CarbonSat, ESA's Earth Explorer-8: Candidate Mission Overview

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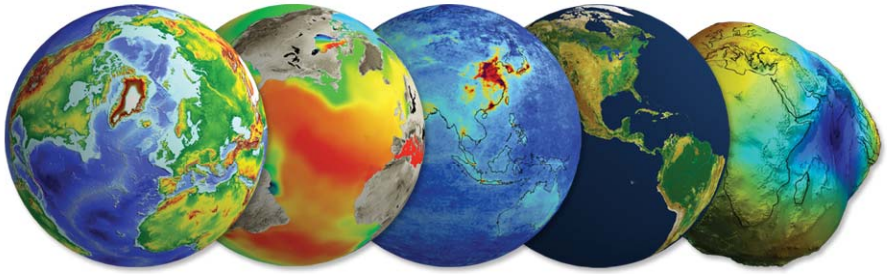
and the CarbonSat MAG &

Science Study Teams



European Space Agency

CarbonSat: Mission Advisory Group (MAG)

Mission Advisory Group:

- Heinrich Bovensmann, IUP, University of Bremen, Bremen, D (Chair)
- Hartmut Bösch, University of Leicester, UK
- Dominik Brunner, EMPA, Dübendorf, CH
- Philippe Ciais, LSCE, Gif-sur-Yvette, F
- David Crisp, JPL, Pasadena, USA
- Han Dolman, Free University, Amsterdam , NL
- Gary Hayman, Centre for Ecology and Hydrology, Wallingford, UK
- Sander Houweling, SRON, Utrecht, NL
- Günter Lichtenberg, DLR-IMF, Oberpfaffenhofen, D

Two scientific study teams:

- Mission Requirement Consolidation Study: IUP University of Bremen (lead), University of Leicester, SRON
- Inverse Modelling Study: NOVELTIS (management lead), LSCE (science lead), SRON, IUP-UB, EMPA, MPI-BGC

Material from both study teams will be used in this presentation

Candidate Earth Explorer 8: CarbonSat Mission Objectives

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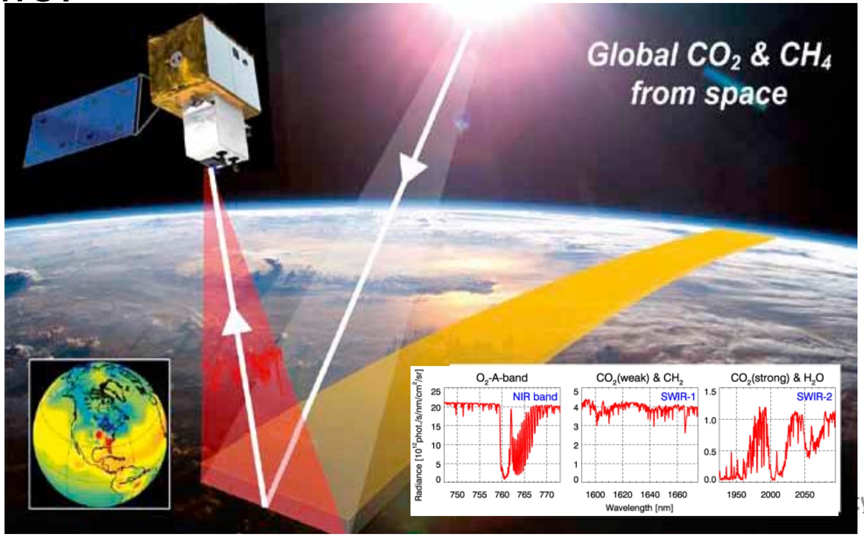
Scientific and societally-relevant objectives:

- quantify CO_2 & CH_4 sources and sinks on global, regional & local scales
- identify CO_2 uptake mechanisms of terrestrial biosphere
- identify response of CO_2 & CH_4 sources and sinks to climate change
- contribute to independently estimate local greenhouse gas emissions

Flux inversion using models in conjunction with measurements of atmospheric CO_2 and CH_4 fields will allow scientists to disentangle anthropogenic and natural sources and sinks of CH_4 and CO_2 from local to global scale from space for the first time.

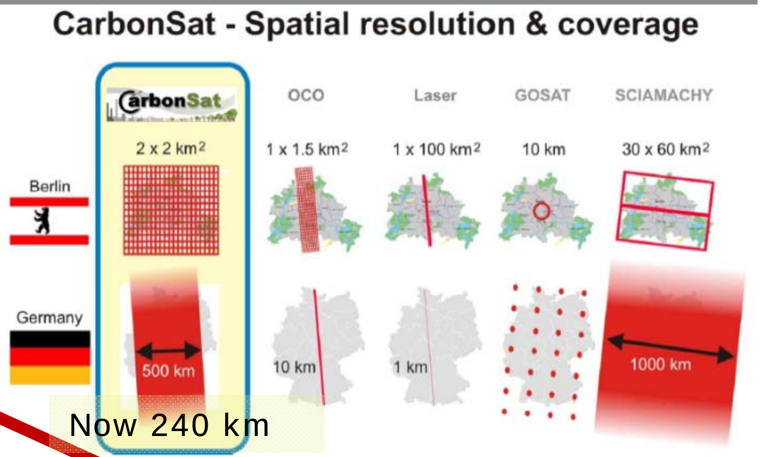
Recent **WMO** press release: http://www.wmo.int/pages/mediacentre/press_releases/pr_965_en.html

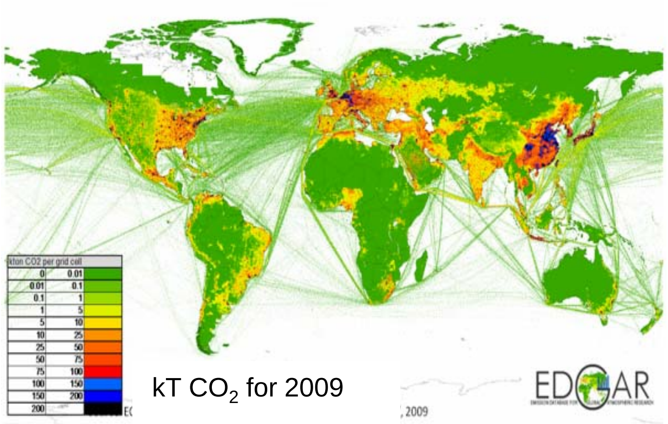


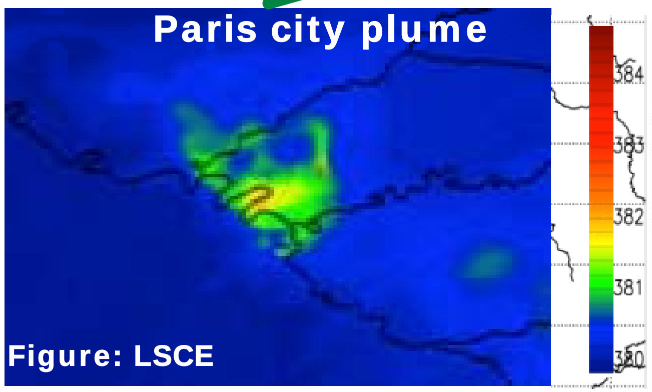
CarbonSat Science Goals

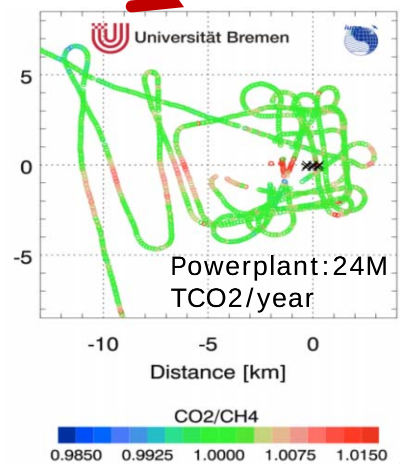
CarbonSat will address:

- Better top-down constrain on regional and country scale flux inversions (mainly **natural fluxes**)
- **New: local scale** top-down constraint
- **New: MegaCity** scale top-down constraints









CarbonSat Science Objectives

Science objectives of CarbonSat after flux inversion:

Objective and scale	Temporal scale (TBC)	Domain scale (TBC)	Spatial scale (lat x lon) (TBC)	Required accuracy (TBC)	
				Goal	Threshold
CO_2 regional	Monthly Annual	Global Global	500x500 km^2 500x500 km^2	0.2 $gC/m^2/day$ (1.5 MtC)[#] 0.05 $gC/m^2/day$ (4.6 MtC)[#]	0.5 $gC/m^2/day$ (3.8 MtC)[#] 0.1 $gC/m^2/day$ (9.1 MtC)[#]
CO_2 city[†]	Overpass time, 1–4 per month	240x240km^2	50x50 km^2	2 $MtCO_2/yr$ [$]	4 $MtCO_2/yr$ [$]
CO_2 point sources[&]	Overpass time, 1–4 per month	80x80km^2	2x2 km^2	1 $MtCO_2/yr$ [$]	2 $MtCO_2/yr$ [$]
CH_4 regional	Monthly	Global	500x500 km^2	5 $mgCH_4/m^2/day$ (38 $ktCH_4$)[#]	15 $mgCH_4/m^2/day$ (114 $ktCH_4$)[#]
CH_4 point sources	Overpass time, 1–4 overpasses per month	80x80km^2	2x2 km^2	4 $ktCH_4/yr$ [$]	8 $ktCH_4/yr$ [$]

[#] Fluxes in parenthesis refer to the spatial and temporal scale of the requirement.
[†] For targets larger than 20 $MtCO_2/yr$ (corresponding to mega-city scale emissions (e.g., Paris, Los Angeles)), the required accuracy is 10% (G)/20% (T).
[$] Instantaneous fluxes expressed on an annual time scale, excl. wind speed error
[&] For targets larger than 10 $MtCO_2/yr$, the required accuracy is 10% (G)/20% (T).

CarbonSat Mission Requirements

Single error of column-averaged mixing ratios
- XCO_2: 1- 3 ppm precision, <0.5 ppm bias
- XCH_4: 6 - 12 ppb precision, <5 ppb bias

High spatial resolution and good coverage:
- 4 km² ground pixel,
- 180–240 km swath width

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

Modes:
- Nadir imaging (main); for land & ocean
- Sun-glint; for optimised ocean coverage

Clear-sky fraction

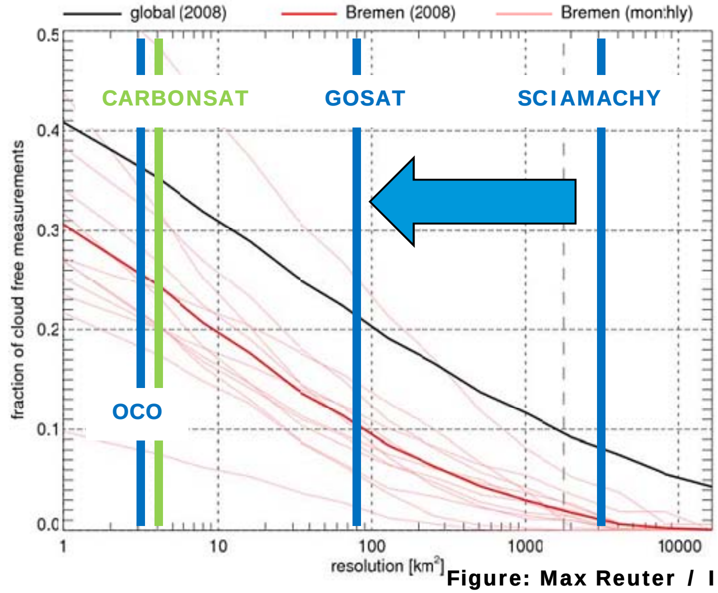
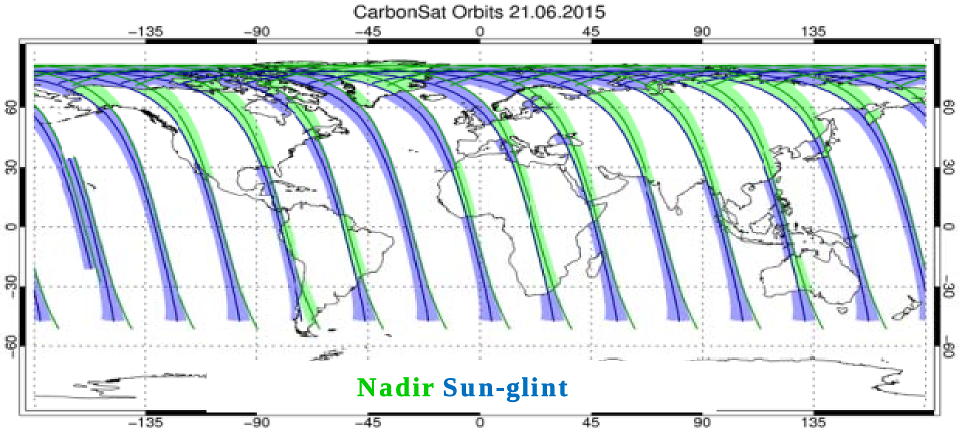


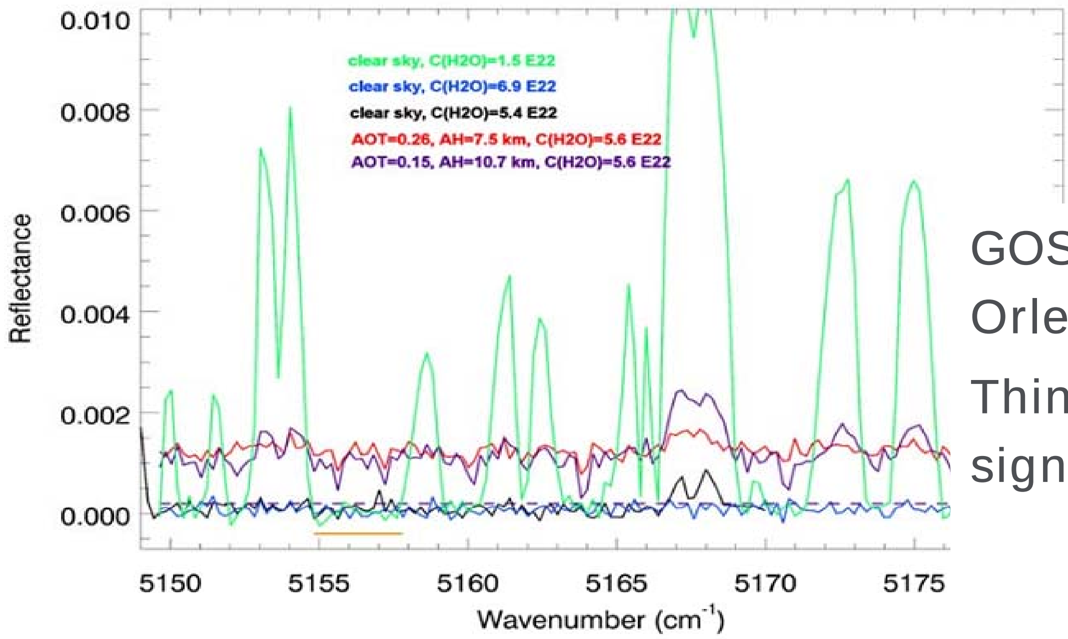
Figure: Max Reuter / IUP



CarbonSat Number of Clear-Sky Observations				
Instrument	Spatial resolution [km^2]	Total number observations per day	Clear-sky frequency	Total number clear-sky observations per day
CarbonSat	4	13.500.000	23%	3.100.000
OCO	3	1,680,000	27%	453,600
GOSAT	85	10,000	13%	1,300
SCIAMACHY	1800	70,000	5%	3,500

Different approach:

- Trade spectral resolution for SNR and observation band width
- Thick clouds → use small spectral bands in continuum at higher SSD
- Thin cirrus → use strong H_2O vapour band around 2 µm
- Clouds → use available spatially oversampled data, i.e. intrinsic imager
- Fluorescence → use more Fraunhofer lines at higher SNR (for corrections, but will also be a secondary product)



GOSAT measurements around Orleans (FR) from 1.93-1.94 µm.

Thin cirrus immediately raise the signal from the noise level.

CarbonSat Observational Requirements

Spectral requirements:

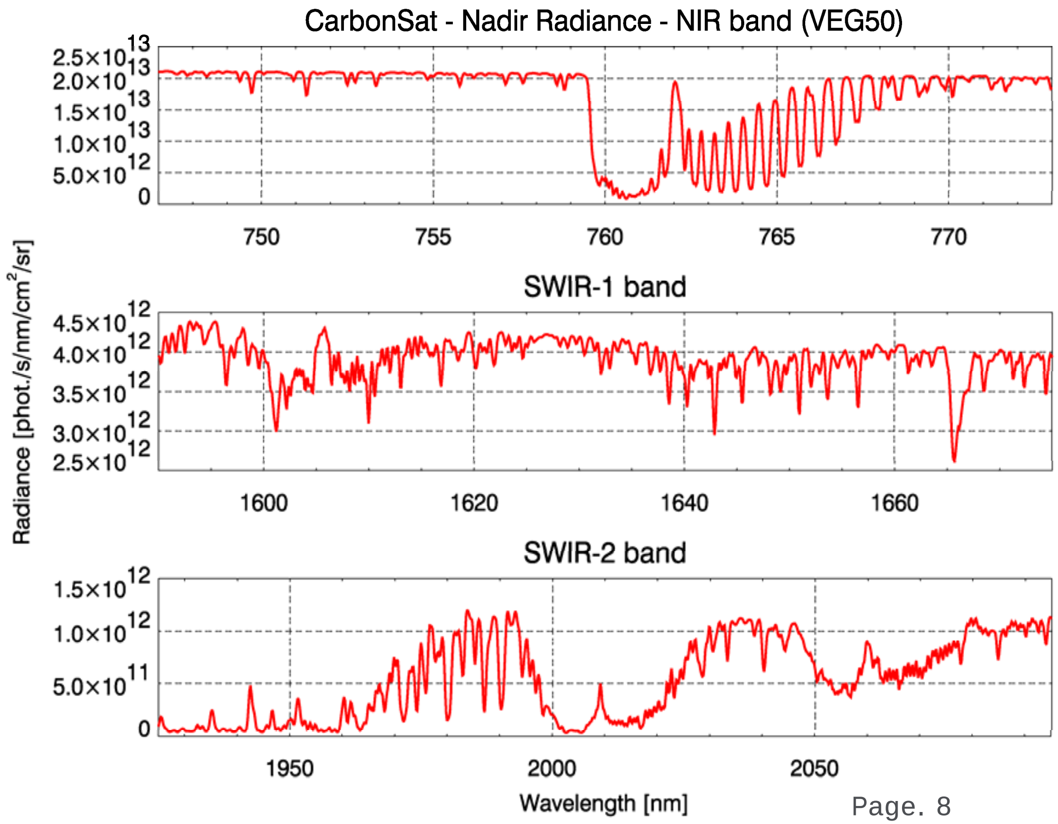
Band	NIR	SWIR-1	SWIR-2
Range [nm]	747 – 773	1590 – 1675	1925 – 2095
Resolution	0.1 nm	0.3 nm	0.55 nm
Sp. sampling	3 – 6	3 - 6	3 – 6

SNR requirements:

Band	L_{ref}	SNR_{ref}
NIR	4.2×10^{12}	150
SWIR-1	1.5×10^{12}	160
SWIR-2	3.8×10^{11}	130

Full performance required in signal dynamic range where

- SZA: 0 – 75 degrees
- Albedos:
  - o 0.10 – 0.5 NIR
  - o 0.05 – 0.4 SWIR-1
  - o 0.05 – 0.4 SWIR-2
- <2% polarization sensitivity
- 2-3% absolute and relative radiometric accuracy



CarbonSat Observational Requirements

Higher spatial sampling (HSS) shall be provided which allows sub-pixel cloud detection:

- Spatially un-binned
- Spectrally binned

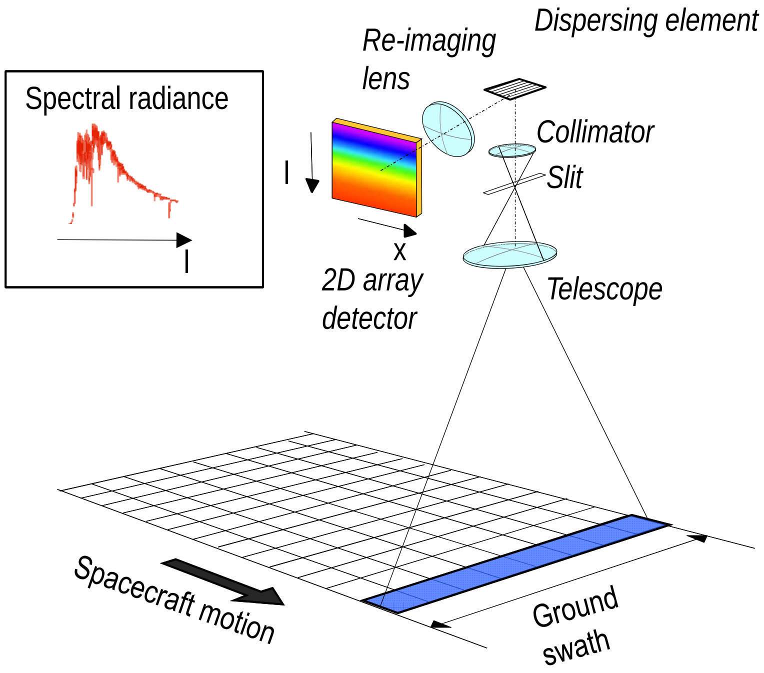
Intrinsic imager!

HSS band ID	Wavelength (nm)	Width (nm)	Information objective
NIR			
HSS-01	750.3	0.3	Surface albedo / continuum level
HSS-02	751.3	0.3	Fluorescence from solar Fraunhofer line
HSS-03	752.0	0.3	Surface albedo / continuum level
HSS-04	757.0	4.0	Surface albedo / continuum level /clouds
HSS-05	762.0	4.0	Cirrus detection from saturated O_2 absorption line
HSS-06	766.0	2.0	Surface pressure from moderate O_2 absorption line with weak temperature dependence
HSS-07	771.0	4.0	Surface albedo / continuum level /clouds
SWIR-1			
HSS-08	1595.4	3.9	Surface albedo / continuum level /clouds
HSS-09	1602.5	3.0	CO_2 absorption line
HSS-10	1618.1	3.9	Surface albedo / continuum level /clouds
HSS-11	1662.0	3.9	Surface albedo / continuum level /clouds
HSS-12	1666.5	3.0	CH_4 absorption line
HSS-13	1671.5	3.9	Surface albedo / continuum level /clouds
SWIR-2			
HSS-14	1935.0	11.0	Cirrus detection from saturated H_2O absorption line
HSS-15	1992.0	2.2	Surface albedo / continuum level /clouds
HSS-16	2010.0	11.0	CO_2 absorption line (strong)
HSS-17	2038.0	5.5	Surface albedo / continuum level /clouds
HSS-18	2070.0	11.0	CO_2 absorption line (moderate)

Page. 9

CarbonSat Concept Overview

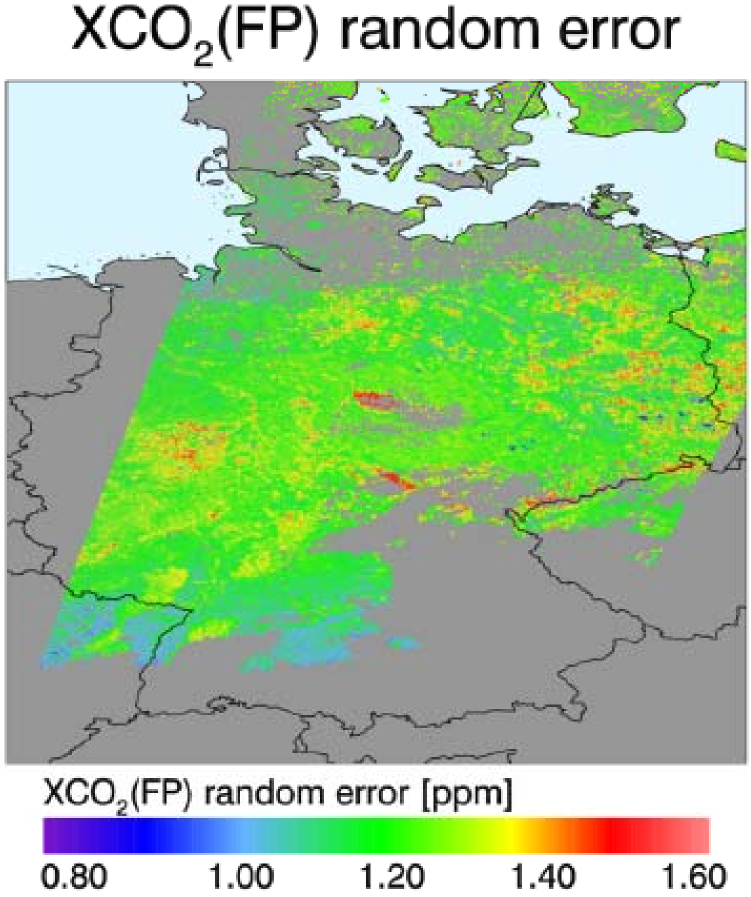
- Pushbroom (across track), along track via spacecraft motion
- 3 imaging grating spectrometers with good spatial and spectral imaging capabilities
- 2-D detectors cooled
- On-board calibration sources (diffusers, lamp, LED)



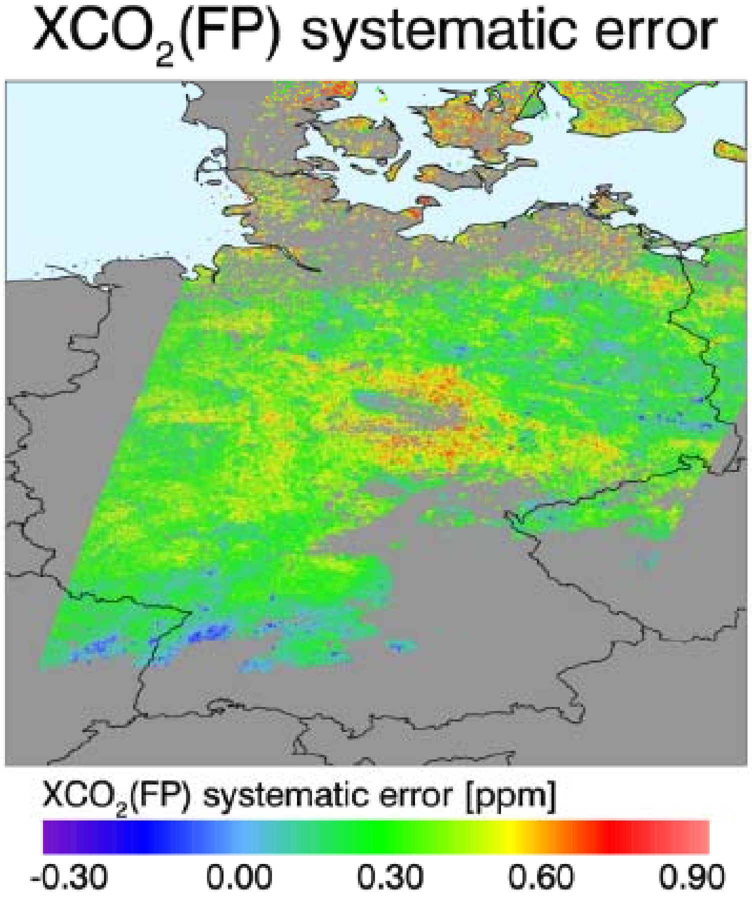
Supporting Scientific Studies

- Study on L1L2 requirements consolidation,
  - Objective to provide the link between L1 and L2
  - Status: started early 2012, led by IUP Bremen and ends mid 2013
  - Provided justification for significant L1 requirement changes while maintaining the mission objectives at L2+
- Study on data assimilation/inverse modelling; LOGOFLUX
  - Objective: to provide the link between L2 and L4 (fluxes)
  - Status: started early 2012, led by NOVELTIS and ends mid 2013
  - Simulated data have been generated providing random and systematic errors based on aerosol, SZA, MODIS clouds, ECMWF p/T/wind, etc
  - Flux inversion tools have been developed and tested to quantify the impact of error sources such as measurement noise, insufficient knowledge on the atmospheric transport, spatial and temporal variations of the fluxes for evaluation of CarbonSat's expected performance at different scales

Full swath XCO_2 random and systematic error



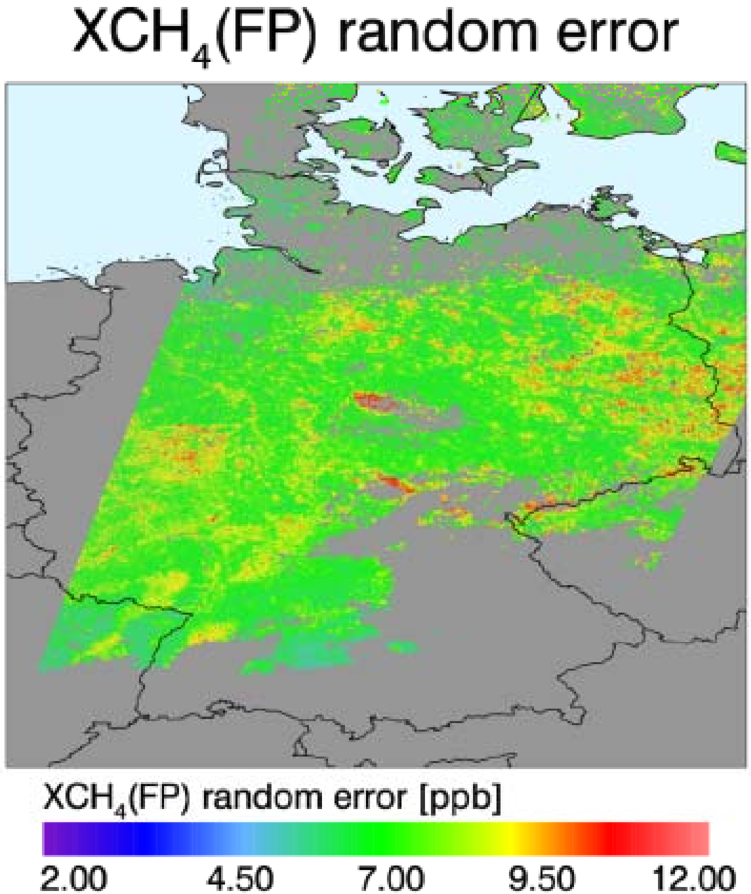
Precision: ~1.2 ppm



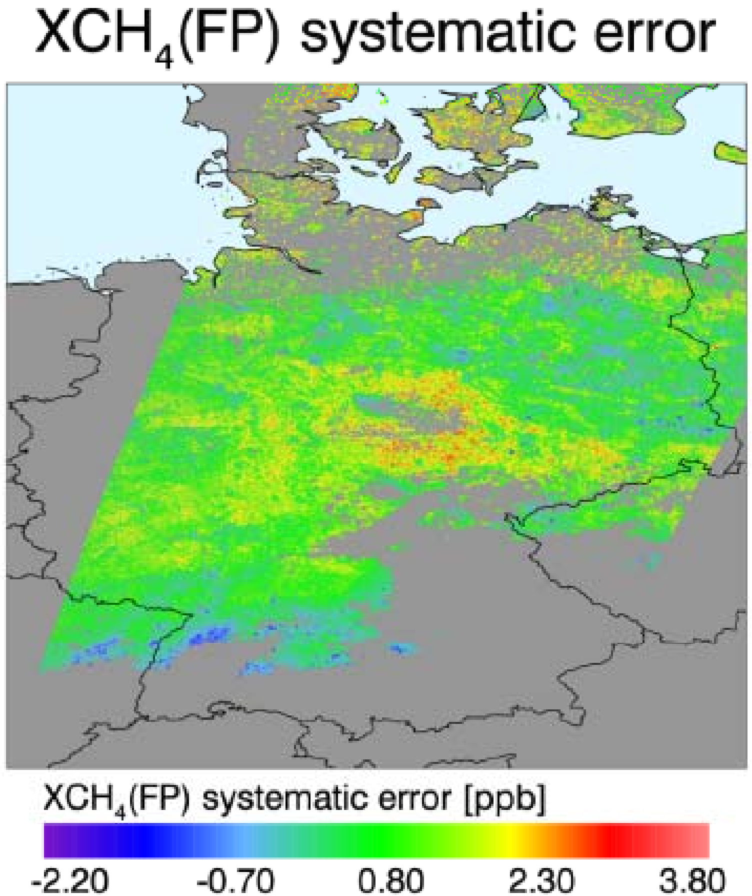
Bias: few 0.1 ppm

Preliminary !

Full swath XCH_4 random and systematic error



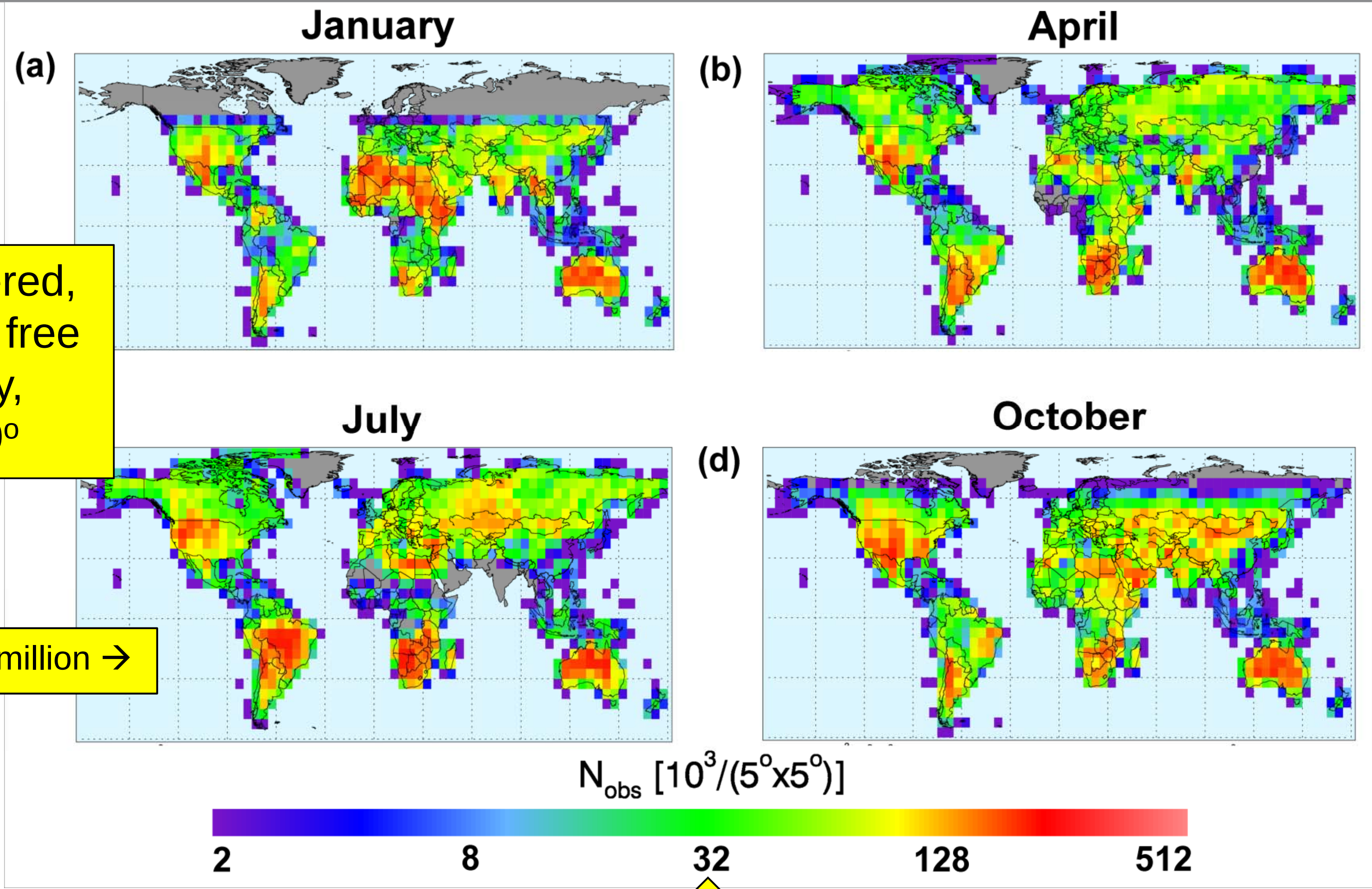
Precision: ~7 ppb



Bias: few ppb

Preliminary !

Simulated CarbonSat data by IUP for 2008: Number of Observations / month per 5° x 5°



Quality filtered, snow & ice free land only, SZA<70°

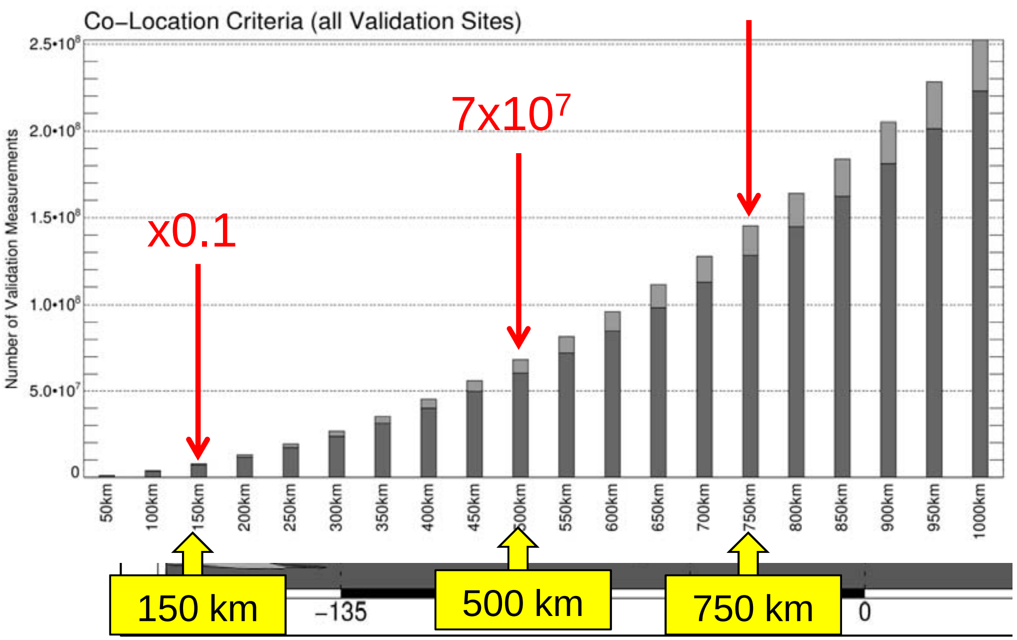
July Total: 46 million →

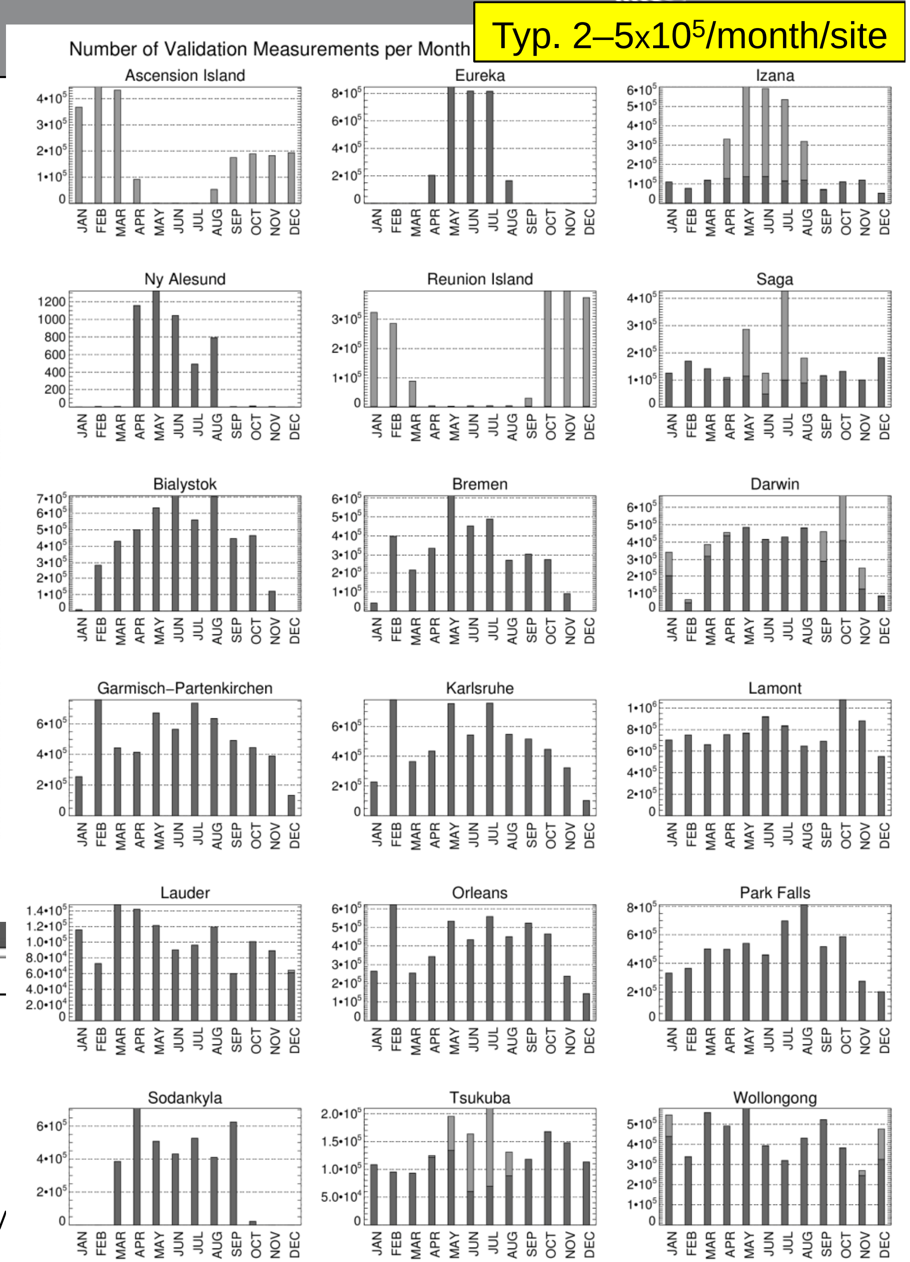
32000 per 5°x5° per month

Buchwitz et al., AMTD (in press)

Validation with TCCON sites

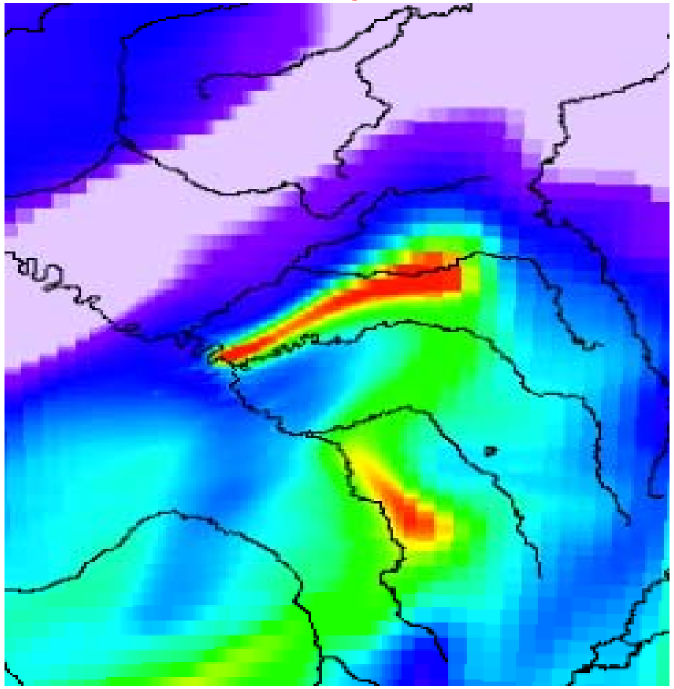
- Within 500km, CarbonSat has about **7×10^7 validation measurements per year**.
- Using 150km would reduce the amount by a factor of 10



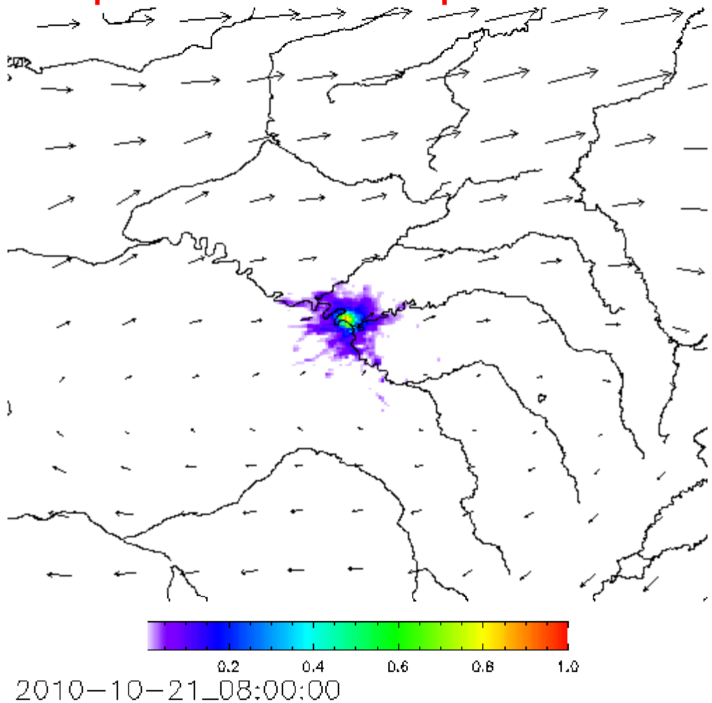


Simulated CO_2 plume from Paris emissions

CarbonSat "Snapshot"



Transport one hour pulse emission



1. Atmospheric transport modelling at high resolution
2. Uses a priori hourly emission, including traffic, household & industry
3. Used to assess CarbonSat capabilities using various flux inversion methods

CarbonSat Campaigns: C-MAPExp (CO_2 & CH_4 Mapping Experiment)

Objectives of C-MAPExp (Aug. 2012)

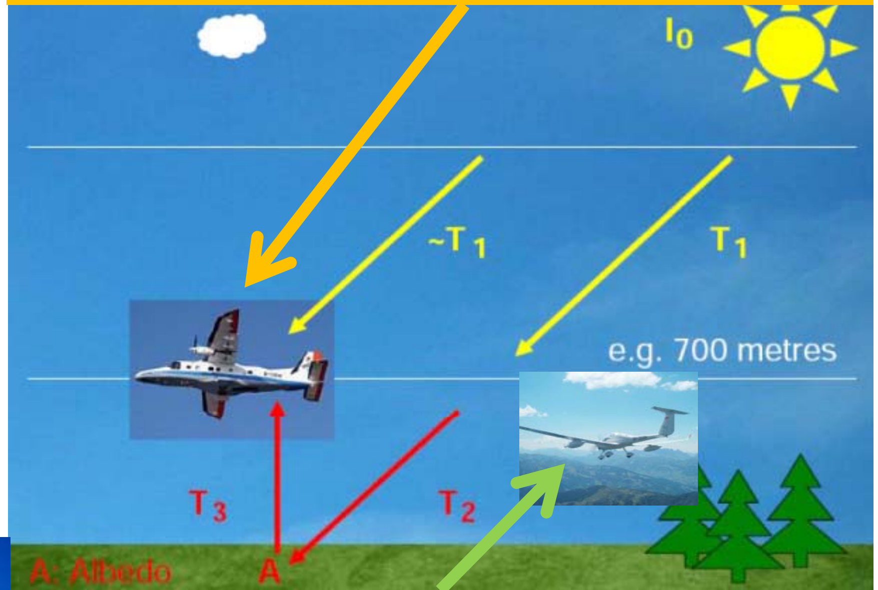
To identify & quantify strong local urban-scale sources of greenhouse gases

Target area:
North Rhine-Westphalia, Germany

Main Sources in the region:

a. Landfills
b. Coal Mining
c. Oil and Gas Refineries
d. Power Plants

Airborne Simulator:
Methane Airborne Mapper–MAMAP from University Bremen



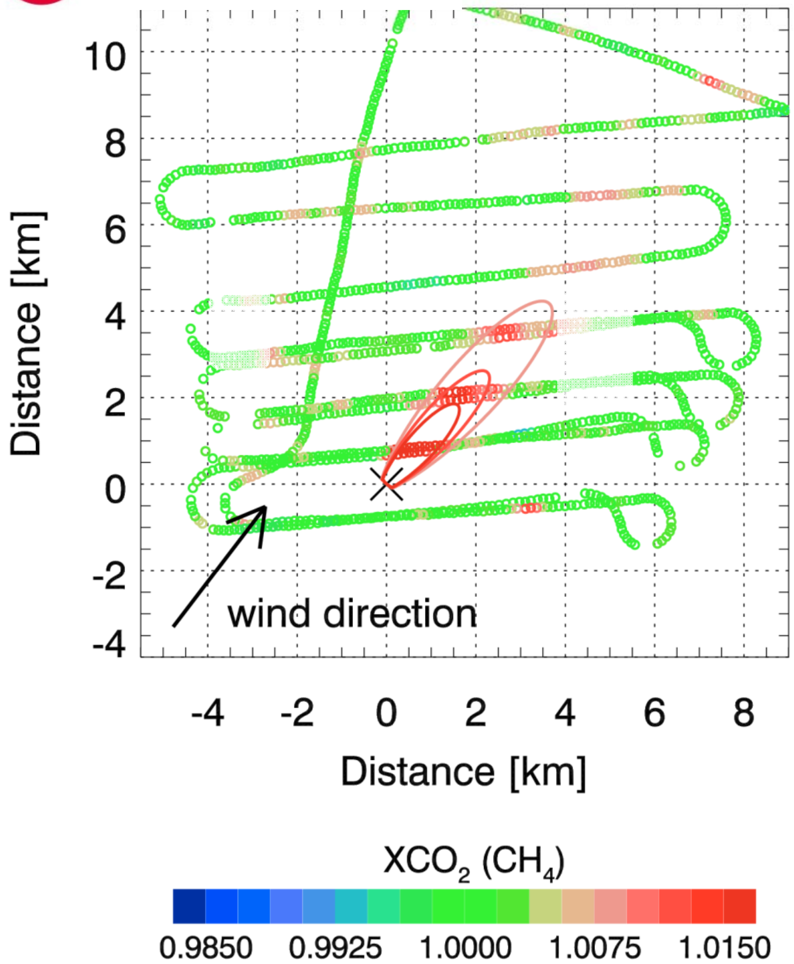
Airborne Validation:
Measuring four-dimensional (time and space) in-situ concentrations CO_2 & CH_4, Wind, Temp, Aerosol

C-MAPExp CO_2: Lignite-fired Power Plant

Universität Bremen

Eschweiler

18.08.2012

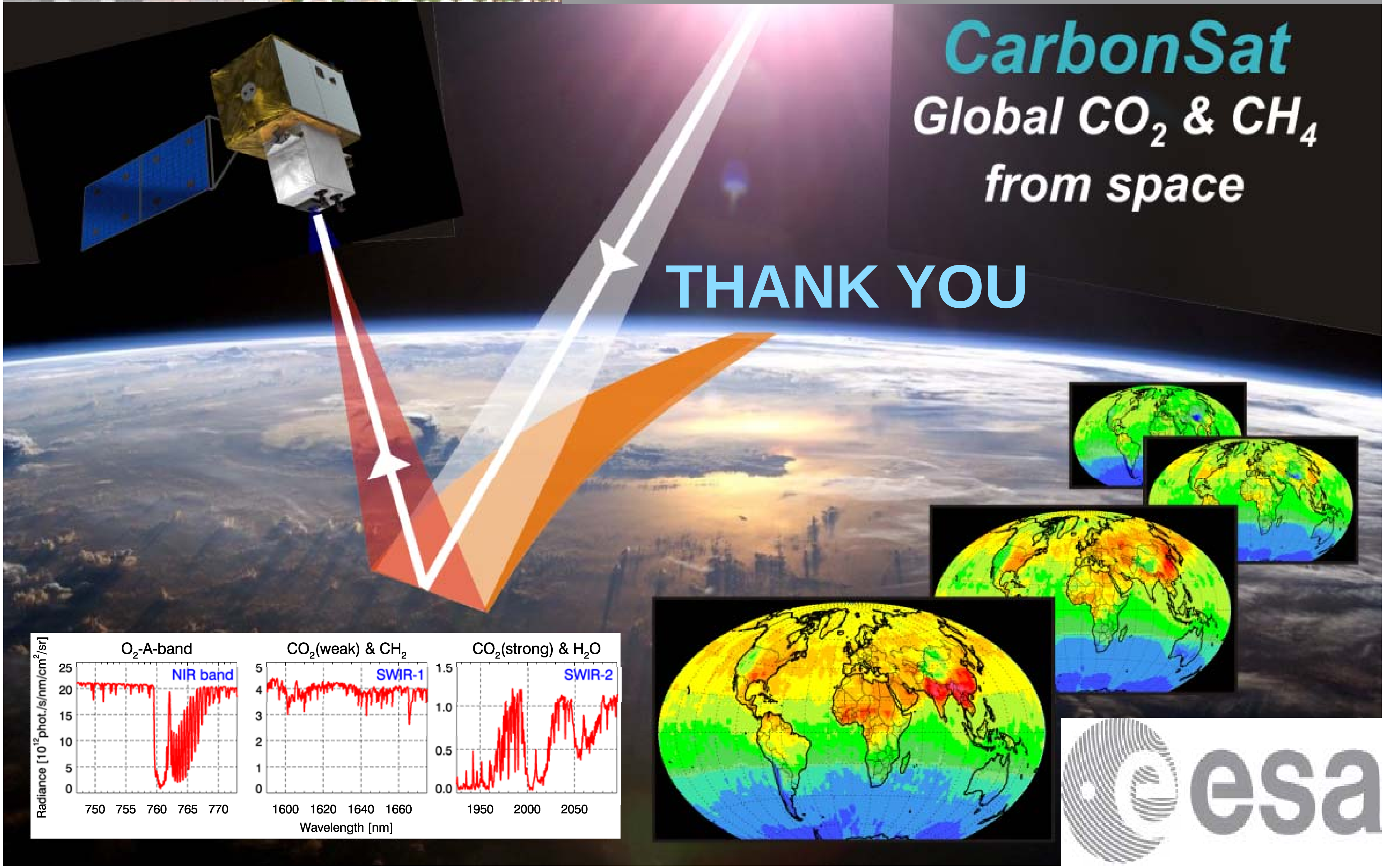


MAMAP XCO2(CH4) measurements over the lignite fired power plant Eschweiler (yearly emission of 19 MtCO2/Yr, E-PRTR 2009)

CarbonSat Summary

- CarbonSat aims to provide: XCO_2 and XCH_4 data (& VCF) with high accuracy, high spatial resolution (**4 km2**) AND good global coverage (**240 km continuous swath**)
- Allowing separation of **natural and anthropogenic** fluxes and **“imaging”** of regions with localised CO_2 and CH_4 emissions
  As a result, to better quantify greenhouse gas **sources and sinks** down to the regional and local scale.
- Two parallel industrial (system studies) on-going
- Supporting scientific studies and campaigns leading to requirement consolidation and concept simplifications
- Other candidate mission is Fluorescence Explorer (FLEX)
- Results from both Earth Explorer-8 candidate missions to be presented at a User Consultation Meeting in 2015 (TBC by ESA)
- Envisaged launch of selected Earth Explorer 8 is around 2020

ESA Earth Explorer 8 Candidate Mission



Simulated typical spectrum: vegetation albedo and SZA of 50 degrees