Tracking Greenhouse Gas Concentrations from Space: The French-German Methane Mission MERLIN

KIEMLE, Christoph

DLR, Institut für Physik der Atmosphäre

D-82234 Oberpfaffenhofen, Germany

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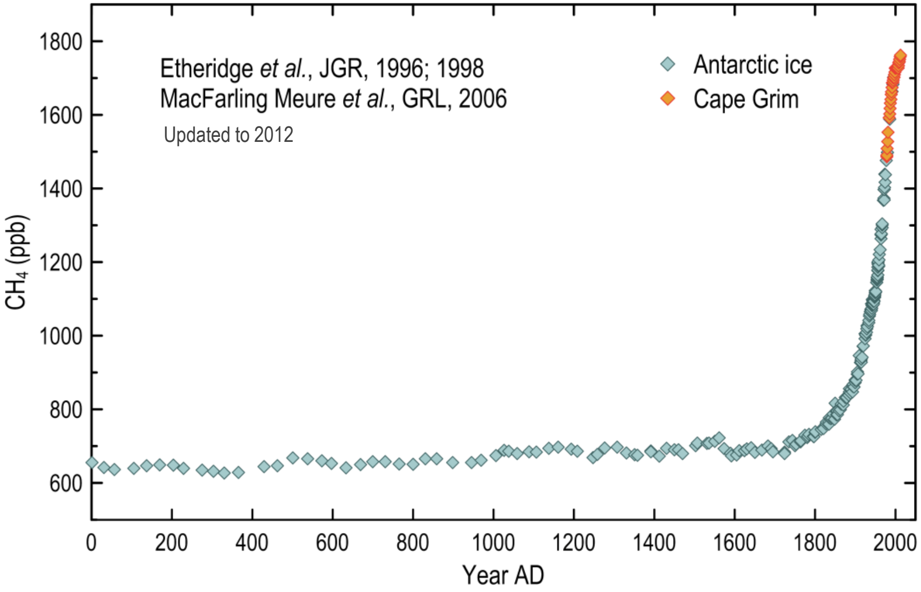
The Context

Introduction Slides from the Global Carbon Project, a project of the IGBP, WCRP, IHDP, and Diversitas.
http://www.globalcarbonproject.org/carbonbudget

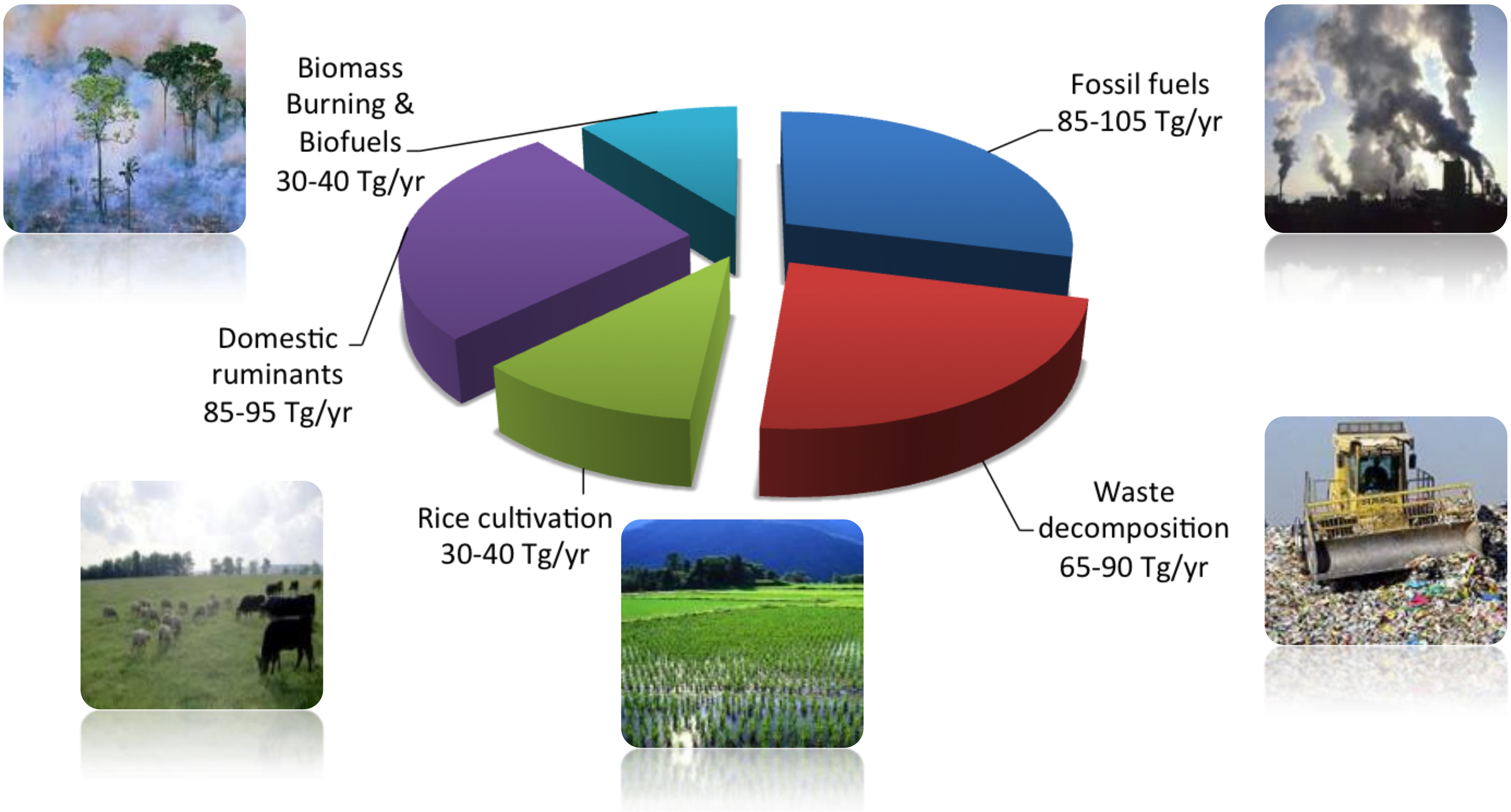
- After carbon dioxide (CO_2), methane (CH_4) is the second most important well-mixed greenhouse gas contributing to human-induced climate change.
- In a time horizon of 100 years, CH_4 has a Global Warming Potential 28 times larger than CO_2.
- CH_4 is responsible for 20% of the global warming produced by all well-mixed greenhouse gases, and constitutes 60% of the climate forcing by CO_2 (0.97 Wm^{-2} vs 1.68 Wm^{-2}) since pre-Industrial time.
- Annual globally averaged CH_4 concentration was 1803±4 parts per billion in 2011 and 722 ppb in 1750. 150% increase since pre-Industrial time.



- CH_4 contributes to water vapor in the stratosphere, and to ozone production in the troposphere, the latter a pollutant with negative impacts on human health and ecosystems.
- The atmospheric life time of CH_4 is approximately 10±2 years.

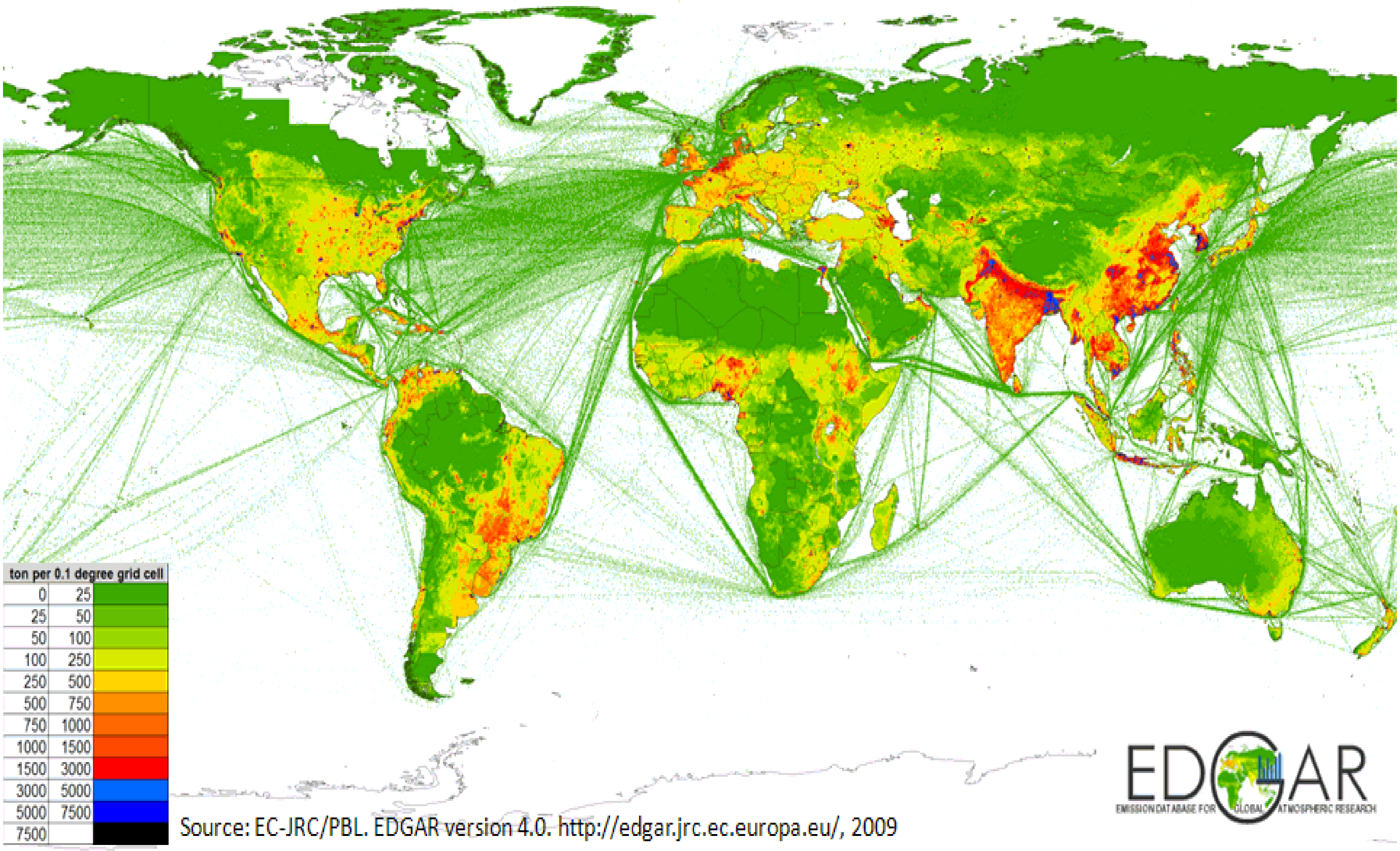
IPCC WGI 2013; Voulgarakis et al. 2013, Atmos. Chem. Phys.

Anthropogenic Methane Sources (2000s)



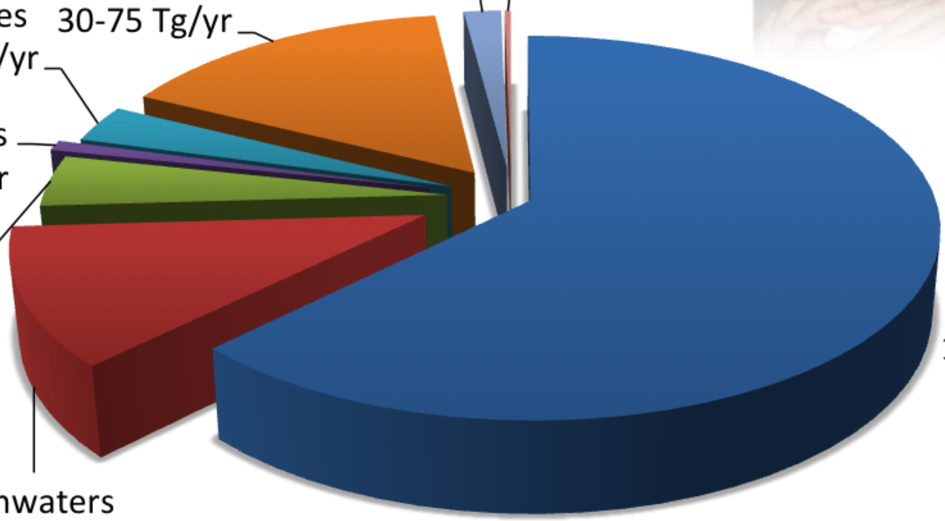
Global Carbon Project 2013; Figure based on Kirschke et al. 2013

Anthropogenic Methane Emissions



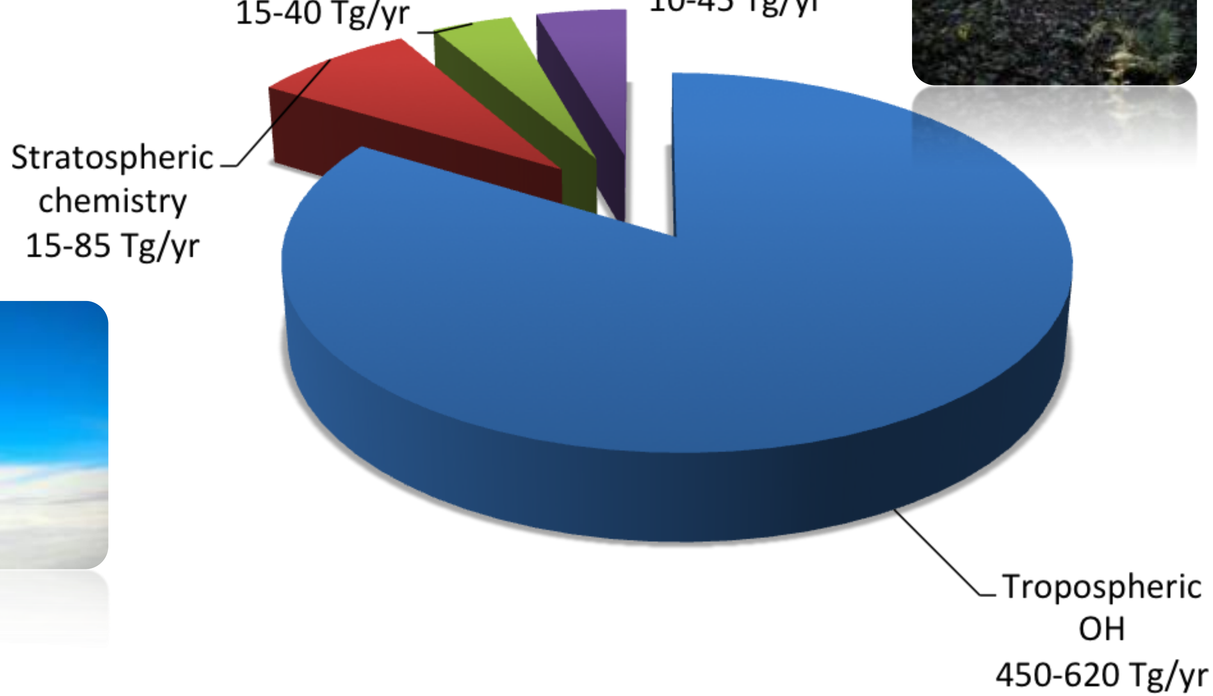
Source: EC-JRC/PBL. EDGAR version 4.0. http://edgar.jrc.ec.europa.eu/, 2009

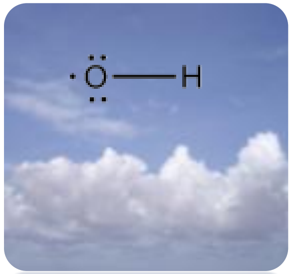
Natural Methane Sources (2000s)



Global Carbon Project 2013; Figure based on Kirschke et al. 2013

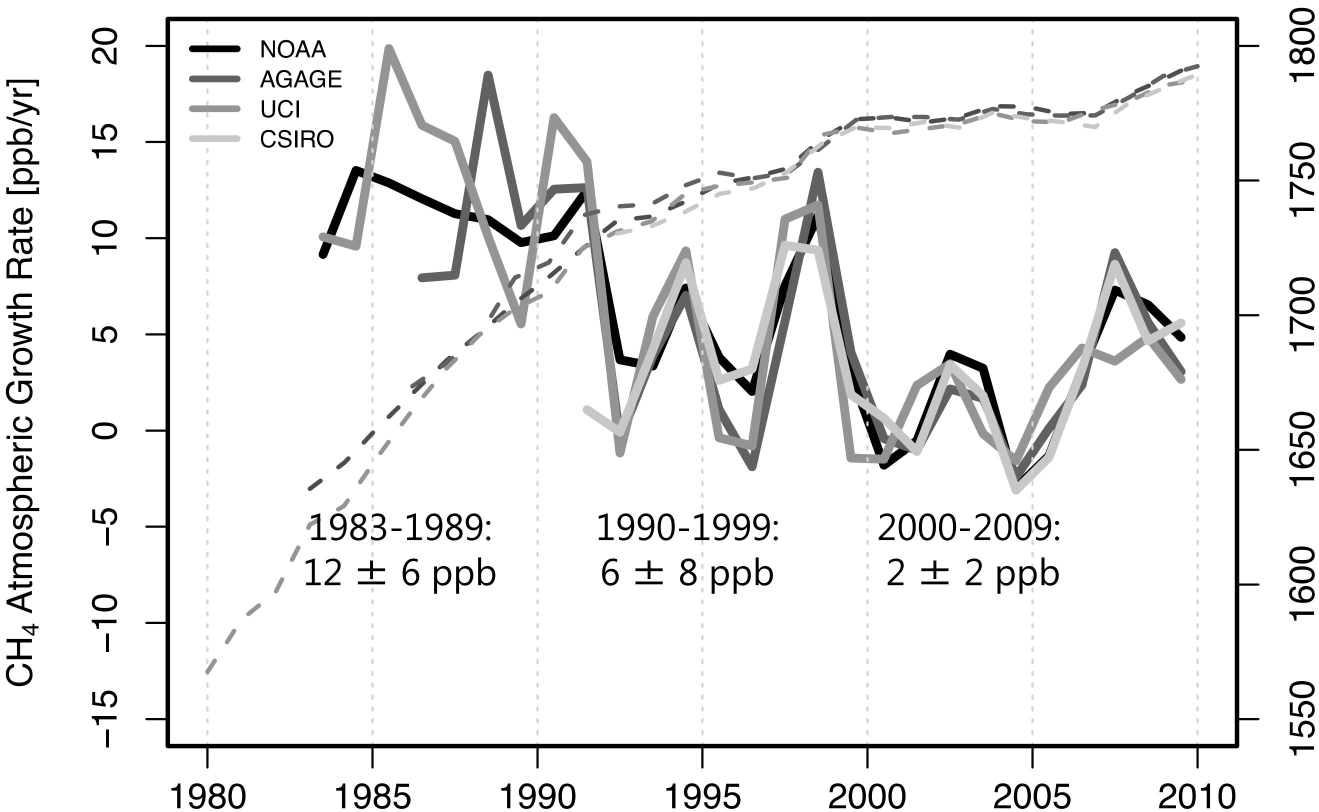
Methane Sinks (2000s)





Global Carbon Project 2013; Figure based on Kirschke et al. 2013

CH_4 Atmospheric Growth Rate, 1983-2009



- Slowdown of atmospheric growth rate before 2005
- Resumed increase after 2006

Kirschke et al. 2013, Nature Geoscience; Data from NOAA, CSIRO, AGAGE, UCI atmospheric networks

Methane in the Atmosphere: Key Issues

- Among datasets and models, consistency is higher on **anthropogenic** decadal **emissions** than natural ones.
- The large uncertainties in the mean emissions from **natural wetlands** limit our ability to fully close the CH_4 budget.
- **Inter-annual variability** is dominated by natural wetlands, with short-term impacts of biomass burning. More robust than decadal means.
- **Still large uncertainties on decadal** means but reduced compared to the IPCC 4th Assessment Report.
- 1999-2006 : ➔➘ fossil fuel emissions.
- Changes after 2005 still debated between ➚ wetlands and ➚ fossil fuels.

It is evident that better and global observations of methane are needed.

Current satellite passive remote sensing observations suffer from low signals at high latitudes, clouds in the tropics and biases by aerosol layers and thin clouds.

French-German Climate Mission MERLIN

Methane Remote Sensing Lidar Mission

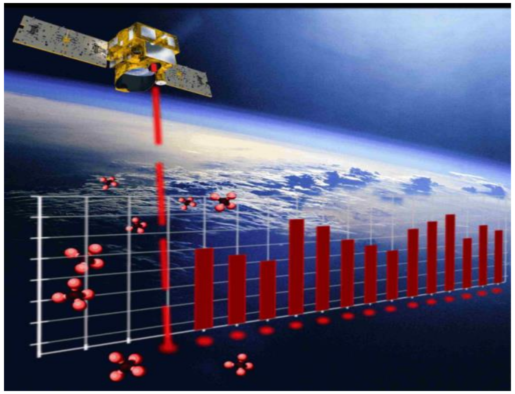
- CNES-DLR proposal of joint climate mission on atmospheric methane (CH_4)
- 2010: French-German ministerial level approval to build and operate a small satellite mission for CH_4 (COP 15)
- 2016: successful PDR and reaffirmation of joint development (COP 21)
- 2020: envisaged launch followed by 3 years of joint operation in space
- **First time Lidar, active remote sensor in space for GHG measurements**

Added value to current obs system

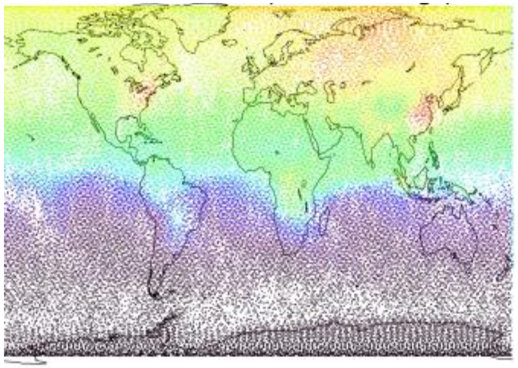
- As an **active RS instrument** based on a differential measurement method, MERLIN will deliver data **day and night** with **lower biases** than current, existing and planned space instruments.

- MERLIN will provide **atmospheric methane columns** at all latitudes, allowing to monitor in particular **Tropical** and **Arctic regions.**

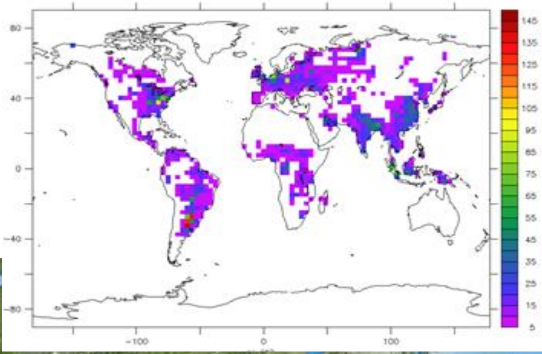
- MERLIN is a **demonstrator of GHG Lidar** measurements from SPACE. It will open a new dimension of space observations of the Earth.



Columns



Emissions



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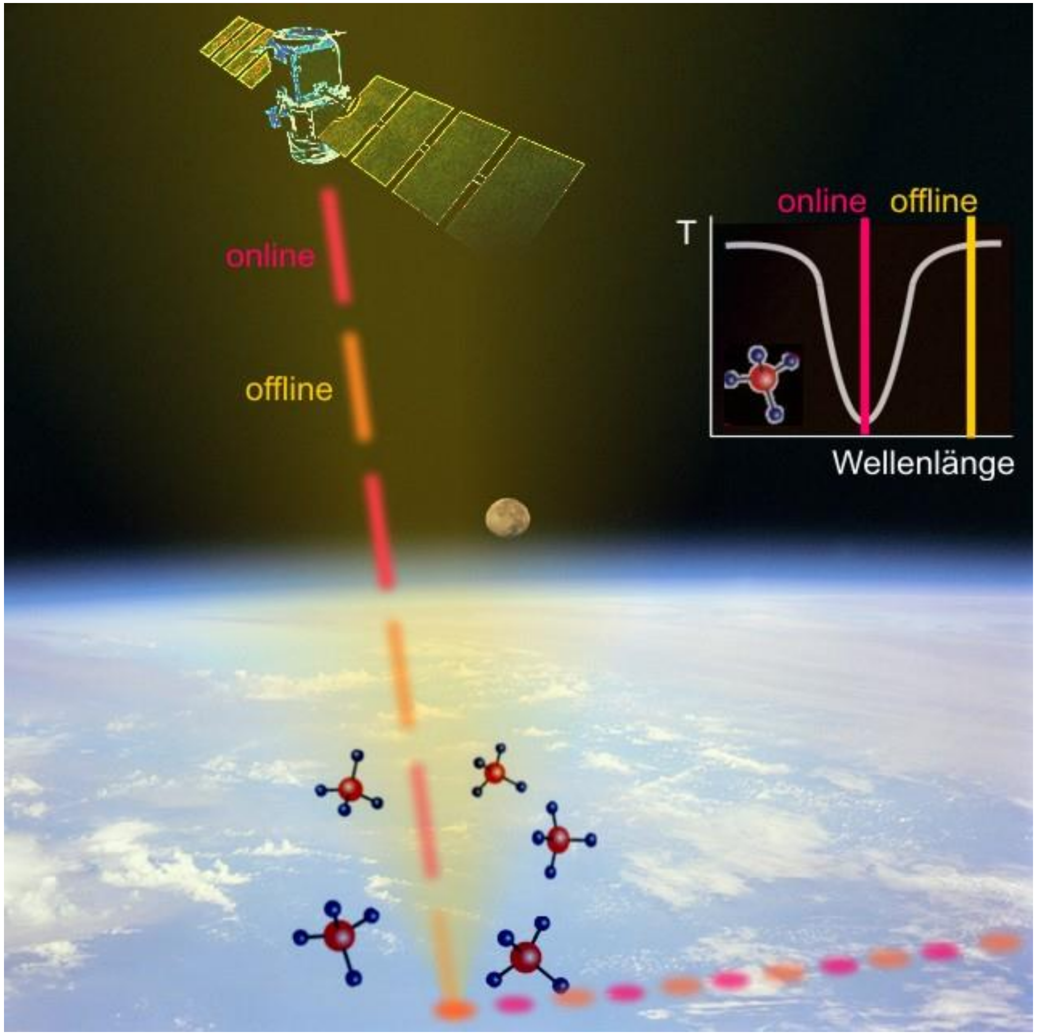
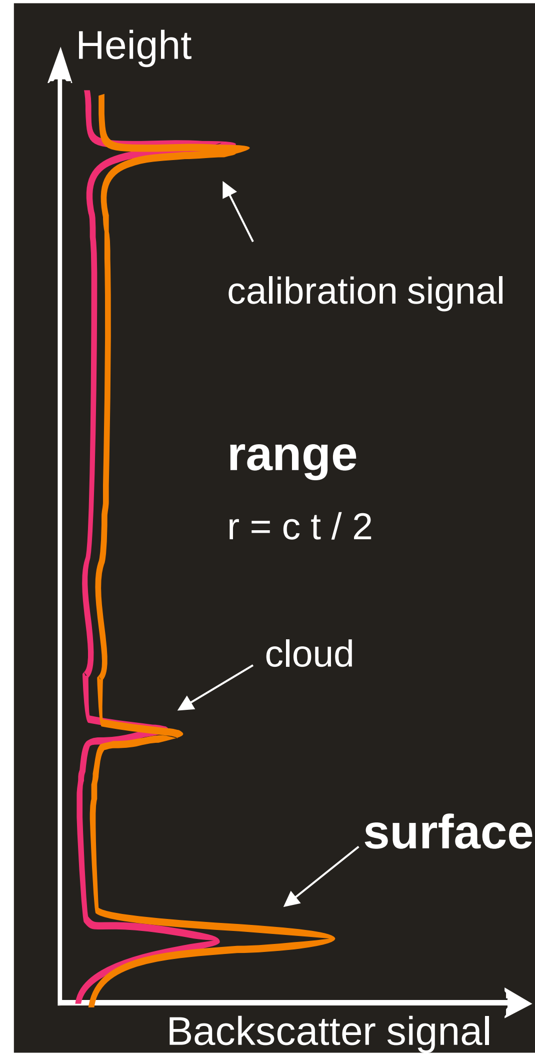
Integrated Path Differential Absorption (IPDA) Lidar





Spin-off data products:
Cloud top and canopy height,
Surface elevation and albedo

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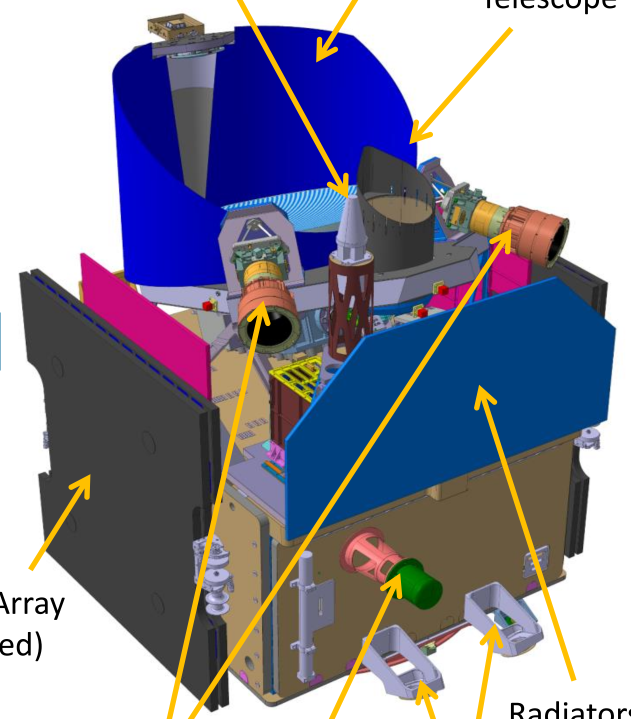
MERLIN satellite main parameters

Satellite platform:	MYRIADE Evolutions
• Satellite mass:	400 kg
• Payload mass allocation:	119 kg
• Satellite power:	> 400 W
• Payload power allocation:	150 W
• Satellite GPS:	2 sensors
• Satellite star tracker:	2 opt. heads

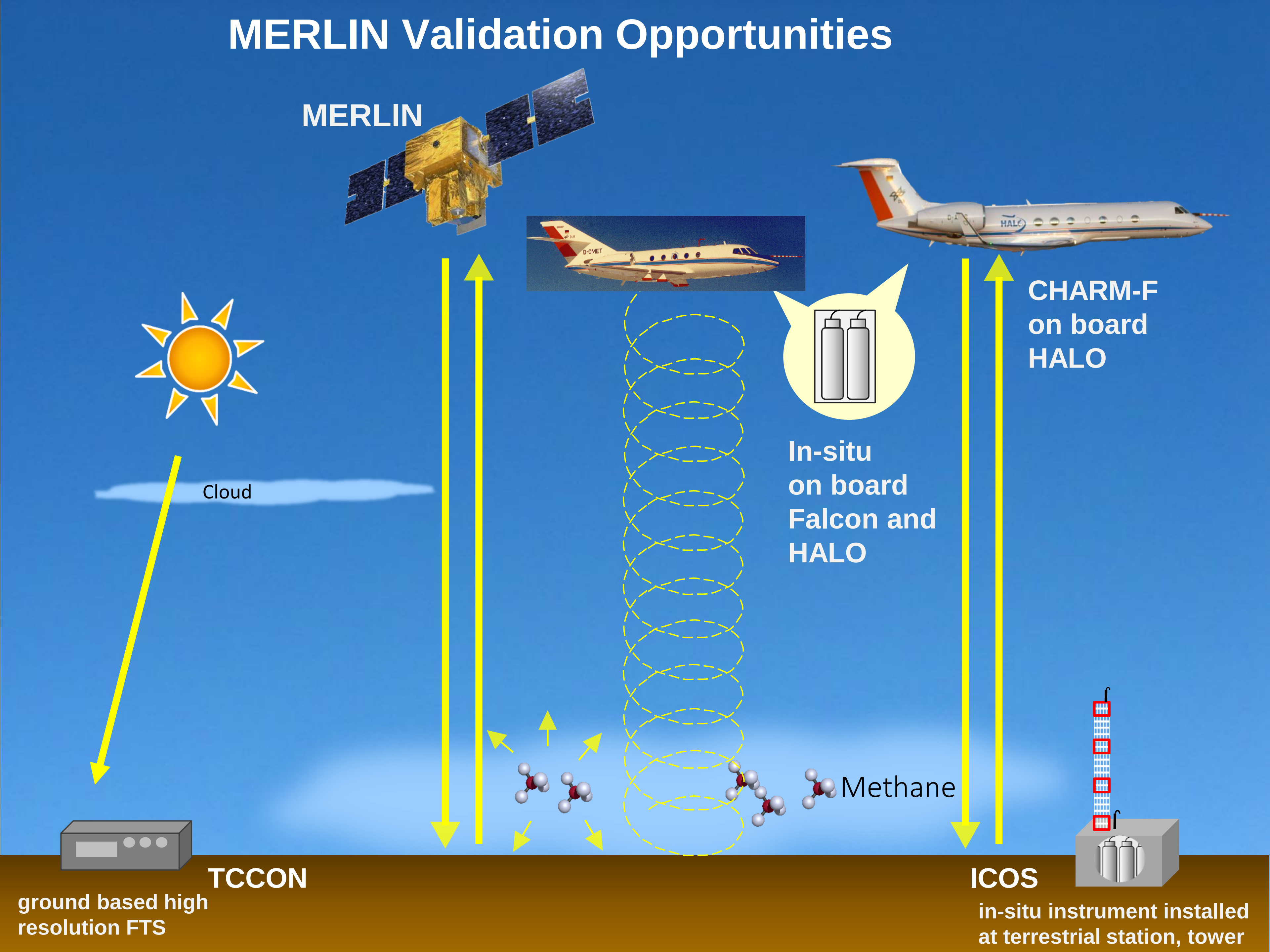
Payload:	Methane IPDA LIDAR
• XCH4 absorption line:	1.645 µm
• Laser emitter type:	Nd:YAG pumped OPO
• OPO pulse energy:	9 mJ
• Laser pulse repetition frequency PRF:	20 Hz
• Receiving telescope size:	69 cm
• Detector:	APD pin diode

Orbit:	Sun synchr. polar LEO
• LTAN:	06:00 h or 18:00 h
• Height:	approx. 500 km



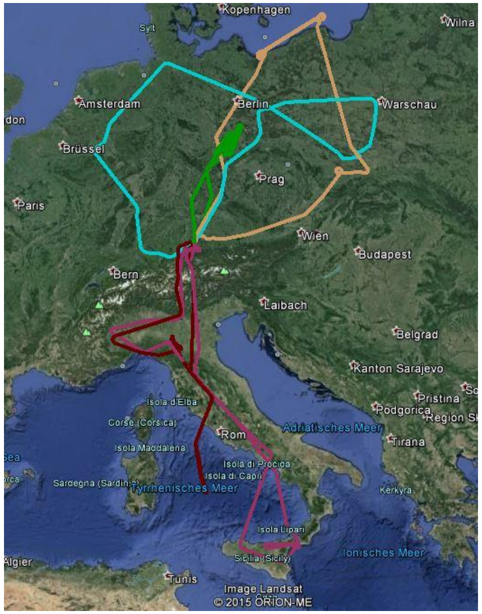
Carbon Cycle Observing Systems

	2010 2012 2014	2016 2018 2020	2022 2024
Space CO_2 and/or CH_4 passive	SCHIAMACHY	***MicroCarb***	*CarbonSat ?*
	GOSAT	***GOSAT 2***	
	OCO 2	OCO 2	
		SENTINEL 5 P	***SENTINEL 5***
CH_4 active		MERLIN	MERLIN
CO_2 active			***ASCENDS***
Aircraft remote sensing		CHARM-F onboard HALO NASA DC-8, …	CHARM-F onboard HALO NASA DC-8, …
aircraft in-situ	IAGOS, HIAPER	IAGOS, HIAPER	IAGOS, HIAPER
Surface in-situ		ICOS	ICOS
sfc rem. sensing	TCCON	TCCON	TCCON



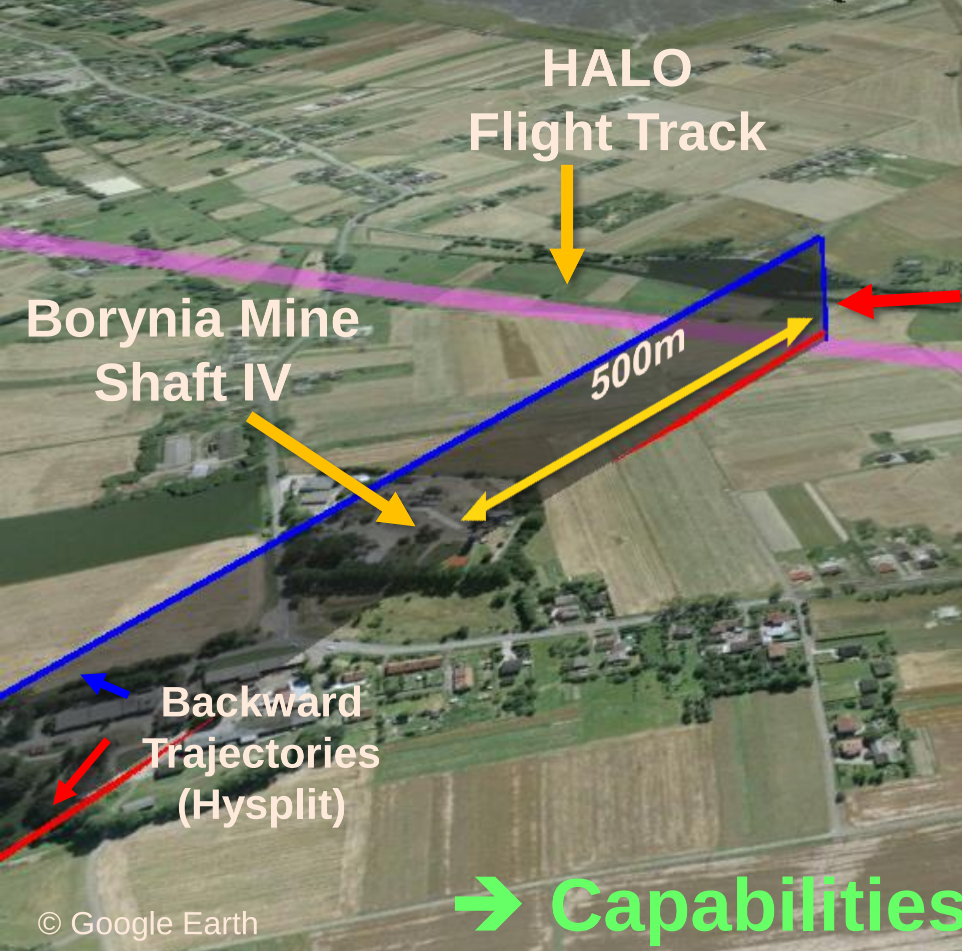
MERLIN Validation Opportunities
MERLIN
CHARM-F
on board
HALO
In-situ
on board
Falcon and
HALO
Cloud
Methane
TCCON
ground based high
resolution FTS
ICOS
in-situ instrument installed
at terrestrial station, tower

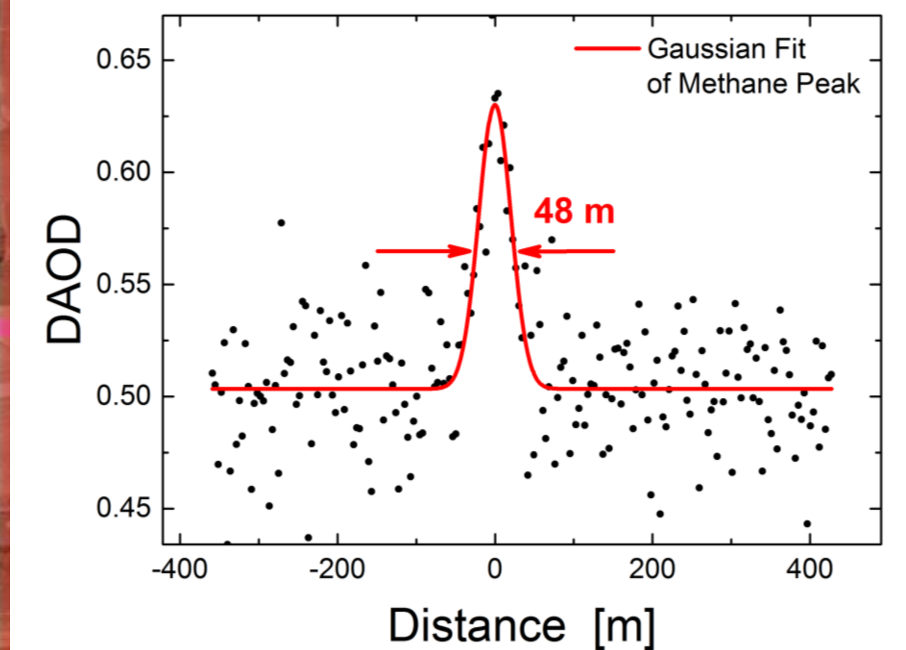
DLR Airborne Demonstrator CHARM-F:
Lidar for CO_2 and CH_4 Column Measurements



- Successful first flight campaign on HALO in 2015
- 5 flights, about 22 flight hours
- Goals:
  - ✓ Completion of the airworthiness certification
  - ✓ System tests
  - ✓ Collection of first data sets

Example:
CHARM-F measured a thin Methane Plume near a Coal Mine Ventilation Shaft in Poland





Calculated CH_4 Flux : ~ 35 m^3/min
Reported : 18-160 m^3/min

➔ Capabilities clearly demonstrated!

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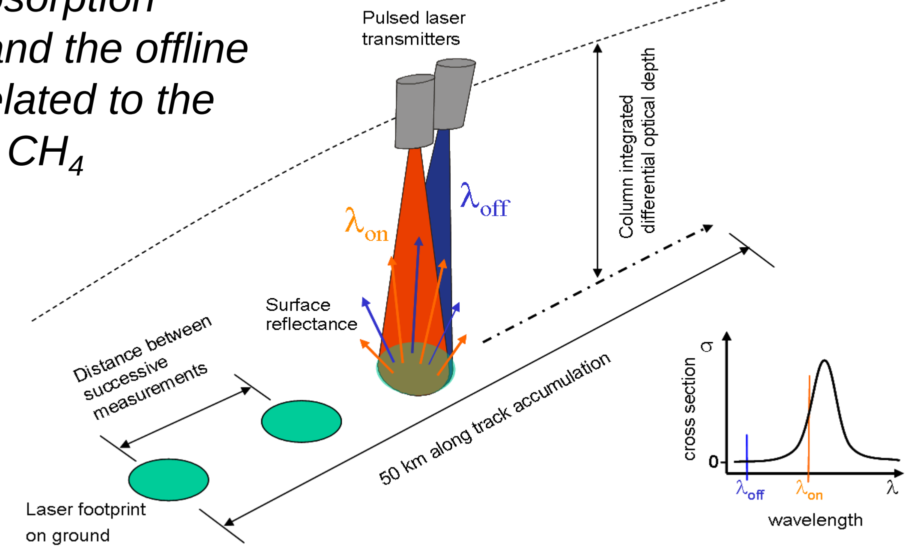
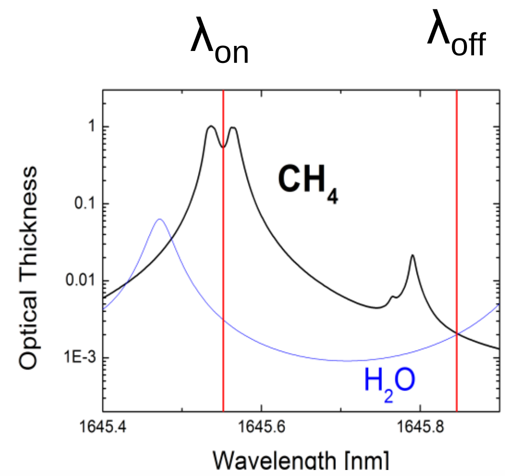
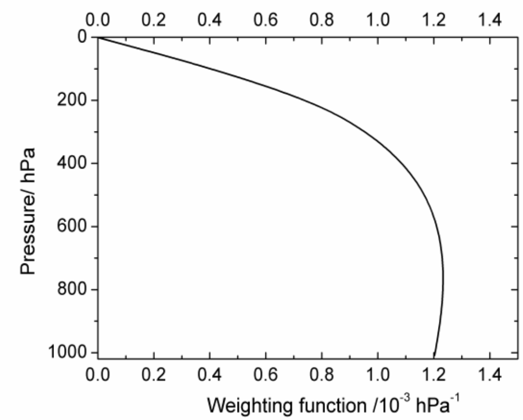
Thank you for your attention!

Measurement principle (IPDA):
Integrated-Path Differential-Absorption LIDAR

The differential absorption between the on- and the offline pulse is directly related to the column density of CH_4







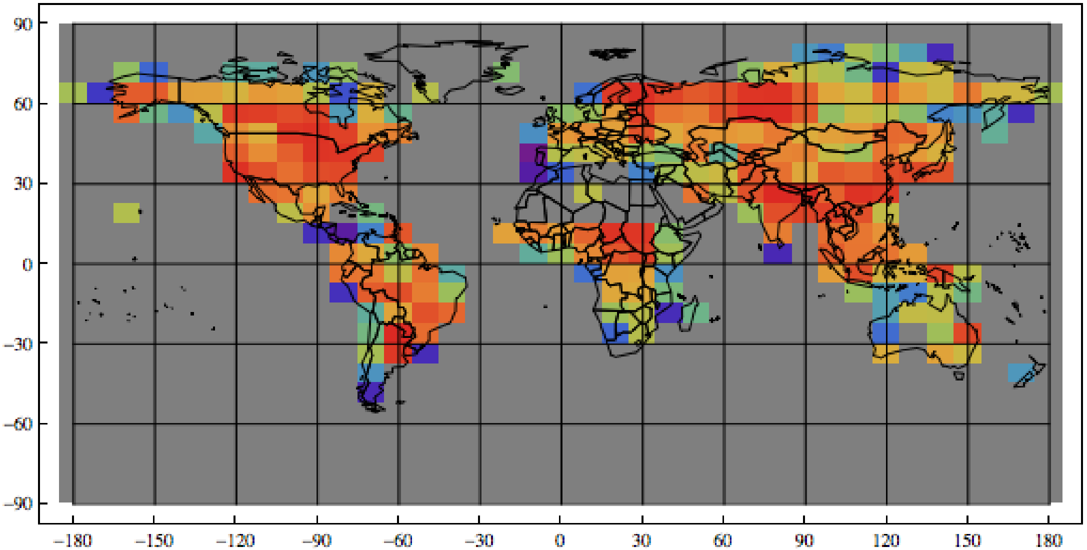
Weighting function (WF)
favours (low) troposphere

Unique features:

- **Direct measurements** of the CH_4 columns, all latitudes, all seasons, day and night
- **Light path well-known*:*** immune against aerosol and thin cirrus scattering, separation of ground return from cloud reflection
- ***Cloud slicing****: permits vertical profile information*
- ***High spatial resolution:*** small footprint (150 m) allows measurements in small cloud gaps (*important in Tropics*)
- **Very low BIAS: for MERLIN < 2.7 ppb** (T, p_0, q, cross section, detector non-linearity & frequency knowledge)

Results from Inverse Modelling using Synthetic MERLIN Observations

M. Heimann, J. Marshall, MPI-BGC, Jena, and C. Kiemle, DLR-IPA



1-$\sigma_{post}/\sigma_{pri}$

Flux improvement / %

Substantial error reduction in key regions with respect to the present knowledge of CH_4 fluxes on regional scale for the month of July

Use of TM3 model resolution of 3 hours x 8° x 10° x 9

aggregation of 50 km lidar observations along track:

calculation of posterior flux covariance matrix

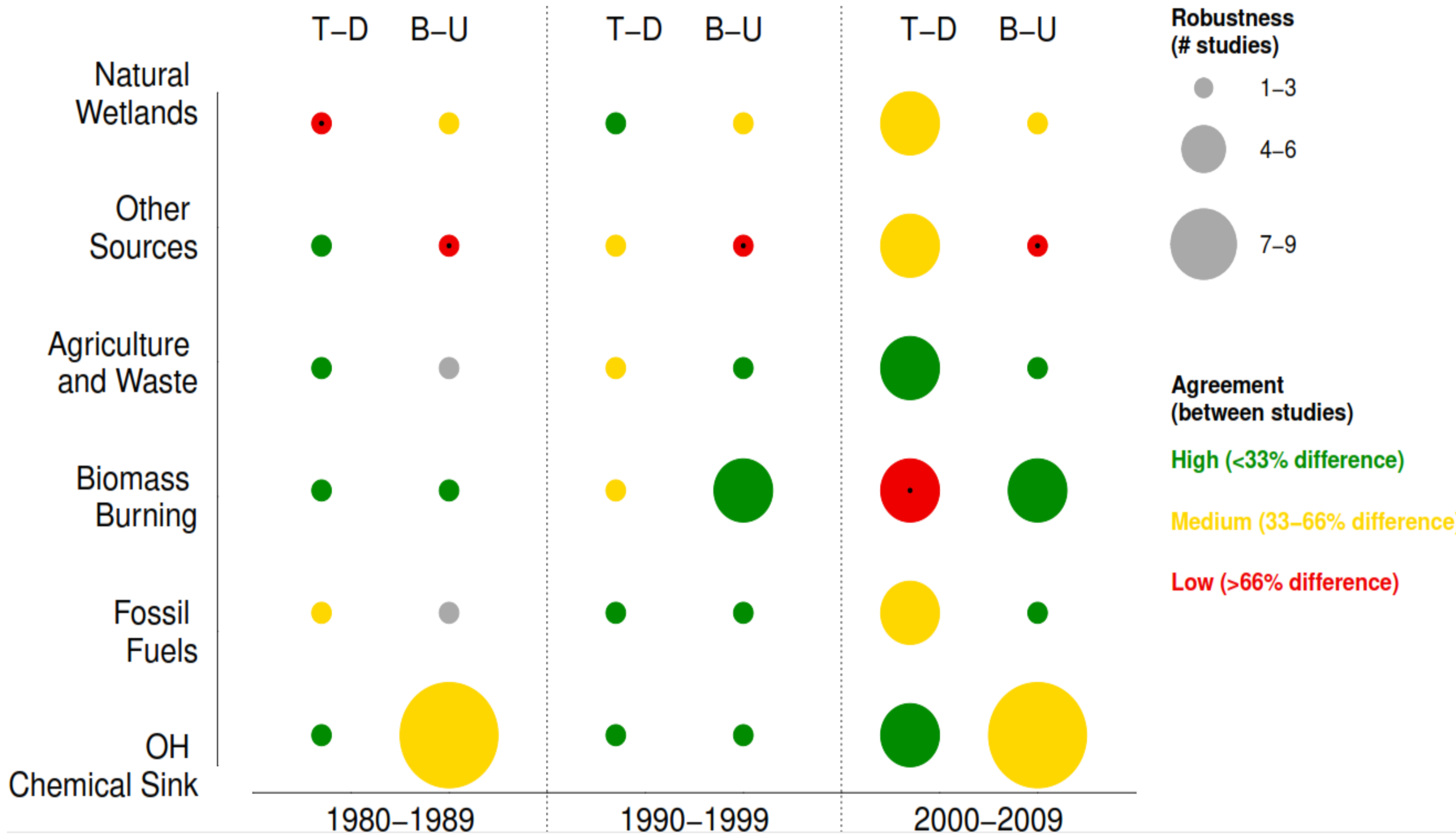
$$C_{x,post}^{-1} = J^T C^{-1}{}_{d,pri} J + C_{x,pri}^{-1}$$

Assumption

- Standard scenario using a priori flux and flux uncertainty based on Mikaloff-Fletcher et al., 2004 with updated, process based, global totals from IPCC AR4
- Neglection of
  - Transport model error
  - "Representation" error

Evolution of Uncertainty: Decadal Budgets

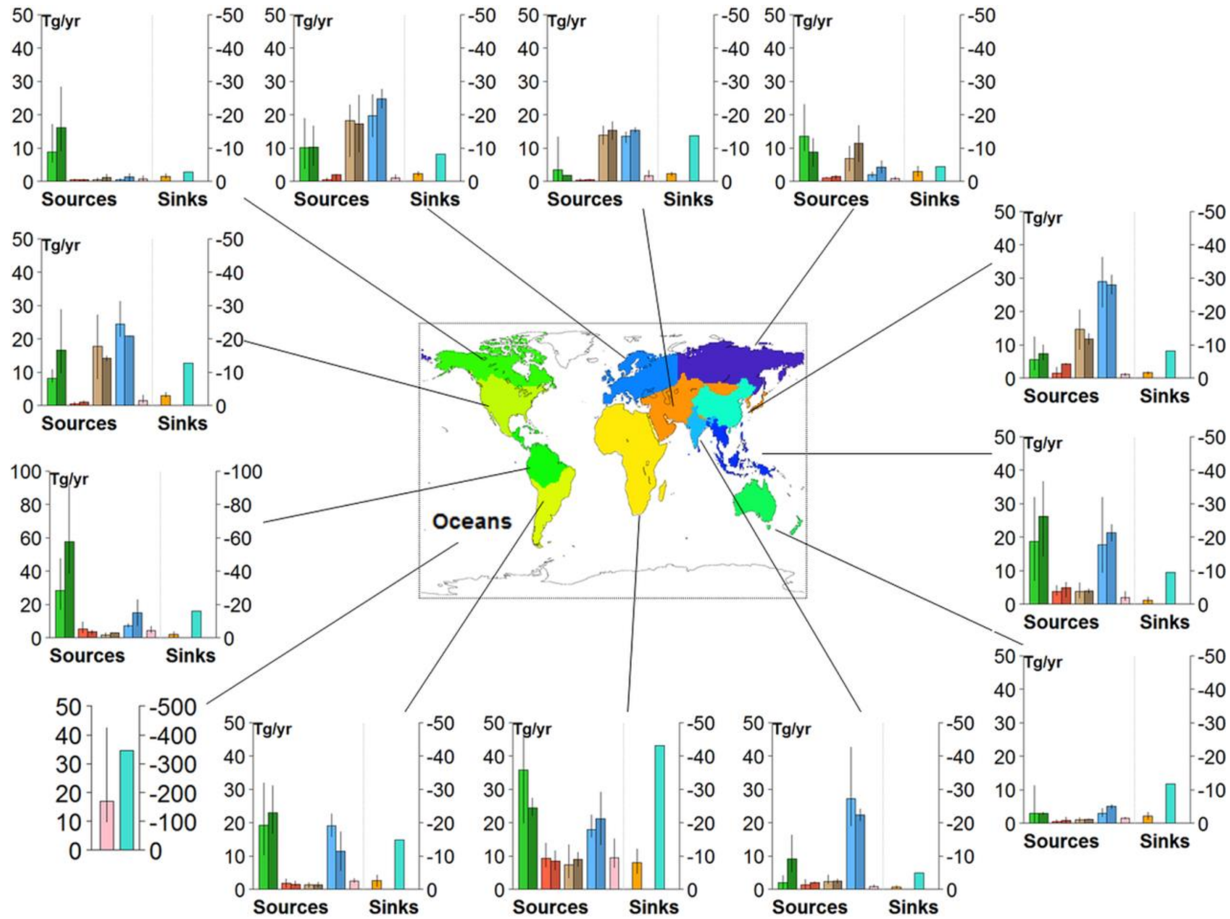
- No source or sink reaches the maximum level of confidence (large green circle)
- Robustness is larger in the 2000s than in previous decades
- Agreement can go down as more studies appear (e.g. fire, wetlands, OH, …)



Kirschke et al. 2013, Nature Geoscience

Regional Methane Budget

- Dominance of wetland emissions in the tropics and boreal regions
- Dominance of agriculture & waste in India and China
- Balance between agriculture & waste and fossil fuels at mid-latitudes
- Uncertain magnitude of wetland emissions in tropical South America between T-D and B-U



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