH_4 sources and sinks ?

How much is emitted where, when and by what?

Are reported emissions correct?



How much CO_2 is absorbed by land and oceans? Where and when?

How will today's CO_2 sinks behave in a changing climate?

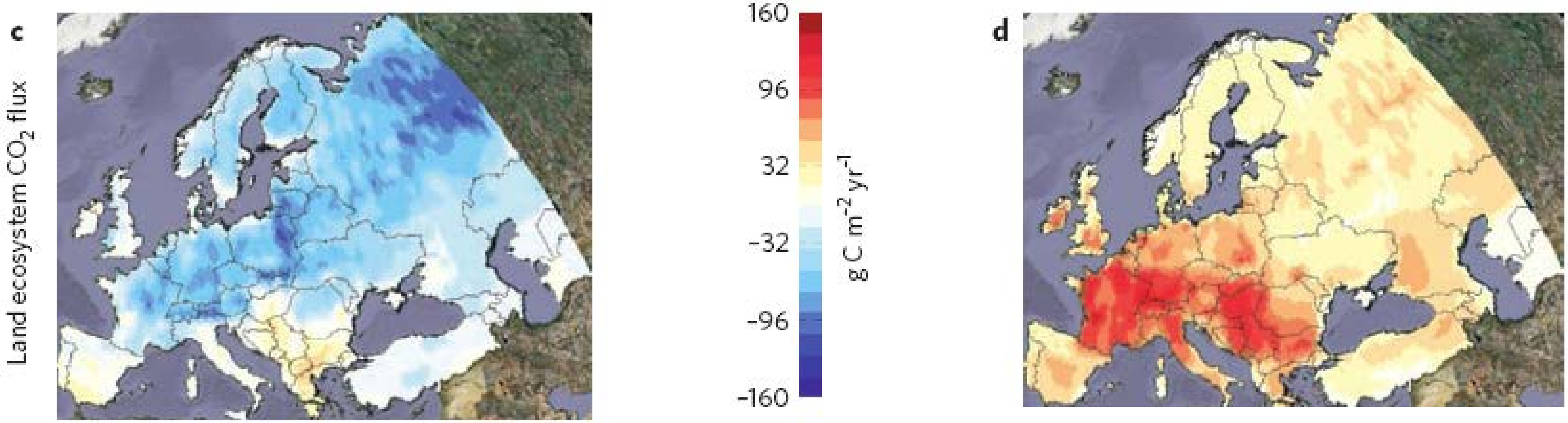
How will today's CH_4 sources (e.g., wetlands) behave in a changing climate?

Will natural sinks turn into sources?

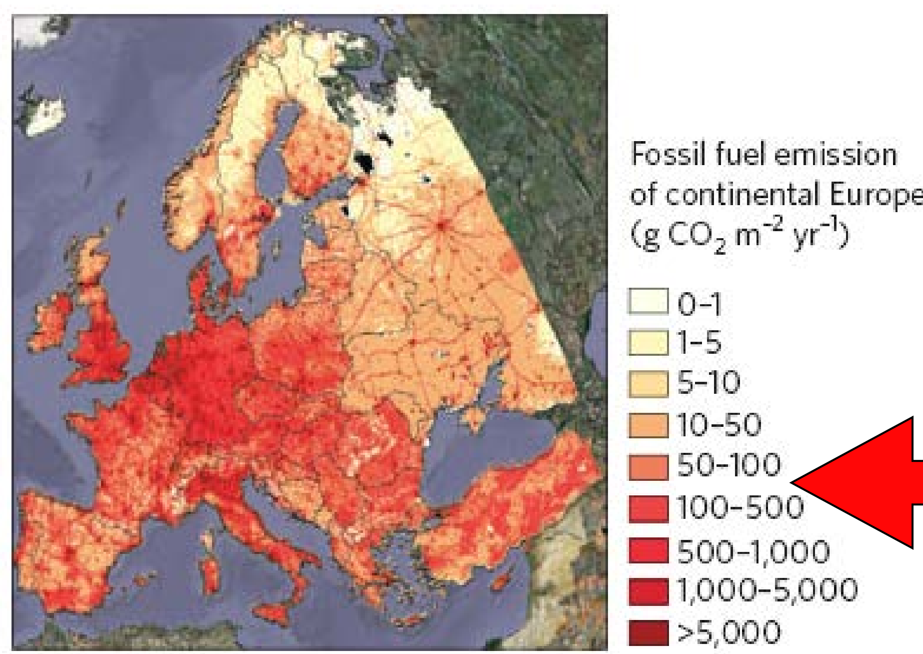
Will natural sources be amplified?

How will sources and sinks behave in a changing climate?

Ecosystem and fossil fuel emissions are often intervowen - example: carbon balance of Europe



ecosystem CO_2 flux 2000-2004 av. sd. **error on ecosystem CO_2 flux**



E. D. Schulze, NGEO, 2009

Mission Objectives of CarbonSat

Improve our understanding of the global carbon cycle by quantifying surface fluxes - **biogenic & anthropogenic** - of CO_2 and CH_4

Specific objective of the mission: Address fluxes at an unprecedented range of scales, spanning and linking:

Global

National

Local

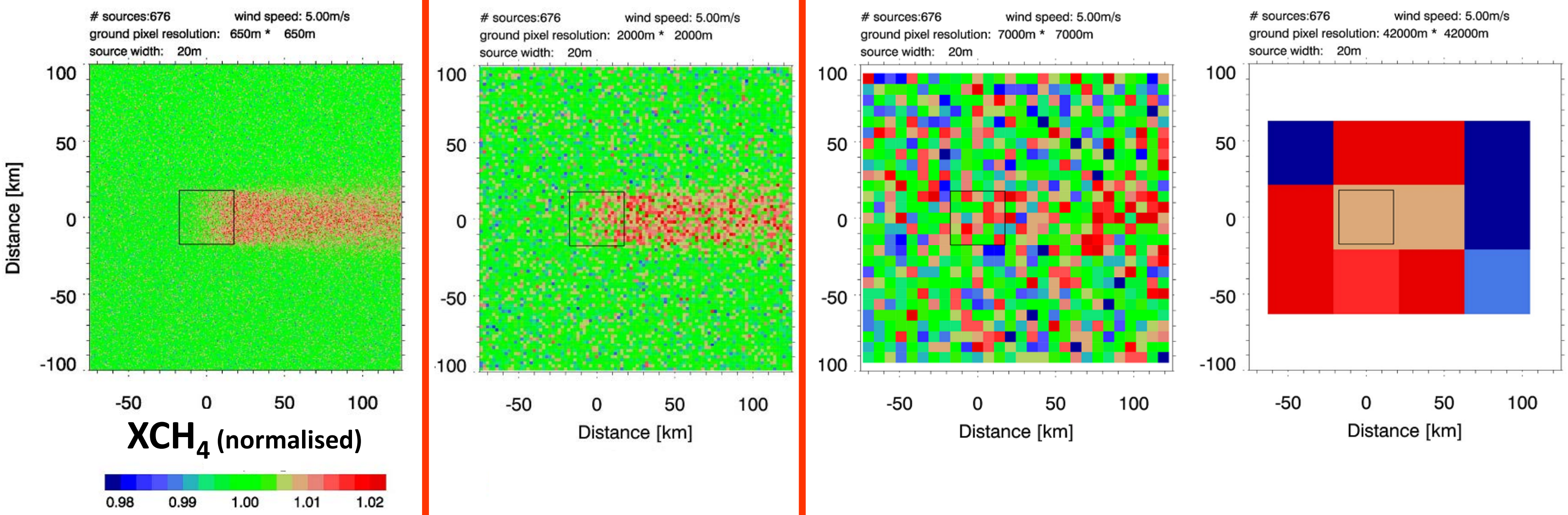
ESA EO Science Strategy (2015):

"Knowledge of todays carbon sources and sinks [..] is one of the essential ingredients [...] for predicting climate change"

CarbonSat

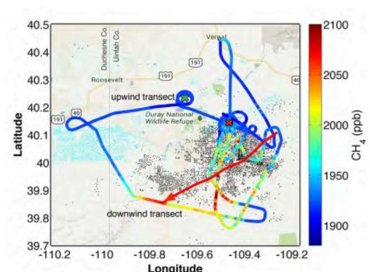
Spatial Resolution Matters
Methane Leackage from Gas Production

Simulation of XCH_4: Emission rate of = 482 $ktCH_4$/yr on an area of ca. 35 km x 35 km (*), 5 m/s wind speed, instrument resolution and single measurement precision as below:



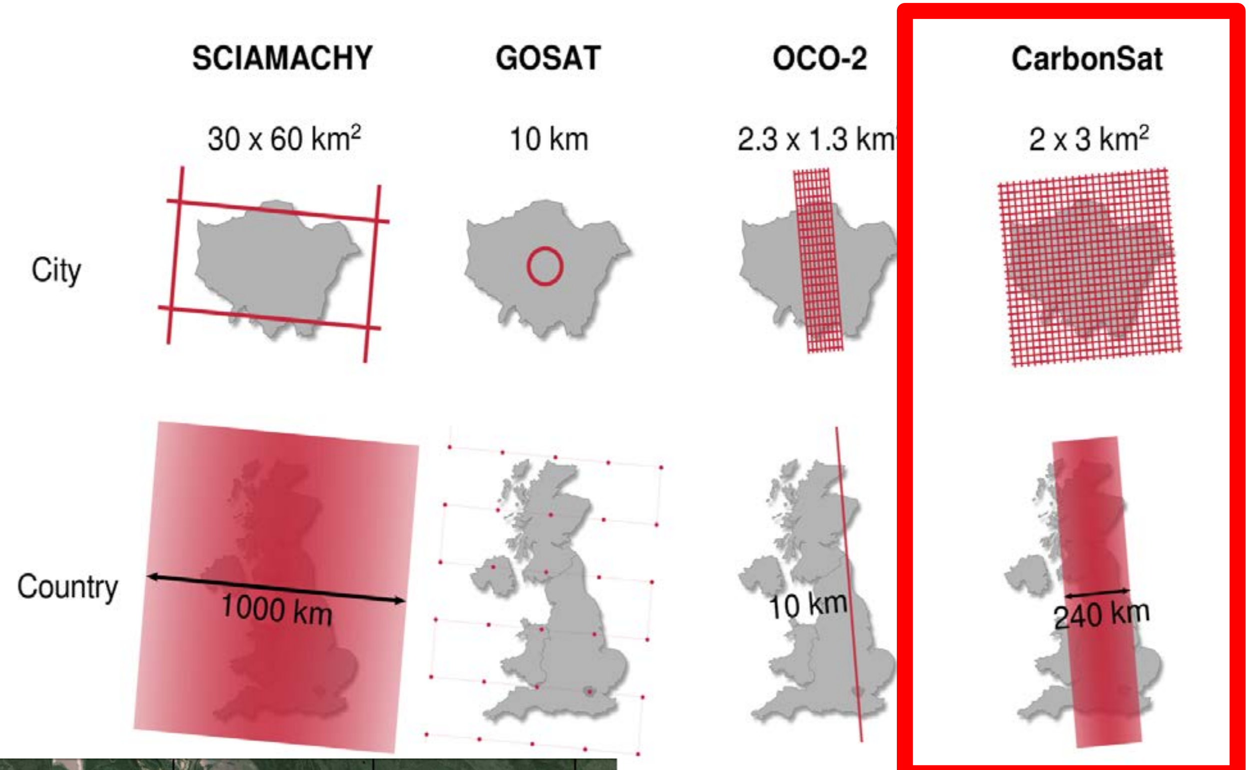
Airborne	CarbonSat	Sentinel 5P	SCIAMACHY
0.5 km x 0.5 km	2 km x 2 km	7 km x 7 km	30 km x 60 km (#)
7 ppb	9 ppb	18 ppb	50 - 80 ppb

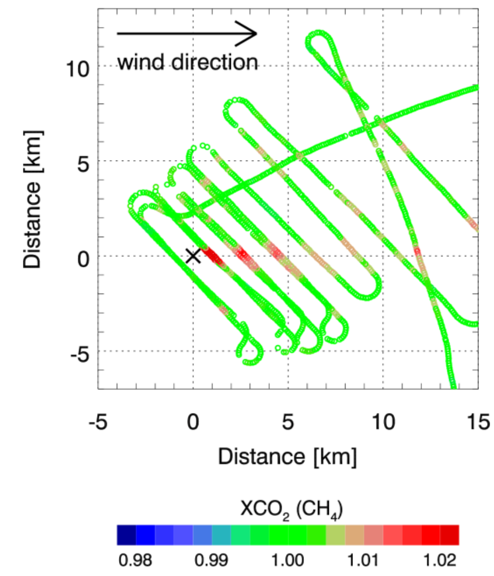
(*) Similar as gas fields in Uintah county, Utah, USA (Karion et al., GRL, 2013)

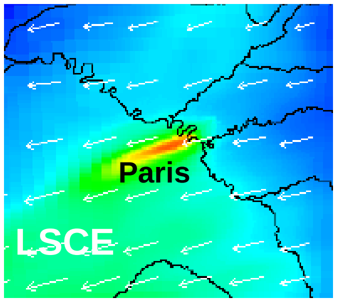


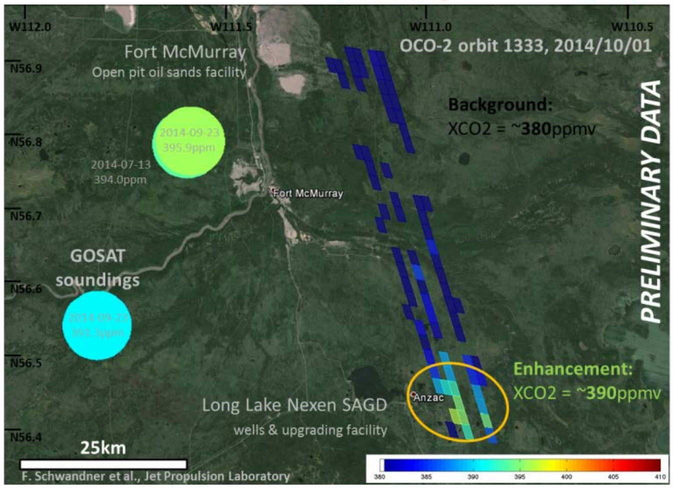
(#) converted to 42 km x 42 km

Spatial Coverage and Resolution matters!









New capabilities:

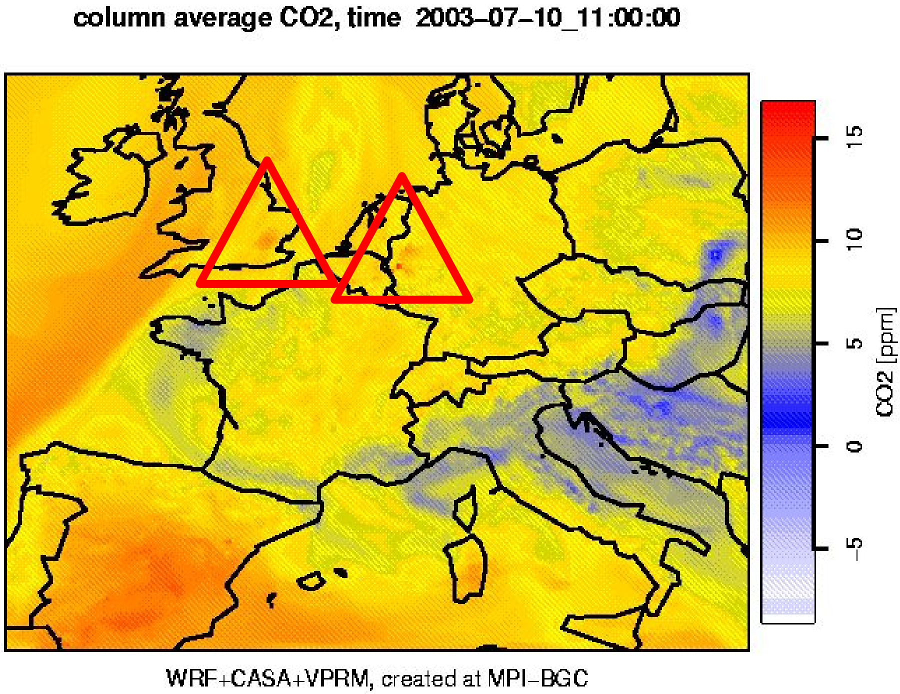
- Country and city scale, power plants, oil & gas fields, geological „point“ sources, volcaneous…
- Improved validation strategies (TCCON etc.)

CarbonSat will disentangle natural & anthropogenic fluxes from space

Using:

- **Images of XCO_2, XCH_4 spatial pattern**
  - demonstrated by airborne campaigns
- **Seasonal XCO_2, XCH_4 variations**
- **Combine with patterns of plant photosynthetic activity (~SIF)**
- Correlation with other trace gases in synergy with Sentinel 5 and IASI-NG (CO, upper trop. CH_4, NO_2, etc.)

Note: combining XCO_2 with vegetation fluorescence, NOx and CO allows e.g. separation of biomass burning vs. biospheric contributions to the carbon budget (Basu et al. 2014, Parazoo et al. 2014, Reuter et al. 2014)



Modelled XCO_2 (Pillai et al., ACP, 2010):

- Coupled biosphere-atmosphere model with anthropogenic emissions
- Constant background removed
- Resolution: 10 km x 10 km

CarbonSat Requirements: Level 2

Geophysical parameter	Precision*		Relative systematic error **	
	Goal (G)	Threshold (T)	Goal (G)	Threshold (T)
XCO_2	1 ppm	3 ppm	0.2 ppm	0.5 ppm
XCH_4	6 ppb	12 ppb	2.5 ppb	5.0 ppb

XCO_2: Column-averaged dry-air mole fraction of CO_2
XCH4: Column-averaged dry-air mole fraction of CH_4

* Required precision for single soundings
** Required systematic error after subtracting potential global offset and after bias correction

CarbonSat Requirements: Spatial & temporal

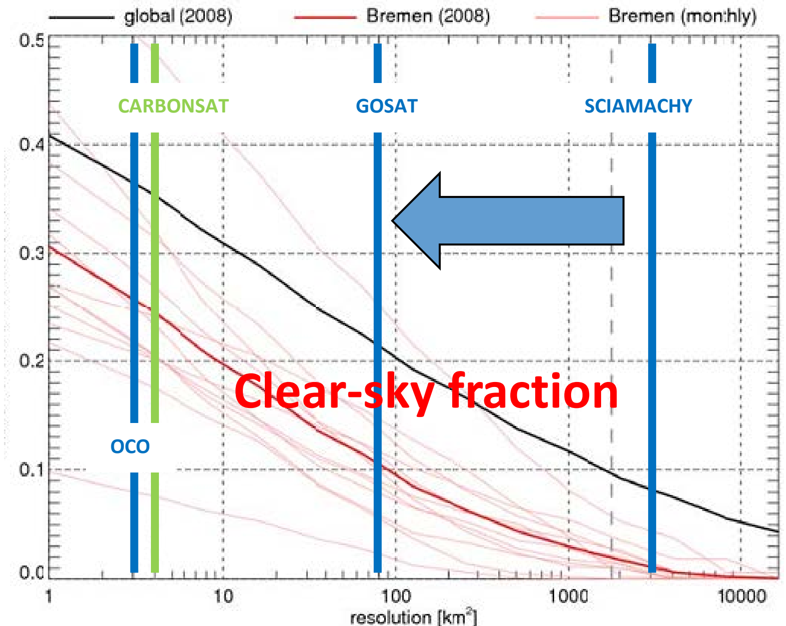
High spatial resolution and good coverage:

- High local spatial resolution: < 2 x 3 km²
- Full 180–240 km swath **imaging**
- Poleward of 40° NH latitude 3 overpasses/month
- Monthly **global coverage**

Orbit: LEO Sun-synchronous, around 11:30 hr LT

Observation modes:

- Nadir (main) → land observations have priority
- Sun-glint → for ocean coverage

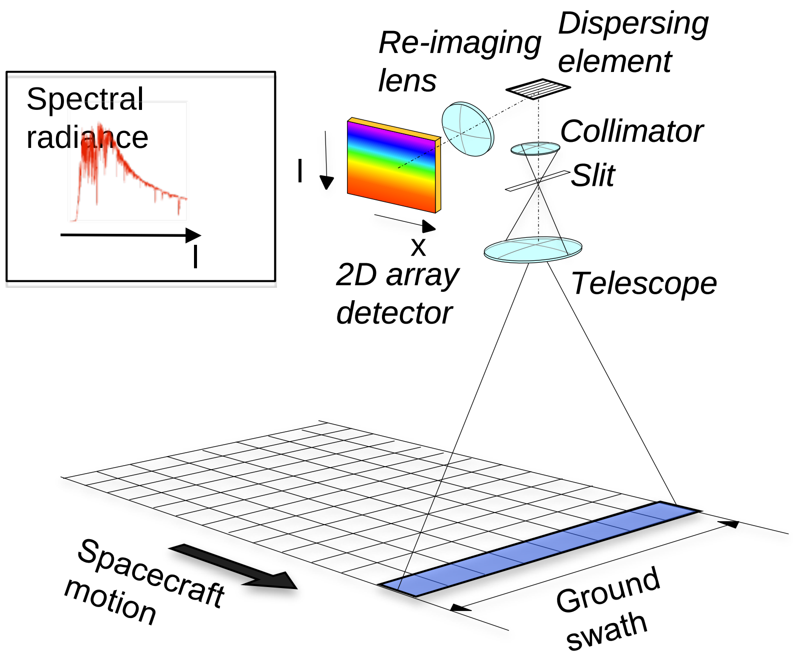


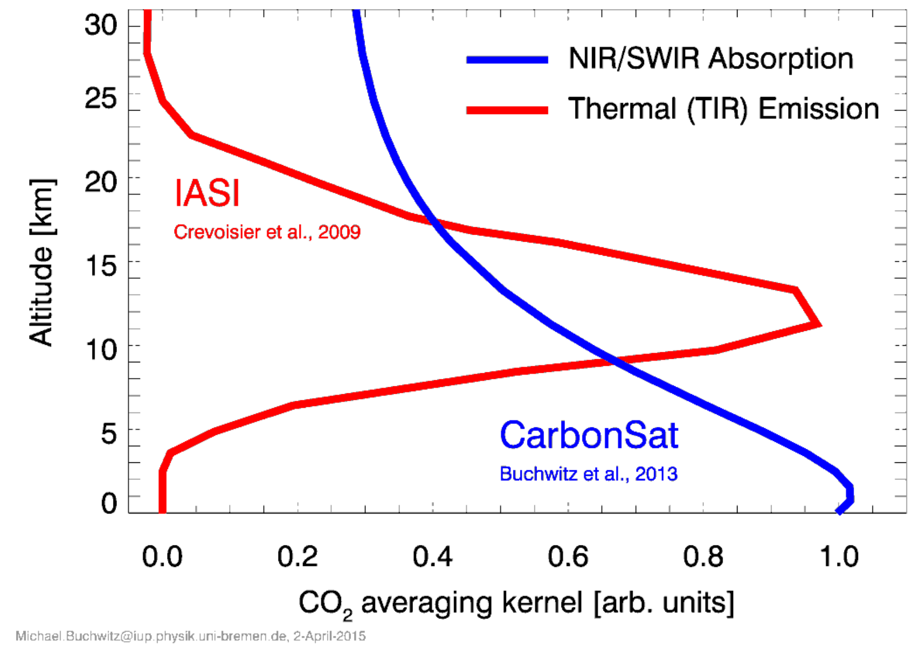
Credit M. Reuter / IUP

Instrument	CO_2	CH_4	*Fluores-cence*	Spatial resolution [km²]	Global average clear-sky frequency	Approx. number clear sky observations per day
CarbonSat 240 km	X	X	X	6	32%	3.000.000
OCO-2	X		X	3	38%	300.000
GOSAT	X	X	X	87	20%	1.700
GOSAT-2	X	X	X	87	20%	11.000
SCIAMACHY	X	X	X	1800	9%	6.000
S5P/S5		X	X	50	22%	1.600.000
MICROCARB	X			25	26%	26.208

CarbonSat Instrument Concept

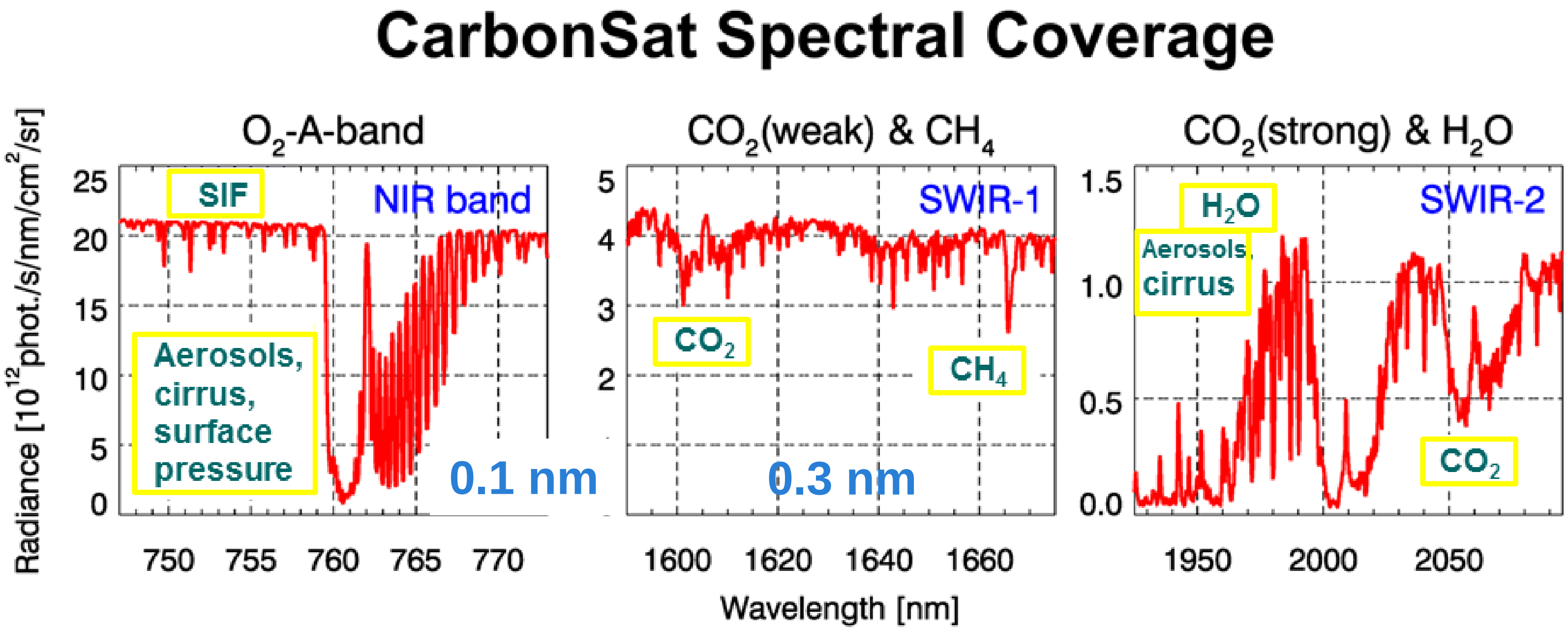
Greenhouse gas imaging at high spatial resolution AND good spatial coverage





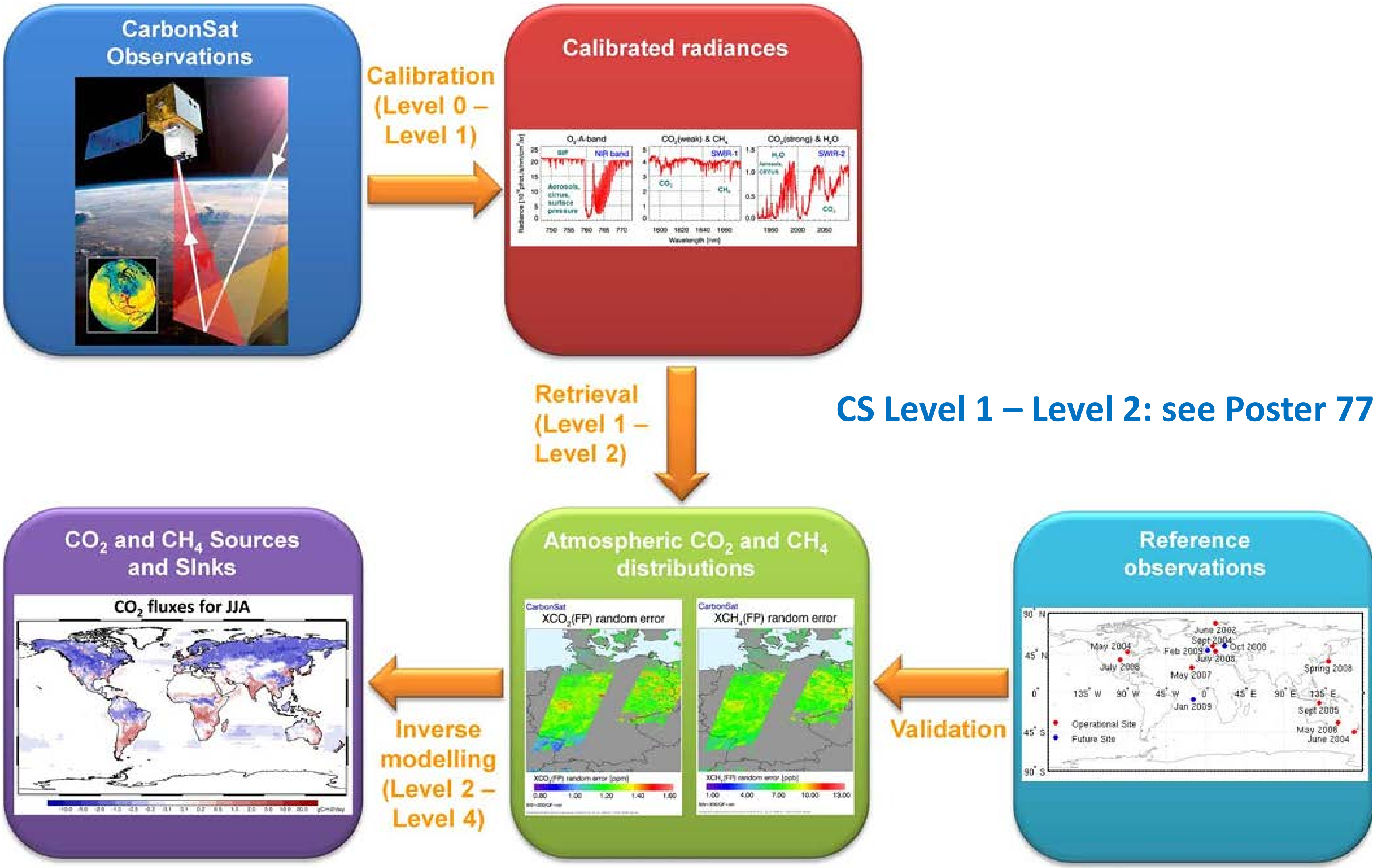
- Imaging grating spectrometer, high SNR, 2-D detectors (cooled)
- Push-broom (across track); along track scanning via spacecraft motion
- Good spatial and spectral imaging capabilities
- High performance on-board calibration sources (diffusers, lamp, LED, …)
- Based on SCIAMACHY, GOSAT, OCO-2 and lessons learned

CarbonSat: Spectral Parameters (Level 1)



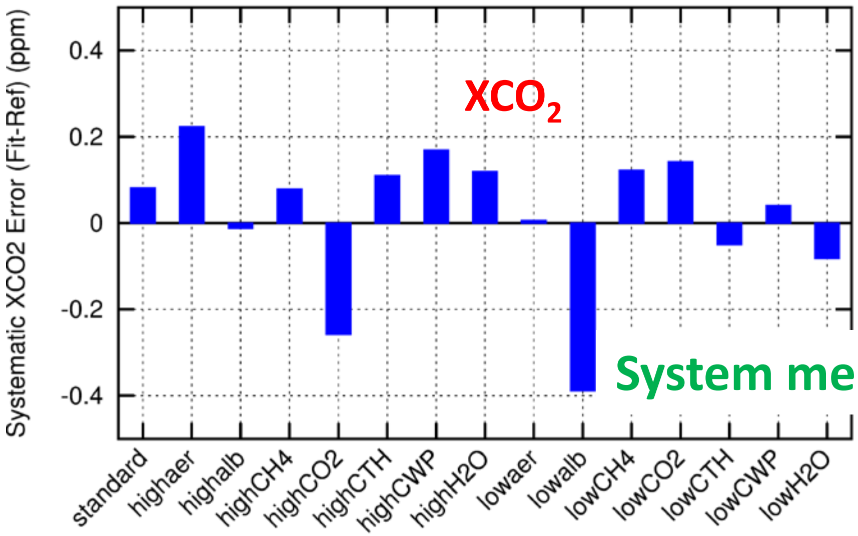
CarbonSat Spectral Instrument Characteristics			
Parameter	**Spectral band**		
	NIR	**SWIR-1**	**SWIR-2**
Spectral range [nm]	747 – 773	1590 – 1675	1925 – 2095
Spectral resolution FWHM [nm]	0.1	0.3	0.55
Spectral Sampling Ratio (SSR) [1/FWHM]	3	3	3
Threshold Signal-to-Noise Ratio (SNR) for SZA 50° and vegetation surface [-]	473	347	274
Radiance for listed SNR in photons/s/nm/cm^2/steradiant	2.0×10^{13}	4.1×10^{12}	9.9×10^{11}

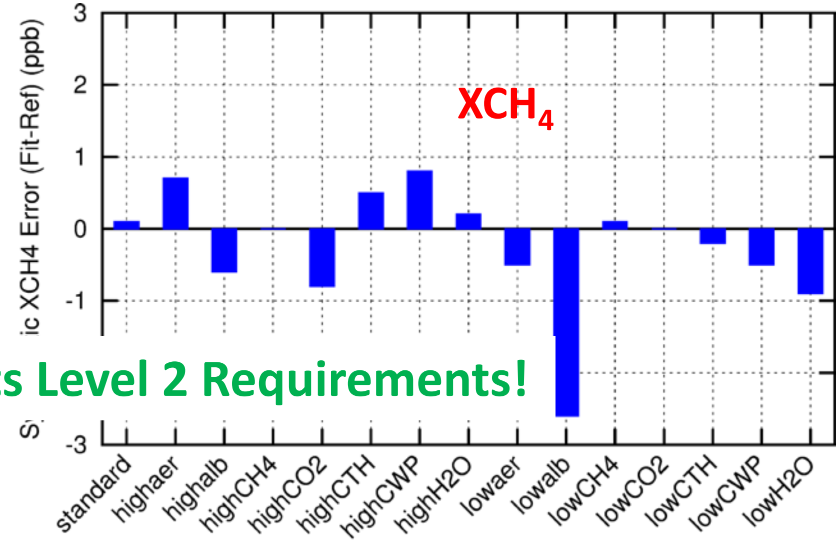
From CarbonSat Observations to Sources and Sinks



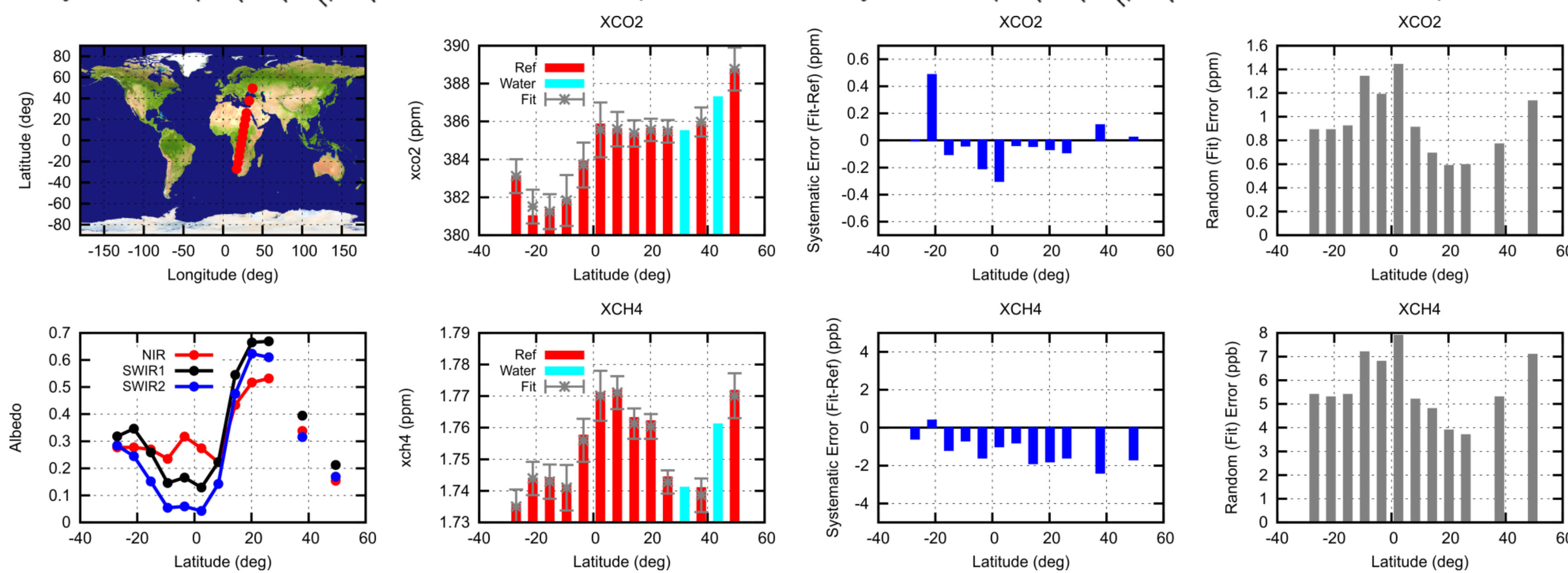
End-to-End Simulations and Observing System Experiments were performed

End-to-End Performance Simulations



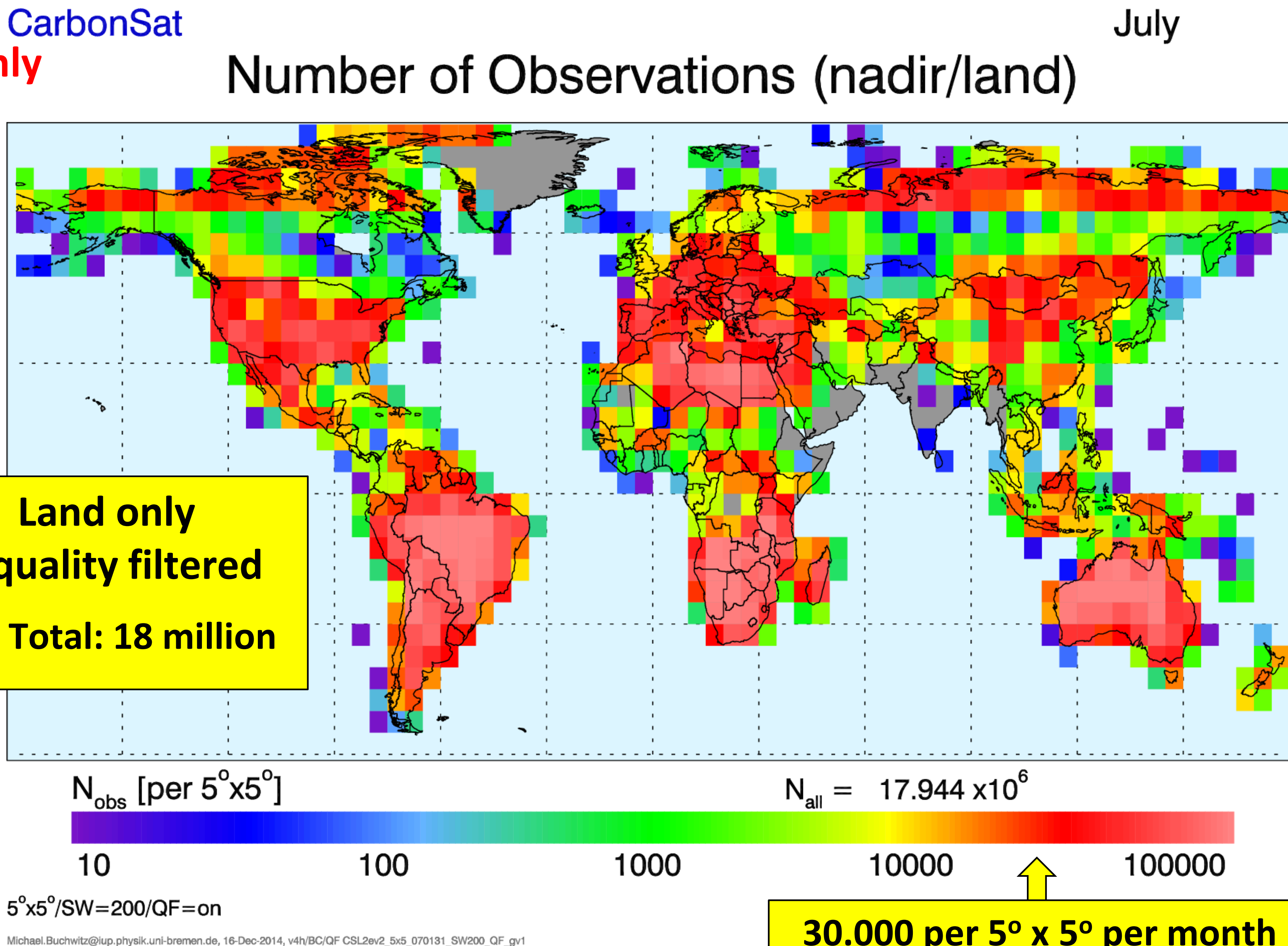


System meets Level 2 Requirements!



CarbonSat: Number of Observations

Monthly
5°x5°



Land only
& quality filtered
July Total: 18 million

30.000 per 5° x 5° per month

Update of Buchwitz et al., AMT, 2013
Assumptions: swath width 200 km, 2x3 km^2 ground pixel size

Comparison of XCO_2 satellite missions

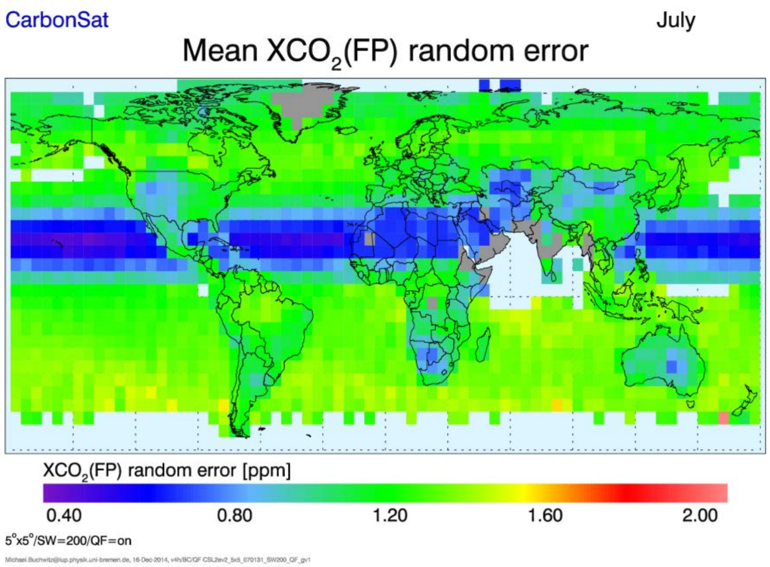
Number of XCO_2 quality filtered Observations Monthly, 5°x 5°

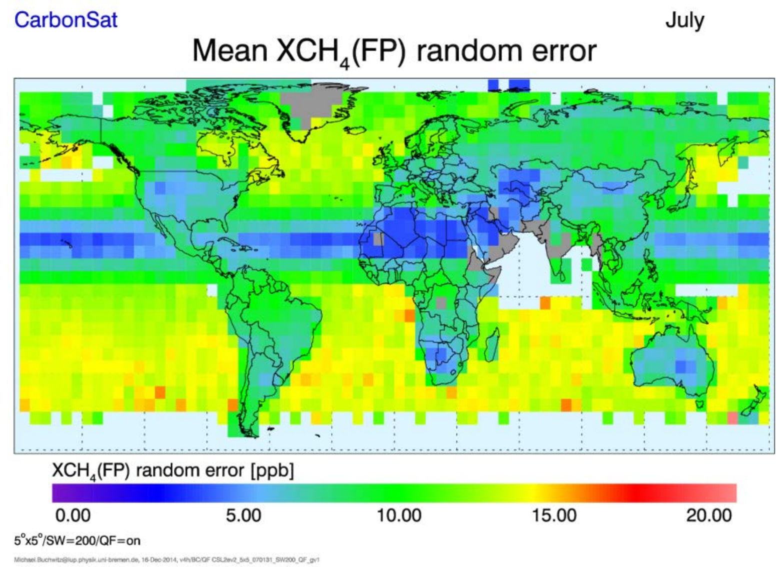
Sensor	Europe		Amazonia	
	Jan	Jul	Jan	Jul
SCIAMACHY	2	22	15	102
GOSAT	1	9	4	15
OCO-2	3.000	5.500	3.500	12.000
CarbonSat	26.000	47.000	31.000	105.000

SCIAMACHY: XCO2 BESD GHG-CCI product 2010 (real data)
GOSAT: XCO2 OCFP GHG-CCI product 2010 (real data)
CarbonSat: Buchwitz et al., AMT, 2013 (simulations)
OCO-2: same cloud/aerosol statistics as CarbonSat, corrected by number of measurements and slighlty higher cloud free probabilty

Europe: lat: 40N-75N (exceptions: see above); lon: 15W-30E
Amazonia: lat: 20S-10N; lon: 80W-40W

CarbonSat: XCO_2 and XCH_4 Precision





XCO_2 precision:

- **Typical: 1.2 ppm**
- Better for
  - Deserts: ~0.5 ppm
  - Ocean glint: ~0.5 ppm
- Worse for
  - Ocean outside glint

XCH_4 precision:

- **Typical: 8 ppb**
- Better for
  - Deserts: ~4 ppb
  - Ocean glint: ~4-6 ppb
- Worse for
  - Ocean outside glint

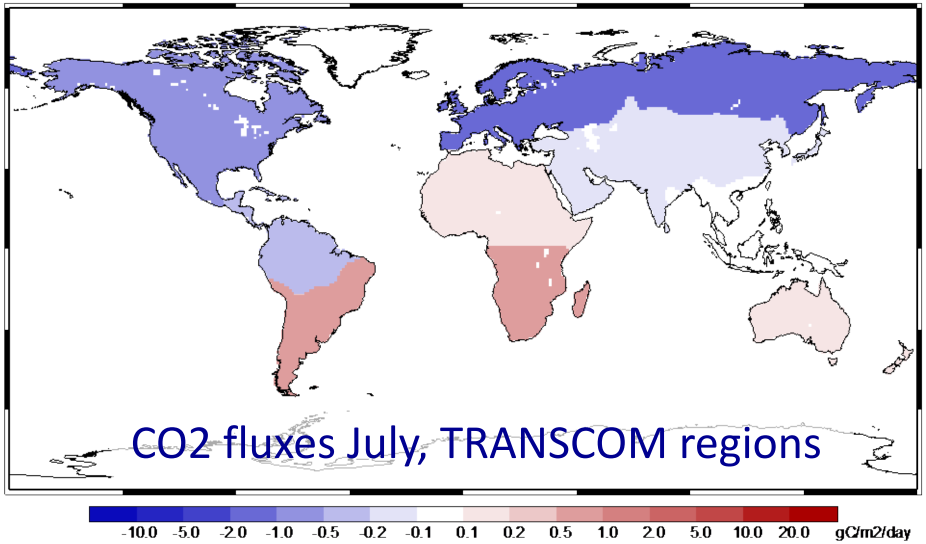
Update of Buchwitz et al., AMT, 2013

L4: Global to regional scale fluxes

State of the art:

Resolution: (sub) continental scale

Compound	Estimation accuracy
CO2	0.5 PgC/yr
CH4	5 TgC/yr



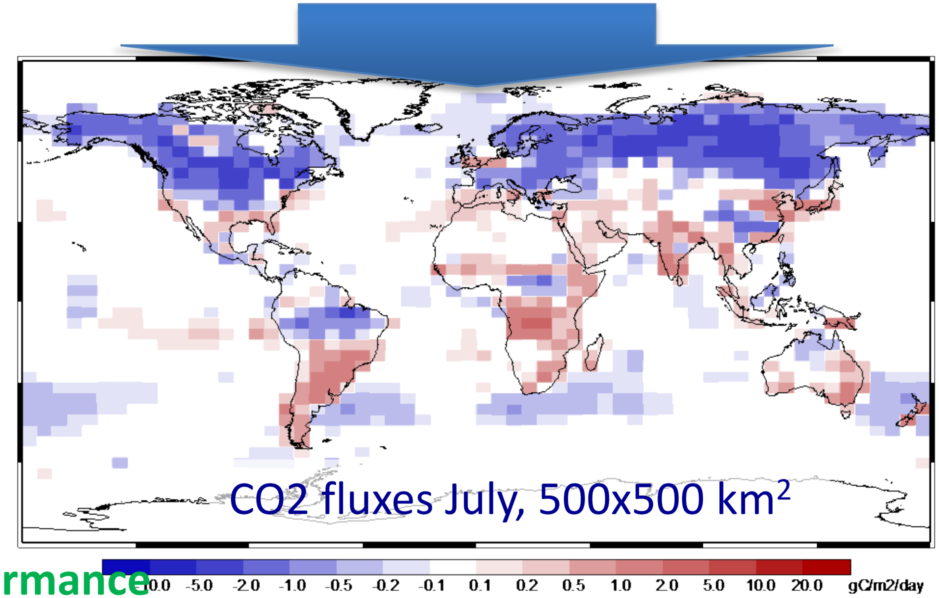
CarbonSat:

Flux resolution: 500 x 500 km^2

Compound	Estimation accuracy
CO2	0.1 PgC/yr
CH4	<1 TgC/yr

breakthrough CO2: 0.5 gC/m2/day

breakthrough CH4: 10 mg/m2/day



Results OSSES'sconfirm breakthrough performance

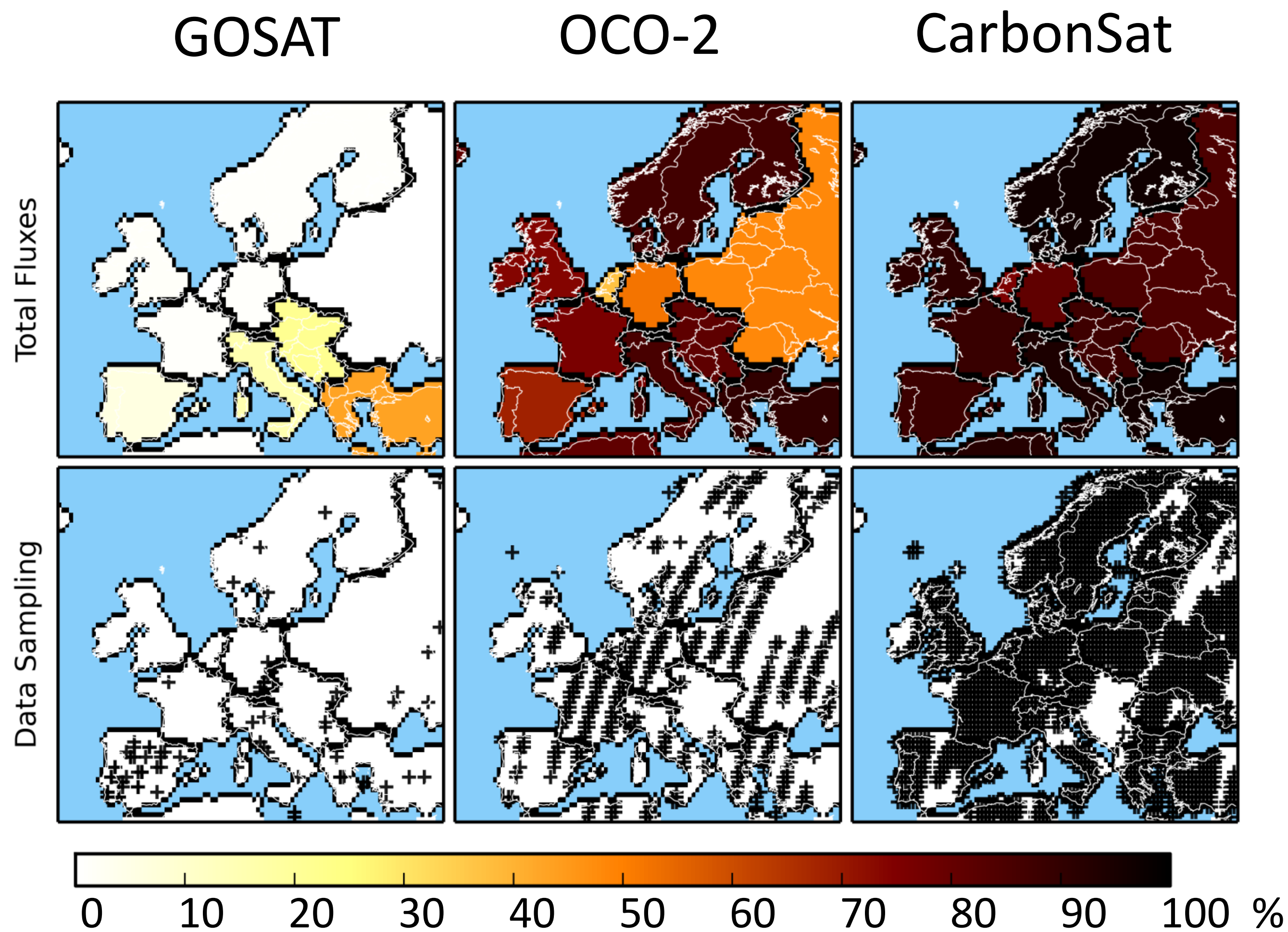
Comparison with other missions – country scale

CarbonSat is superior to other missions due to combination of:

- Large swath (200 km)
- Small IFOV (2x3 km2)
- Excellent precision and accuracy

1st satellite mission for estimating fluxes at country scale

Initial OSSE's indicate potential to constrian fossil fuel and biosphere flux seperately

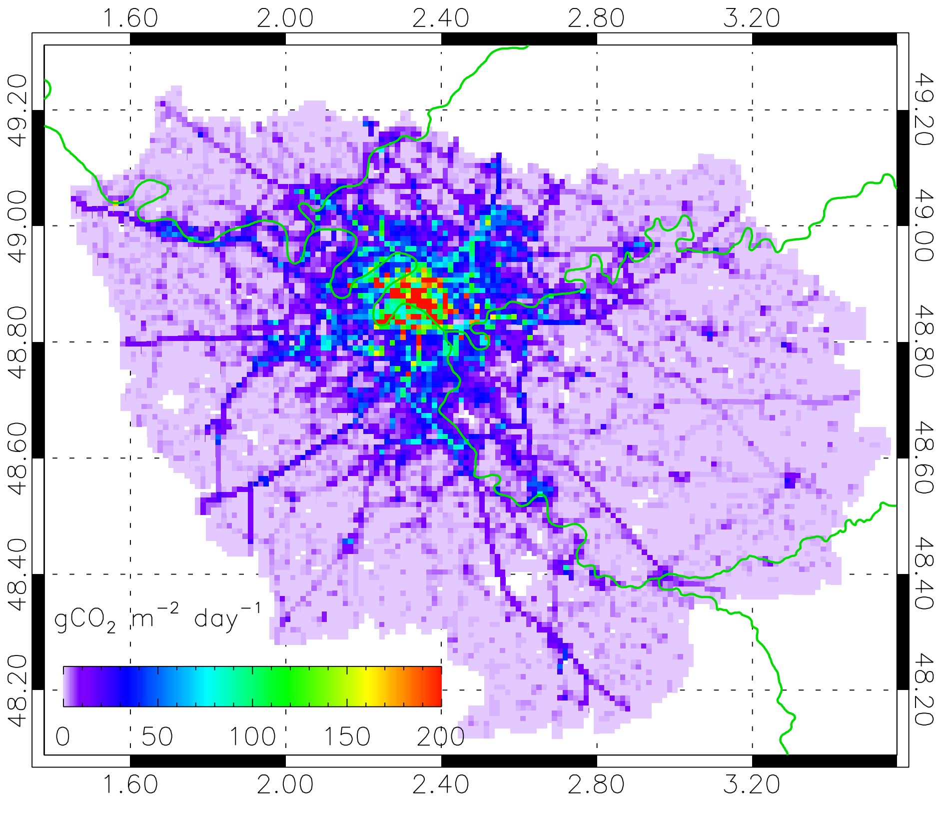


Uncertainty reduction – one week of data assimilated

Preliminary, courtesy of G. Broquet, LSCE (Land data only)

Anthropogenic emissions: City scale

CO_2 fossil fuel emission from Paris



Courtesy of F.-M. Bréon, LSCE

First mission designed for quantifying
Of emissions from cities.

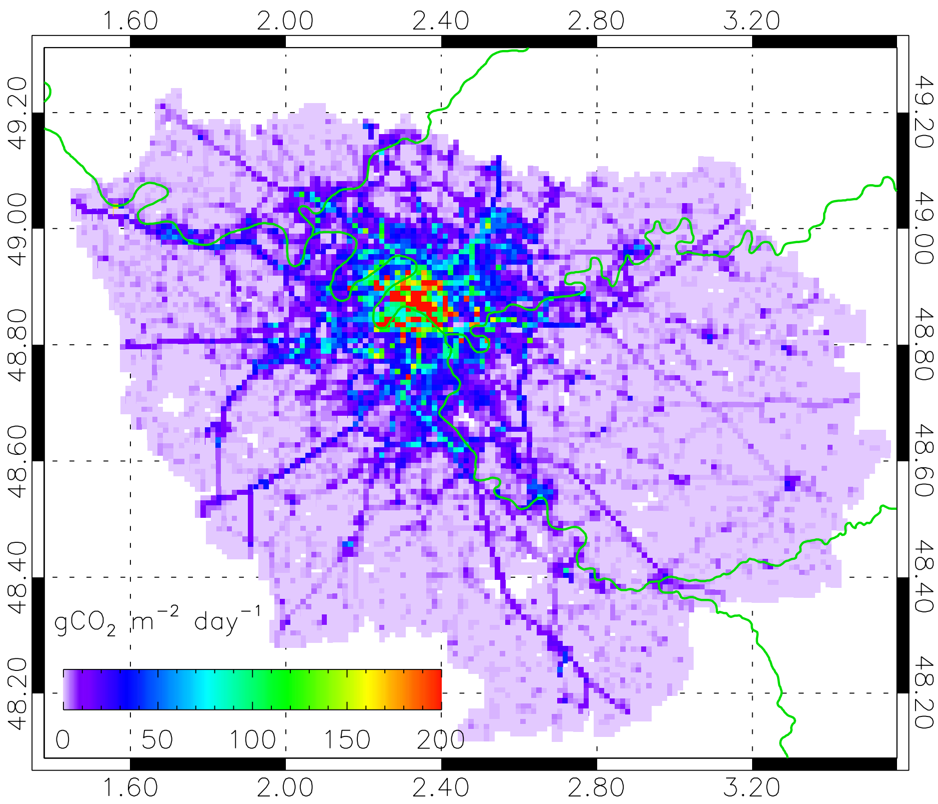
Aim:
Cities emitting >35 $MtCO_2$/yr within 10% uncertainty

World wide the number of large cities is growing. Their emissions are not well quantified.

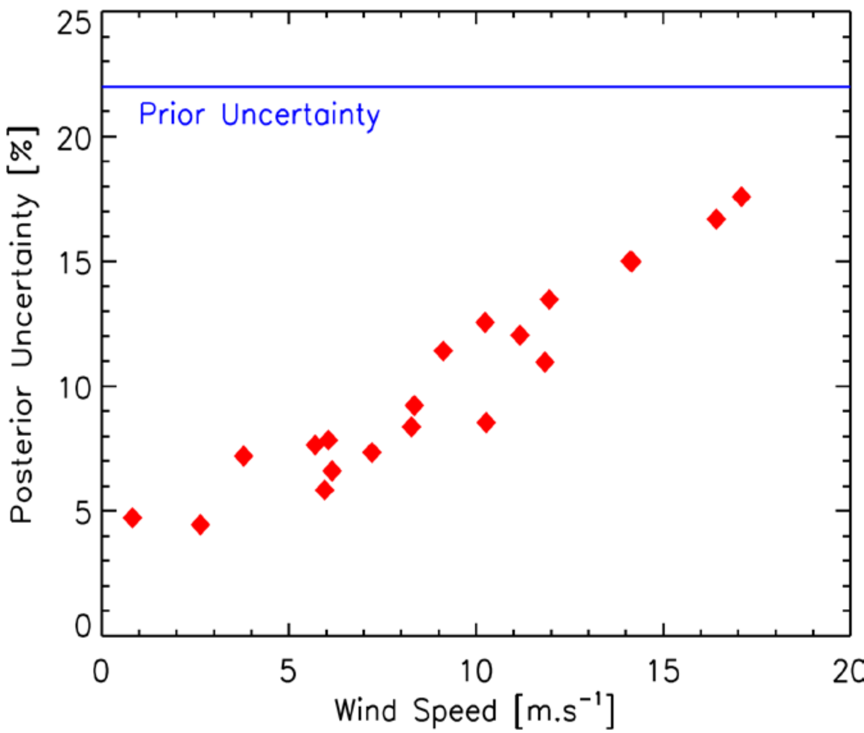
Anthropogenic emissions: City scale

- OSSEs experiments have been conducted for Paris and Berlin
Example: Simulation of Paris using the mesoscale model Chimere

CO_2 fossil fuel emission from Paris



Uncertainty reduction CO_2 fossil fuel

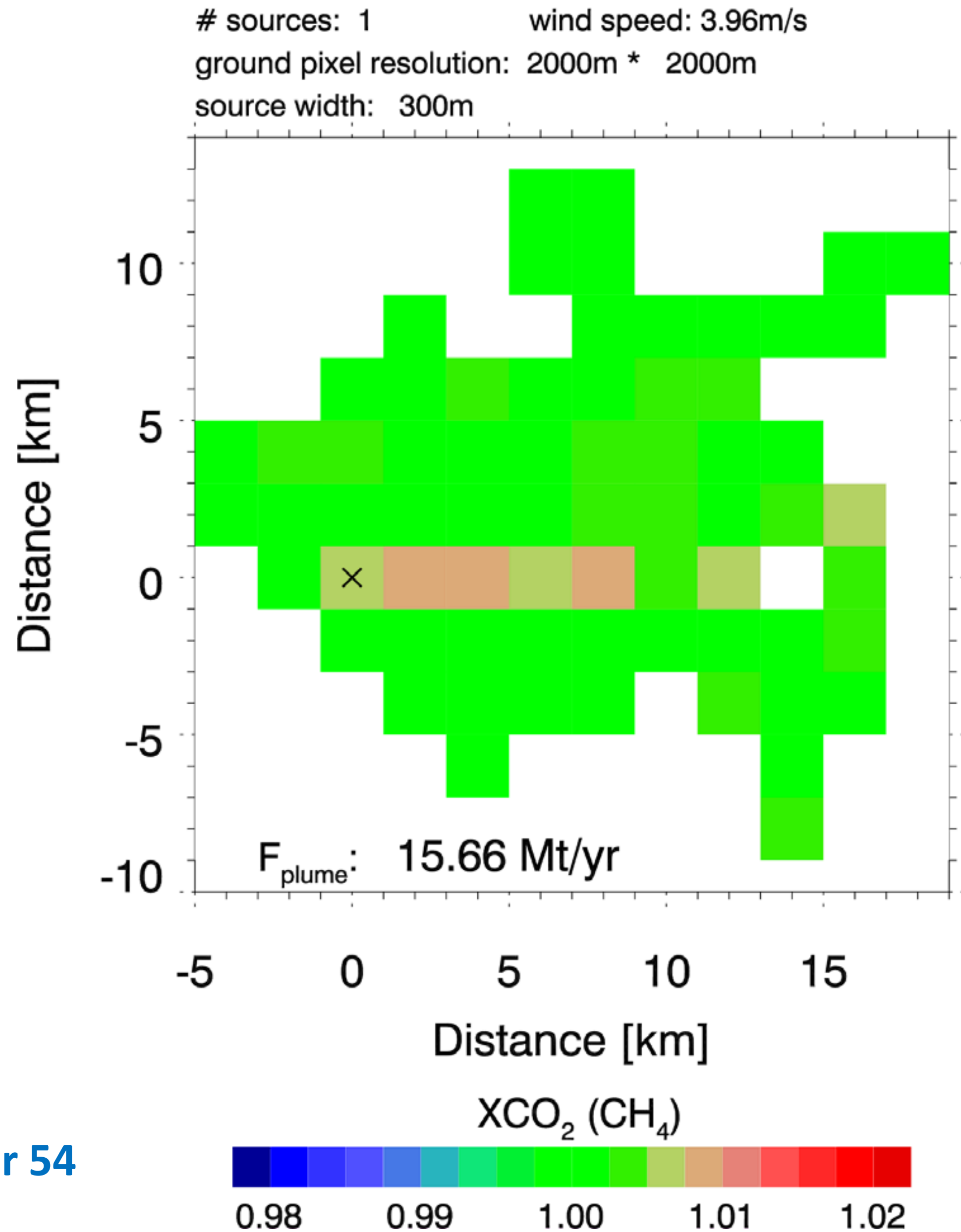


Results confirm breakthrough performance

Courtesy of F.-M. Bréon, LSCE

Power plant Weisweiler

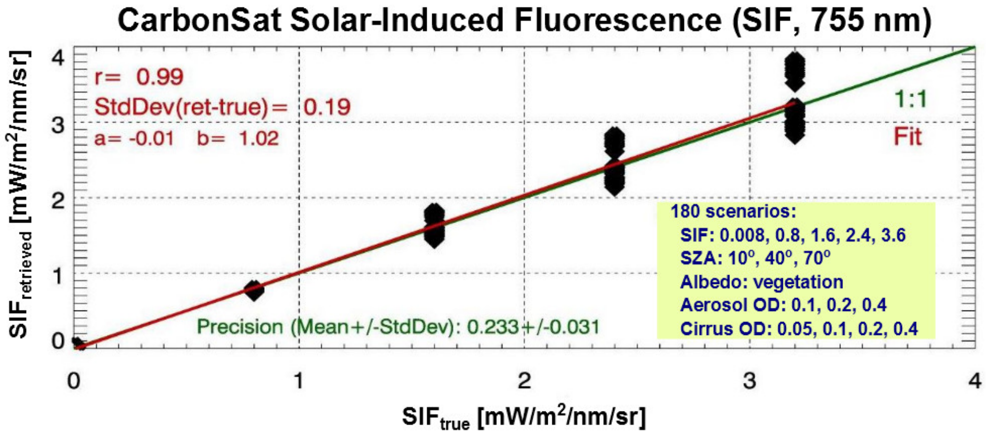
- Recorded remote sensing data at MAMAP resolution (approx. 100m x 100m) including plume inversion result (16.2 Mt/yr)
- Recorded remote sensing data gridded to spatial resolution of approx. 2 km x 2 km
- Including plume inversion result
- Derived emission: 15.7 Mt/yr at the time of measurements

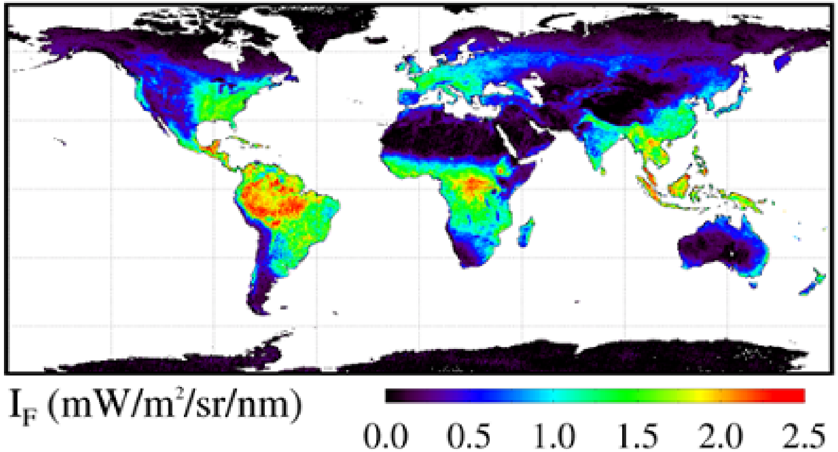


More on airborne CO_2, CH_4: see Poster 54

CarbonSat Secondary Product: Chlorophyll Fluorescence

- Chlorophyll fluorescence provides patterns of photosynthetic active vegetation
- O_2-A band itself is „disturbed“ by sun induced plant fluorescence and needs correction to derive XCO_2 accurately (done within CarbonSat).
- Analysis of GOSAT, SCIAMACHY and GOME-2 data demonstrated that chlorophyll fluorescence can be derived using solar Fraunhofer lines (Joiner et al, Frankenberg et al., Guanter et al., etc.)





@737 nm, 0.5° (J. Joiner et al. AMTD 2013)

CarbonSat:

Measurement precision: ~0.3 mW/m2/nm/sr

Std. dev. of systematic error: ~ 0.2 mW/m2/nm/sr

Summary of Unique Research Contributions by CarbonSat

Regional to global scales: CS will provide a breakthrough in the quantification and attribution of regional-scale surface-to-atmosphere fluxes (incl. Oceans) of CO_2 and CH_4 and climate impact on it (temperature, fires, precipitation, etc.).

Country scale (or equally sized biomes)**:** CS will increase the flux resolving power of greenhouse gas observing satellites to the scale of medium-sized countries, allowing detailed research of climate feedbacks on fluxes (temperature, fires, precipitation, etc.).

Local scale (city and below): CS will pioneer the space-borne detection, characterization, and quantification of strong local source areas of CO_2 and CH_4.

Summary

- Quantification of **natural and anthropogenic** CO_2 and CH_4 sources and sinks ("fluxes") accros scales linking **global regional, country and city scale**
- First satellite mission to explore detection and quantification of **CO_2 and CH_4 emission hot spot areas** via greenhouse gas imaging
- Evolution of Greenhouse Gas (GHG) missions
  - GOSAT → point sampling
  - OCO-2 → line sampling
  - **CarbonSat → imaging & global mapping**
- **XCO_2 and XCH_4** observations with high accuracy & precision, high spatial resolution (2x3 km^2 = **6 km^2**) AND good coverage (~**200 km continuous swath**); **solar induced chlorophyll fluorescence (SIF)** as spin-off product
- System, scientific support studies and campaign data analysis under finalisation
- Report for Mission Selection available in summer 2015
- User Consultation in September 2015

CarbonSat: http://www.iup.uni-bremen.de/carbonsat/

Earth Explorer-8 User Consultation Meeting

http://congrexprojects.com/2015-events/15m24/introduction

- Introduction
- Meeting agenda
- Reports
- Registration
- Venue
- Accommodation
- Contact

Earth Explorer-8 User Consultation Meeting

15–16 September 2015

Academy of Fine Arts, Krakow, Poland

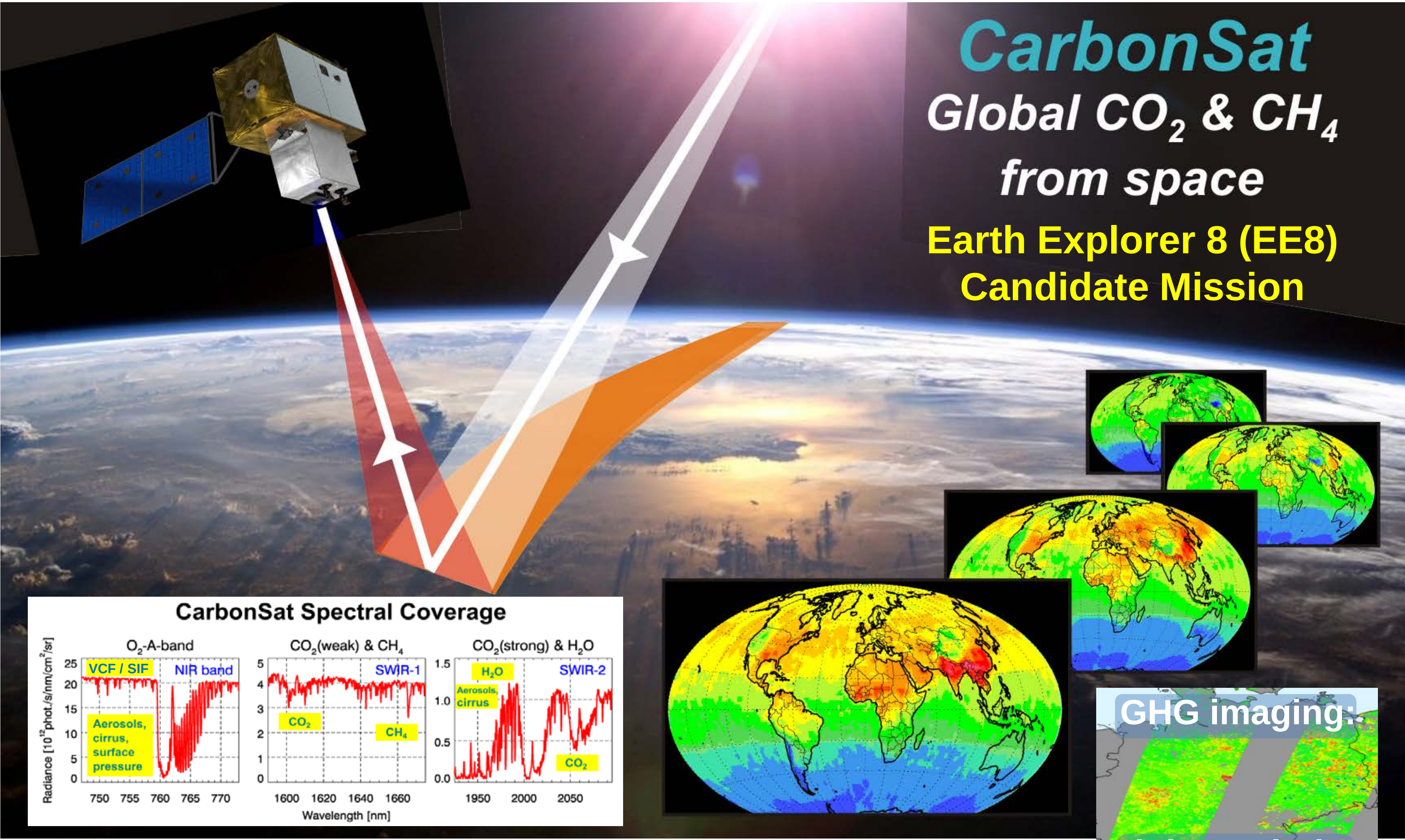
As a critical input to the decision-making process that will lead to the selection of ESA's eighth Earth Explorer mission, the Earth observation scientific community is invited to a User Consultation Meeting at the Academy of Fine Arts in Krakow, Poland on 15–16 September 2015.

Topic: EE8: CarbonSat or FLEX ?

15-16 Sept 2015, Krakow, Poland

Registration deadline: 15 Aug 2015

Thank you very much for your attention



www.iup.uni-bremen.de/carbonsat