Measuring Greenhouse Gases from Space

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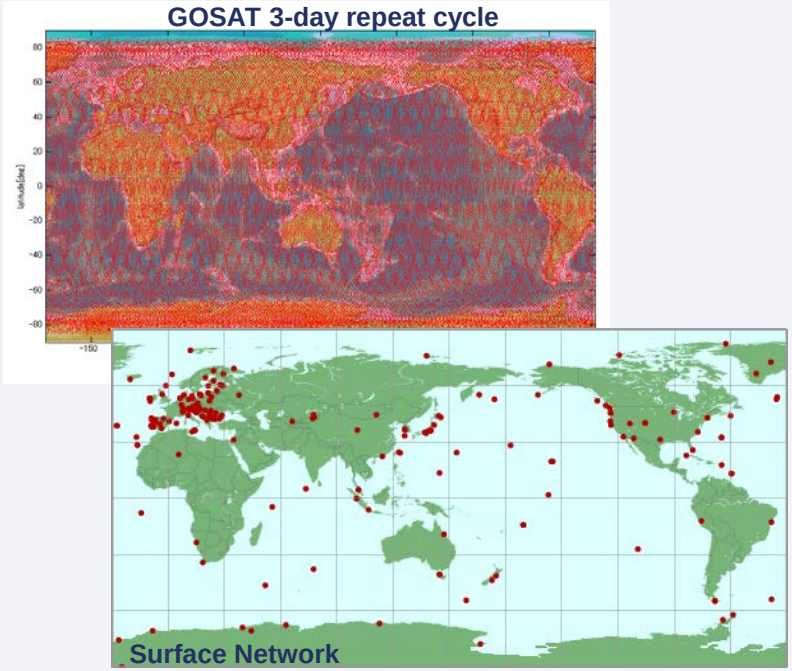
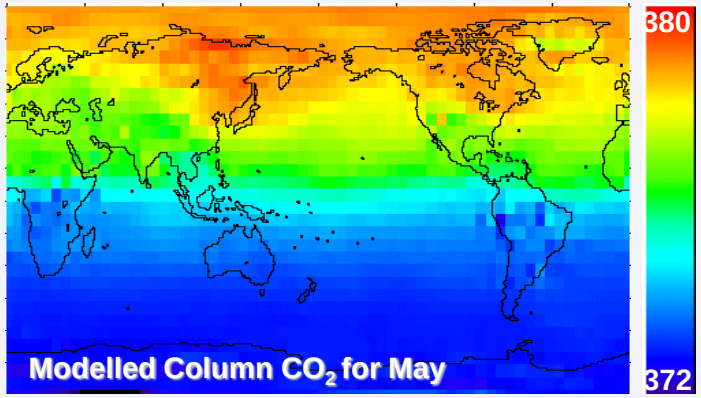
Space based Observations of GHGs

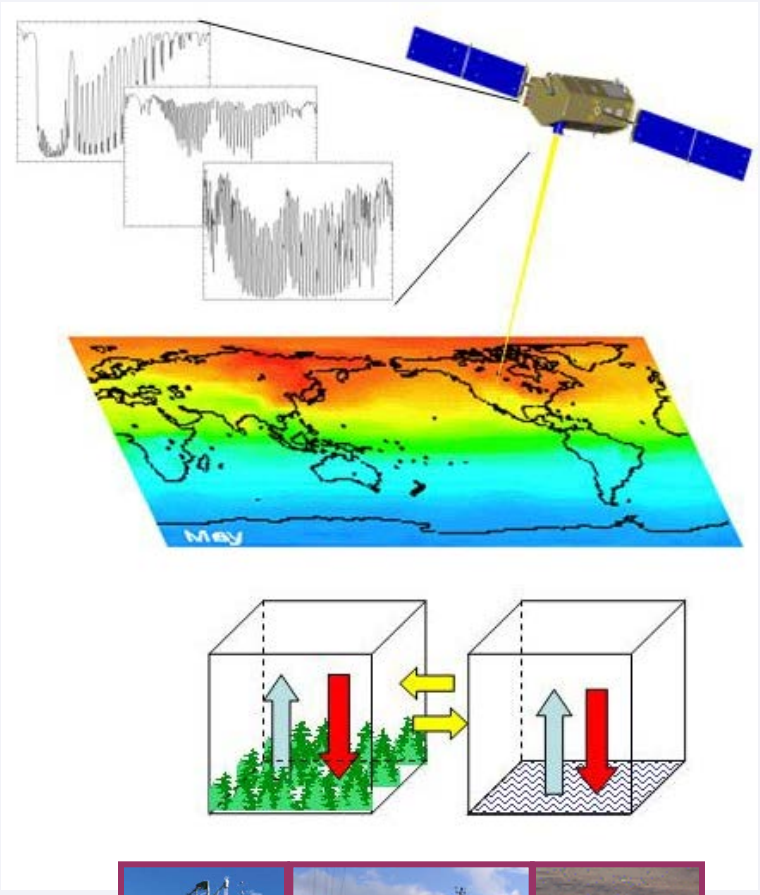
- **Primary benefit:**
  - Uniform coverage of the globe
  - High spatial resolution
- **Primary challenges:**
  - Sensitivity to GHGs in boundary layer
  - High precision needed to quantify small changes in columns (<0.25%)
  - Need to minimize spatial & temporal biases
- **Future Challenges**
  - Persistent cloud cover
  - Need for improved time resolution & spatial coverage
  - Discrimination of the near-surface layer





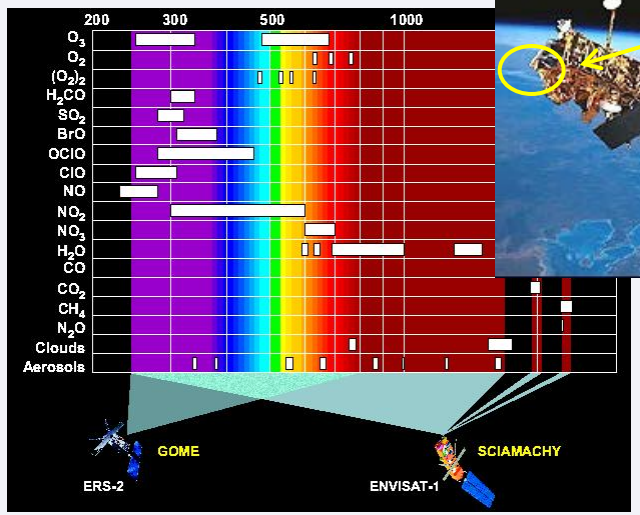
Measurement Approach

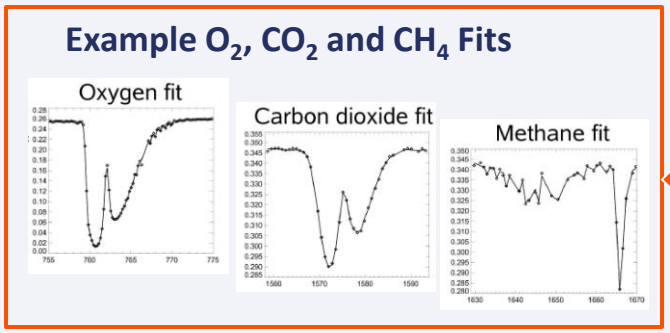
- Collect high-resolution spectra of CO_2 and O_2 absorption in reflected sunlight
  - Mitigates effects from scattering and topography
  - Provides high sensitivity to air near the surface
- Use these data to resolve variations in the *column averaged CO_2 dry air mole fraction, X_{CO2}* over the sunlit hemisphere
- Validate measurements to ensure X_{CO2} accuracies ('tie data to WMO standard')

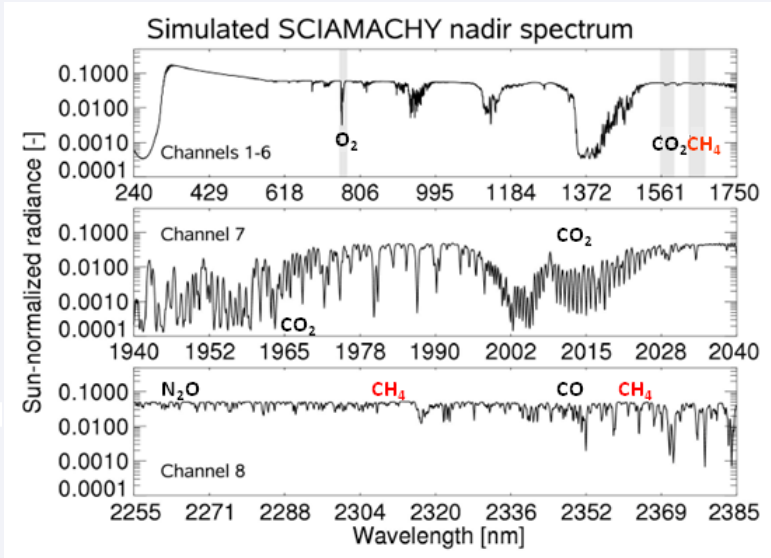


SCIAMACHY - First Satellite Instrument to Measure CH_4 and CO_2 Columns from Space

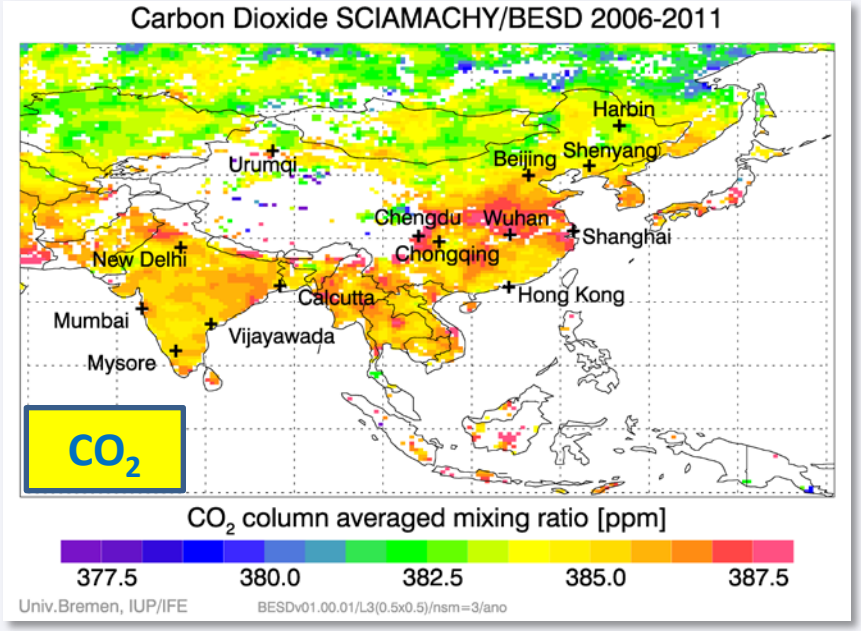
- SCIAMACHY onboard ENVISAT (launched in 2002, ended 2012)
- 8 Channel UV-Vis-NIR imaging spectrometer
- Large nadir footprint (30 × 60 km^2)
- Low spectral resolution (0.2- 1.5 nm)
- Ch. 7 + 8 contain highly resolved CH_4 and CO_2 bands, but channels are strongly impacted by build-up of ice layer on detector

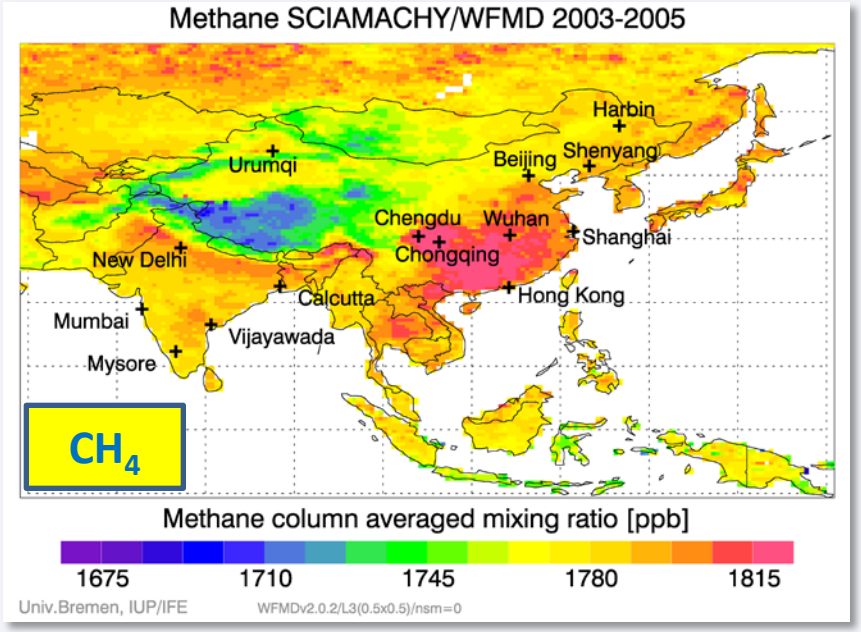


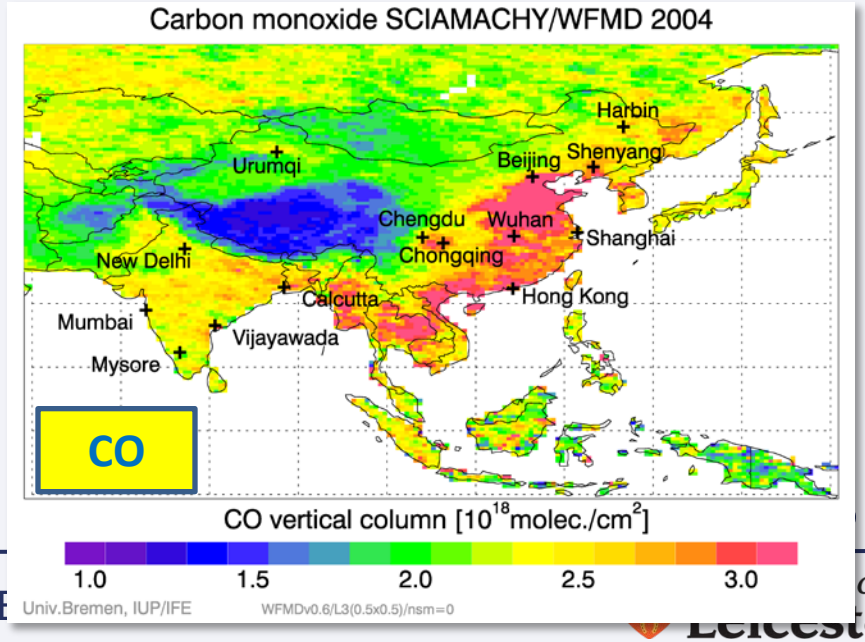




„Carbon Gases“ from SCIAMACHY







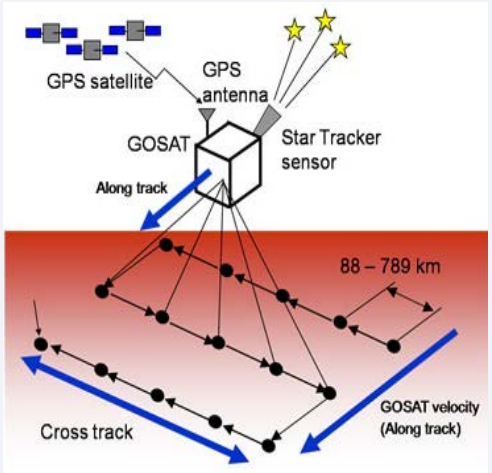
SCIAMACHY

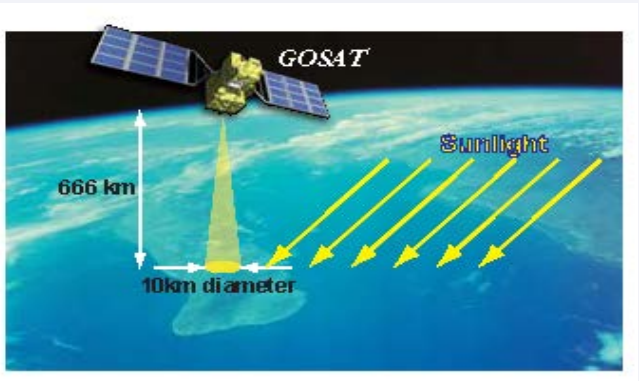
Universität Bremen

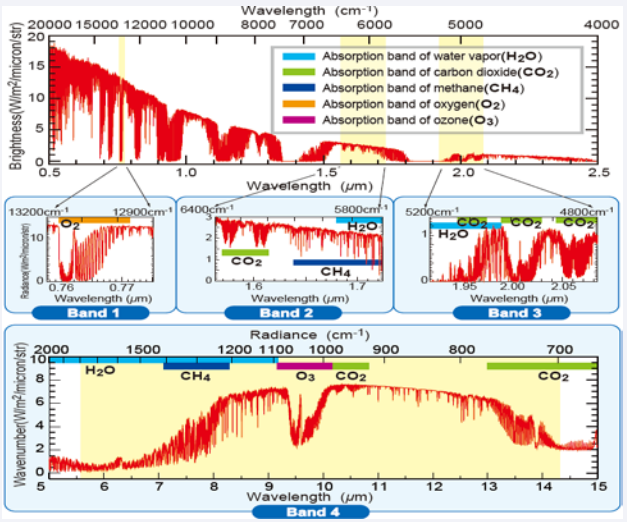
Greenhouse gases Observing SATellite (GOSAT) launched January 23rd 2009

Mission objectives:

1) To monitor the density of greenhouse gases precisely and frequently worldwide.
2) To study the absorption and emission levels of greenhouse gases per continent or large country over a certain period of time.
3) To develop and establish advanced technologies that are essential for precise greenhouse-gas observations.



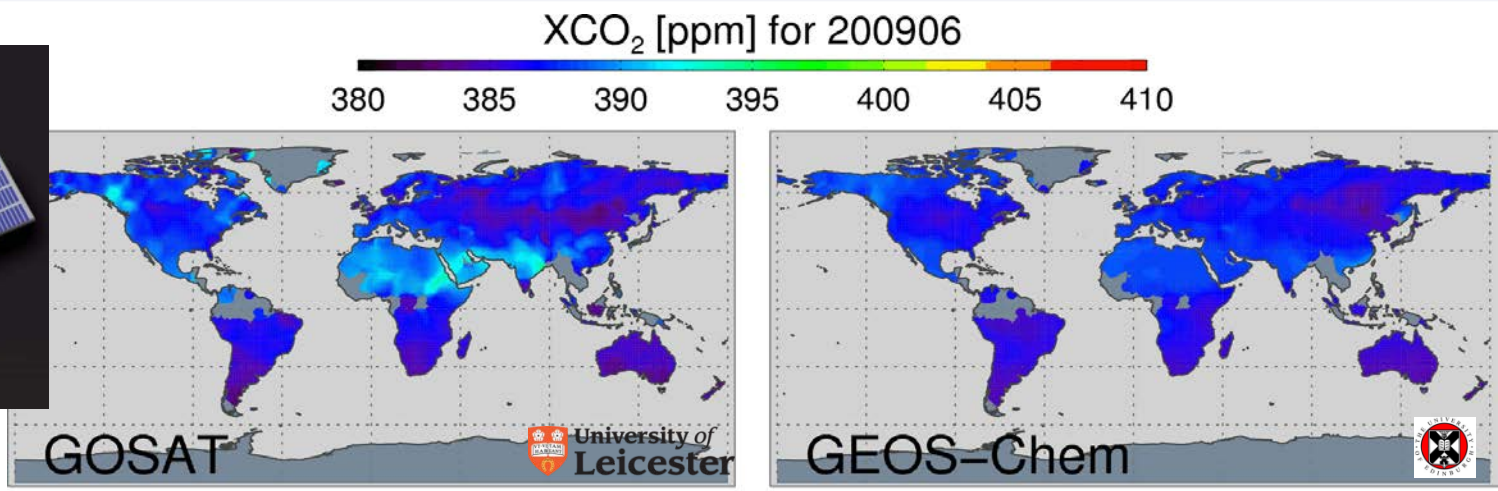




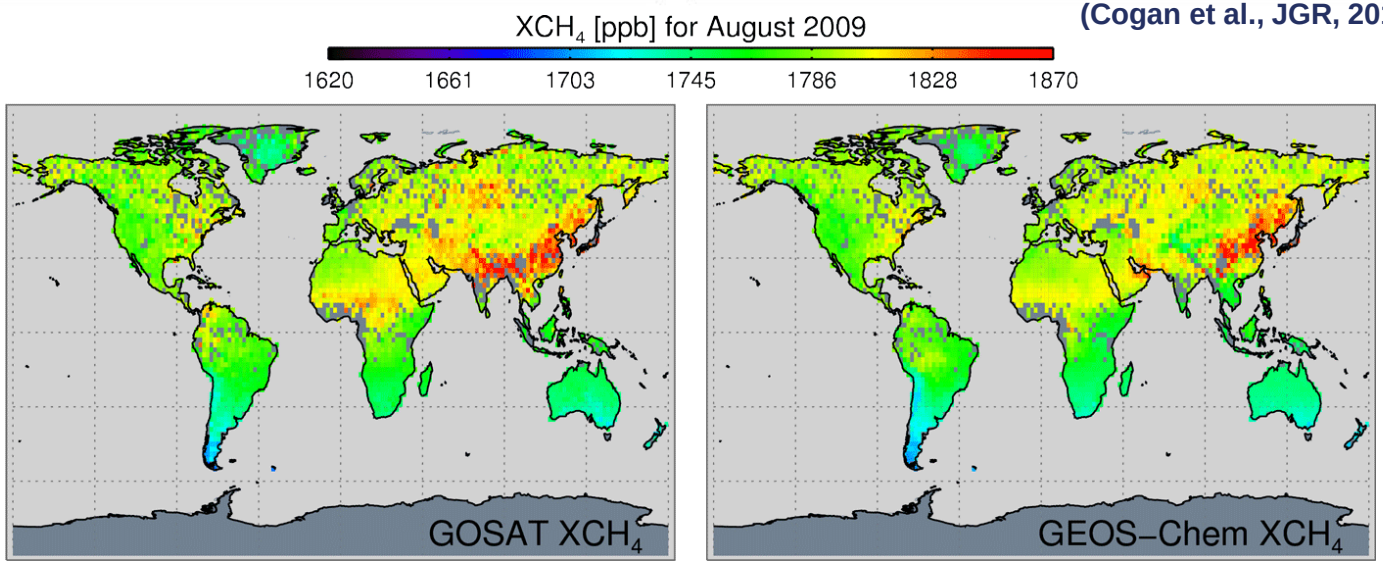
Testing Model Calculations with GOSAT

Dedicated satellite missions provide unprecedented global view of release and uptake of CO_2 and CH_4 by surface processes to critically test and improve models and to track main emission regions

GOSAT – first dedicated GHG satellite



(Cogan et al., JGR, 2012)



(Parker et al., GRL, 2011)

Data Access

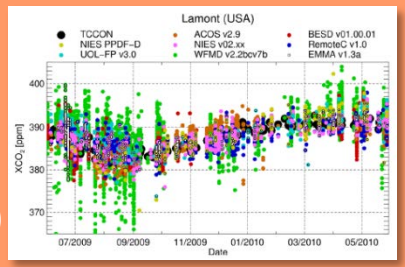
www.leos.le.ac.uk/GHG/data/

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

ESA Climate Change Initiative (GHG CCI)

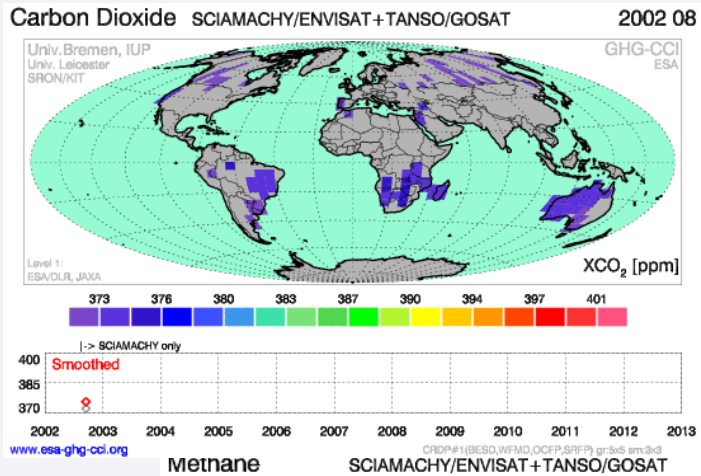
The goal of the GHG-CCI project is to generate and deliver the Essential Climate Variable (ECV) "Greenhouse Gases" (GHG) meeting GCOS (Global Climate Observing System) requirements

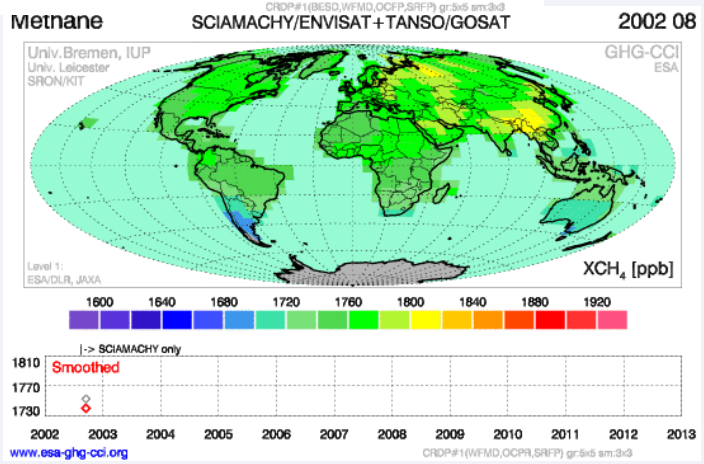
XCO_2: Satellite vs TCCON (Jun 2009 – May 2010)



Algorithm	#	σ [ppm]	Δ [ppm]
ACOS v2.9	1530	2.1	0.9
BESD v01.00.01	2789	2.3	0.9
NIES PPDF-D	460	3.1	0.8
NIES v02.xx	1062	1.9	0.7
RemoteC v1.0	1084	2.5	0.9
UOL-FP v3.0	1086	2.3	0.8
WFMD v2.2bcv7b	8884	4.4	1.3
GCOS:			1ppm
URD:			0.5 ppm

Core ECVs: CO_2 and CH_4 from SCIAMACHY and GOSAT

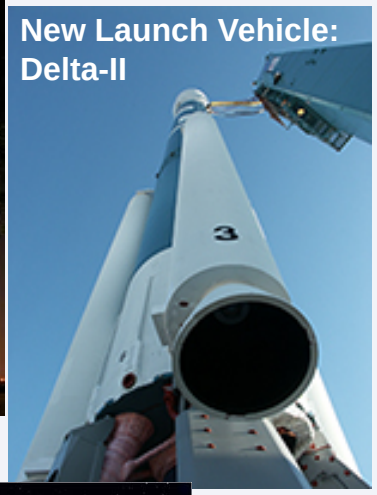


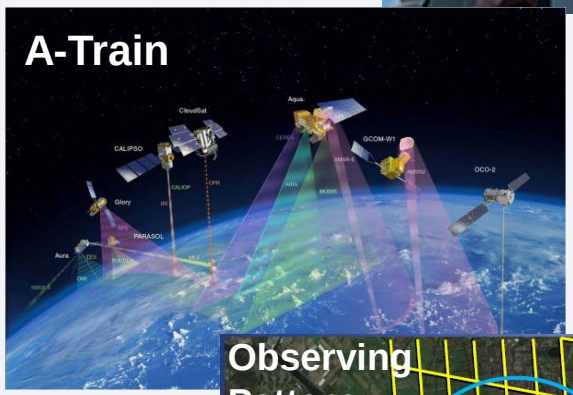


Press releases (4 Sept 2013): Ten years of satellite observations of greenhouse gases (CO_2 and methane)

The next CO_2 Mission: NASA OCO-2

- NASA decided to build-to-print "Carbon Copy" of OCO (OCO-2) scheduled for launch **1 July 2014**
- OCO-2 will fly at the head of A-Train, but 217 km East of AQUA (joint with Cloudsat and Calipso)
- OCO-2 will deliver
  - Smaller footprints (3km^2)
  - Higher precision (0.2-0.3%)
  - Near-global sampling over continents and ocean (sunglint and nadir sounding)
- ➢ UK Links: OCO-2 STM (Boesch, Palmer)

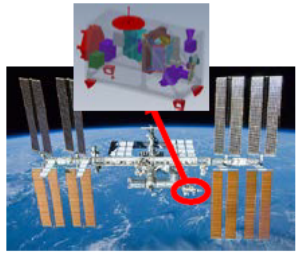




The next Generation of SWIR CO_2 Missions

- **TanSat (2015)** - First Chinese greenhouse gas satellite
  - Uses same O_2 and CO_2 bands and similar orbit as OCO-2
  - Cloud and Aerosol Imager: 0.38, 0.67, 0.87, 1.38 and 1.61µm channels

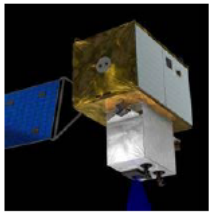
- **OCO-3 *(2017)** - OCO-2 spare instrument, to be deployed on ISS
  - First solar CO_2 instrument to fly in a low inclination, precessing orbit



- **GOSAT-2 (2017)** – High precision CO_2, CH_4, CO, and NO_2
  - Improved precision (0.5 ppm), spatial resolution, and range of ocean glint spot expected to improve coverage
  - Exploring additions of an FTIR channel to measure CO, a wider NIR channel for chlorophyll fluorescence, and a UV channel for NO_2

- **CNES MicroCarb (2019)** – high sensitivity at low cost
  - Flies in the A-Train, providing data continuity for OCO-2
  - ~1/2 to 1/3 of the size (and cost) of OCO-2, with similar sensitivity.
    - Enables constellations of low-cost CO_2 monitoring satellites

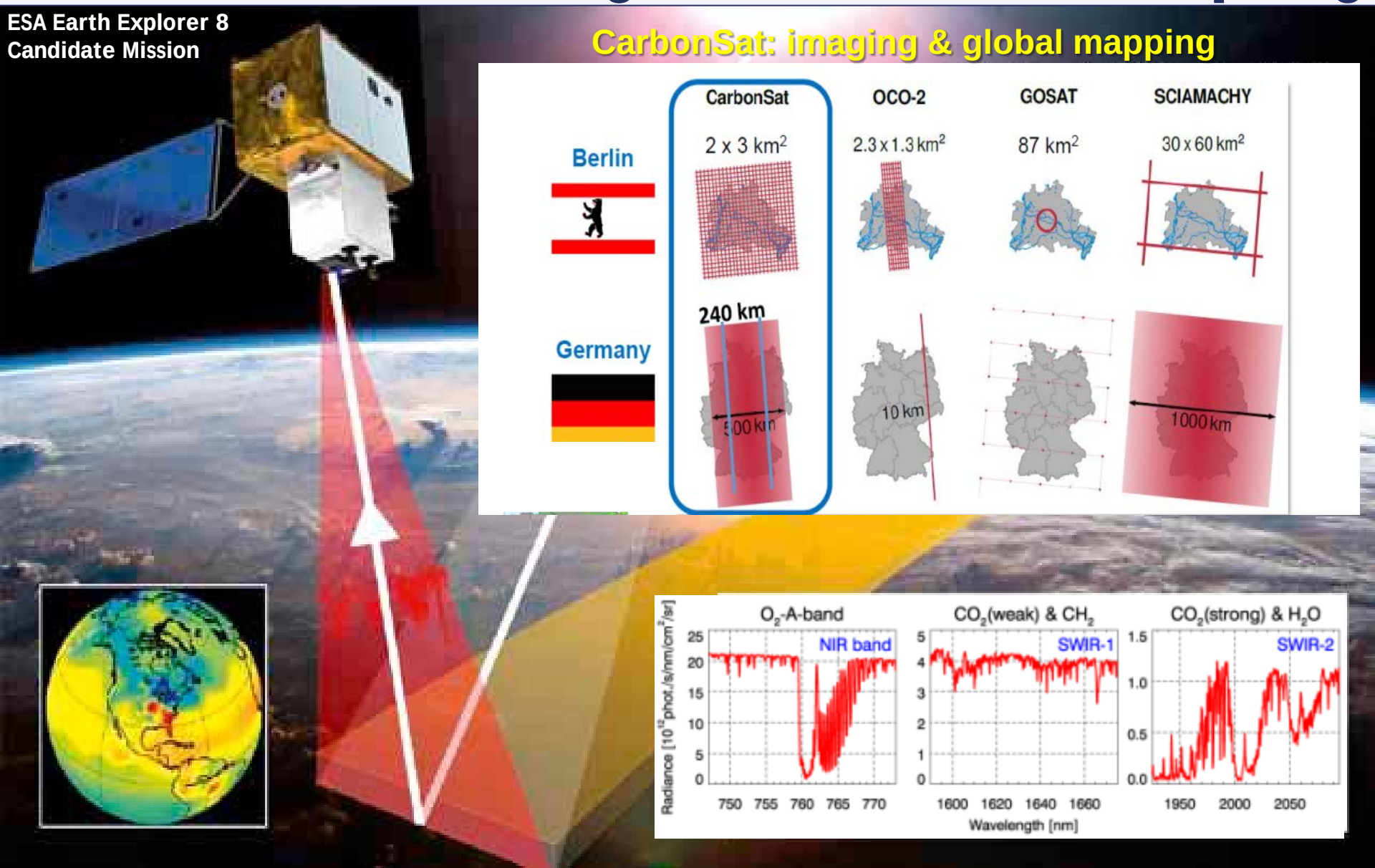
- **ESA CarbonSat (2022)** – CO_2 and CH_4 at high resolution over a broad swath
  - Combines a high precision target (1 ppm) over a broad swath (160 to 500 km) to yield complete coverage of sunlit hemisphere at high resolution (2 km x 2 km) on 6-12 day time scales



(Slide from D. Crisp, JPL)

Carbonsat: Towards Increased Coverage and Denser Sampling

ESA Earth Explorer 8
Candidate Mission



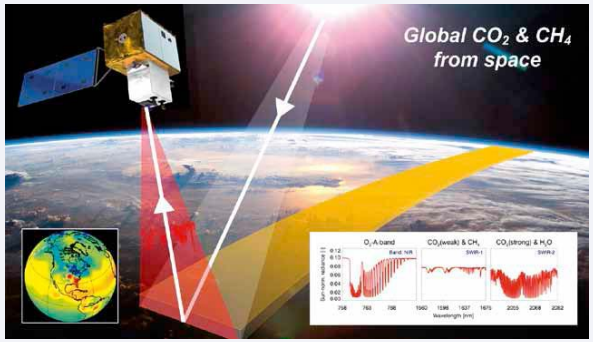
CarbonSat: imaging & global mapping

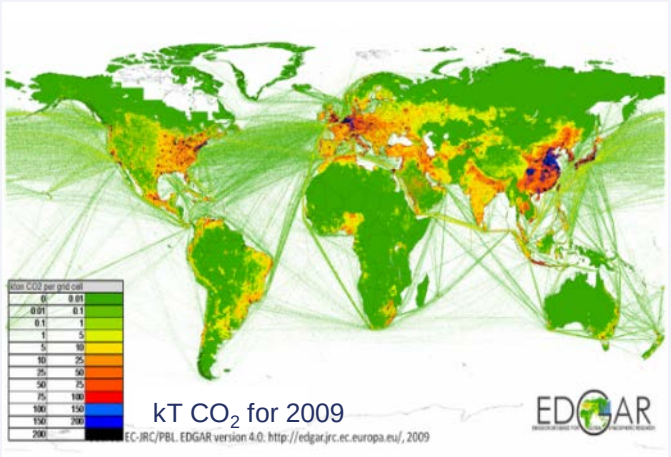
CarbonSat Science Goals

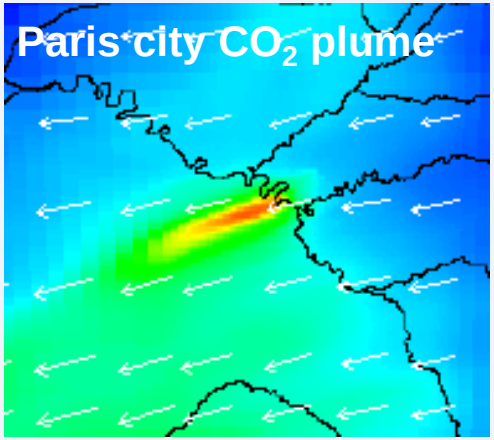
CarbonSat aims to support better separating natural and anthropogenic fluxes with global XCO2 and XCH4 (secondary: vegetation fluorescence) data and "imaging" of strong localised CO_2 and CH_4 emission areas.

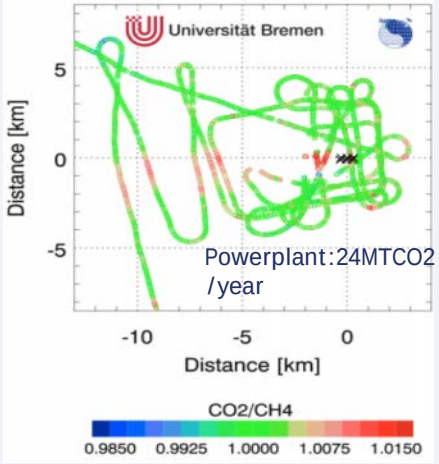
In combination with inverse modelling and robust validation (TCCON) this will address:

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







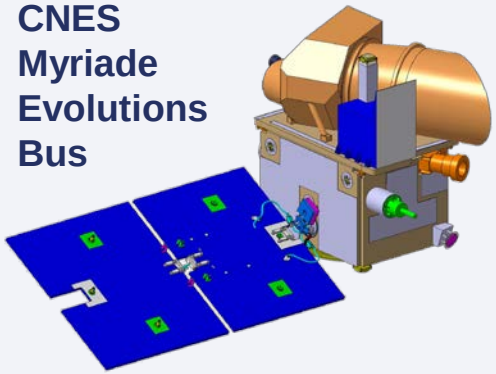


UK Members of CarbonSat ESA MAG (Boesch, Hayman)

CNES MicroCarb Mission

- **Goal: Development of compact and affordable instrument to measure CO_2 for an accommodation on a Micro-Satellite:**
  - **Demonstrator for future constellation and monitoring concepts**
  - **Priority given to accuracy rather than high spatial coverage and resolution**
- **Observation concept similar to OCO-2**
  - **3 channel grating spectrometer with very high resolution**
- **Phase A completed (end of 2013)**
- **Mission can be developed in a limited time (5 years from start to launch) and budget**

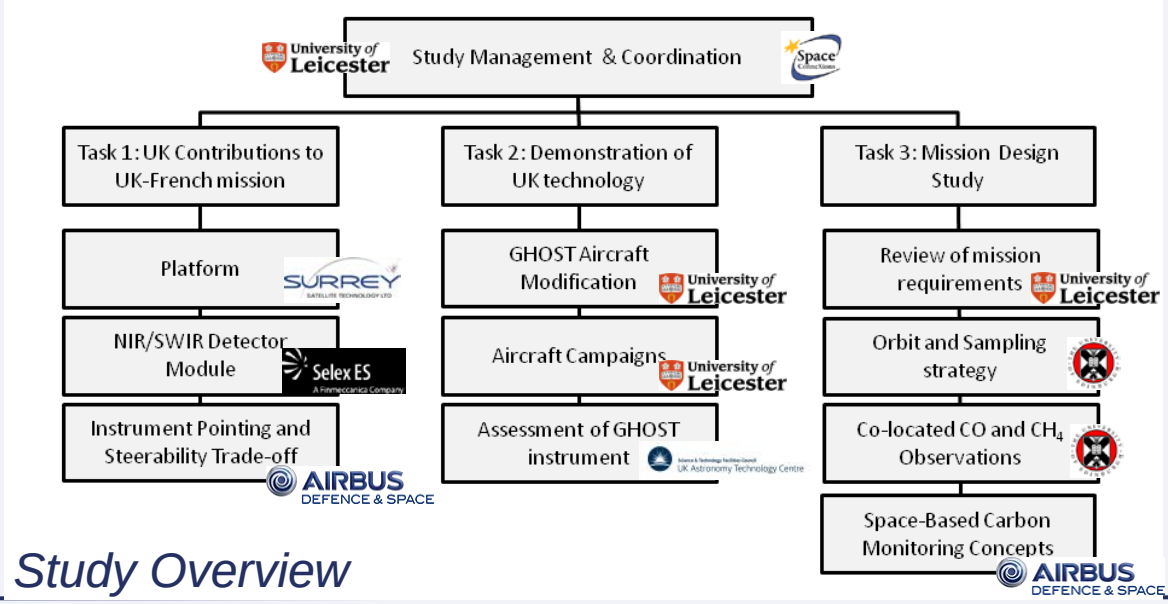
CNES Myriade Evolutions Bus



Development of a Bilateral Carbon Mission

UKSA/CEOI funded-study to develop a bilateral carbon mission concept with CNES

- **Develop specific solutions for UK industry contributions to a bilateral carbon mission with CNES based on the MicroCarb concept**
- **Demonstrate cutting-edge UK instrument technology for GHG measurements**
- **Evaluate and optimize the science return of the mission**
- **Assess potential of constellation concepts and for commercial downstream services**



Study Overview

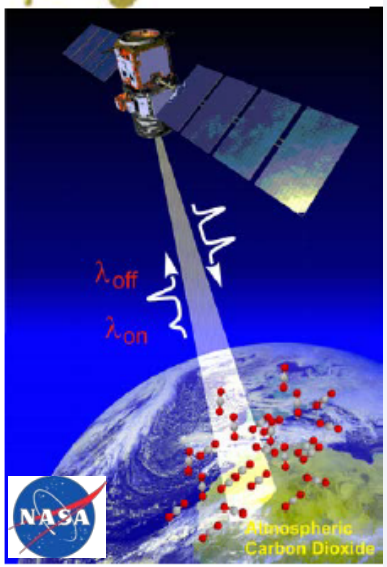
Project Kick off: 29 April 2014

Active GHG Missions

Active missions allow full-column observations during day and night during all seasons (high latitudes in winter time) without potential biases from aerosol and cloud scattering

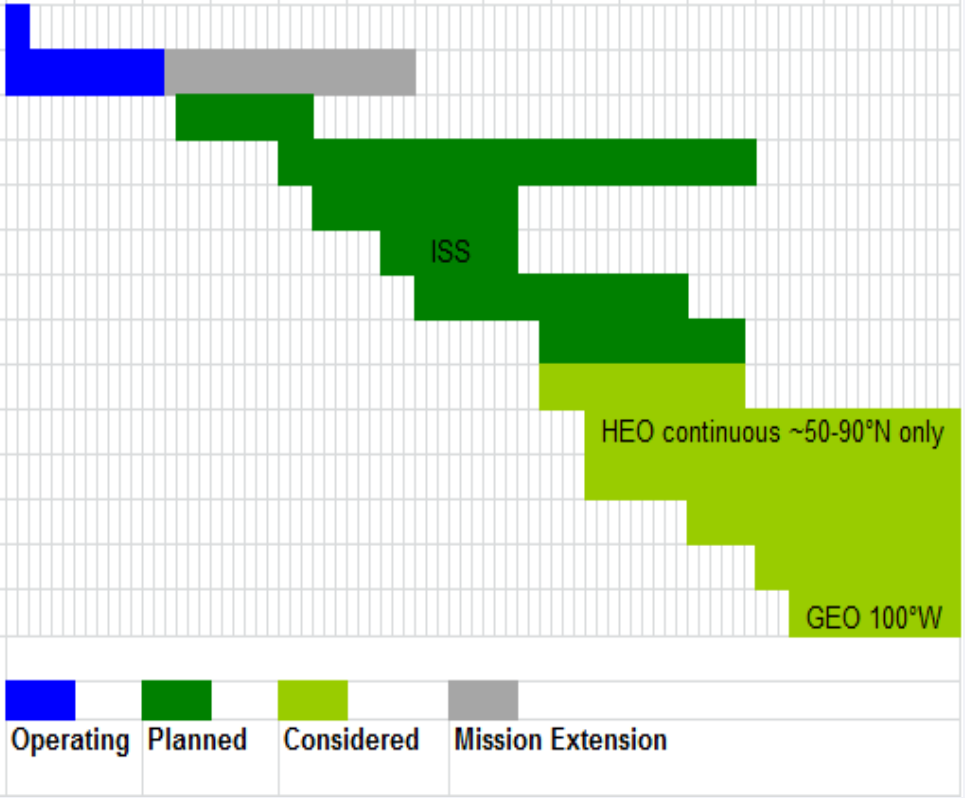
- MERLIN (2019): First CH_4 LIDAR (IPDA)
  - Science focus: Precise (1-2%) X_{CH4} retrievals for studies of wetland emissions, inter-hemispheric gradients and continental scale annual CH_4 budgets
  - Orbit: 6AM/6PM, 28-day repeat

- ASCENDS* (2021): First CO_2 LIDAR
  - Precise (0.3%) global measurements of X_{CO2}, over days, nights, including winter high latitude regions to quantify continental and oceanic CO_2 sources and sinks
  - Should provide many useful soundings in partially cloudy regions because of near vertical sounding



Current and Planned GHG Missions

Satellite, Instrument (Agencies)	CO_2	CH_4	FOV
ENVISAT SCIAMACHY (ESA)	●	●	30x60 km^2
GOSAT TANSO-FTS (JAXA-NIES-MOE)	●	●	10.5 km (d)
OCO-2 (NASA)	●		1.29x2.25 km^2
Sentinel-5P TROPOMI (ESA)		●	7x7 km^2
TanSat (CAS-MOST-CMA)	●		1x2 km^2
OCO-3 (NASA)	●		~4 km^2
GOSAT-2 TANSO-FTS (JAXA-NIES-MOE)	●	●	10.5 km (d)
MERLIN (DLR-CNES)		●	0.135 km (w)
MicroCarb (CNES)	●		25 km^2
PCW-PHEOS-FTS (CSA)	?	●	10x10 km^2
MetOpSG Sentinel-5 (ESA-EUMETSAT)		●	7x7 km^2
CarbonSat (ESA)	●	●	2x3 km^2
ASCENDS (NASA)	●		0.100 km (w)
GEO-CAPE (NASA)		●	4x4 km^2
(GEOCARB)			*d = diameter*
Based on information from various sources			*w = width of a narrow strip along orbit track*
Proposed or funding not confirmed			

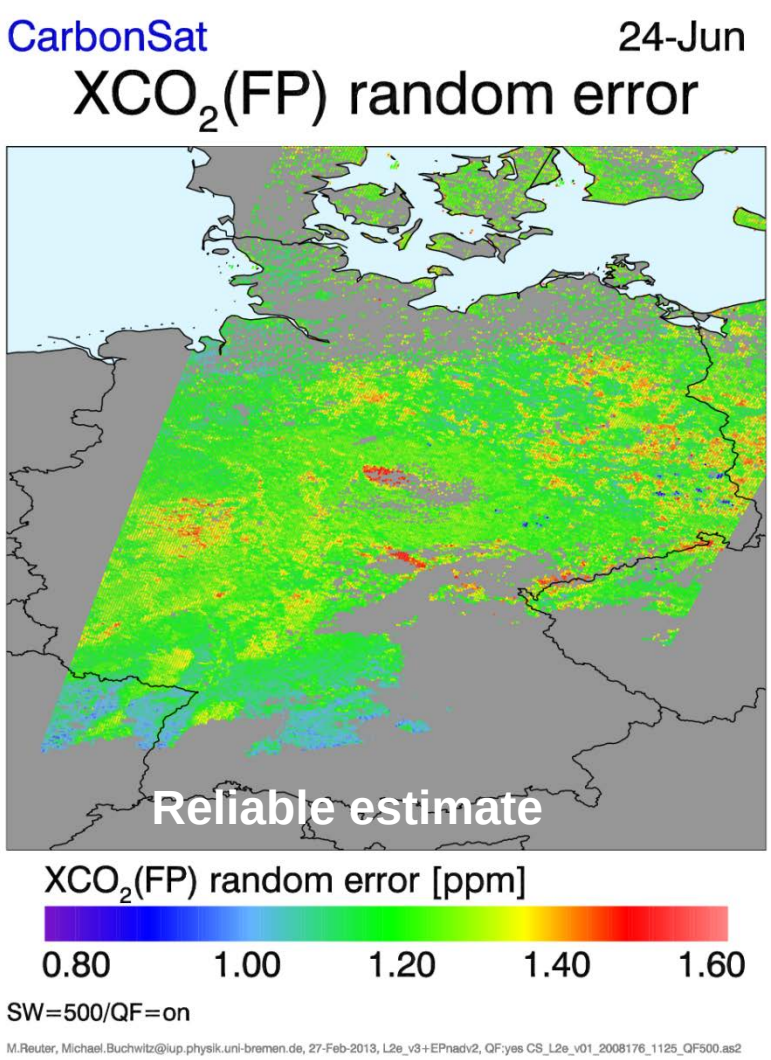


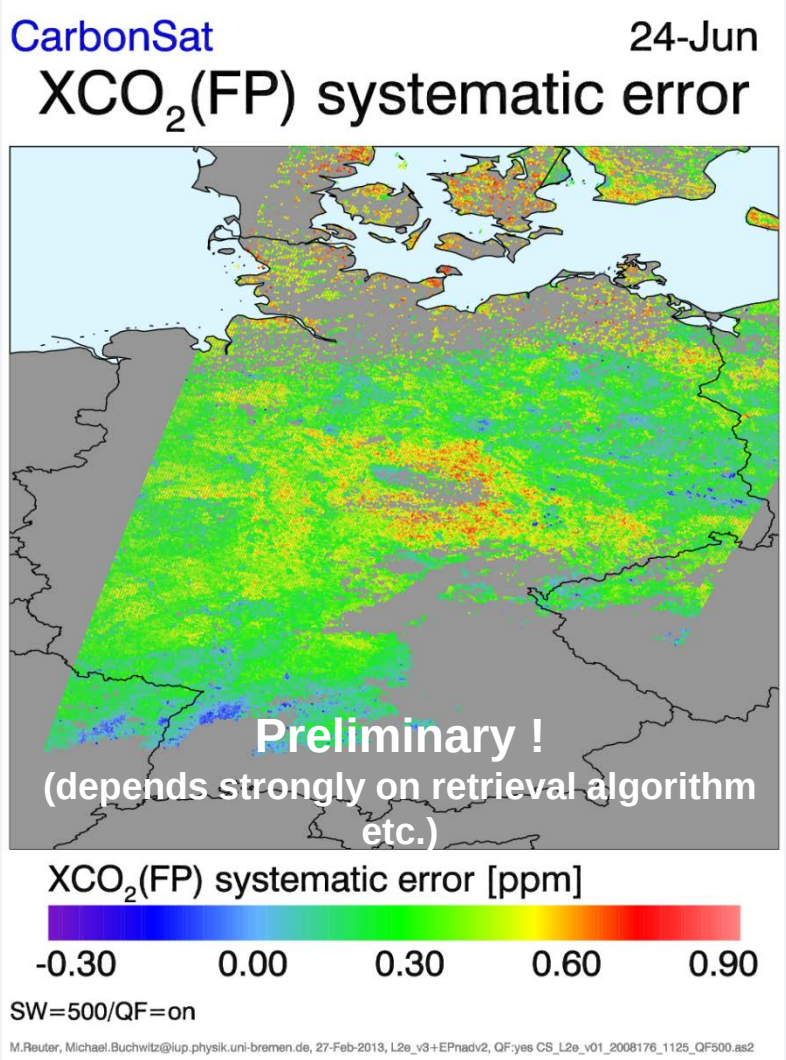
- A coordinated global network of surface and space-based CO_2 and CH_4 monitoring systems is needed for **long-term monitoring** of sources and sink
- Heterogeneous, un-coordinated constellation might be possible leading to global coverage every day in near future
- Longer-term need: coordinated constellation

Concluding Remarks

- Feasibility of greenhouse gas remote sensing from satellites is now well established and data products have reached a high level of maturity (e.g. ESA CCI project) and are extensively used by modelling and data assimilation groups
- First dedicated GHG missions:
  - JAXA/NIES: First dedicated GHG sensor launched in 2009 (GOSAT)
  - OCO-2 re-launch in July 2014
- Over the next decade, a succession of missions with a range of CO_2 and CH_4 measurement capabilities will be deployed in low Earth orbit
  - Each mission is required to obtain a continuous presence
  - Inclusion of CH_4 column observations in Copernicus Space Segment (Sentinel) but not CO_2
  - Missions such as EE8 Carbonsat (or GEO missions) can provide much improved coverage and additional constraints on city and local scale
  - Active missions (new challenge) can complement passive missions (e.g. winter high latitudes, boreal wetlands)

CarbonSat: Germany Overpass



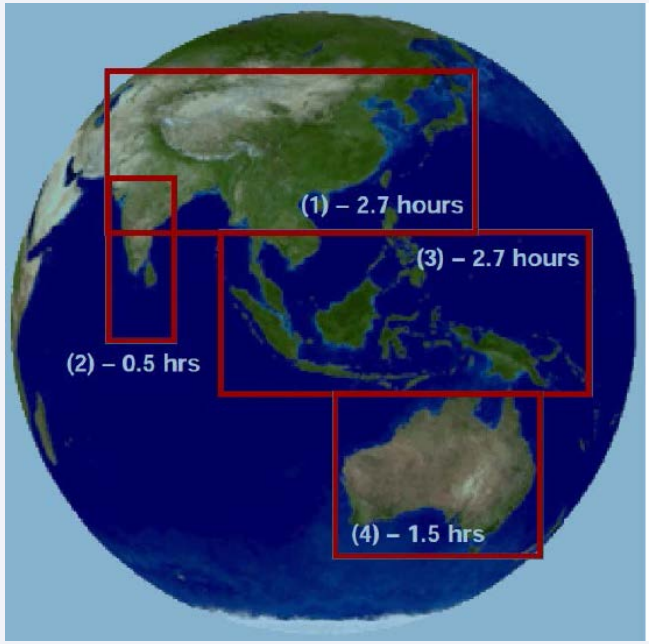


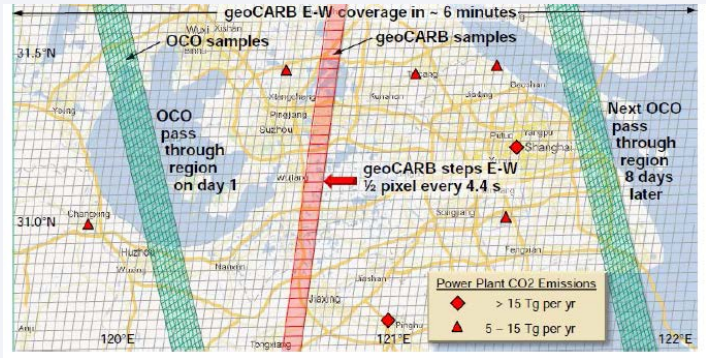
Buchwitz et al., AMT, 2013

(2x2 km², swath=500 km)

GEO Stationary GHG Missions

- **GeoCarb is a proposal for a Geostationary mission at nominal longitude of 110 E (±10) over Asian-Pacific region.**
- **GeoCarb is a multi-channel grating spectrometer covering O_2 A Band, 1.6, 2 and 2.3 micron bands with high resolution**
- **GeoCARB employs a steerable mirror system to scan over a region with complete coverage in <8hours**
- **Spatial resolution: 3 km at sub-satellite point**





CO2 Only Mission: TANSAT

- Chinese Carbon Satellite
- Mission and Payload very similar to OCO-2:
  - Lower resolution in 1.6 and 2 micron bands to avoid undersampling
  - Aerosol imager CAPI: 5-channel high resolution imager
  - Calibration requirements reduced compared to OCO-2
- Significant validation effort in China:
  - 3 Bruker 125 FTS
  - 3 Optical Spectrum Analyzer
  - Large aerosol network
- Planned launch: Mid 2016
- UK Links: ESA Dragon 3 Collaboration with TanSat Team (Boesch, Palmer)

760nm Prototype

Electrical and thermal experiment