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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• Gary Hayman,	CEH, Wallingford, UK
• Sander Houweling,	SRON, Utrecht, NL
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Global Carbon Project

Fate of Anthropogenic CO_2 Emissions (2004-2013 average)

32.4±1.6 $GtCO_2$/yr 91%

3.3±1.8 $GtCO_2$/yr 9%

+

15.8±0.4 $GtCO_2$/yr 44%

10.6±2.9 $GtCO_2$/yr 29%

Calculated as the residual of all other flux components

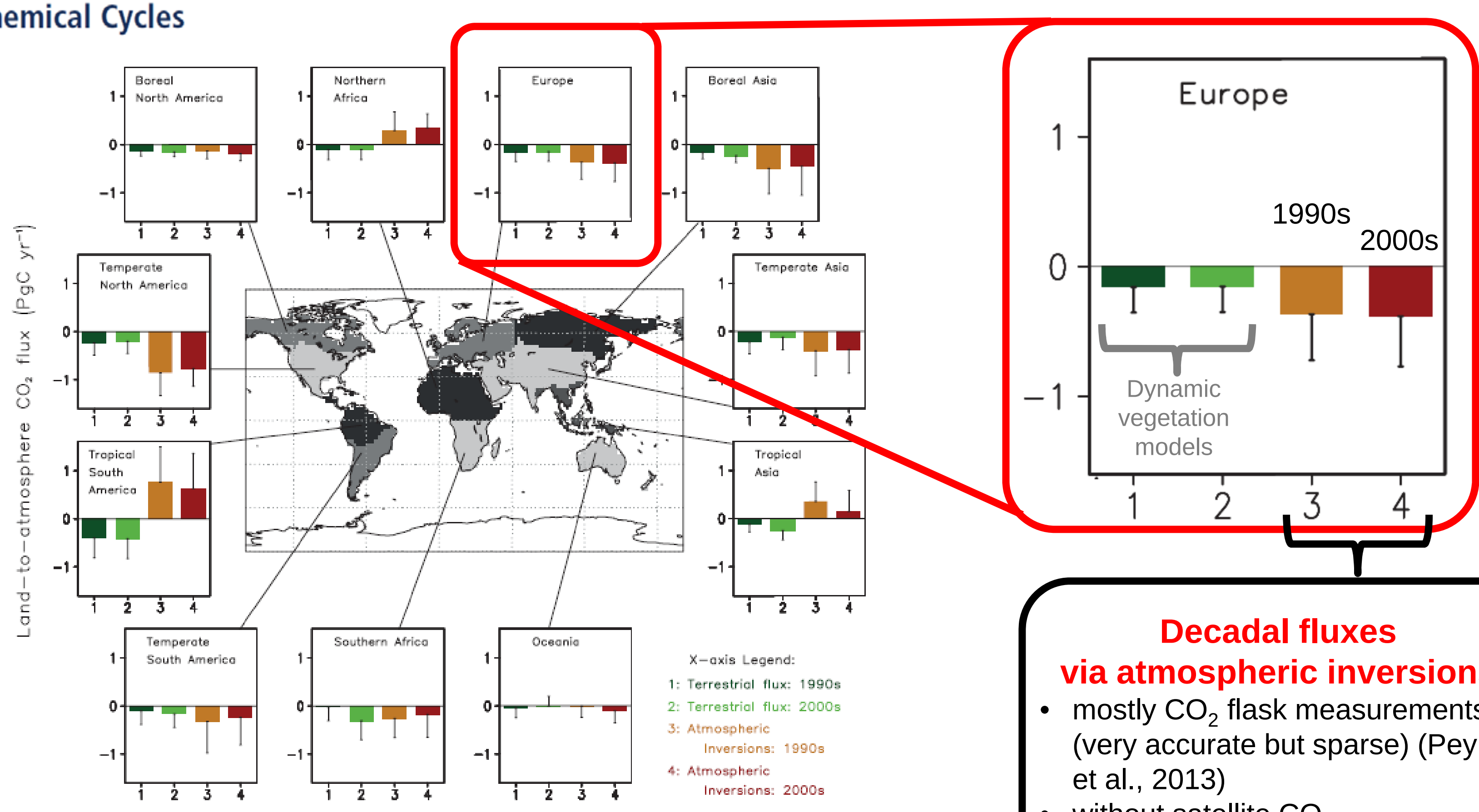
26%

9.4±1.8 $GtCO_2$/yr

Source: CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2014; Global Carbon Budget 2014

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) (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 ?

Gaps in Data

Ground-based Networks

- Sparse spatial sampling

SCIAMACHY

- low spatial resolution
- relatively large uncertainties

GOSAT

- Sparse sampling (300 to 1000 cloud-free XCO_2 and XCH_4 soundings each day)

OCO-2

- XCO_2 only
- greater sampling density (> 100,000 cloud free soundings/day), but tracks separated by more than 1.5 degrees of longitude and sample less than 7% of the Earth's surface each month.

Despite the progress to date in measuring atmospheric CO_2 and CH_4 distributions from space-based sensors, these measurements still do not provide the coverage and resolution needed to map CO_2 and CH_4 fluxes at the sub-continental scale down to the city scale - where the majority of the anthropogenic emissions take place, as recognised by CEOS (CEOS, 2014).

CarbonSat Research Objectives

Regional to global scales: To provide a breakthrough in the quantification and attribution of regional-scale surface-to-atmosphere fluxes of CO_2 and CH_4 and climate impact on it (droughts etc.)

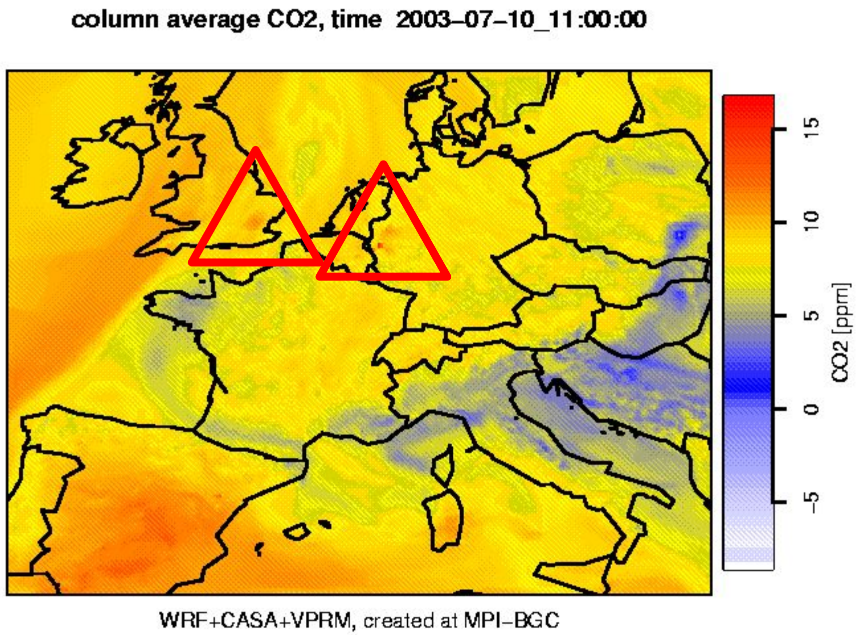
Country scale (or equally sized ecosystems)**:** To increase the flux resolving power of greenhouse gas observing satellites to the scale of medium-sized countries.

Local scale (city and below): To pioneer the space-borne detection, characterization, and quantification of strong local sources of CO_2 and CH_4.

Disentangling Natural & Anthropogenic Contributions from Space:

- **Imaging 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 IASI-NG and Sentinel 5 (CO, upper trop. CH_4, NO_2, etc.)**
- *Diurnal variation -> geostationary orbit or constellation*
- *Isotopes …*

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

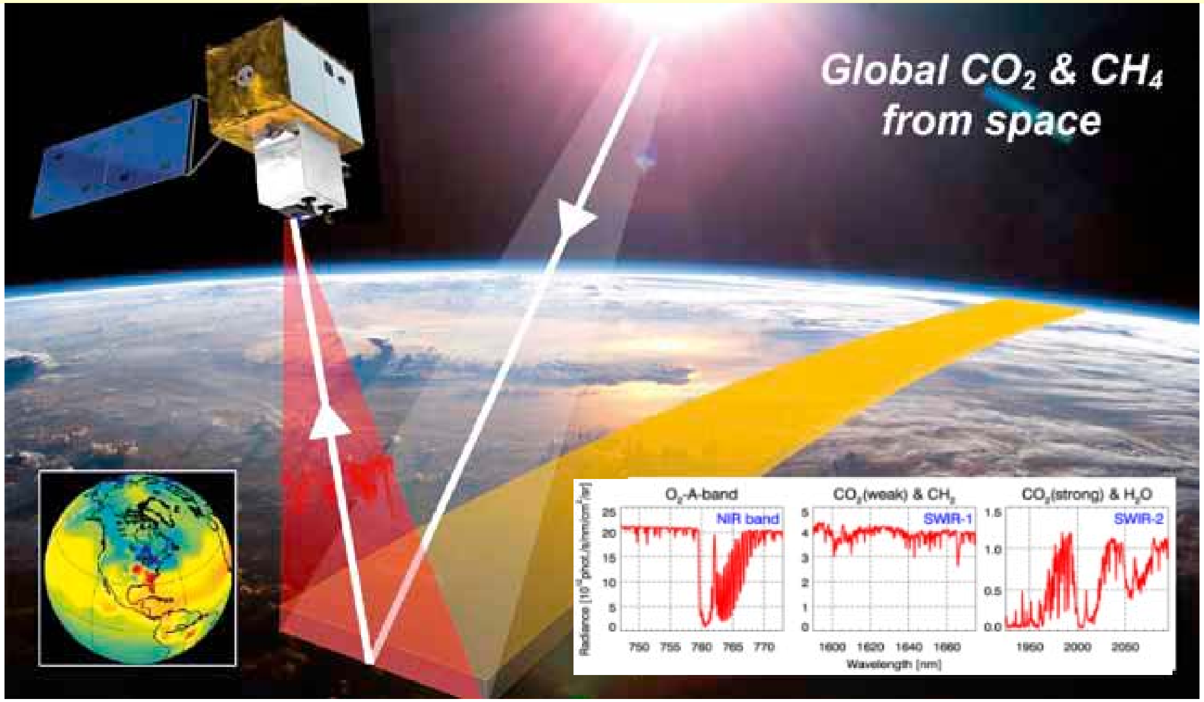


Modelled XCO_2 (Pillai et al., ACP, 2010):

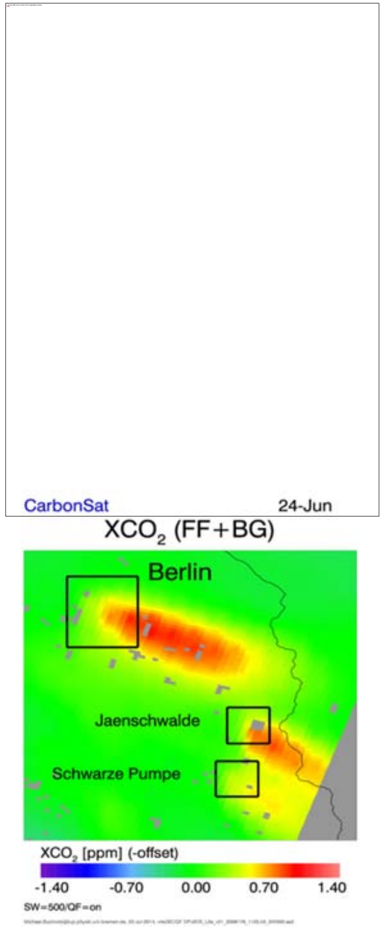
- Coupled biosphere-atmosphere model with anthropogenic emissions
- Constant background removed
- Resolution: 10 km x 10 km

CarbonSat: Mission Objectives

CarbonSat aims to support quantification of **natural and anthropogenic CO_2 and CH_4 sources and sinks ("fluxes")** and their changes via global atmospheric **XCO_2 and XCH_4** observations including **"imaging"** of strong localised CO_2 and CH_4 emission areas. In addition, several secondary products will be delivered such as high-quality Solar Induced Fluorescence (**SIF**).

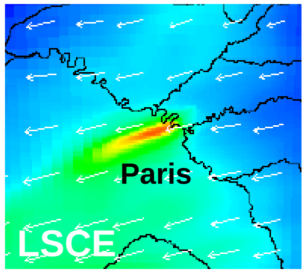


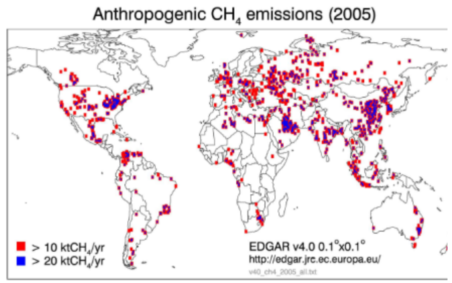
From SCIAMACHY to CarbonSat



New capabilities:

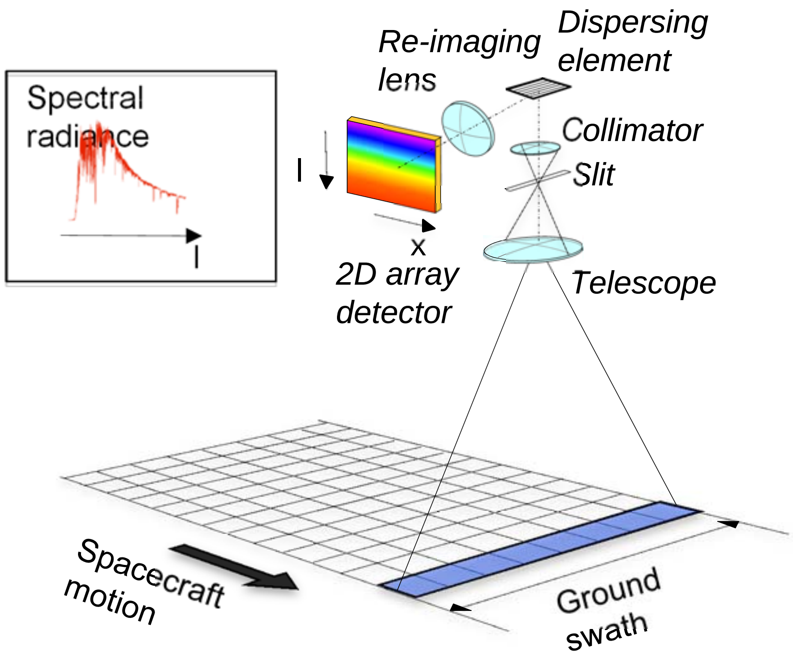
- Country and city scale, power plants, oil & gas fields, geological „point“ sources, volcaneous…
- Improved validation strategies (TCCON etc.)

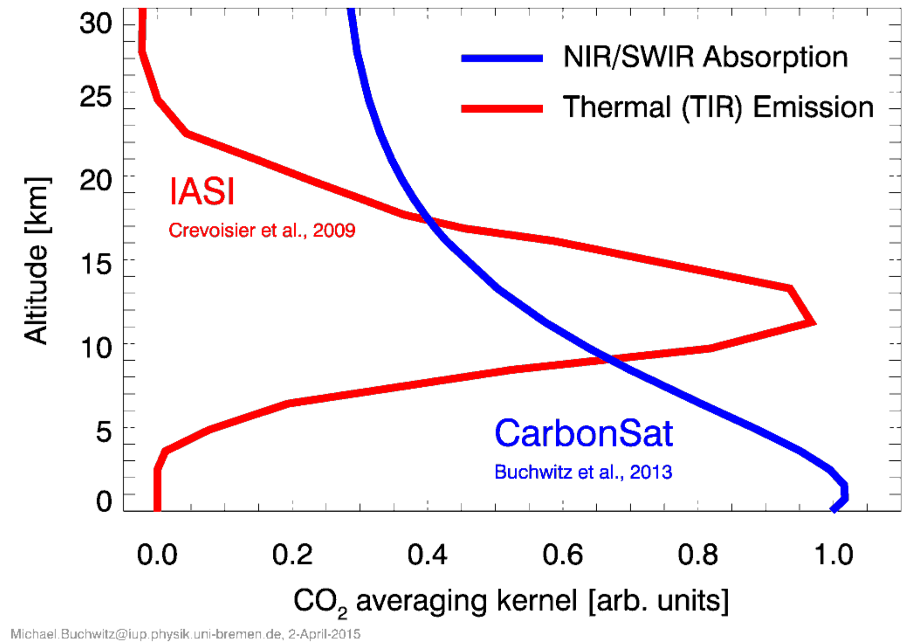




CarbonSat Instrument Concept

Greenhouse gas (GHG) imaging at high spatial resolution <u>AND</u> 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 Requirements: Spatial & temporal

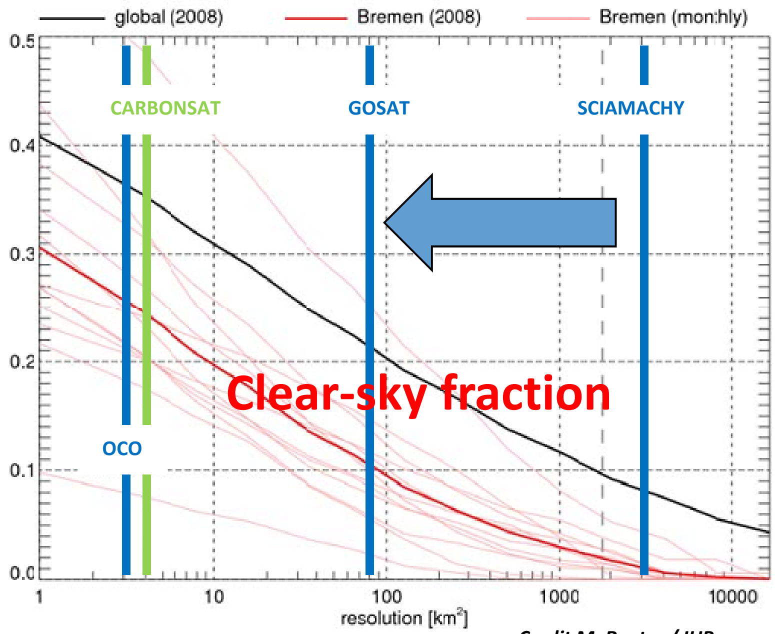
High spatial resolution and good coverage:

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

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

Observation modes:

- Nadir (main) → for land & ocean
- Sun-glint → for optimised 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 Requirements: Level 2

CarbonSat Mission Requirements at geophysical product level

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

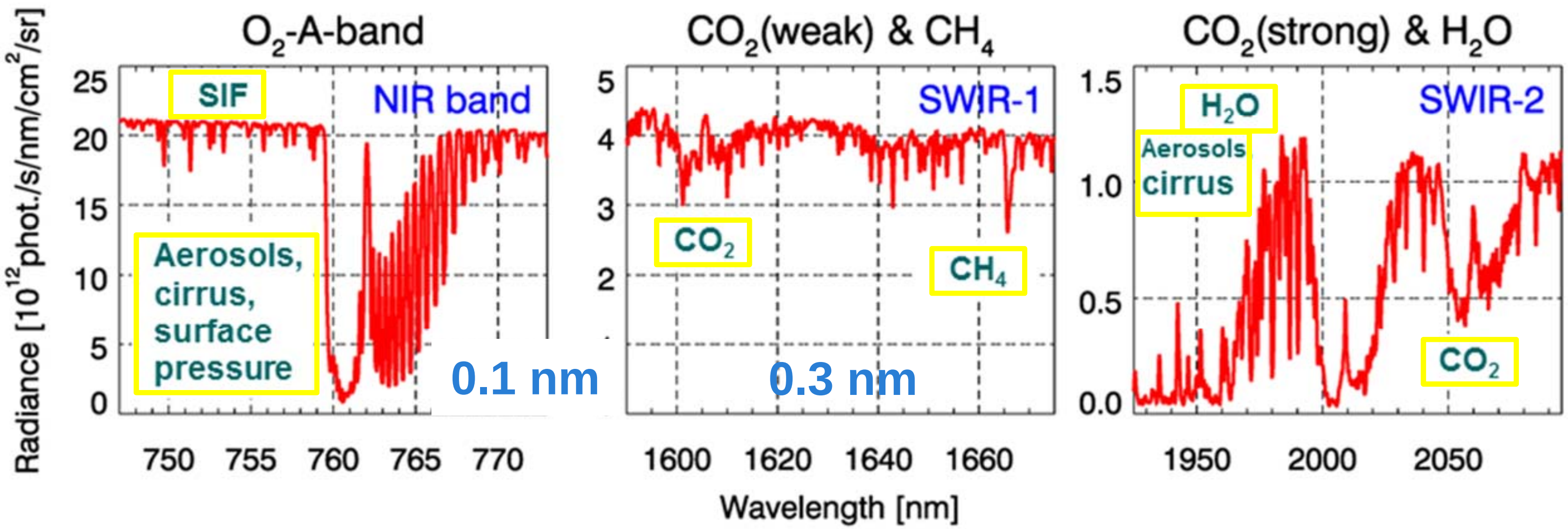
XCO_2: Column-averaged dry-air mole fraction of CO_2
XCH4: Column-averaged dry-air mole fraction of CH_4

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

CarbonSat: Spectral Parameters (Level 1)

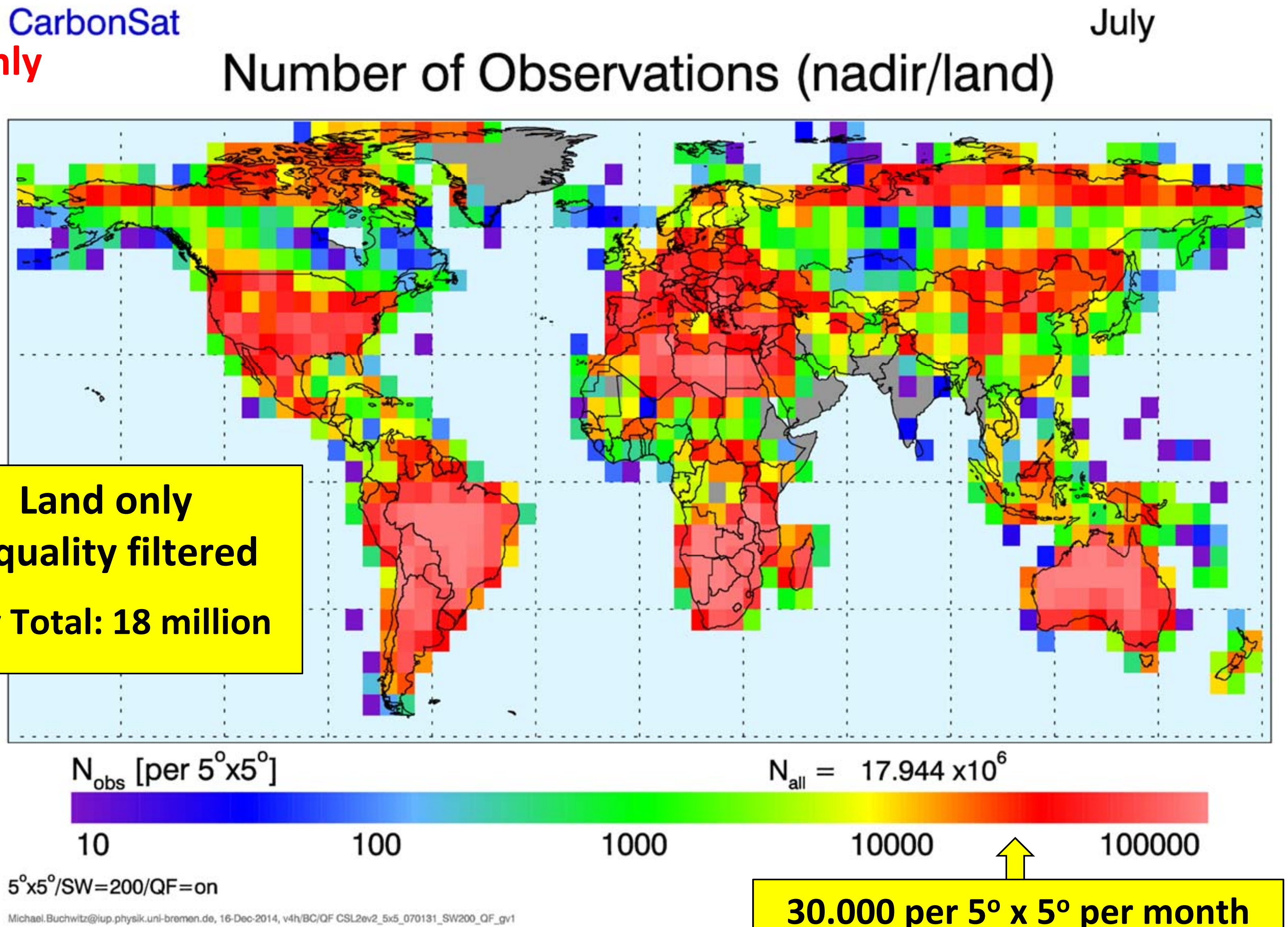
CarbonSat Spectral Instrument Characteristics			
Parameter	Spectral band		
	NIR	SWIR-1	SWIR-2
Spectral range [nm]	747 – 773	1590 – 1675	1925 – 2095
Spectral resolution FWHM [nm]	0.1	0.3	0.55
Spectral Sampling Ratio (SSR) [1/FWHM]	3	3	3
Threshold Signal-to-Noise Ratio (SNR) for SZA 50° and vegetation surface [-]	473	347	274
Radiance for listed SNR in photons/s/nm/cm²/steradiant	2.0×10^{13}	4.1×10^{12}	9.9×10^{11}

CarbonSat Spectral Coverage



CarbonSat: Number of Observations

Monthly 5°x5°



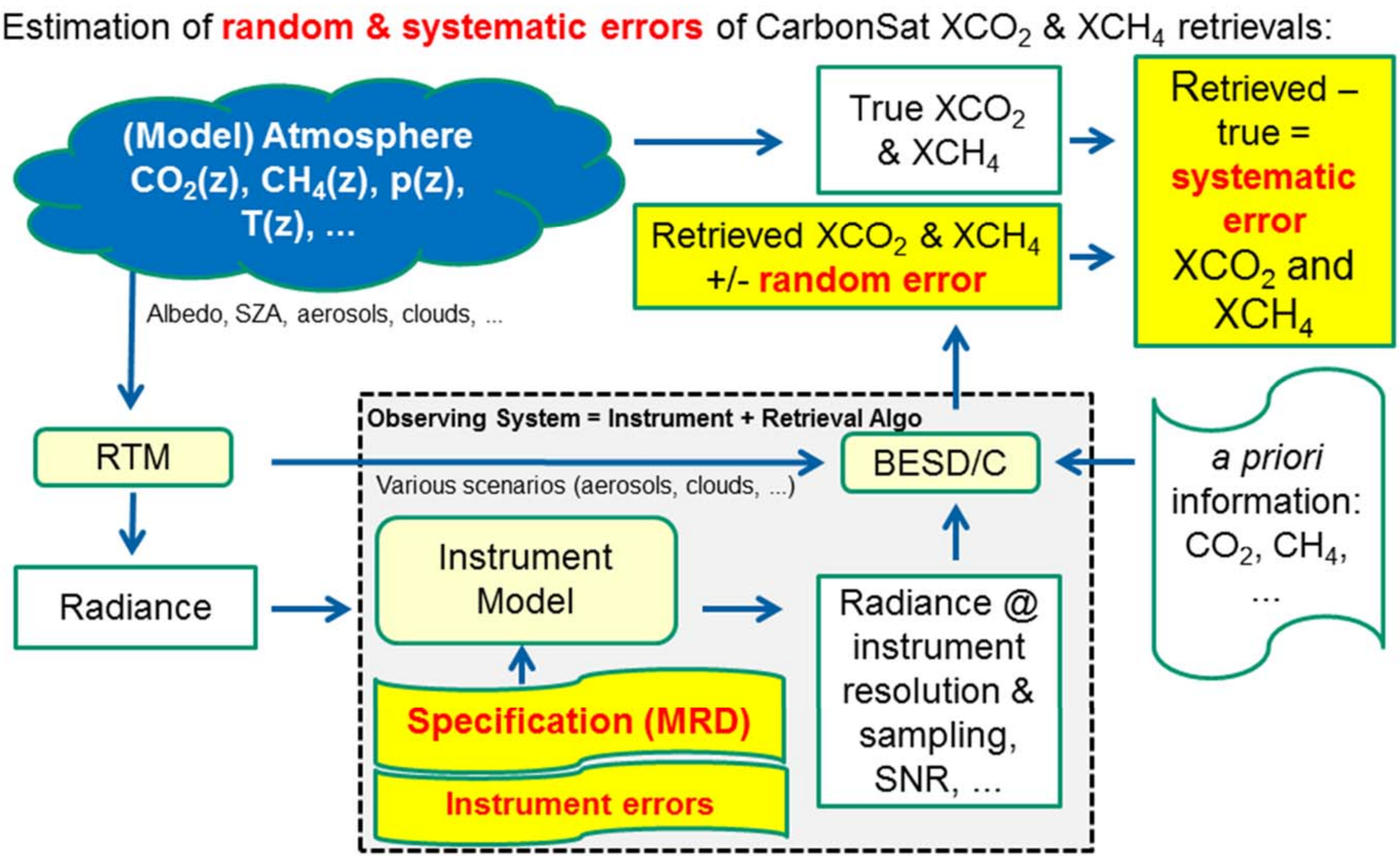
Land only
& quality filtered

July Total: 18 million

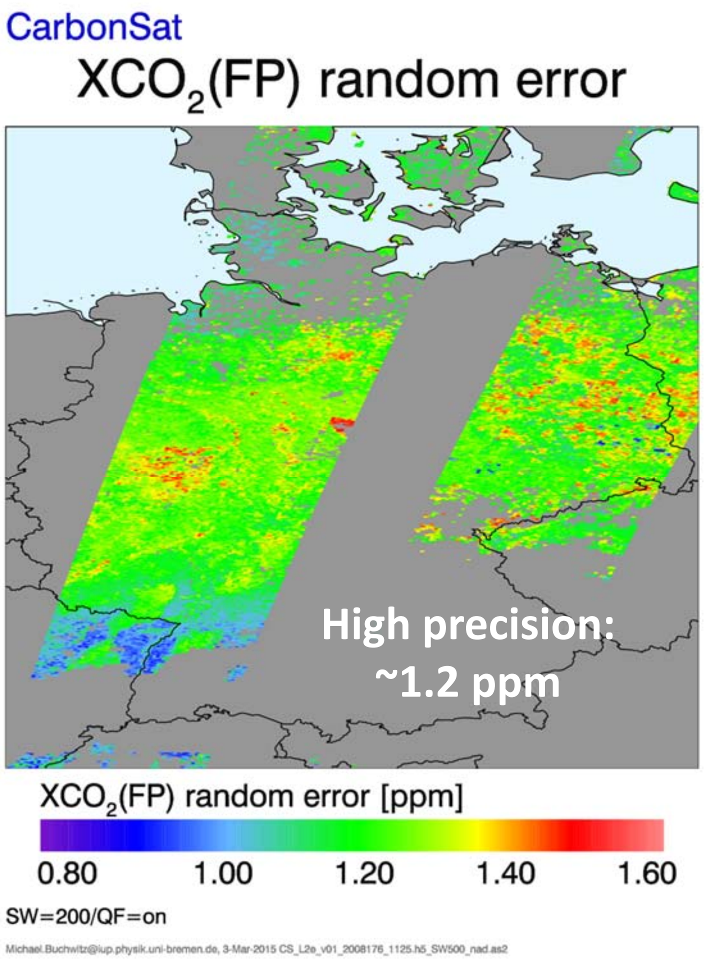
30.000 per 5° x 5° per month

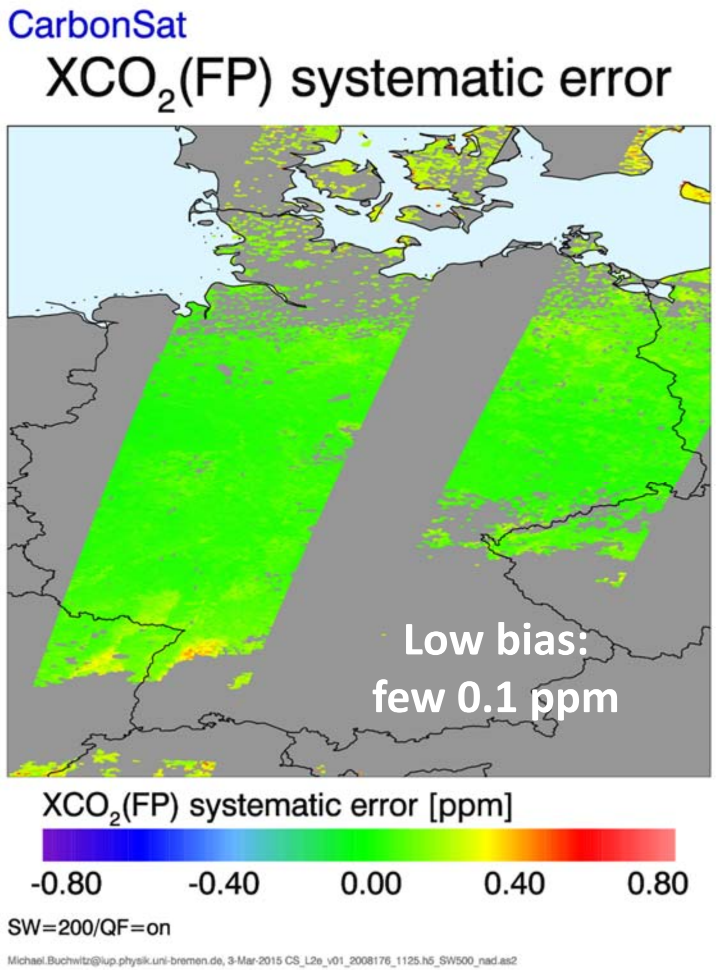
Update of Buchwitz et al., AMT, 2013
Assumptions: swath width 200 km, 2x3 km^2 ground pixel size

CarbonSat Simulation Framework



CarbonSat: Single ground pixel XCO_2

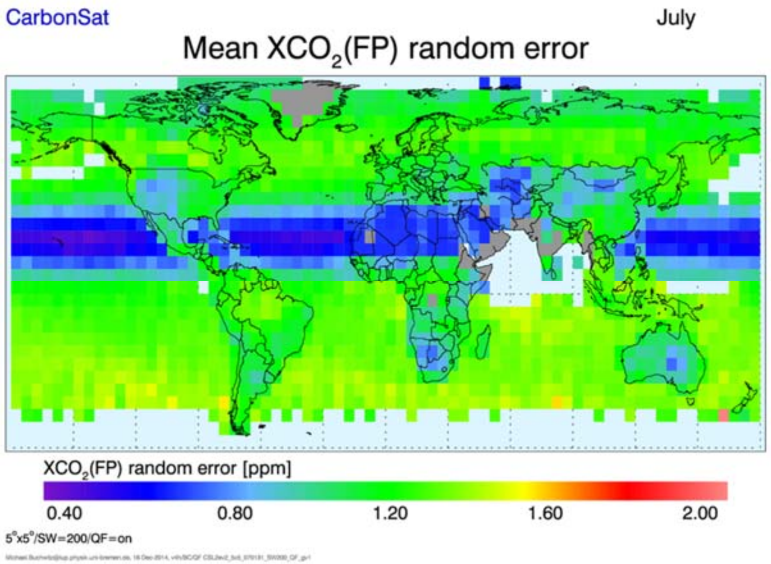


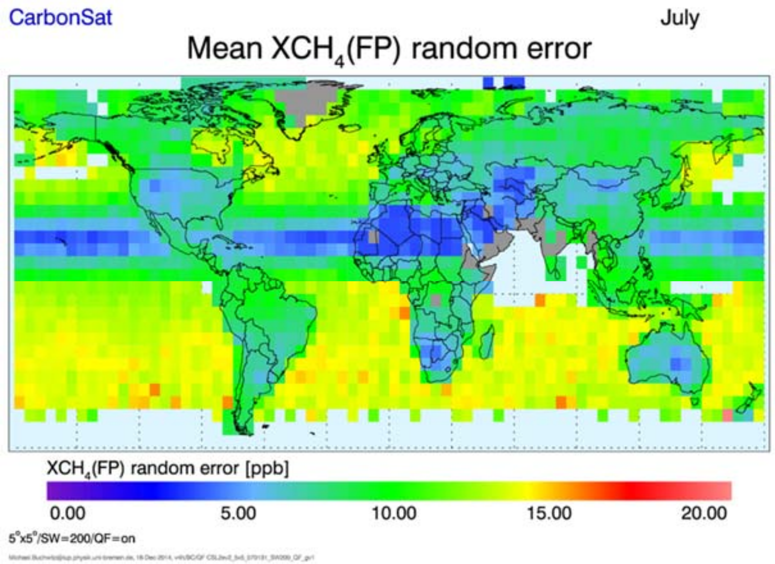


Swath: 200 km

Update of Buchwitz et al., AMT, 2013

CarbonSat: XCO_2 and XCH_4 Precision





XCO_2 precision:

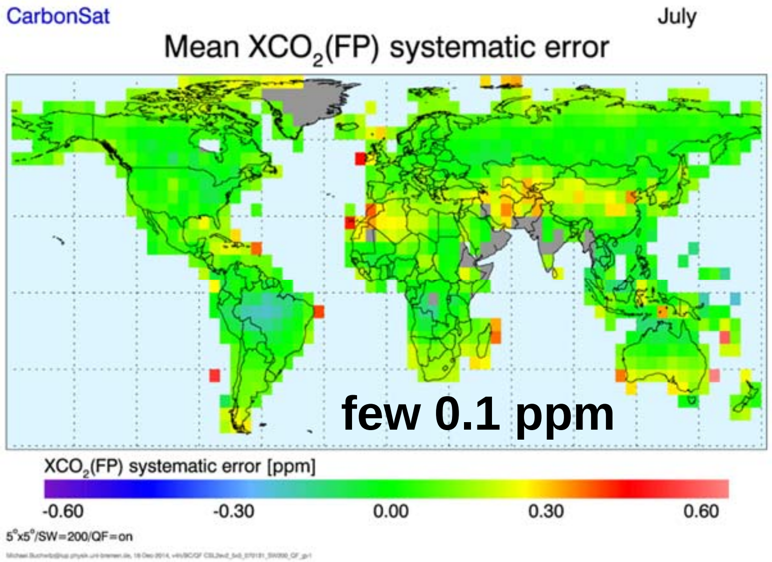
- **Typical: 1.2 ppm**
- Better for
  - Deserts: ~0.5 ppm
  - Ocean glint: ~0.5 ppm
- Worse for
  - Ocean outside glint

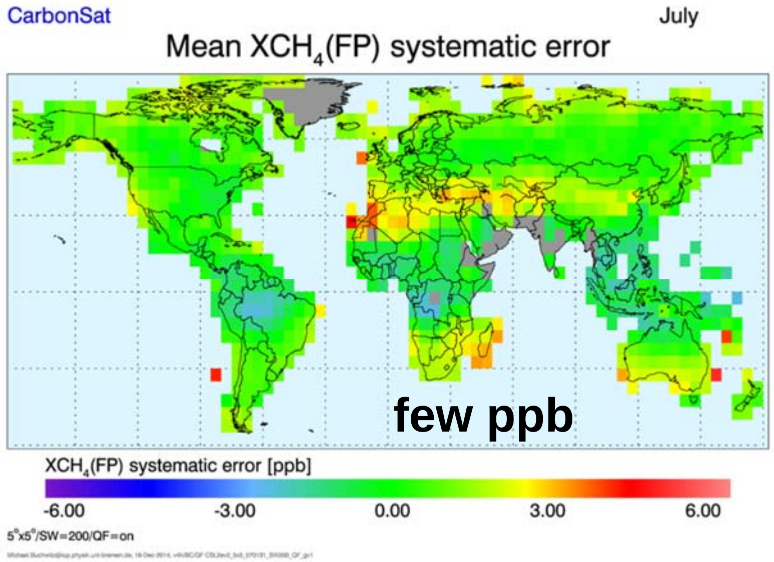
XCH_4 precision:

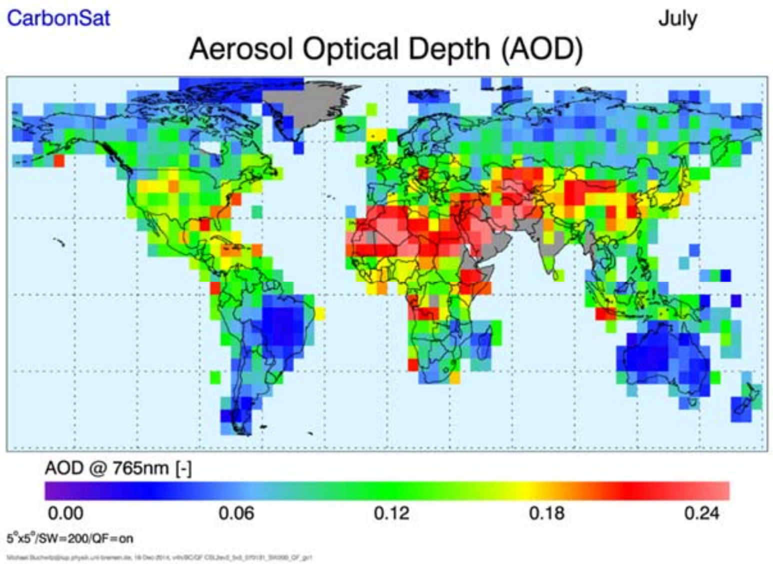
- **Typical: 8 ppb**
- Better for
  - Deserts: ~4 ppb
  - Ocean glint: ~4-6 ppb
- Worse for
  - Ocean outside glint

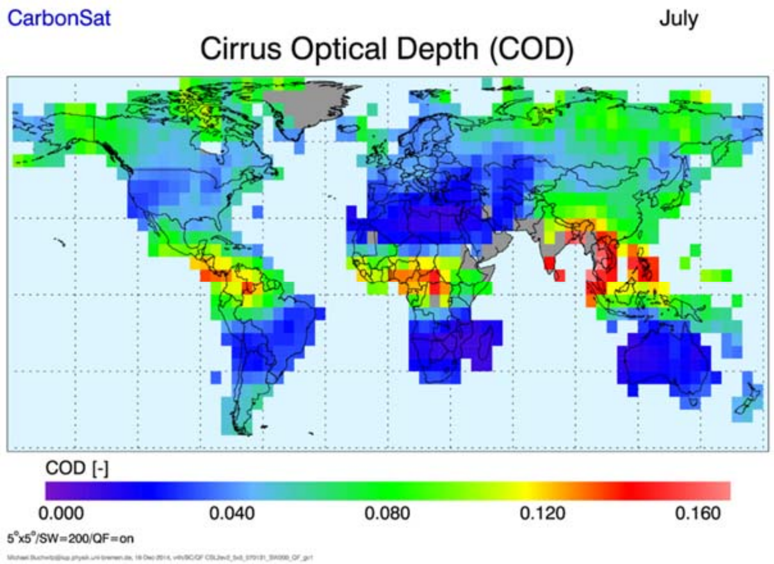
Update of Buchwitz et al., AMT, 2013

CarbonSat: XCO_2 and XCH_4 systematic errors



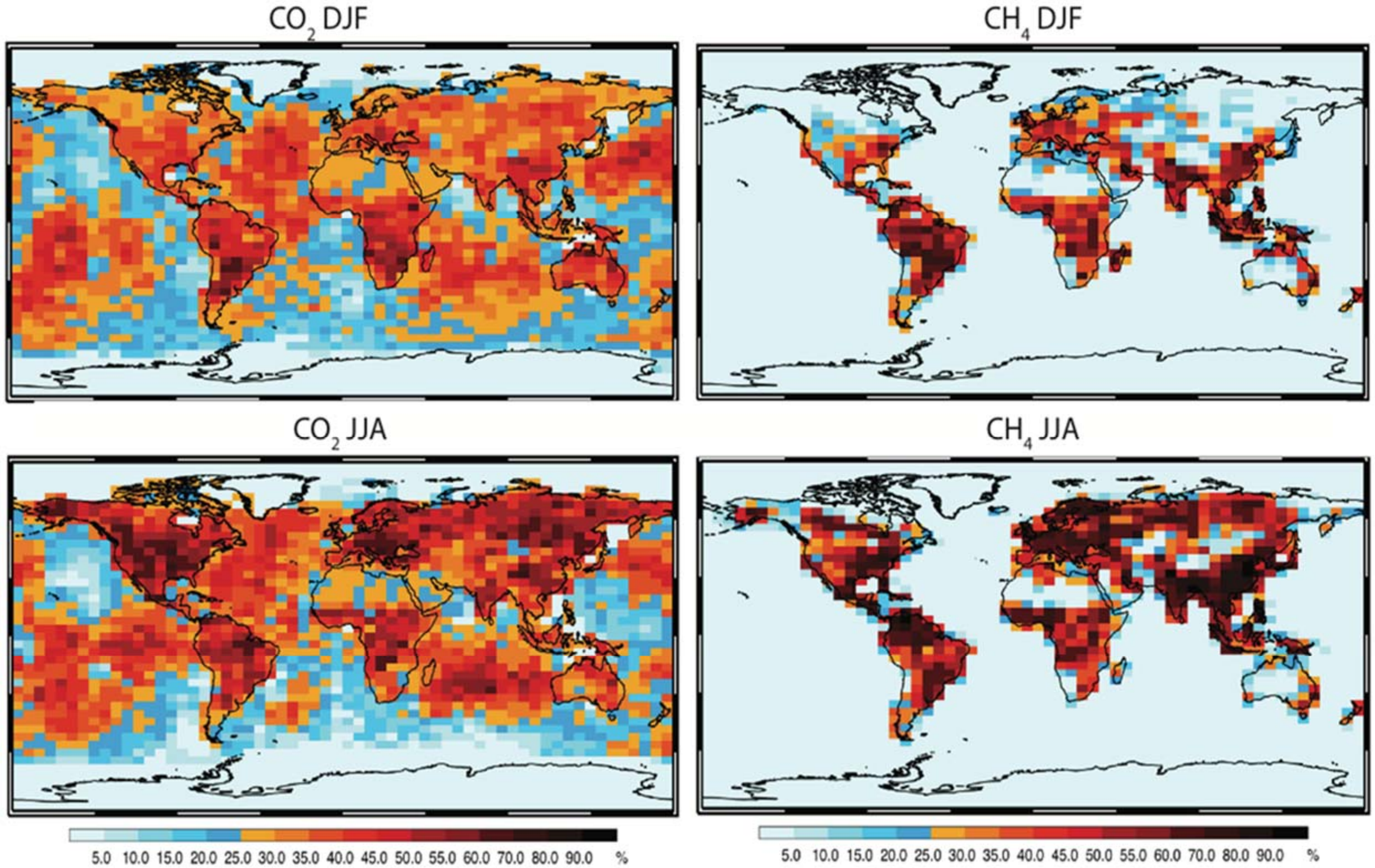






Update of Buchwitz et al., AMT, 2013

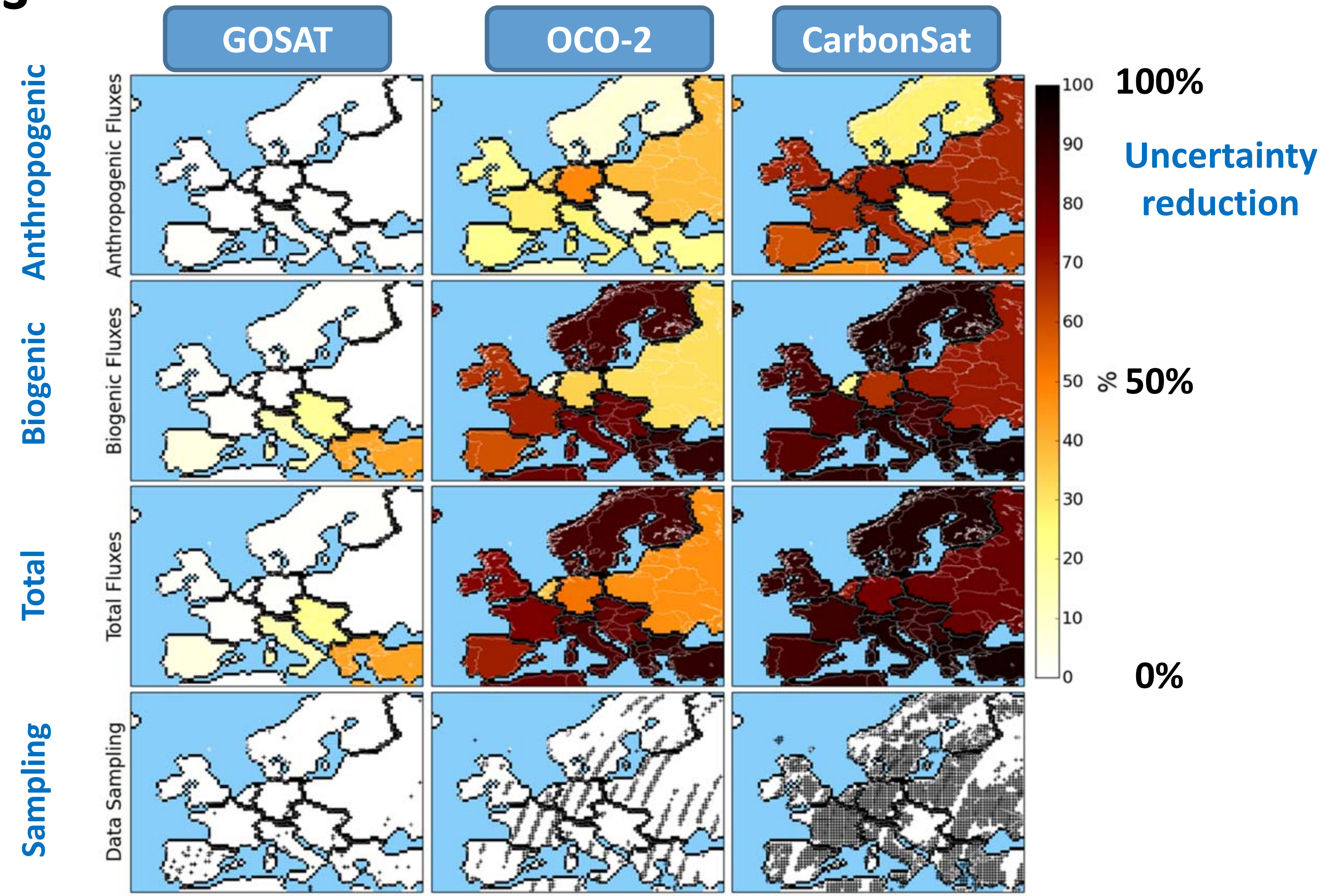
Evaluation of CarbonSat's contribution at global scales



Uncertainty reduction of surface-to-atmosphere flux, 500x500km^2

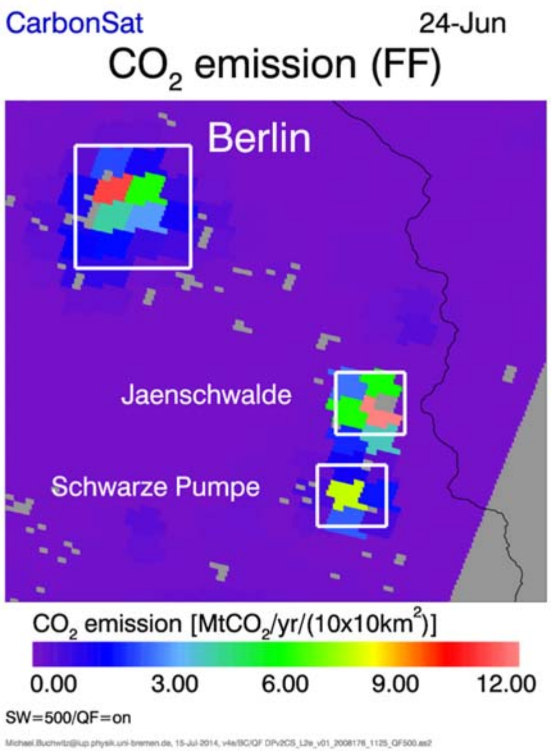
courtesy of S. Houweling, SRON

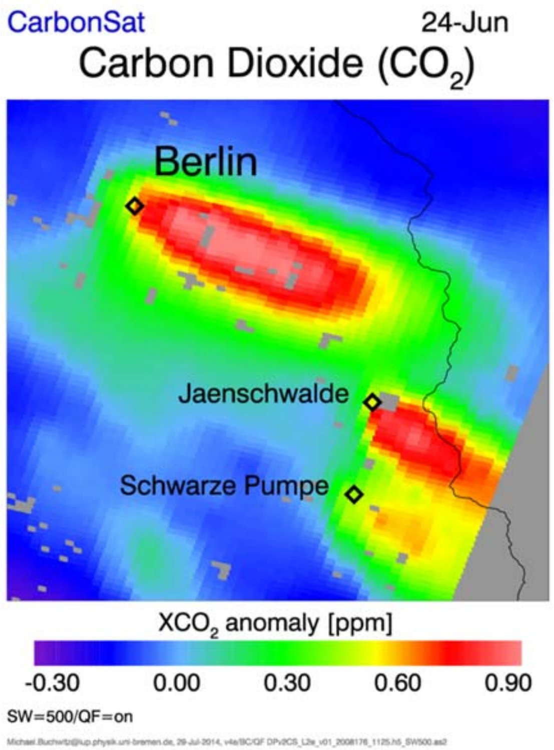
Evaluation of CarbonSat's contribution at national scales



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

CarbonSat: Emission Hot Spots: Berlin area





CarbonSat: City CO_2 Emissions: Berlin

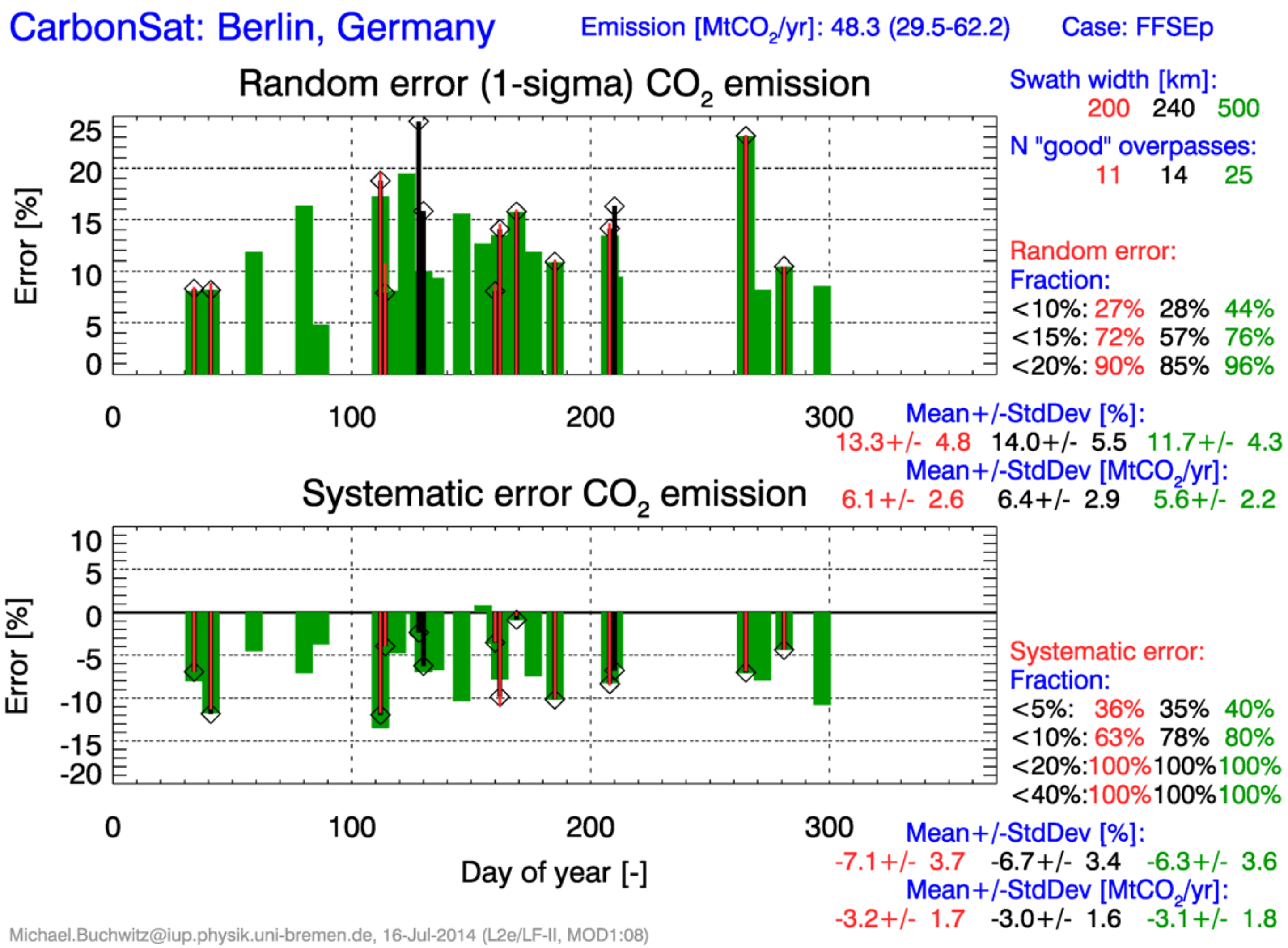
Very strict cloud filtering

Precision:

~7 $MtCO_2$/yr
(~15% for Berlin)

Accuracy:

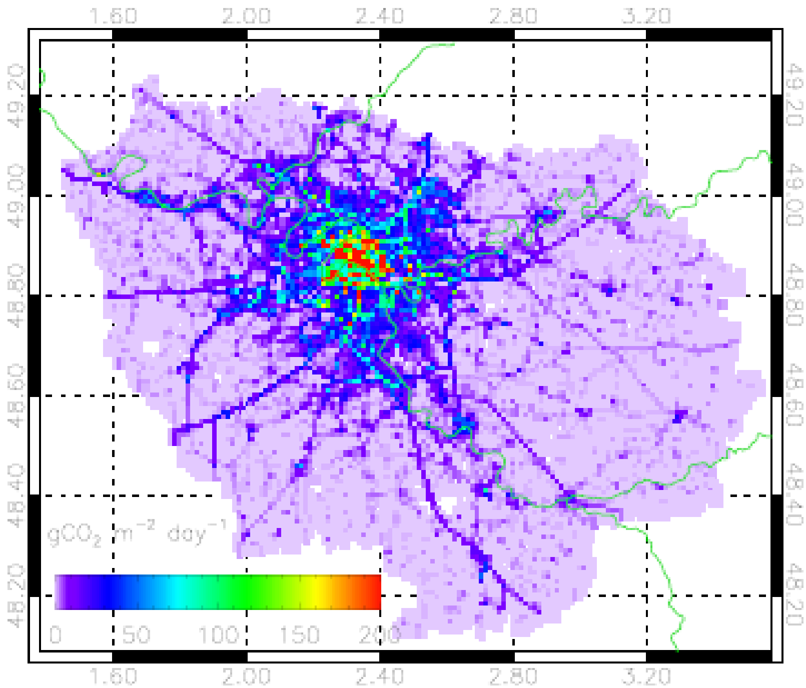
~5 $MtCO_2$/yr
(~10% for Berlin)



Update of Buchwitz et al., AMTD, 2013
(ground-pixel size 2x3 km^2, …)

CarbonSat: City CO_2 Emissions: Paris

Fossil fuel CO_2 emissions
Paris & surroundings



Prior uncertainty vs **CarbonSat**

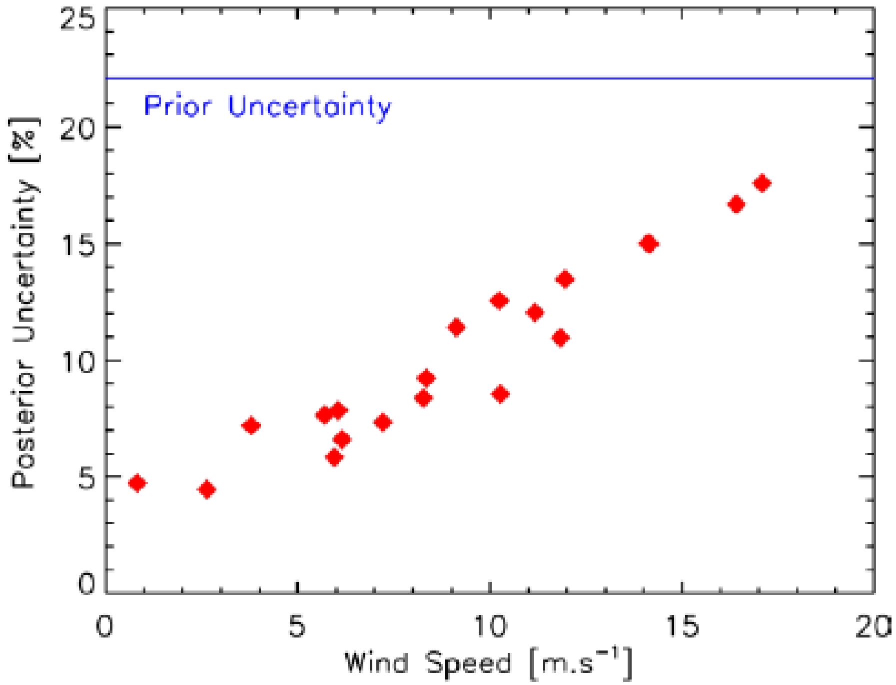
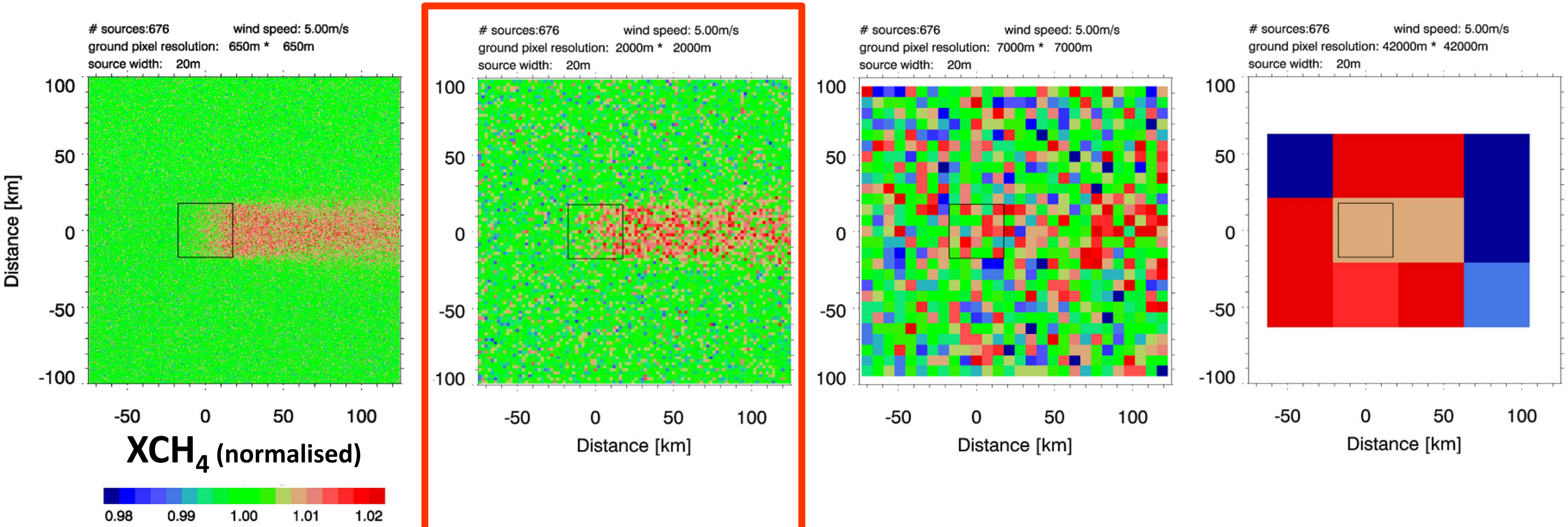


Figure 24: Left: Map of the estimated fossil fuel CO2 emissions in the Ile de France region surrounding Paris. Right: Uncertainty in the 6-11AM fossil fuel emissions for the Paris area as a function of wind speed. The blue line shows the estimated current uncertainty. The red dots are uncertainty when CarbonSat data is applied and account for CarbonSat sampling (clouds) and atmospheric transport conditions.

Courtesy of F.-M. Bréon, LSCE

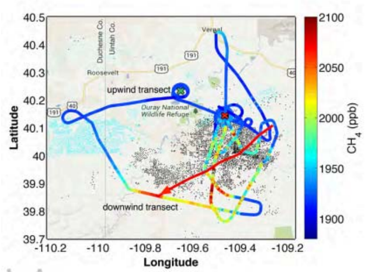
Methane Leackage from Gas Production

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)

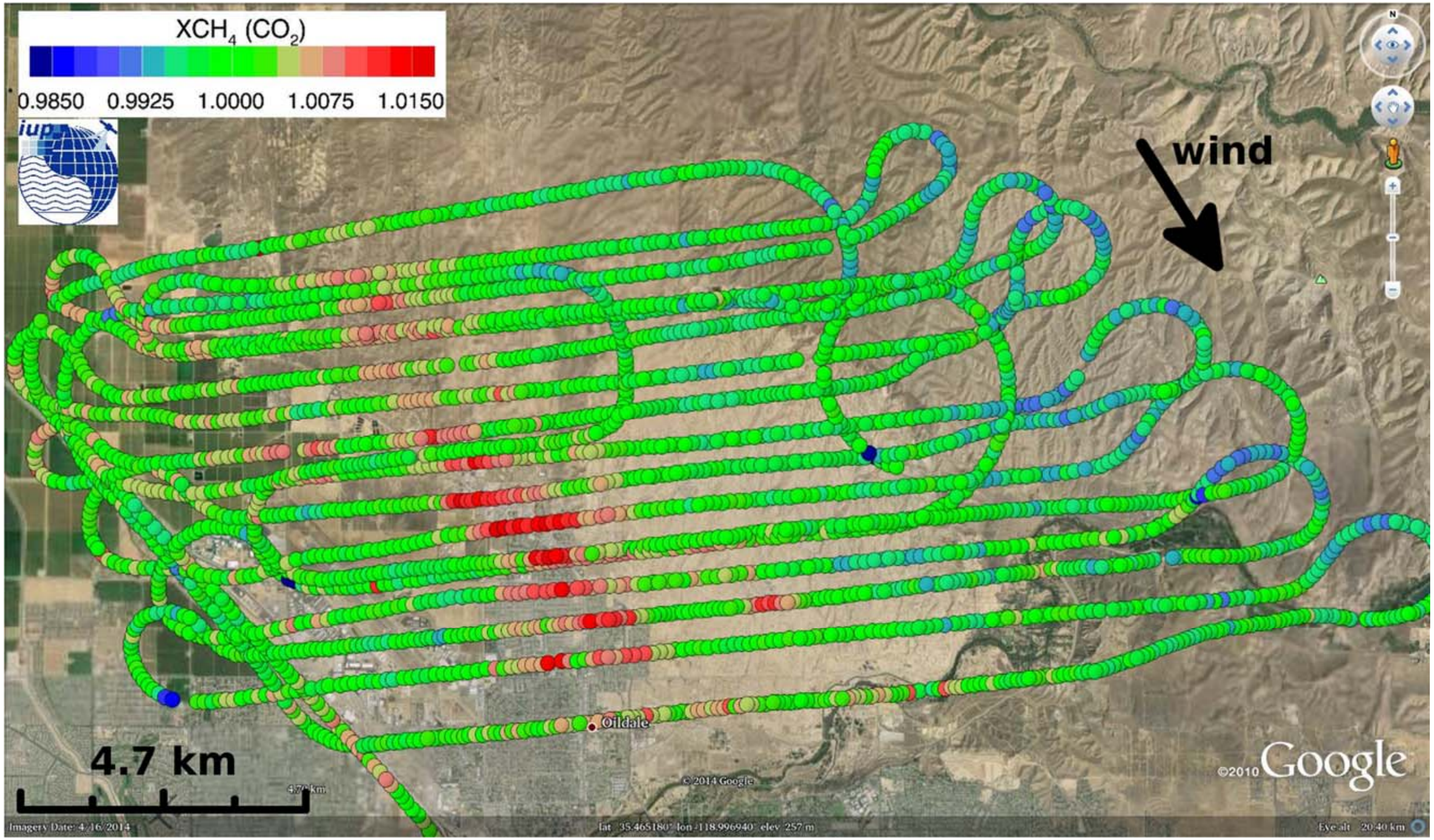


(#) converted to 42 km x 42 km

Bovensmann et al., ESA Living Planet Symposium, Edinburgh, 2013
based on Krings et al.

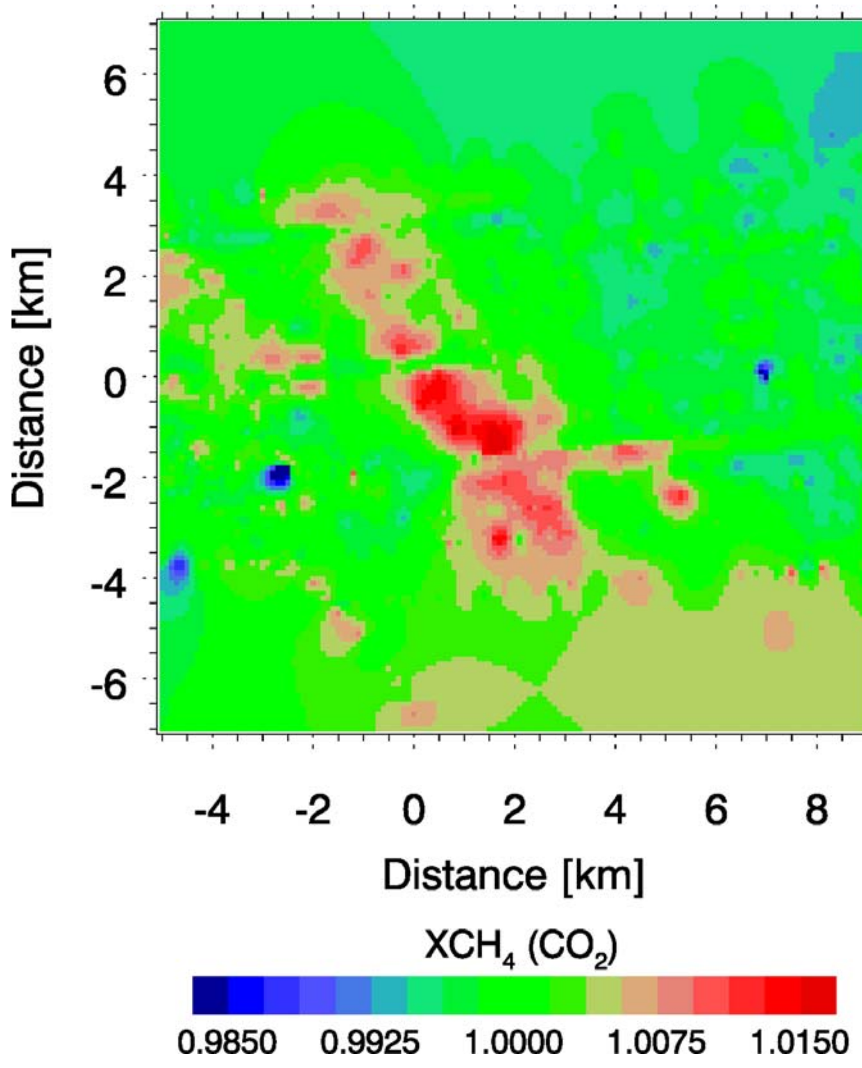
COMEX Campaign (USA) Results: Oil Field CH_4

Airborne remote sensing data (MAMAP) from California, August/Sept. 2014, **NASA/ESA funded Campaign COMEX**

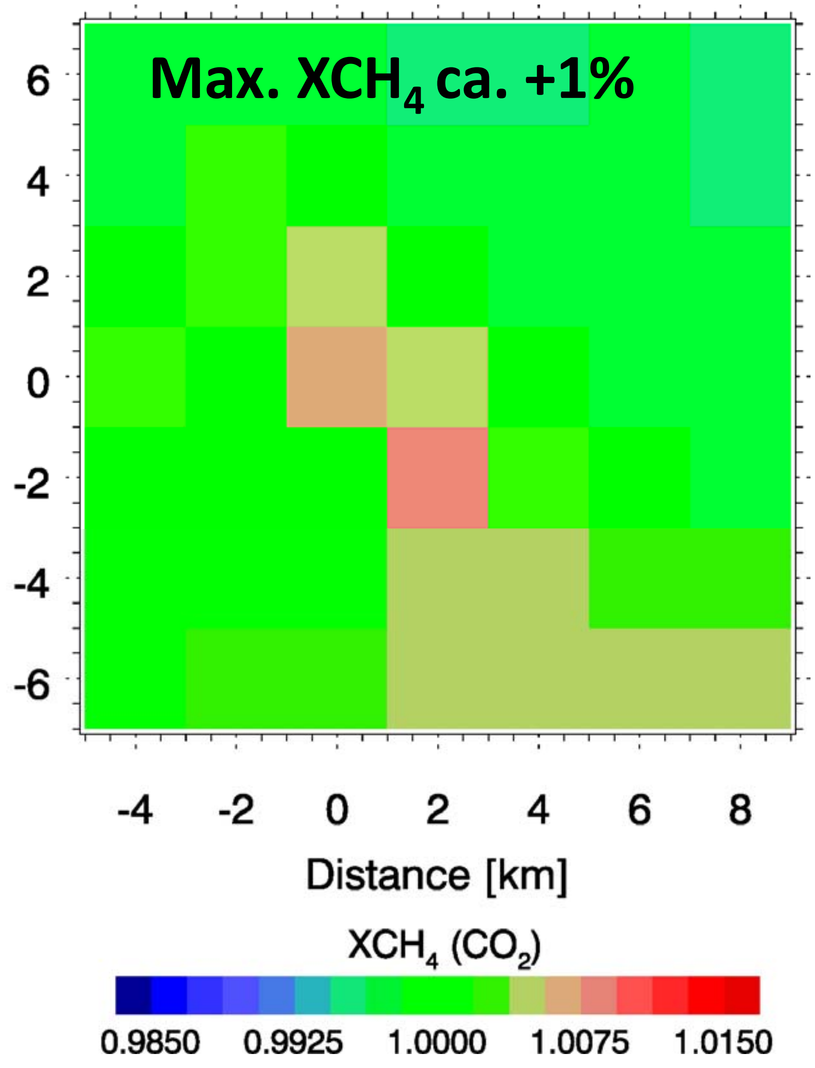


California Oil Field CH_4

MAMAP interpolated:



What CarbonSat will see at 2x2 km² resolution:



Summary

- 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
- Quantification of **natural and anthropogenic** CO_2 and CH_4 sources and sinks ("fluxes") **on various temporal and spatial scales**
- First satellite mission optimized for detection and quantification of **CO_2 and CH_4 emission hot spots** via greenhouse gas imaging
- System, scientific support studies and campaign data analysis on-going
- 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

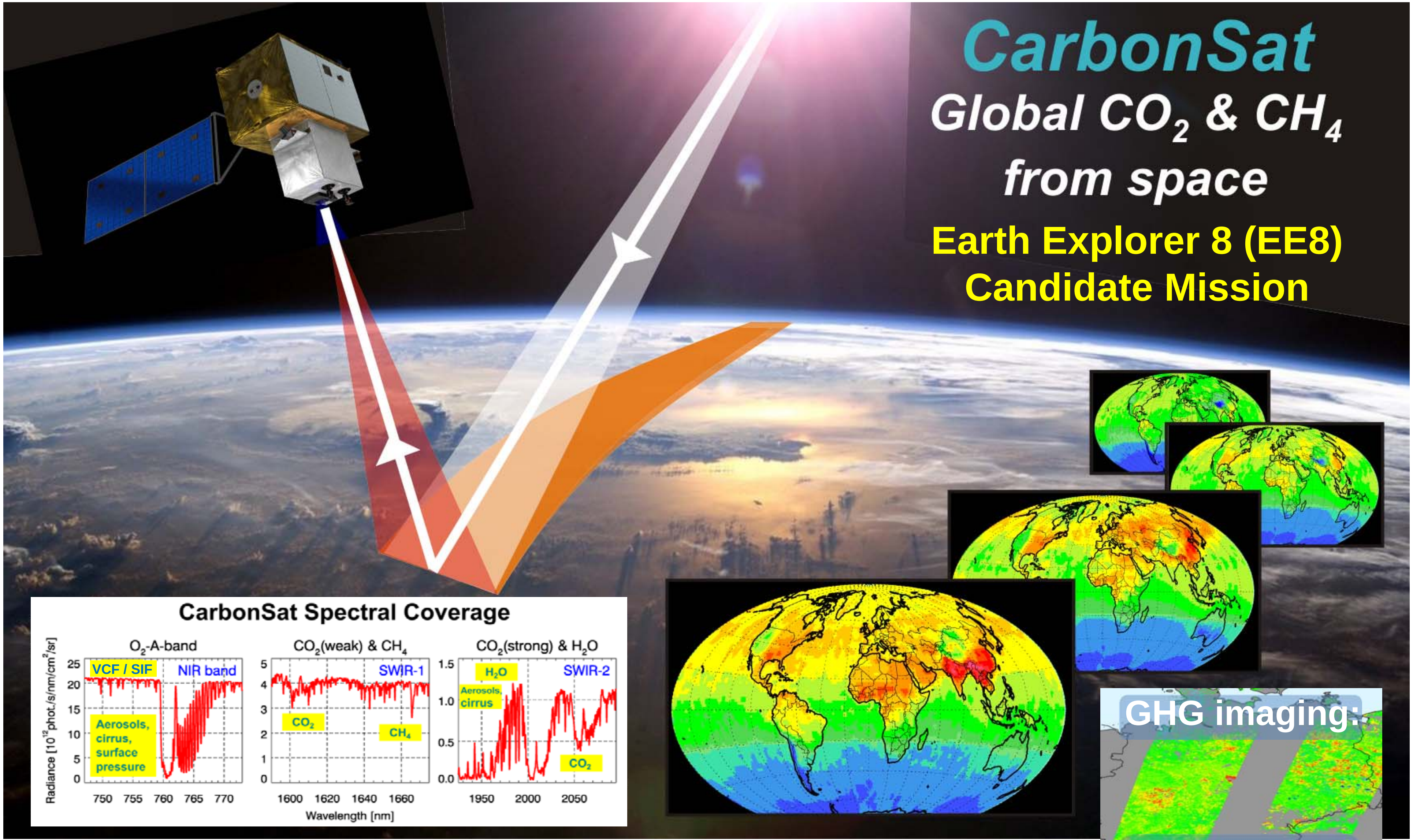
As a critical input to the decision-making process that will lead to the selection of ESA's eighth Earth Explorer mission, the Earth observation scientific community is invited to a User Consultation Meeting at the Academy of Fine Arts in Krakow, Poland on 15–16 September 2015.

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