

Summerschool, Alpbach, Austria, 2010

Greenhouse gas observations from space: Current Status and Future Needs^{*)}



^{*)} CO₂ & CH₄

Michael Buchwitz, Maximilian Reuter
reuterm@loz.de

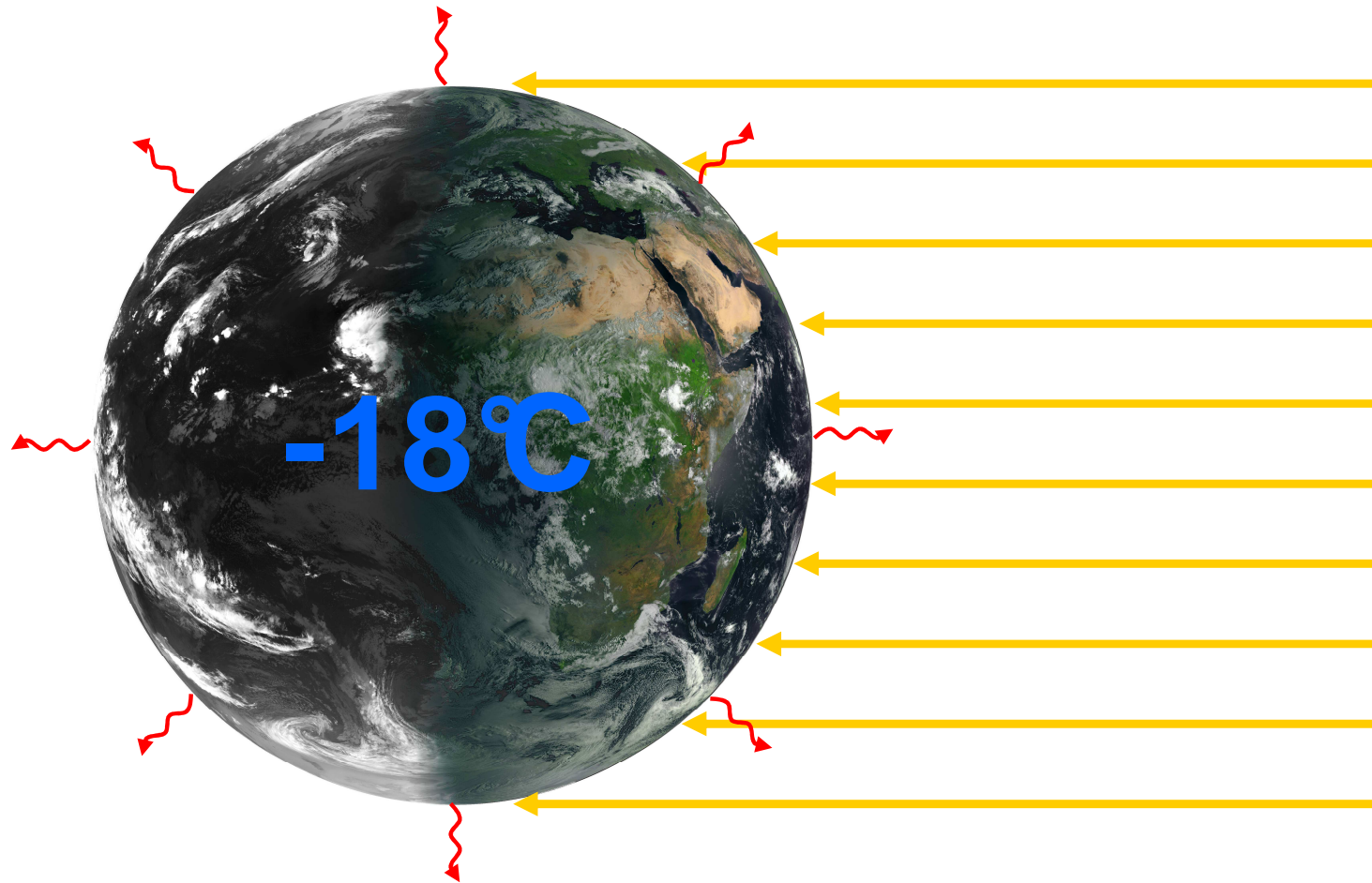
Institute of Environmental Physics (IUP), University of Bremen, Germany

Outline

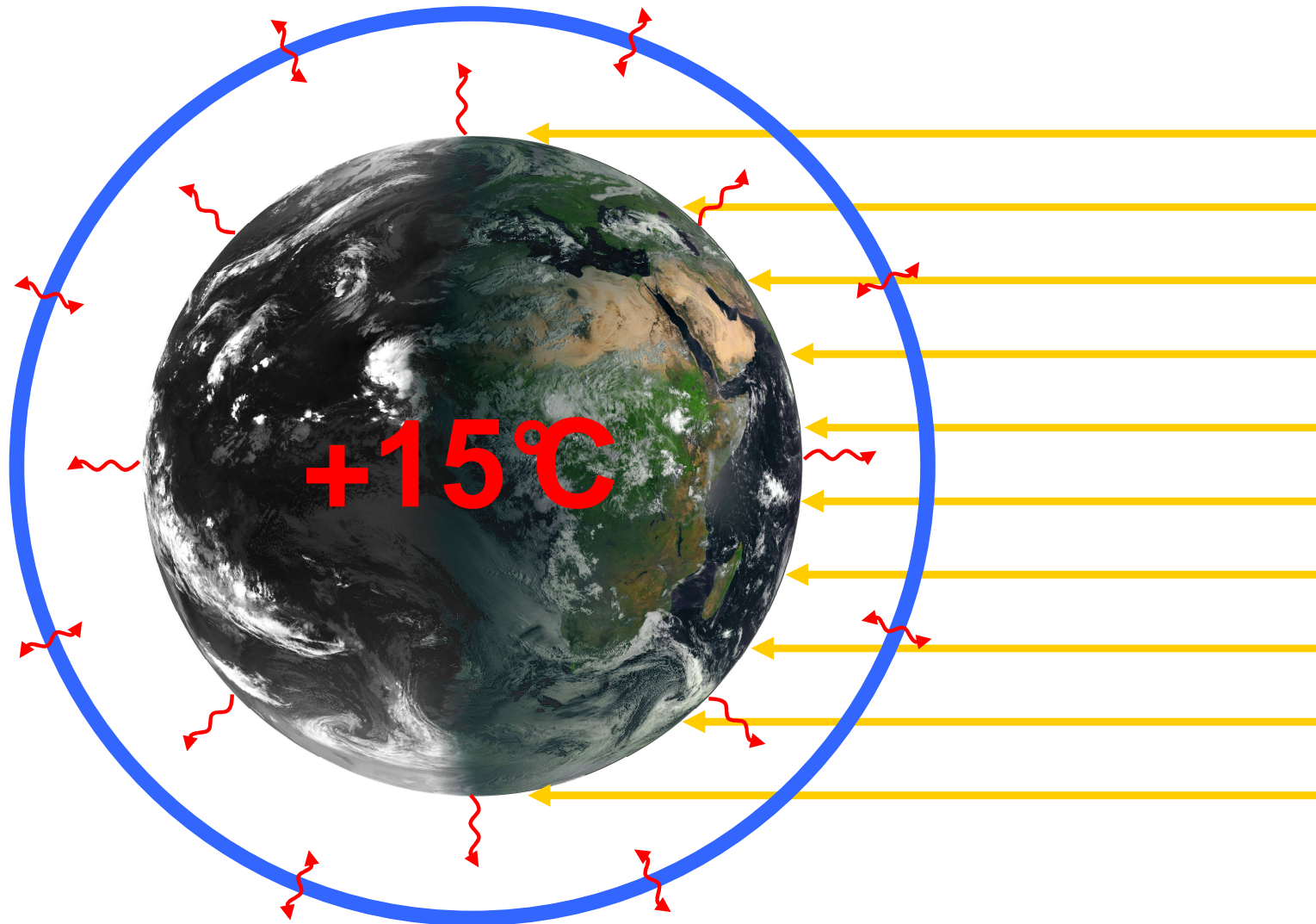
- Why greenhouse gas observations from space ?
- Measurement techniques
- Existing and planned satellites
 - = Current status and future needs

Fundamentals

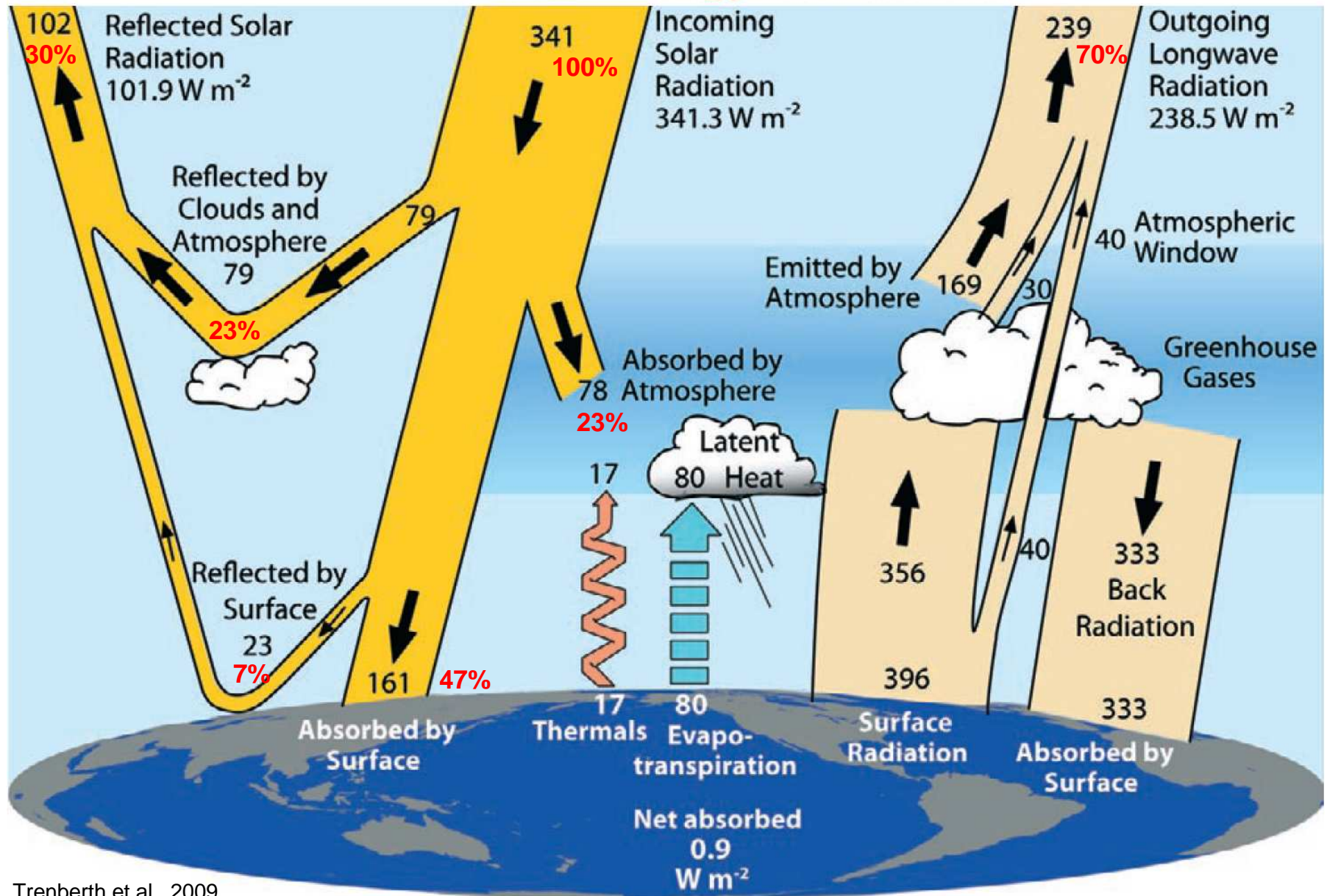
The Greenhouse Effect



The Greenhouse Effect



Global Energy Flows $W m^{-2}$



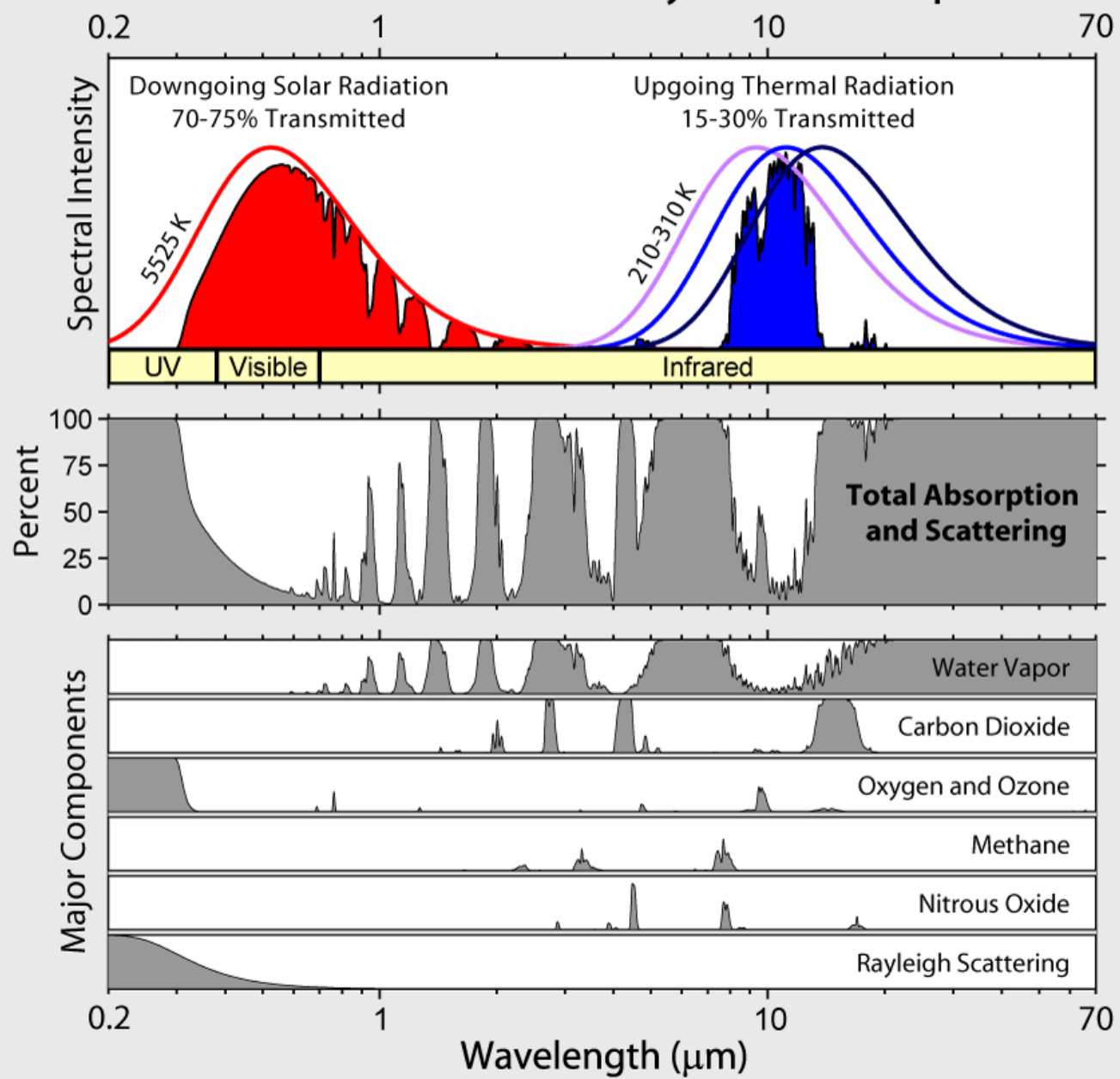
The natural Greenhouse Effect

Treibhausgas	Beitrag am natürlichen Treibhauseffekt	Atmosphärischer Anteil (Säulenmittel)
Wasserdampf (H ₂ O)	62%	4000ppm
Kohlendioxid (CO ₂)	22%	380ppm
Ozon (O ₃)	7%	0.3ppm
Lachgas (N ₂ O)	4%	0.3ppm
Methan (CH ₄)	2.5%	1.7ppm

The anthropogenic Greenhouse Effect

Treibhausgas	Beitrag am anthropogenen Treibhauseffekt	Atmosphärischer Anteil (Säulenmittel)
Wasserdampf (H ₂ O)	nur indirekt	4000ppm
Kohlendioxid (CO ₂)	55%	380ppm
Ozon (O ₃)	10% (indirekt)	0.3ppm
Lachgas (N ₂ O)	5%	0.3ppm
Methan (CH ₄)	18%	1.7ppm

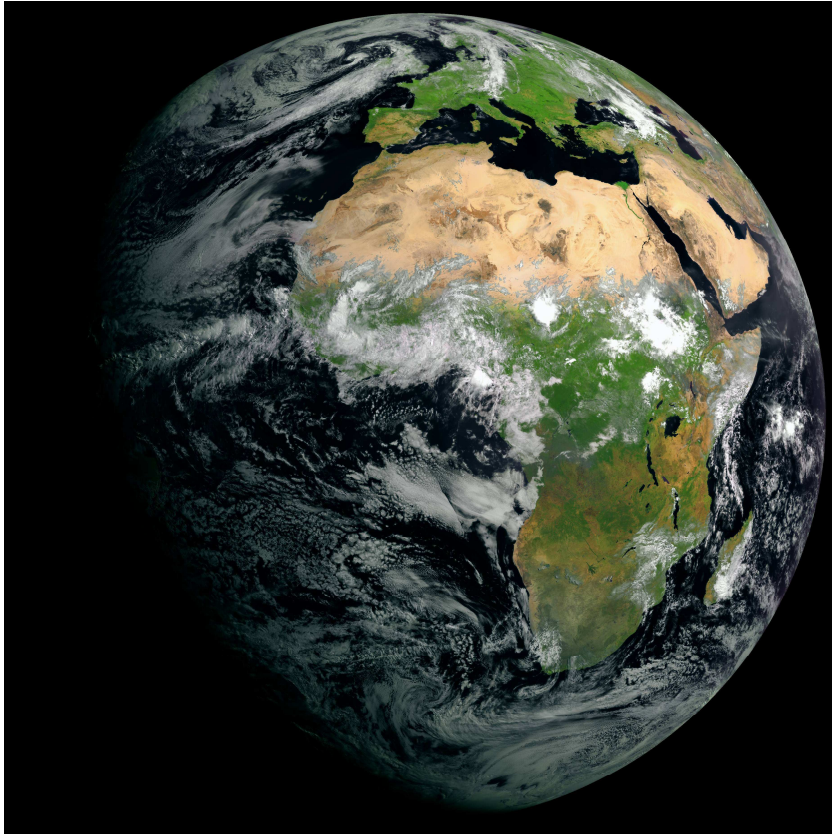
Radiation Transmitted by the Atmosphere



www.globalwarmingart.com

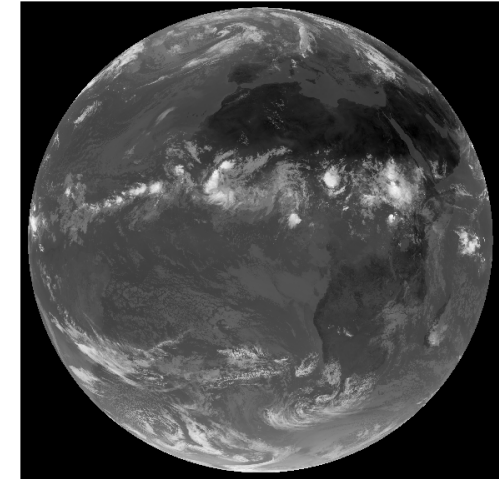
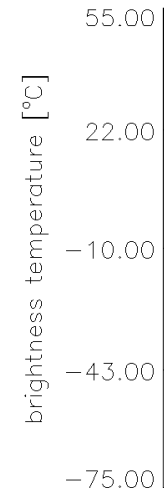
Solare Einstrahlung

0.6 μm , 0.8 μm , 1.6 μm

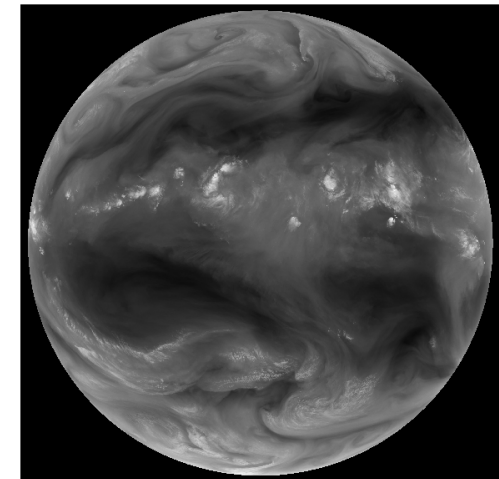


Thermische Ausstrahlung

10.8 μm



6.2 μm



„Der Anstieg des CO₂ wird zukünftigen Menschen erlauben,
unter einem wärmeren Himmel zu leben“

1896 Svante Arrhenius:
Verdopplung CO₂
→ 2.1°C

2007 IPCC:
Verdopplung CO₂
→ 2.0-4.5°C

$$\Delta T \sim \Delta F \sim \ln \frac{C}{C_0}$$



Svante Arrhenius, (de.wikipedia.org)

THE
LONDON, EDINBURGH, AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* By Prof. SVANTE ARRHENIUS*.

I. *Introduction: Observations of Langley on Atmospheric Absorption.*

A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndal † in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of the temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this: Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier ‡ maintained that the atmosphere acts like the glass of a hot-house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pouillet §; and Langley was by some of his researches led to the view, that “the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to -200° C., if that atmosphere did not possess the quality of selective

* Extract from a paper presented to the Royal Swedish Academy of Sciences, 11th December, 1895. Communicated by the Author.

† ‘Heat a Mode of Motion,’ 2nd ed. p. 405 (London, 1835).

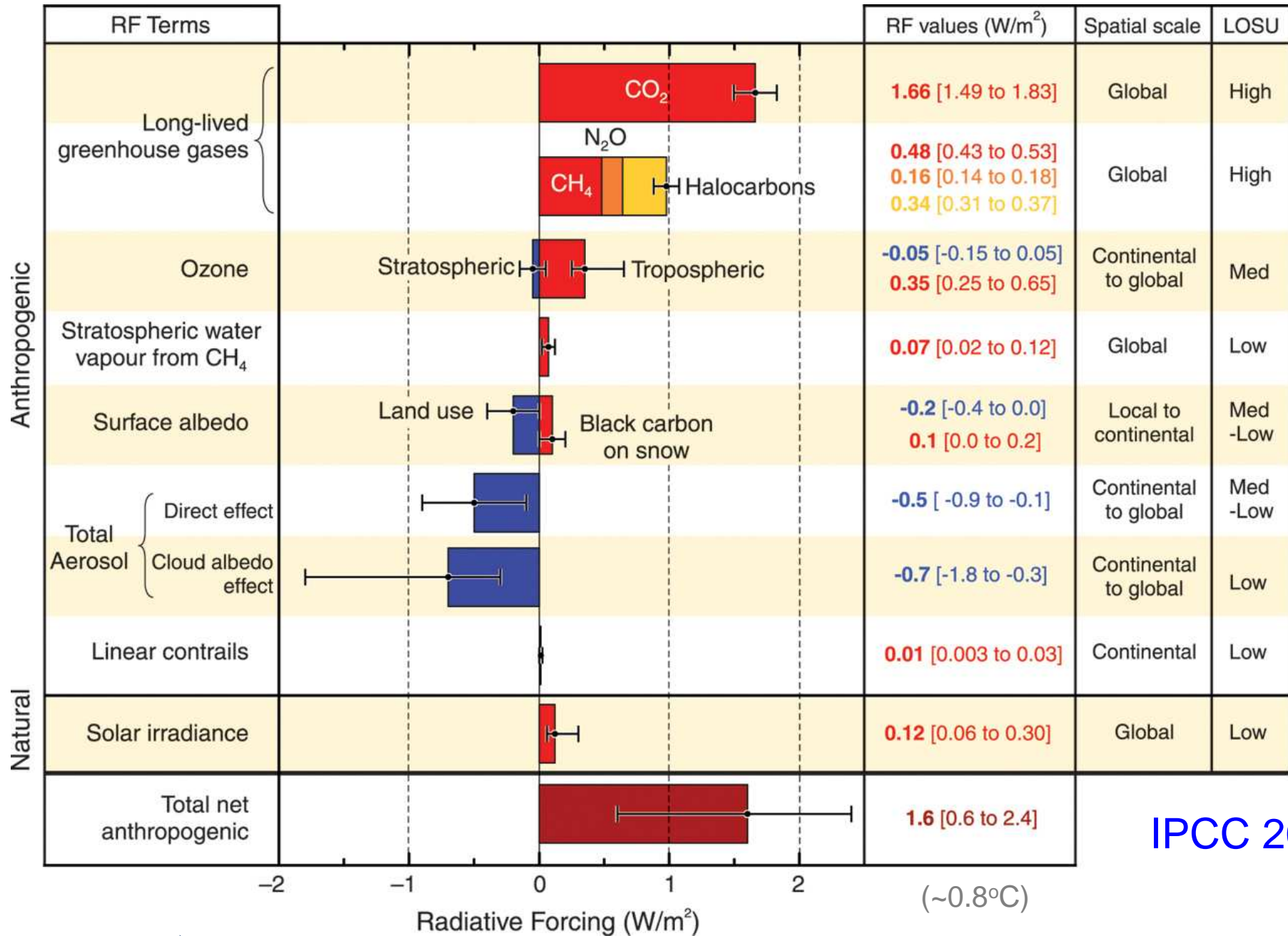
‡ *Mém. de l’Ac. R. d. Sci. de l’Inst. de France*, t. vii. 1827.

§ *Comptes rendus*, t. vii. p. 41 (1838).

Phil. Mag. S. 5. Vol. 41. No. 251. April 1896. S

www.globalwarmingart.com

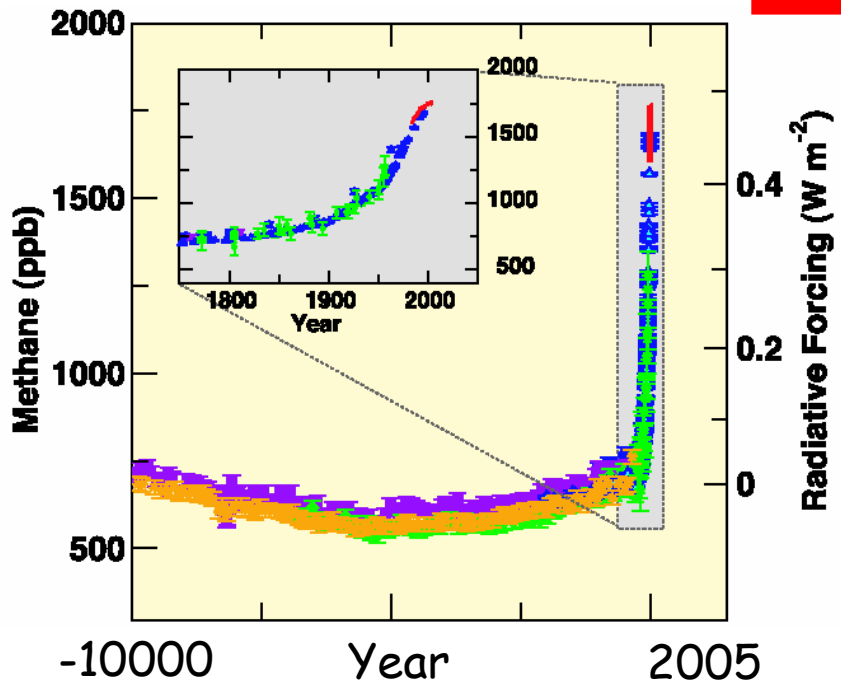
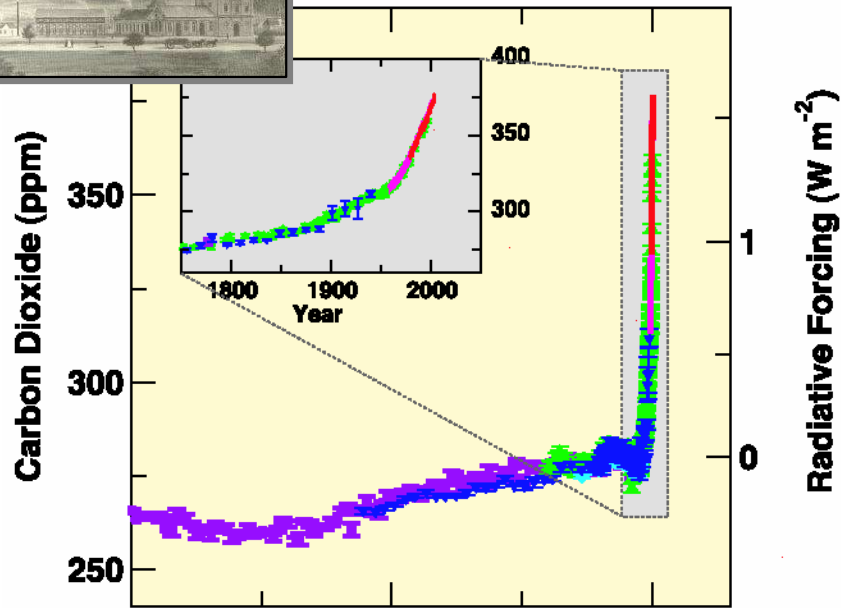
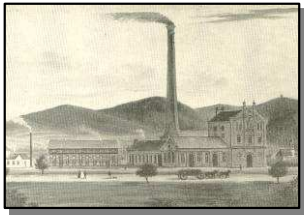
Radiative forcing



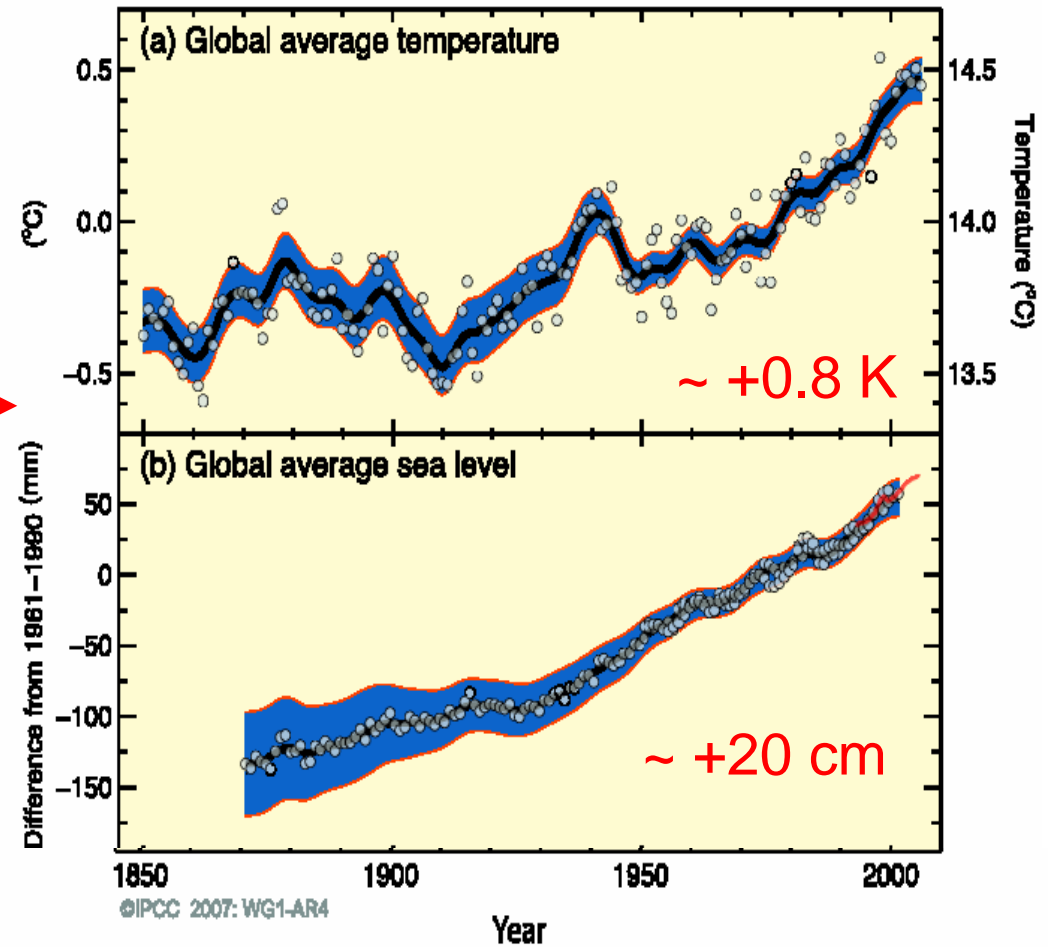
IPCC 2007

➔ CO₂ and CH₄ main contributors to global warming !

Past & present observations



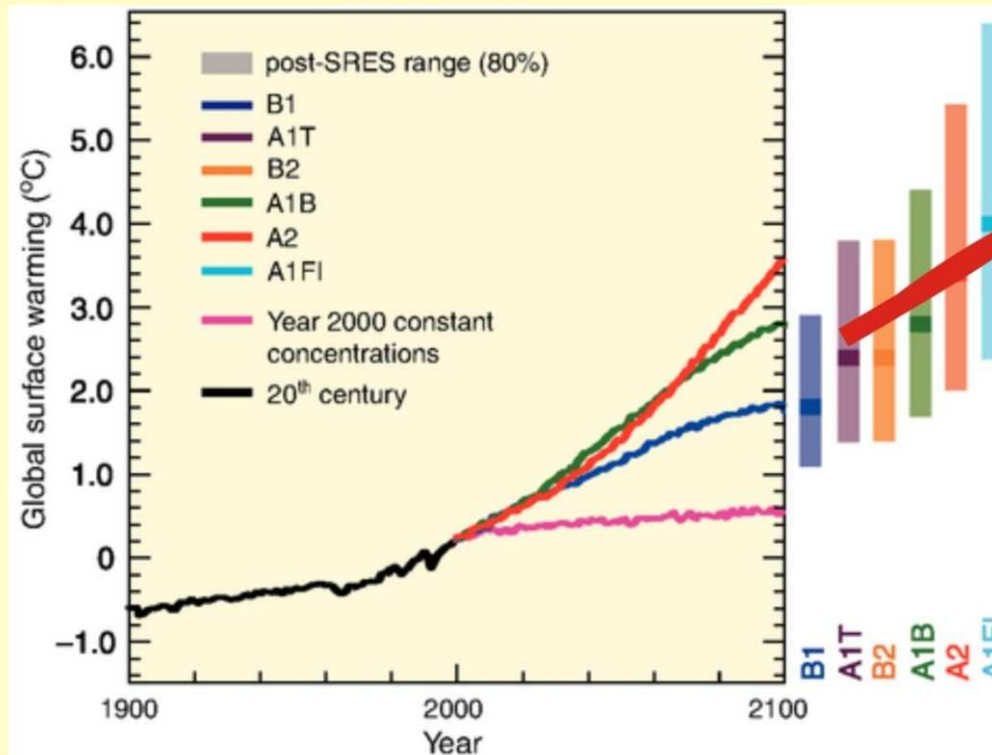
Some consequences:



Why greenhouse gas observations
from space?

Our Future ?

Predicted surface temperature according to IPCC 2007



Factors influencing our future climate

Economy ?

Technology ?

Population ?

CO₂ sources ?

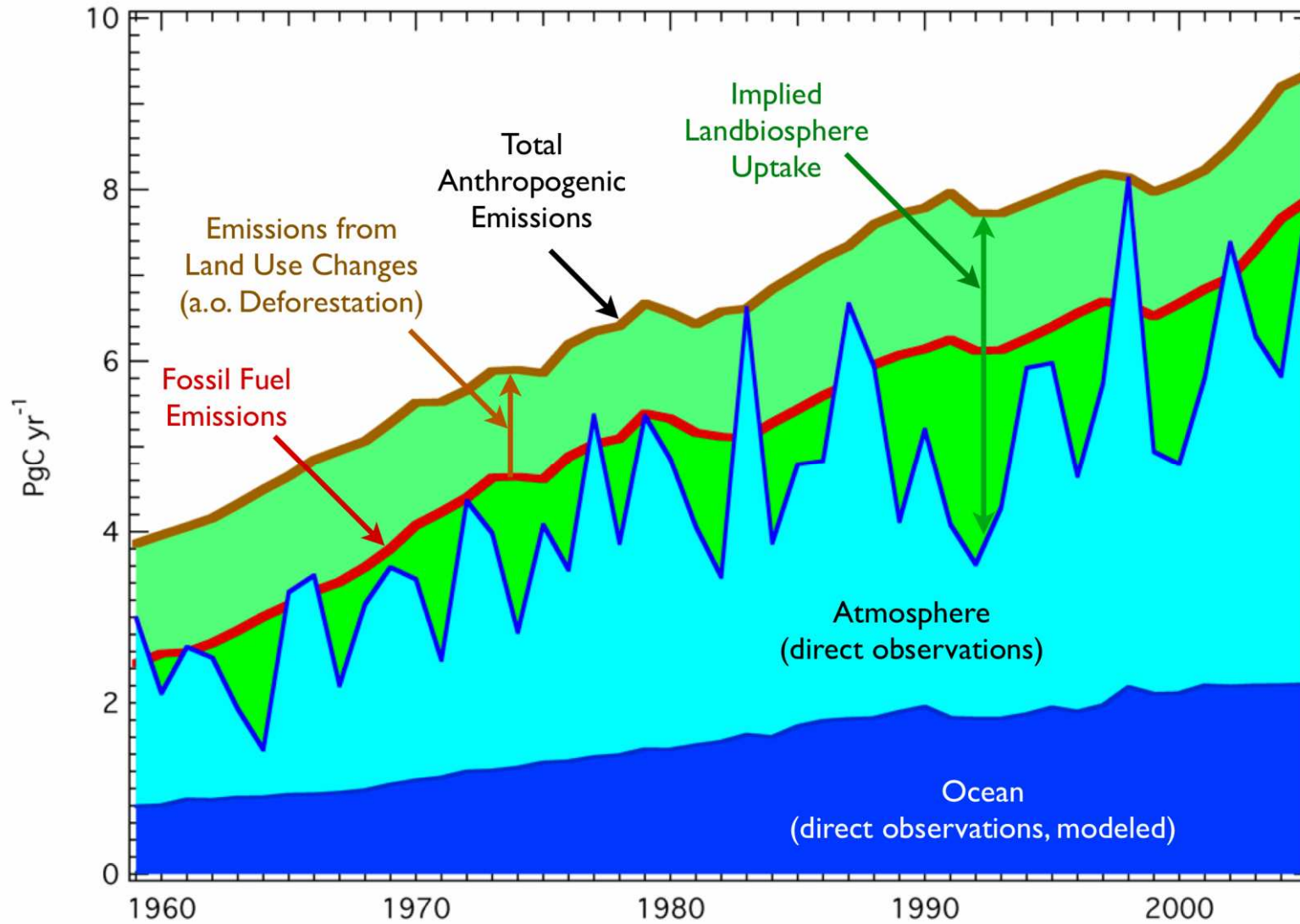
CO₂ sinks ?

CH₄ sources ?

Global observations of atmospheric CO₂ and CH₄ combined with (inverse) modeling needed to deliver important missing information on GHG sources & sinks !

Cost effective solution: Satellites !

CO₂ sources and sinks



http://www.carboscope.eu/img/carbon_cycle_fig2.png



Where is the CO₂ disappearing ?

NEWS FEATURES

Missing carbon mystery: Case solved?

Scientists claim to have located the 'missing carbon sink' in tropical forests that are absorbing around one billion tonnes more carbon than previously thought. Jane Burgermeister investigates.

Stephens et al., Science , 2007

Missing sink:

-1 GtC/yr

Tropics:

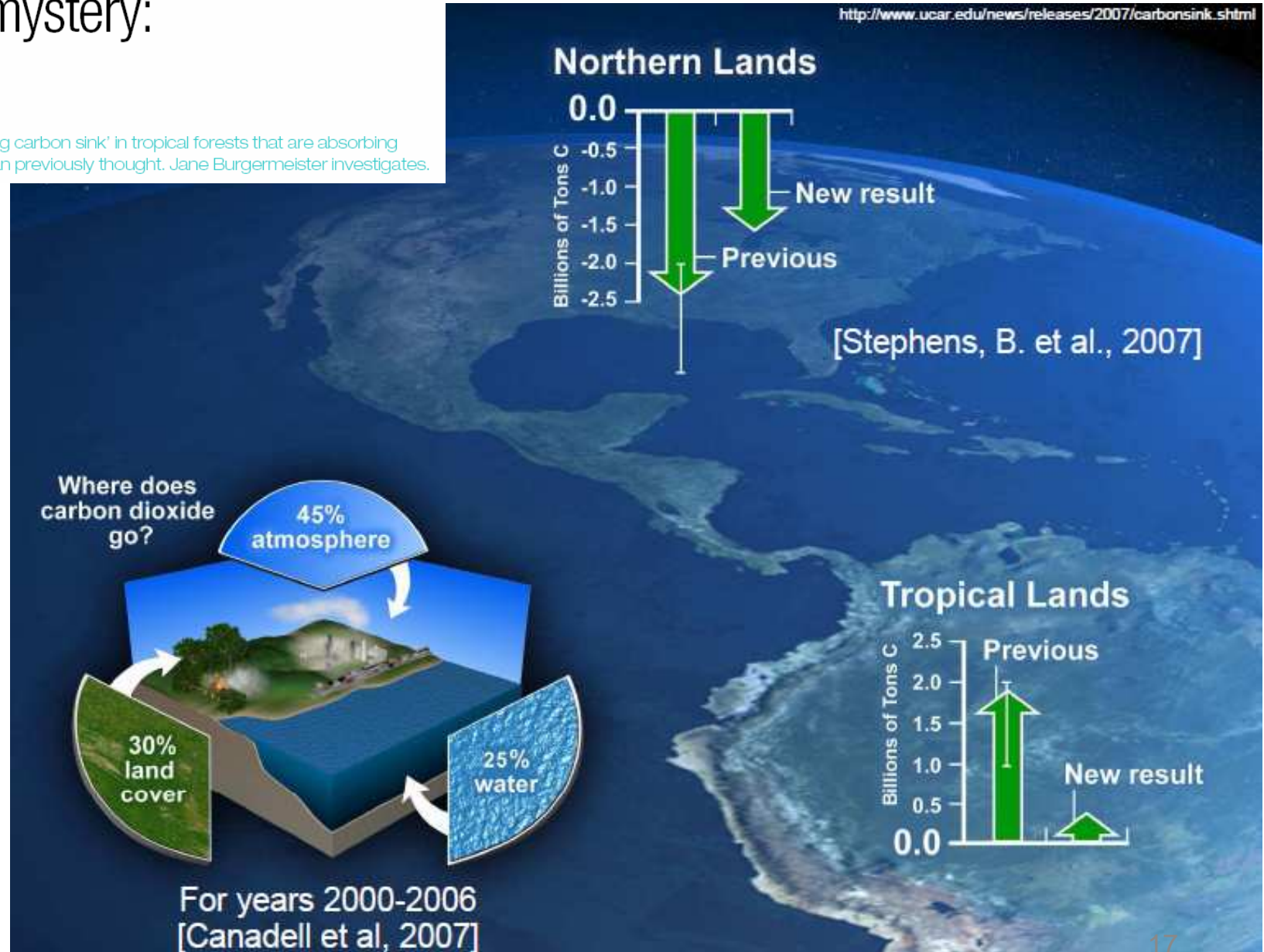
- 2 GtC/yr

(net 0 instead of source)?

NH land:

+1 GtC/yr

(weaker sink)?



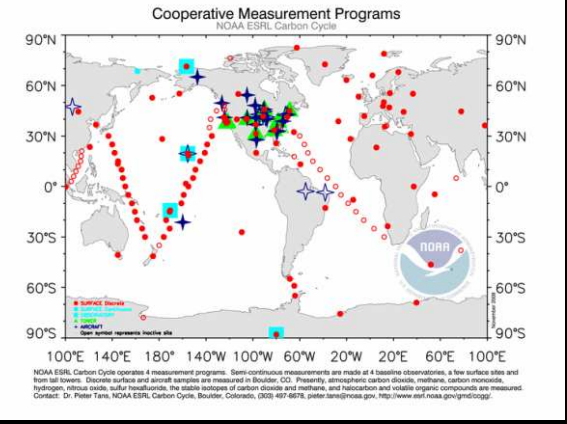
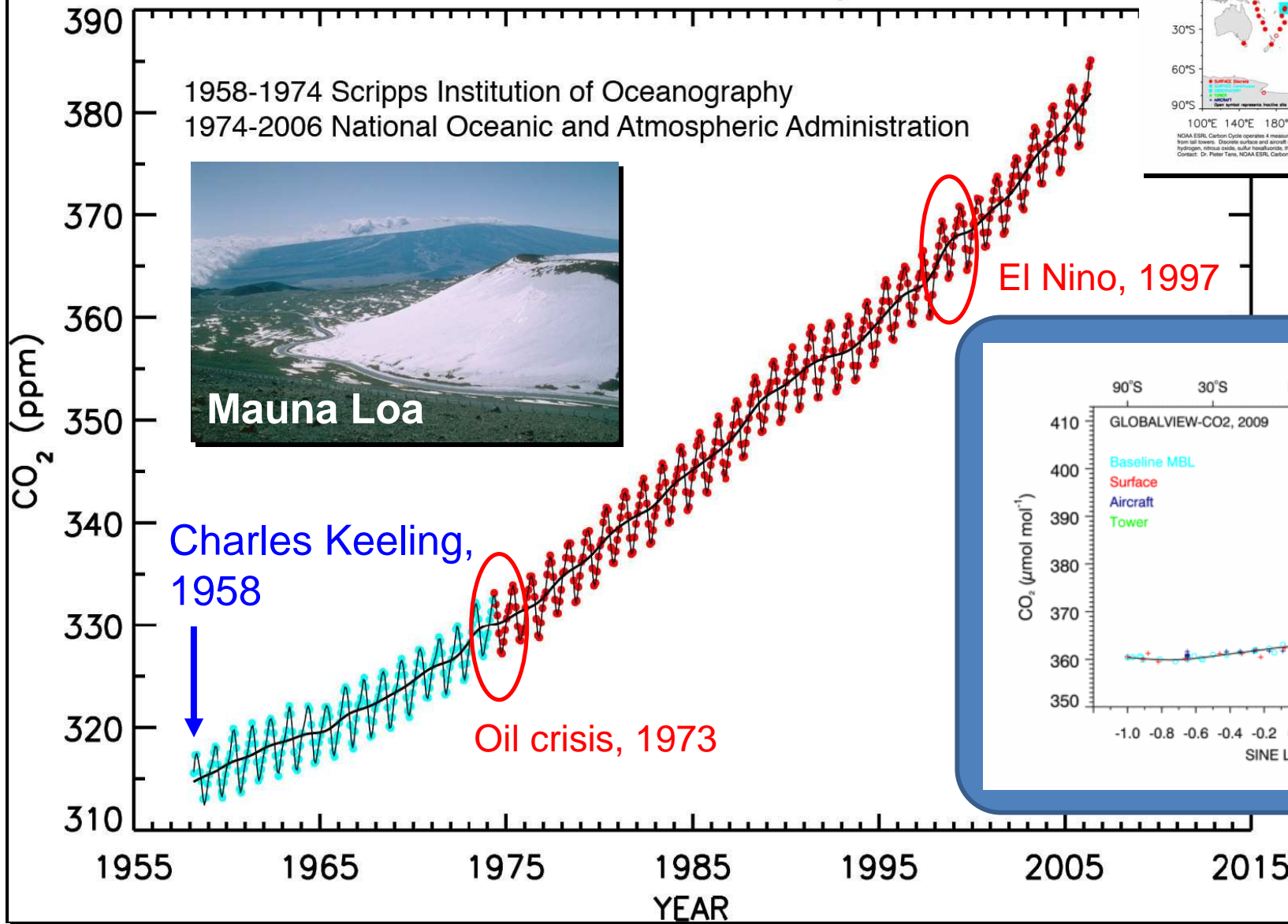
CO₂ surface observations

Mauna Loa Monthly Mean Carbon Dioxide

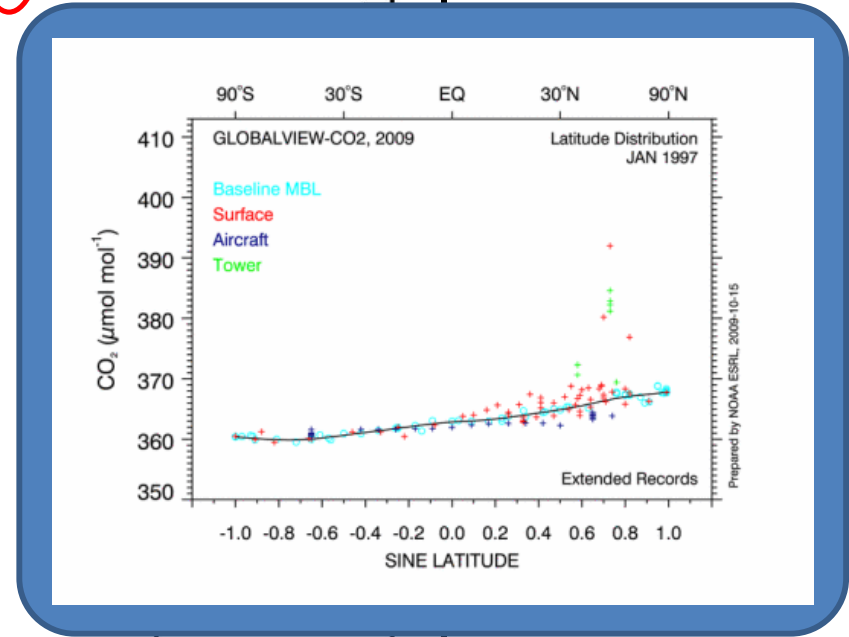
NOAA ESRL GMD Carbon Cycle

1958-1974 Scripps Institution of Oceanography

1974-2006 National Oceanic and Atmospheric Administration

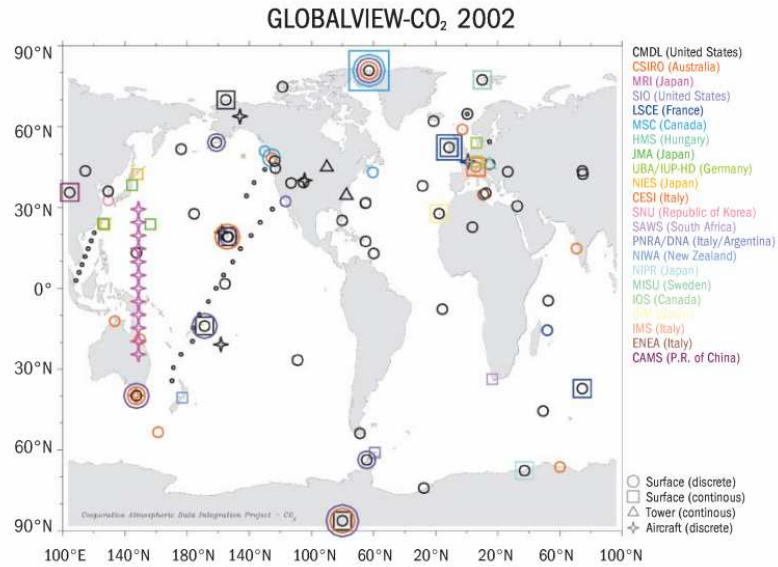


Status: Nov 2009



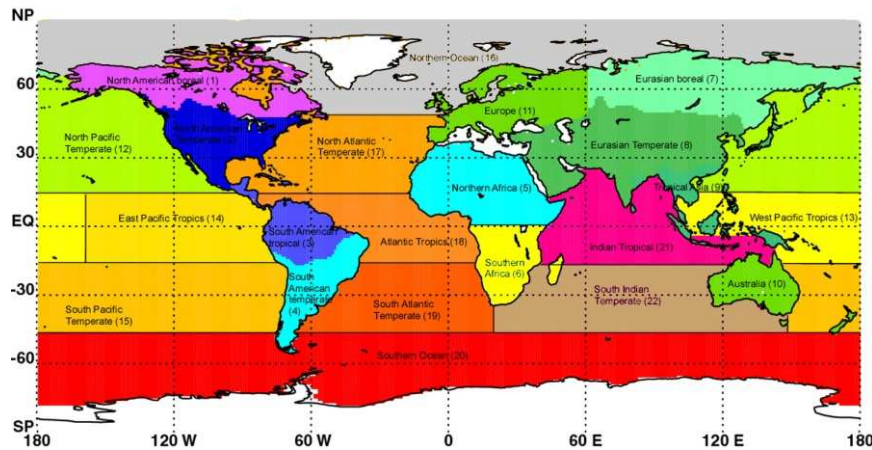
CO₂ fluxes from surface observations

Surface CO₂ network

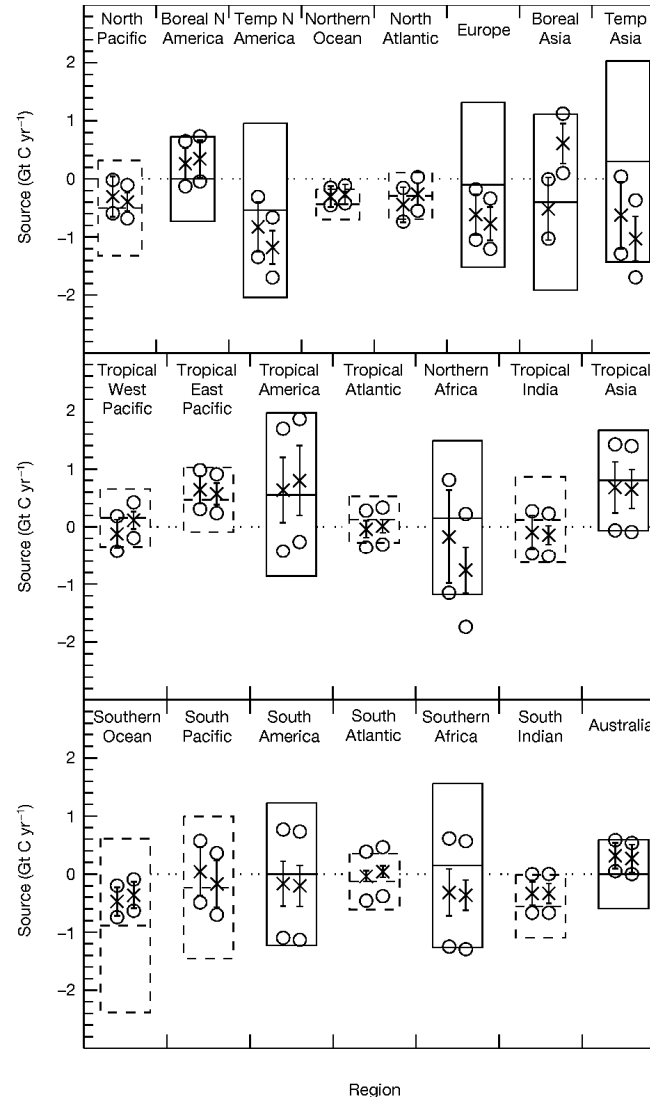


<http://www.cmdl.noaa.gov/ccgg/globalview/>

TransCom 3 regions



TransCom 3 regional CO₂ flux inversions



Very accurate but sparse

Information content sources & sinks (fluxes):

Large regions only (continents, ocean basins)

Large uncertainties (often +/- 100%)

Gurney et al., Nature, 2002

Methane sources

NATURE|Vol 439|12 January 2006

Global by source category

GLOBAL CHANGE

A green source of surprise

David C. Lowe

a

Identified methane sources	Estimates ⁸	Range of estimates ²
Total wetlands	145	92-237
Rice agriculture	60	40-100
Ruminant animals	93	80-115
Termites	20	20-20
Biomass burning	52	23-55
Energy generation	95	75-110
Landfills	50	35-73
Ocean	10	10-15
Hydrates (marine and terrestrial)	5	5-10
Total identified sources	530	500-600

b

Identified methane sinks	Estimates	Range of estimates
Tropospheric oxidation	507	450-510
Stratospheric loss	40	40-46
Soils	30	10-44
Total identified sinks	577	460-580

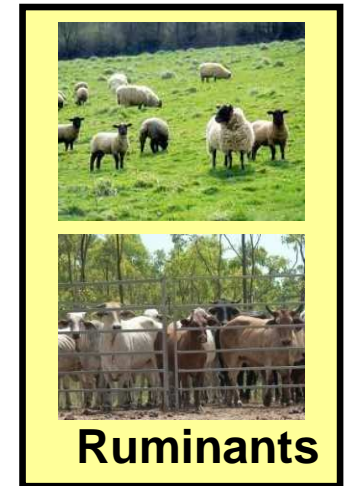
Total sources-sinks	-47	-80 to +140
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Wetlands



Rice



Ruminants



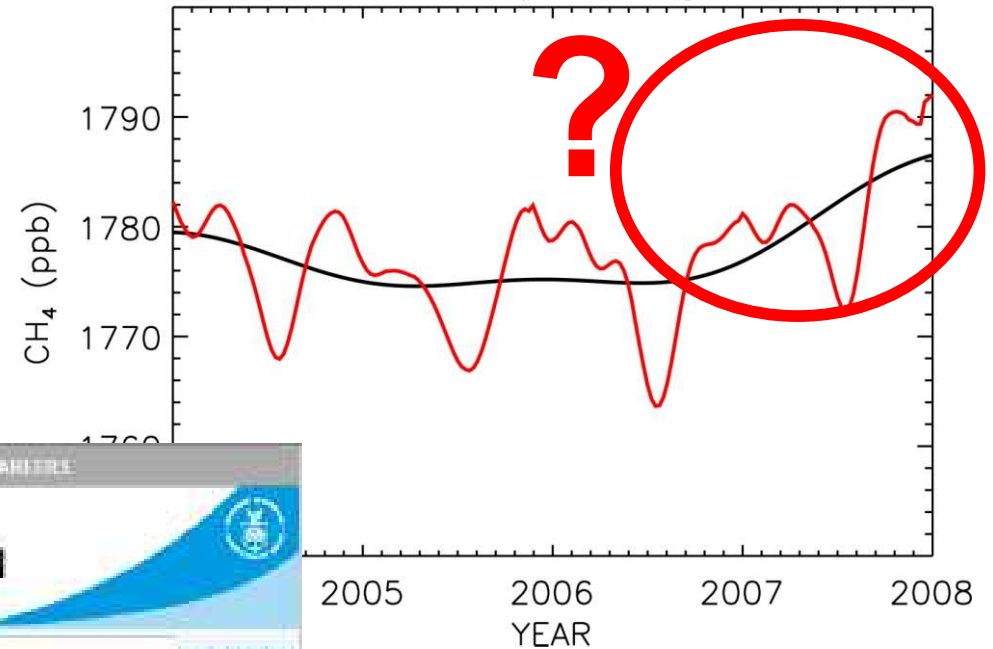
Coal mining

Regionally, the uncertainties are even much larger !

Methane: Recent surface observations

Unexpected and poorly understood increase

NOAA Globally Averaged CH₄



NOAA HOME WEATHER OCEANS FISHERIES CHARTING SATELLITES CLIMATE RESEARCH COASTS CAREERS

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
UNITED STATES DEPARTMENT OF COMMERCE

» About NOAA » Contacts » Staff Directory » Help

Weather.gov Forecast
City, ST GO

» Active Weather Alerts

» NOAA Organizations

» Working With NOAA

» Media & Constituents

» NOAA in Your State

» Emergency Information for NOAA Employees

Media Contact
» Jana Goldman
301-734-1123

Unusual Arctic Warmth, Tropical Wetness Likely Cause for Methane Increase

September 25, 2009

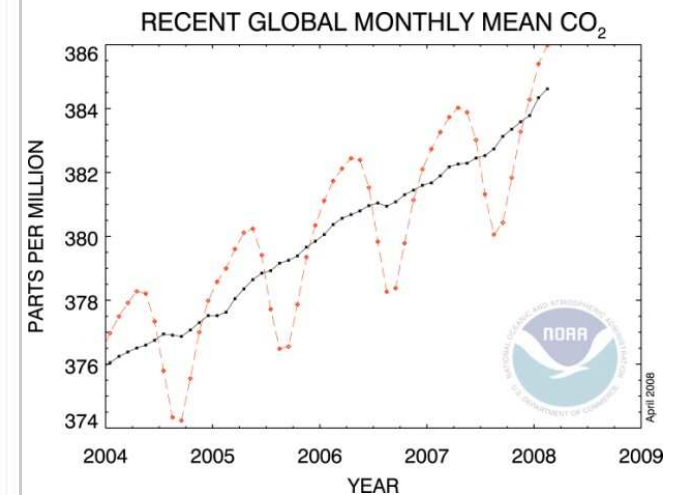
Unusually high temperatures in the Arctic and heavy rains in the tropics likely drove a global increase in atmospheric methane in 2007 and 2008 after a decade of near-zero growth, according to a new study. Methane is the second most abundant greenhouse gas after carbon dioxide, albeit a distant second.

NOAA scientists and their colleagues analyzed measurements from 1993 to 2008 from air samples collected weekly at 46 surface locations around the world. Their findings will appear in the September 28 print edition of the American Geophysical Union's Geophysical Research Letters and are available online now.



Wetlands at the Parker River restoration site.
[High resolution](#) (Credit: NOAA)

"At least three factors likely contributed to the methane increase," said Ed Dlugokenny, a methane expert at NOAA.



What about anthropogenic CO₂ emissions ?

How accurate are reported power plant emissions ?

Comparison of Two U.S. Power-Plant Carbon Dioxide Emissions Data Sets

KATHERINE V. ACKERMAN* AND
ERIC T. SUNDQUIST

*U.S. Geological Survey, 384 Woods Hole Road, Woods Hole,
Massachusetts 02543*

*Received January 22, 2008. Revised manuscript received
May 1, 2008. Accepted May 6, 2008.*

TABLE 1. The Average Signed and Average Absolute Differences Relative to the Mean for the Subsets of Individual Power Plants^a

	average signed difference, relative to mean (%) ^b		average absolute difference, relative to mean (%)		number of plants
	electricity emissions	total emissions	electricity emissions	total emissions	
Whole data set	-3.5	1.8	25.3	16.9	2900
Nonconventional fuel plants	-47.3	-33.3	99.4	78.9	252
Coal-, oil- and gas-fired plants	0.7	5.1	18.3	11.0	2648
Monitoring method (conventional-fuel data set)					
Stack measurements	4.6	5.4	17.1	16.6	828
Stack or fuel calcs (combo)	21.0	21.7	24.8	24.4	285
Fuel calculations	-5.1	1.9	17.7	5.5	1535
CHP plants (conventional-fuel data set)					
CHP plants	-6.8	0.2	37.9	12.7	493
Non-CHP plants	5.3	5.3	9.5	9.5	1888
Fuel calculation subset (conventional-fuel data set)					
All plants in this subset	5.1	1.9	17.7	5.5	1535
CHP plants	-8.2	0.0	37.7	9.5	435
Non-CHP plants	0.6	0.6	1.8	1.9	898

^a All values shown are for 2004. ^b Positive average signed differences indicate that, on average, the eGRID values are larger than the EIA values, and vice versa for negative average signed differences.

fossil-fuel emissions. However, the corresponding average absolute differences between estimates of emissions from individual power plants were much larger, 16.9% and 25.3%, respectively. By statistical analysis, we identified several potential sources of differences between EIA and eGRID estimates for individual plants. Estimates that are based partly or entirely on monitoring of stack gases (reported by eGRID only) differed significantly from estimates based on fuel consumption (as reported by EIA). Differences in accounting methods appear to



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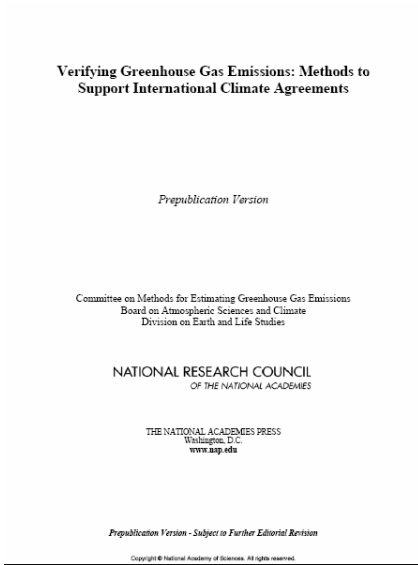
Our analysis demonstrates that plant-level and conterminous U.S. estimates of CO₂ emissions can be improved by resolution of identifiable sources of bias. However, it is important to recognize that the ongoing quantification of accuracy and uncertainties will always require the application of multiple independent estimation procedures. As strategies for mitigation of greenhouse gas emissions are debated and implemented, we suggest that attention be devoted to the importance of designed redundancy and transparency in the monitoring of power-plant emissions.

Conclusion:

- Need for multiple redundant independent & transparent emission estimation procedures



Need for monitoring anthropogenic CO₂ emissions



Verifying Greenhouse Gas Emissions: Methods to Support International Climate Agreements

Committee on Methods for Estimating Greenhouse Gas Emissions; National Research Council

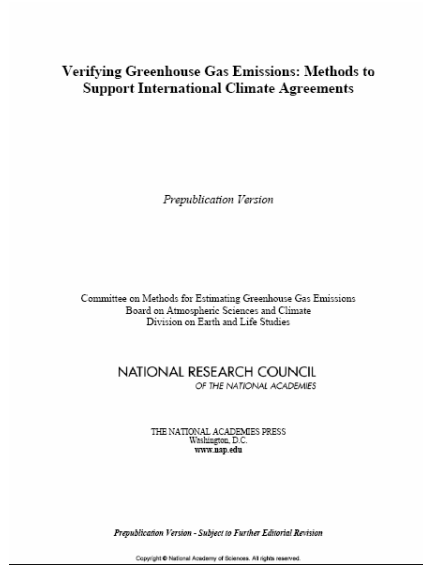
ISBN: 0-309-15212-7, 144 pages, 8 1/2 x 11, (2010)

TABLE S.1 Current and Near-Term Capabilities for Estimating National Anthropogenic Greenhouse Gas Emissions

Gas	Major Sectors or Activities	Method	Current Uncertainty for Annual Emissions ^a	Possible Improvements in 3-5 Years	Uncertainty of Improved Methods
CO ₂	Total anthropogenic	UNFCCC inventory	1 (developed countries) ^b	Adopt most accurate methods in all countries	1
CO ₂	Fossil-fuel combustion	UNFCCC inventory	1-2 (developed countries)	Adopt most accurate methods in all countries	1
CO ₂	Fossil-fuel combustion	Atmospheric measurements and models	4-5	Develop improved tracer-transport inversion through new observations (¹⁴ CO ₂ , additional ground stations, Orbiting Carbon Observatory [OCO] replacement) and data assimilation	1-3 (annual) 1-2 (decadal change)
CO ₂	Large local sources (e.g., cities, power plants)	Atmospheric measurements and models	5	Develop and deploy a CO ₂ satellite program, including an OCO replacement, new in situ measurements in cities, and a research program to guide network design and satellite validation	2 (annual) 1 (decadal change)

Large local sources: emissions highly uncertain – satellites ↑ can improve this 24

Need for monitoring anthropogenic CH₄ emissions



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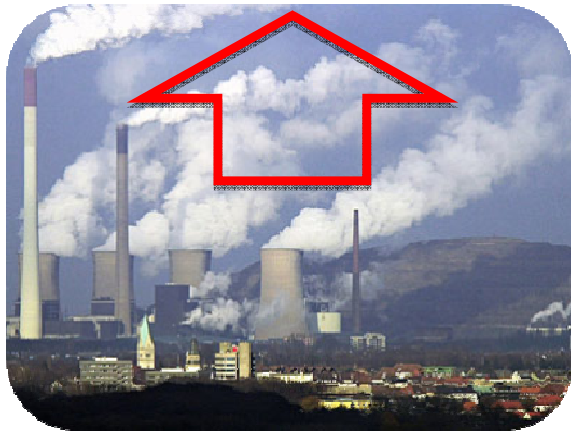
Gas	Major Sectors or Activities	Method	Current Uncertainty for Annual Emissions ^a	Possible Improvements in 3-5 Years	Uncertainty of Improved Methods
(...)					
CH ₄	Total anthropogenic	UNFCCC inventory	2-3 (developed countries)	Adopt most accurate methods and activity data and improved emission factors through research	1-3
CH ₄	Total anthropogenic	Atmospheric measurements and models	3-5	Develop improved tracer-transport models, new satellite and in situ observations, and improved emission models through research	2-3
CH ₄	Energy, industrial processes, and waste	UNFCCC inventory	1-5 (developed countries)	Adopt most accurate methods and activity data and improved emission factors through research	1-2
CH ₄	AFOLU	UNFCCC inventory	2-4 (developed countries)	Adopt most accurate methods and activity data and improved emission factors through research	2-3

Important open questions

... w.r.t. the sources and sinks of CO₂ and methane are for example:

Who / what emits how much ?

(Sources)

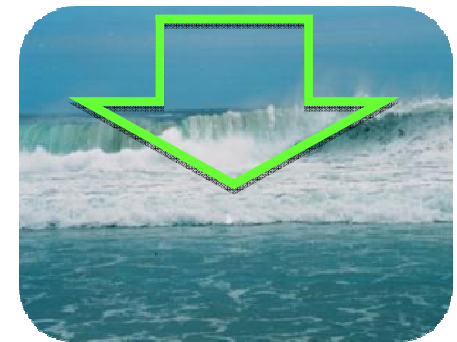


Are the reported emissions correct ?



How much methane will be released by melting permafrost areas ?

How much CO₂ will be taken up by forests and the oceans ? (Sinks)



How will the sinks behave in the future when the climate is different ?

Will sinks turn into sources ?

Merit of satellite observations of CO₂ (similar for CH₄)

Rayner & O'Brien, GRL, 2001

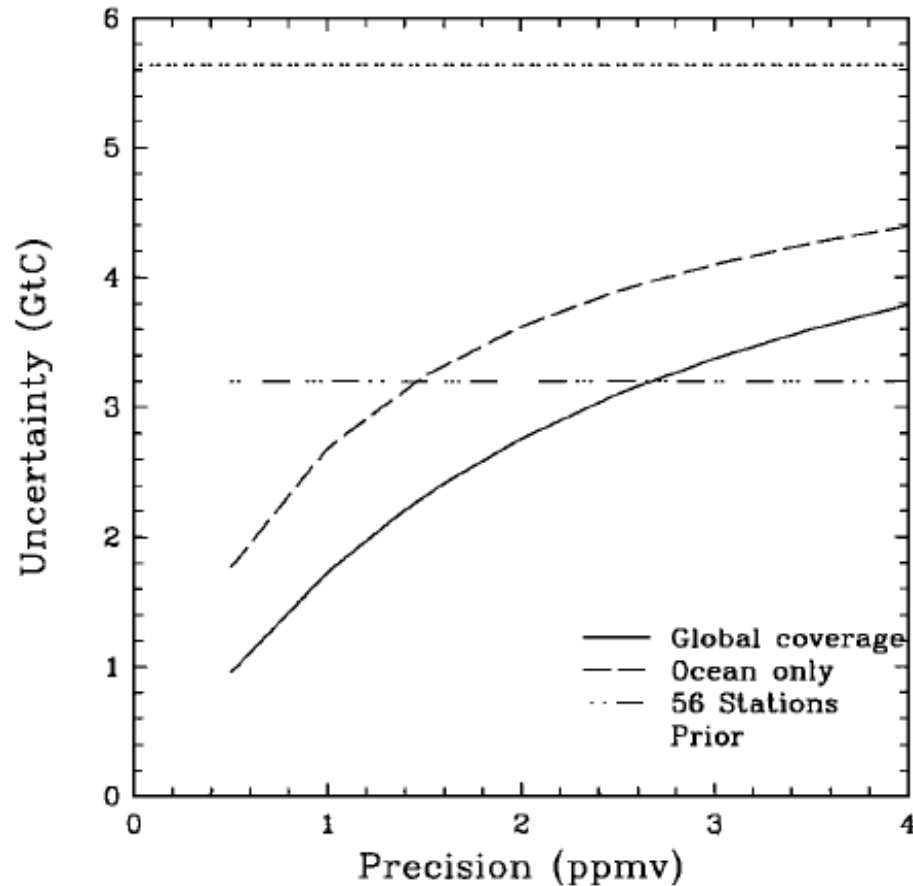


Figure 3. Plot of “total uncertainty” (see Eq. 1) in GtC yr⁻¹ against the precision (ppmv) of column-integrated data. The dotted horizontal line shows the prior uncertainty while the dash-dot horizontal line shows the case for the surface network of Fig. 1.

Global CO₂ flux uncertainty
~ 6 GtC/yr

Reduced to ~ 3 GtC/yr
using surface stations

Satellites can improve this if
sensitive to PBL and if
uncertainty < 2 ppm (0.5%)
for monthly 8°x10° column-
averaged CO₂ („XCO₂“)

Measurement techniques

Viewing Geometries

Satellite Observation Geometries

Nadir

SCIAMACHY,
AIRS, IASI, TES,
GOSAT, OCO-2,
CarbonSat,
A-SCOPE,
MERLIN,
ASCENDS

**Most relevant for GHG
source / sink
application**

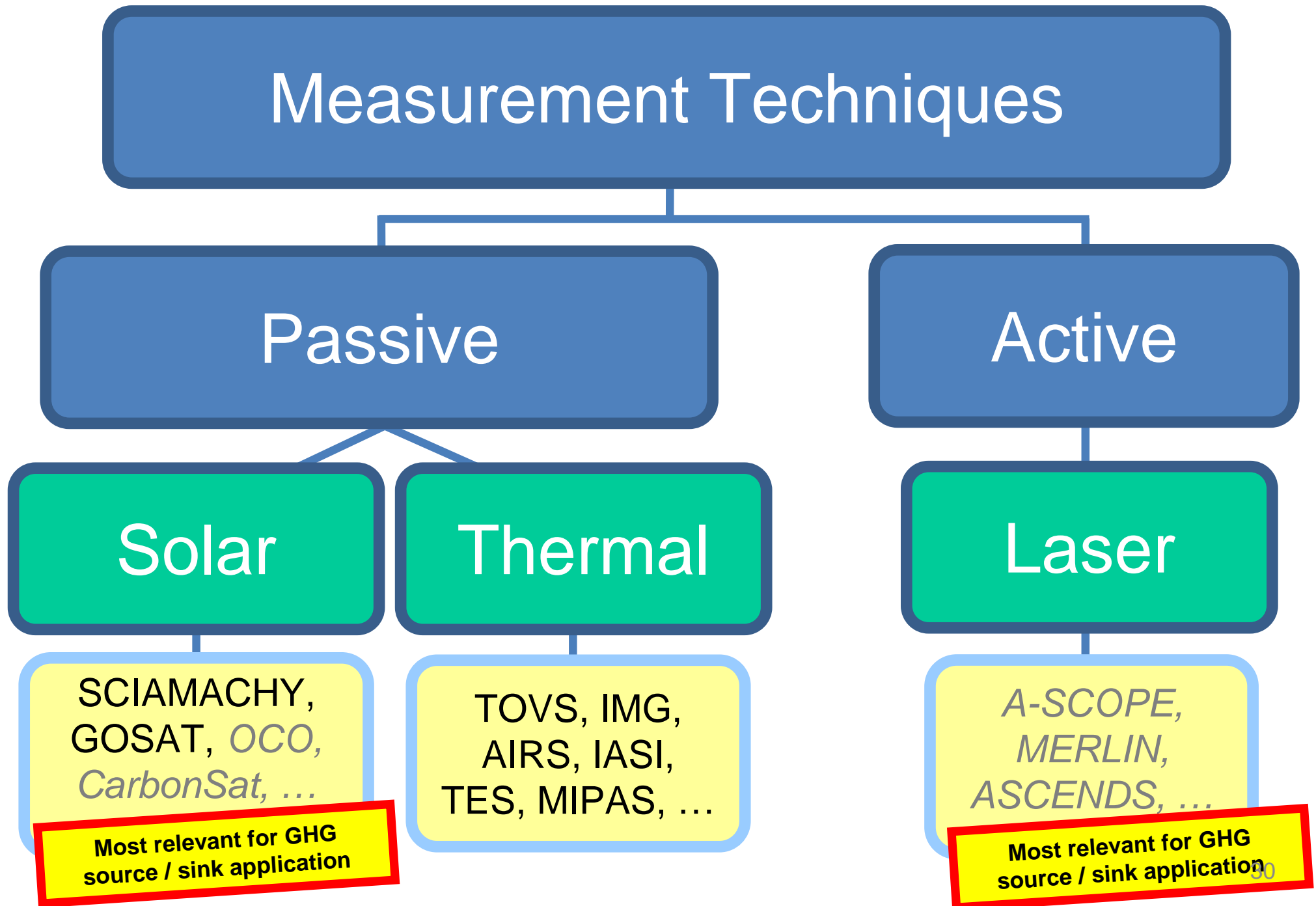
Limb

SCIAMACHY,
MIPAS, ...

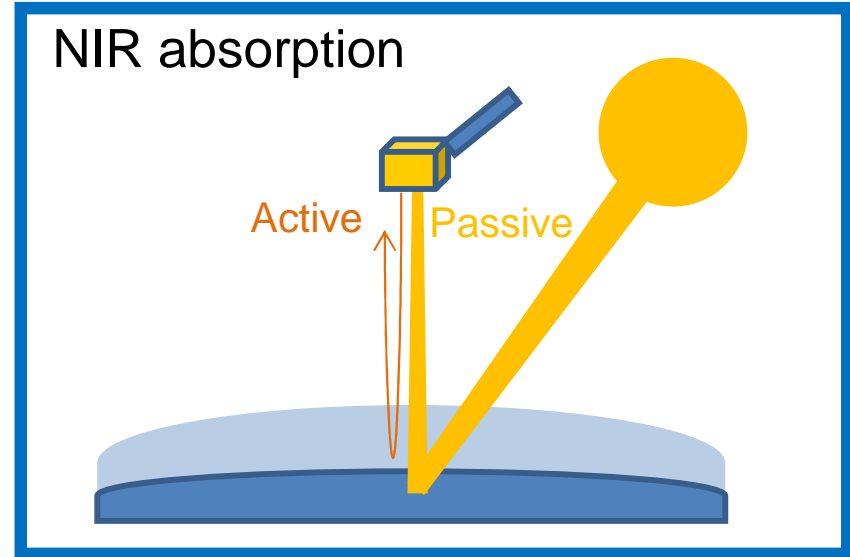
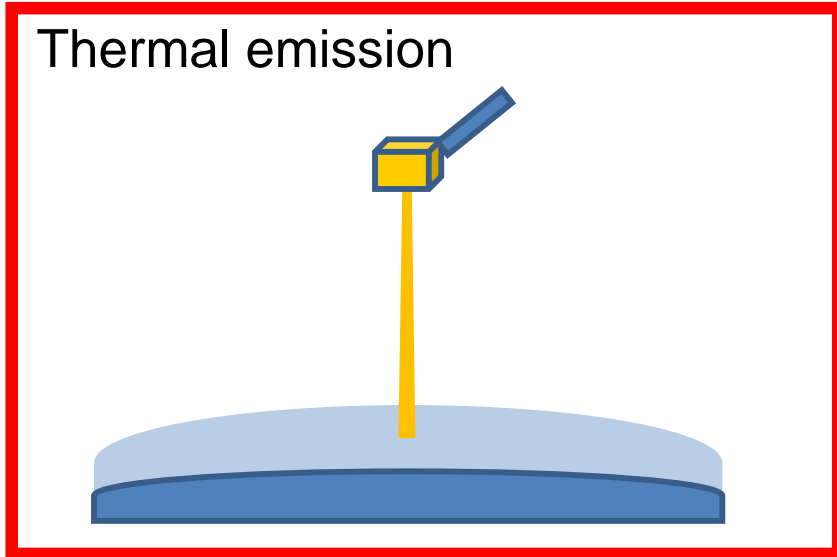
Occultation

SCIAMACHY,
ACE-FTS, ...

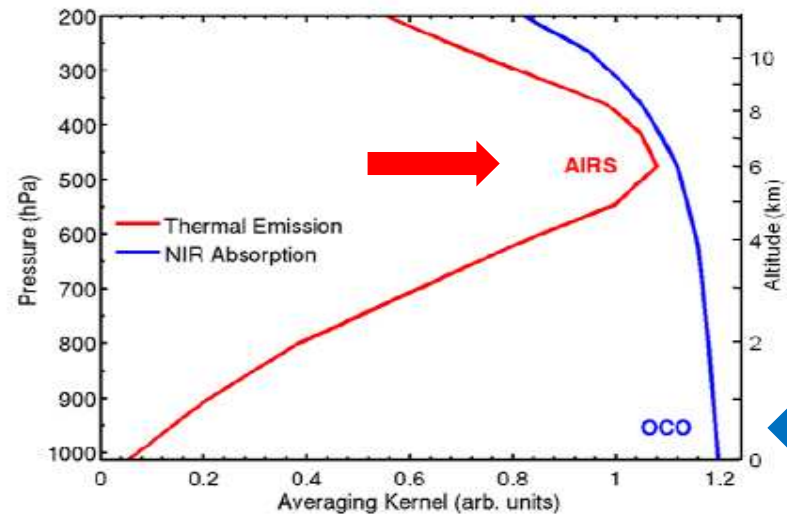
Measurement Techniques



Reflected solar (NIR/SWIR) vs thermal (TIR)



Sensitive to mid/upper troposphere



Sensitive to near-surface GHG concentrations

Figure 7. Representative vertical averaging kernels for column CO₂ soundings using NIR absorption of reflected sunlight in the 1.61 μm CO₂ band (blue) and thermal IR emission near 14.3 μm (red). TIR soundings are less sensitive to near-surface CO₂ because of the small surface-atmosphere temperature contrast (Crisp *et al.*, 2004; Chahine *et al.*, 2005).

Estimated uncertainty reduction of (weekly) CO₂ surface fluxes

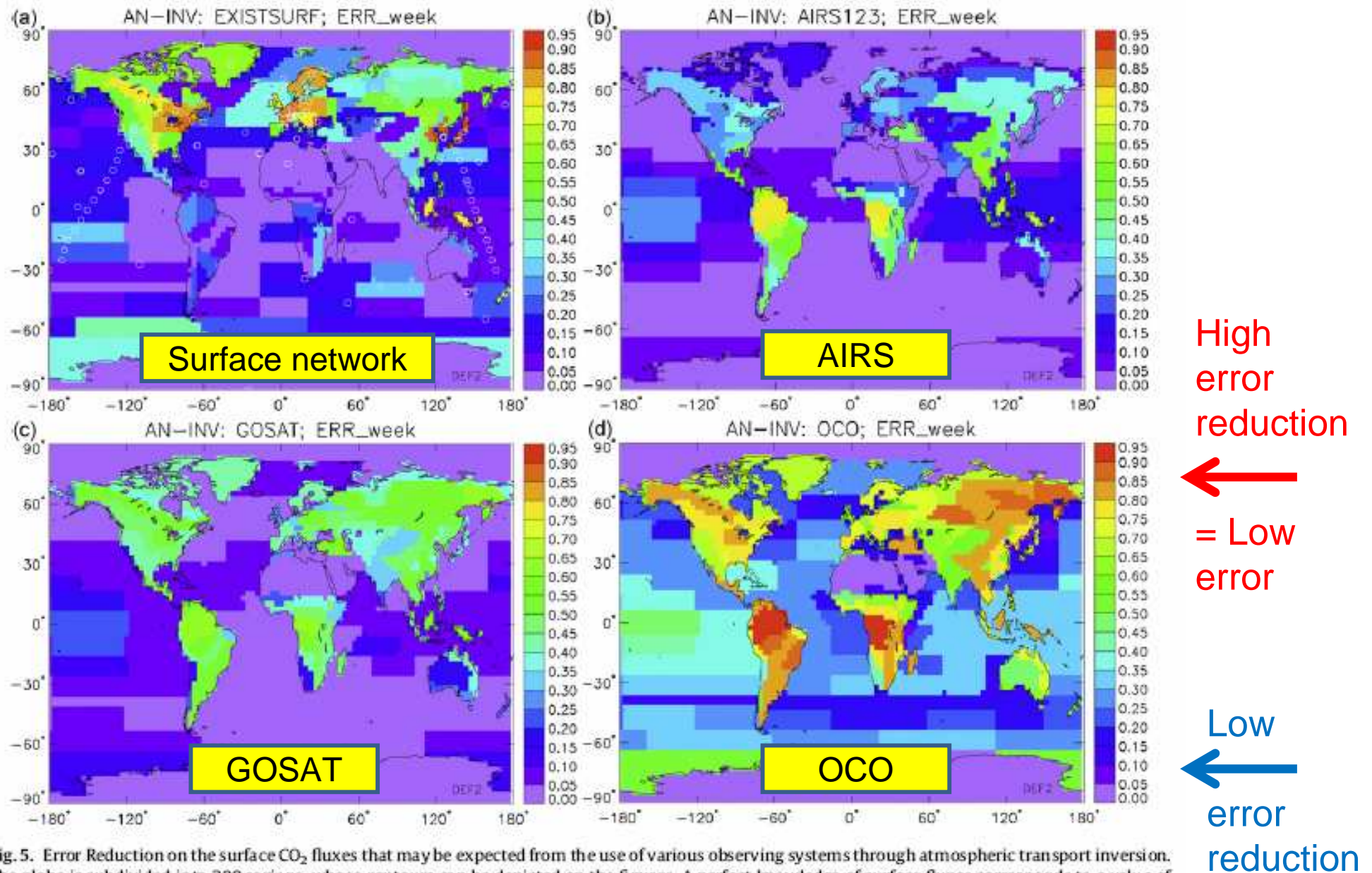
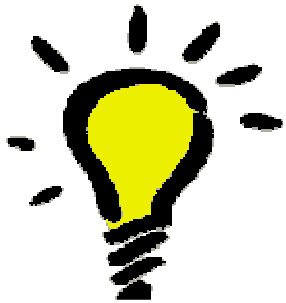
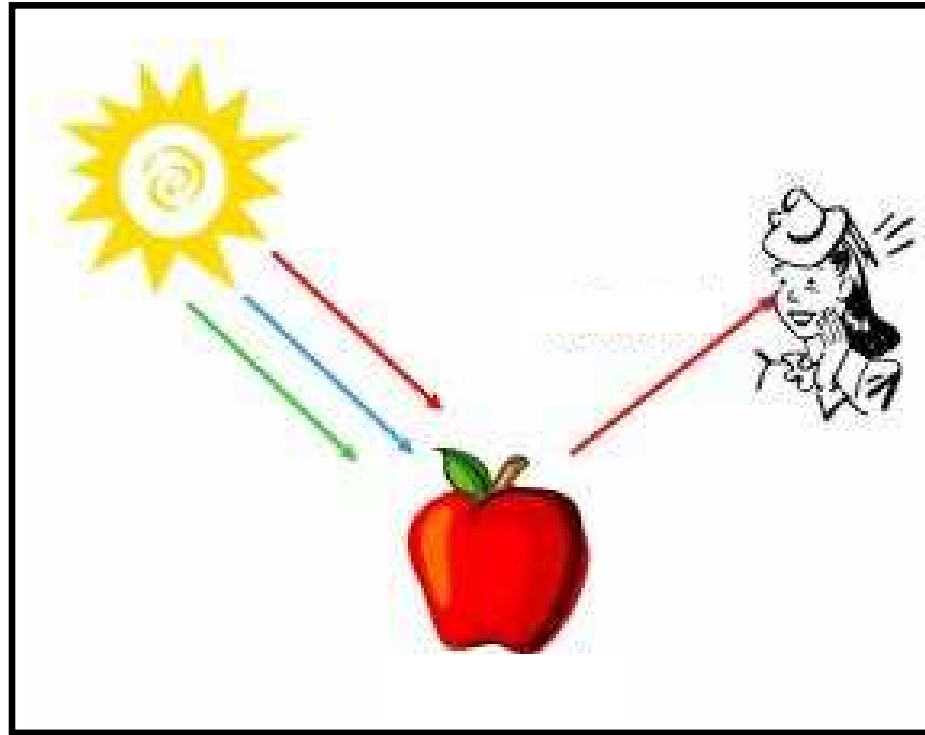
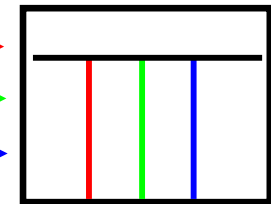
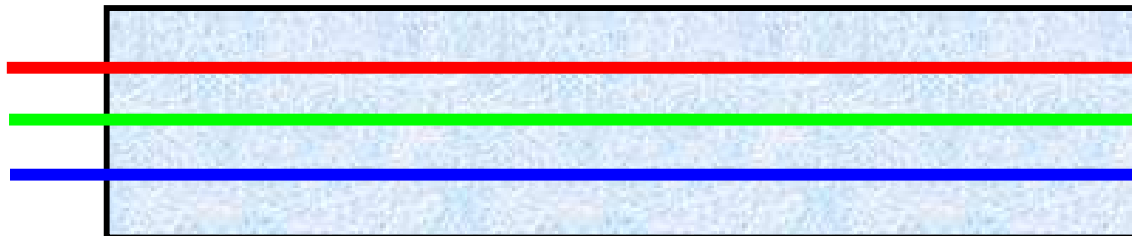


Fig. 5. Error Reduction on the surface CO₂ fluxes that may be expected from the use of various observing systems through atmospheric transport inversion. The globe is subdivided into 200 regions, whose contours can be depicted on the figures. A perfect knowledge of surface fluxes corresponds to a value of unity, whereas no additional knowledge from the first guess corresponds to a value of zero. From left to right and top to bottom: The existing surface network of about 100 stations, the AIRS instrument onboard the Aqua satellite, the JAXA/GOSAT mission, and the NASA/OCO mission. These results have been obtained at the *Laboratoire des sciences du climat et de l'environnement*, in the context of a study funded by the European Space Agency using the LMDz atmospheric transport model.

Measurement principle „Solar backscatter“

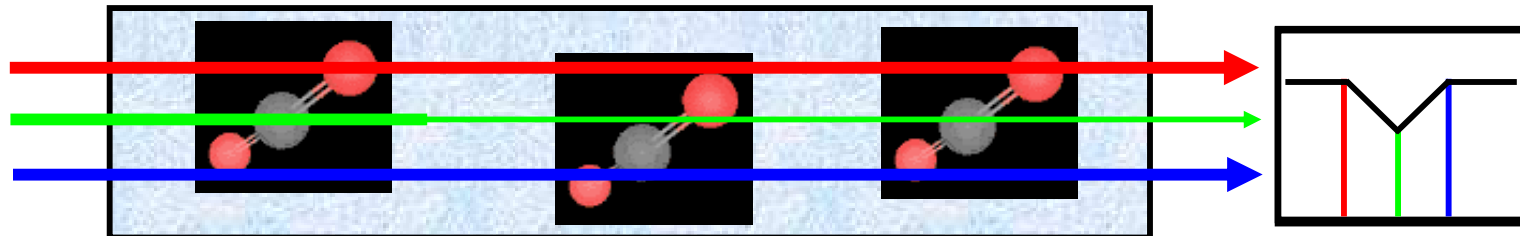
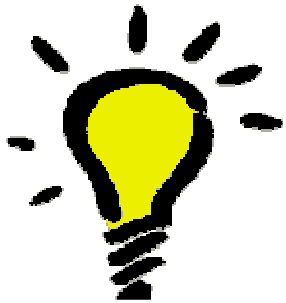
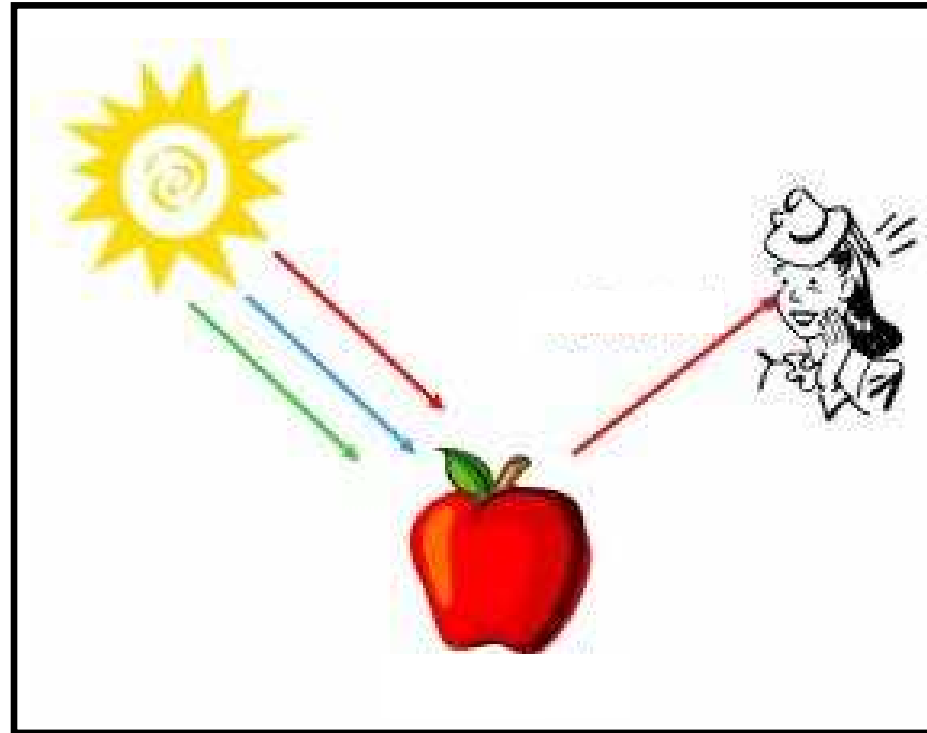


R_0



$R = R_0$

Measurement principle (cont.)



R_0

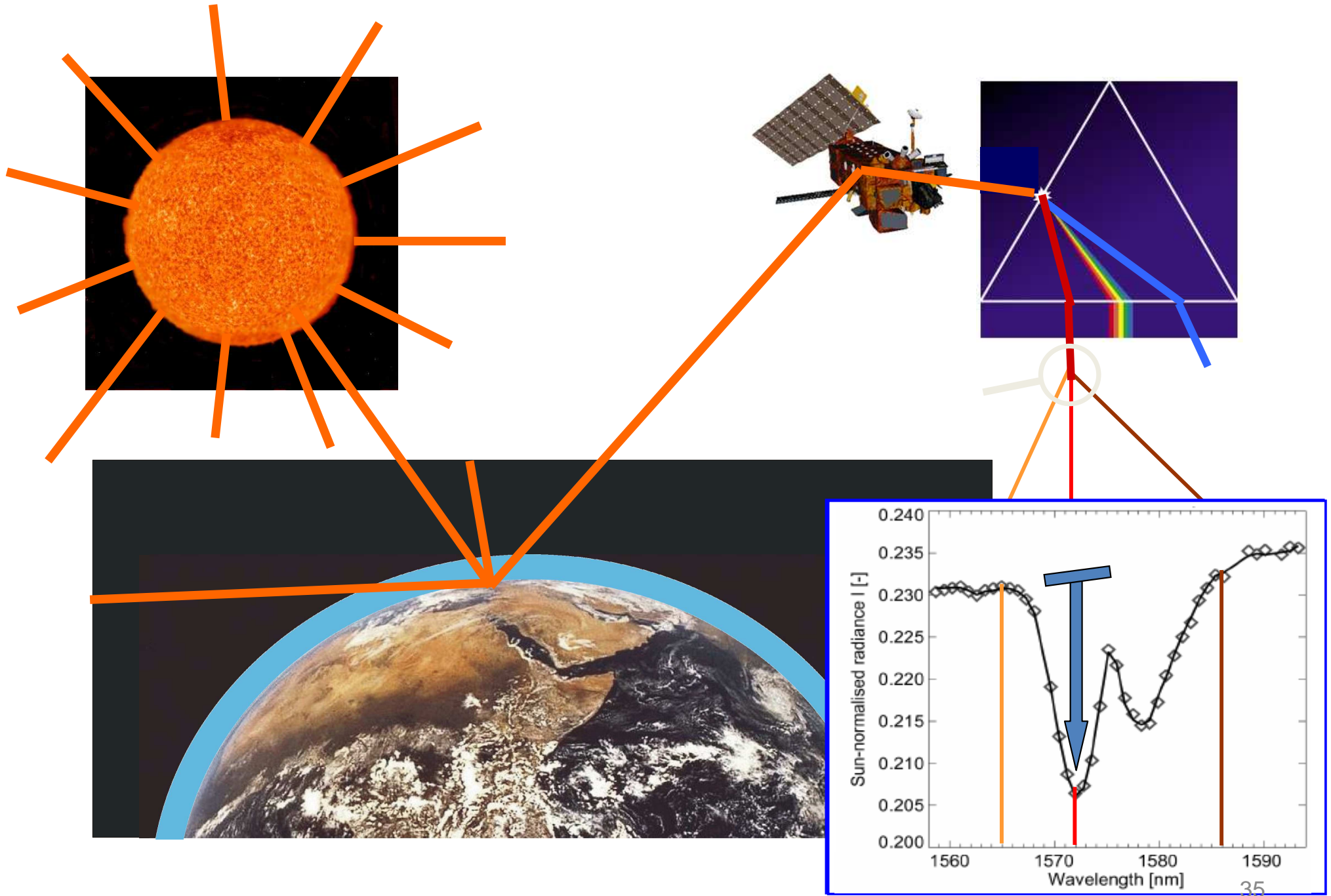
c = gas concentration [molecules/cm³]

l = length of light path [cm]

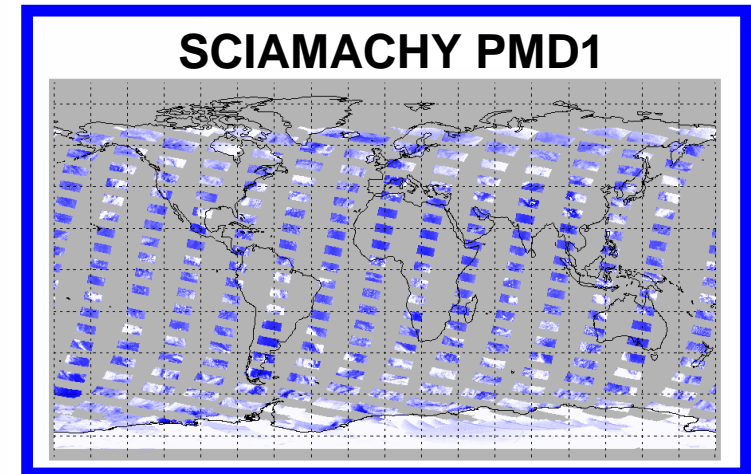
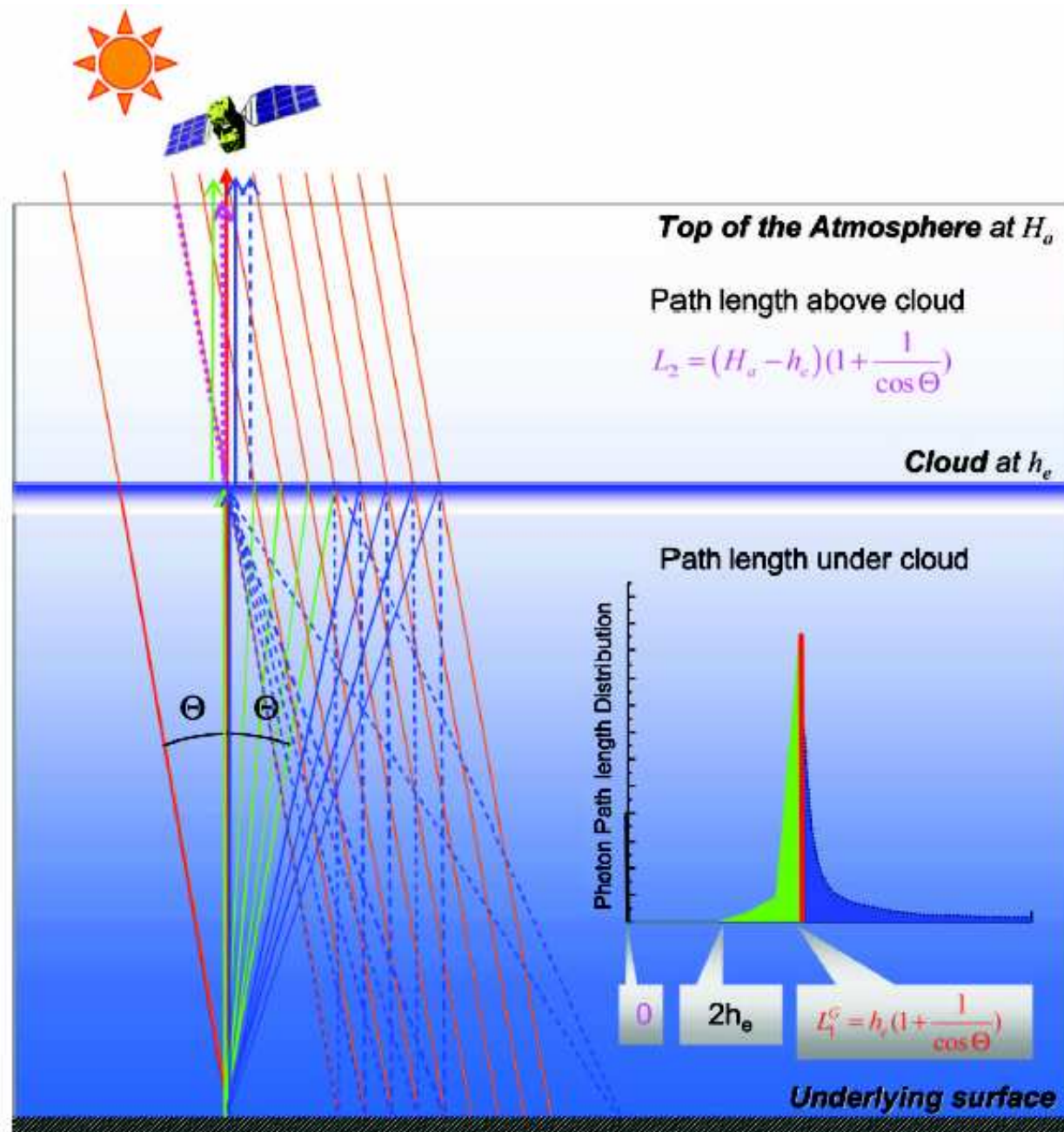
x = gas absorption cross-section [cm²/molecule]

$$R = R_0 \exp(-clx)$$

Measurement principle (cont.)



Issue: Light path - clouds & aerosols



Overview ESA CCI Project „GHG-cci“

Global satellite observations

Global information on near-surface CO₂ & CH₄

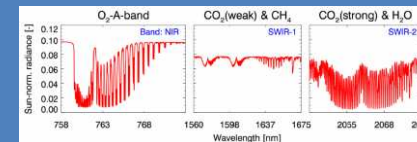
Upper layer CO₂ & CH₄



**AIRS,
IASI,
TES,
MIPAS,
SCIA/occ,
ACE-FTS,
...**

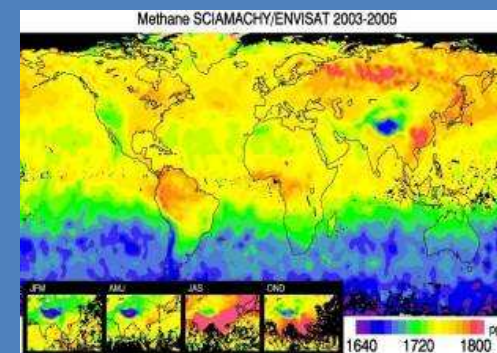
Calibration (L 0-1)

Calibrated radiances

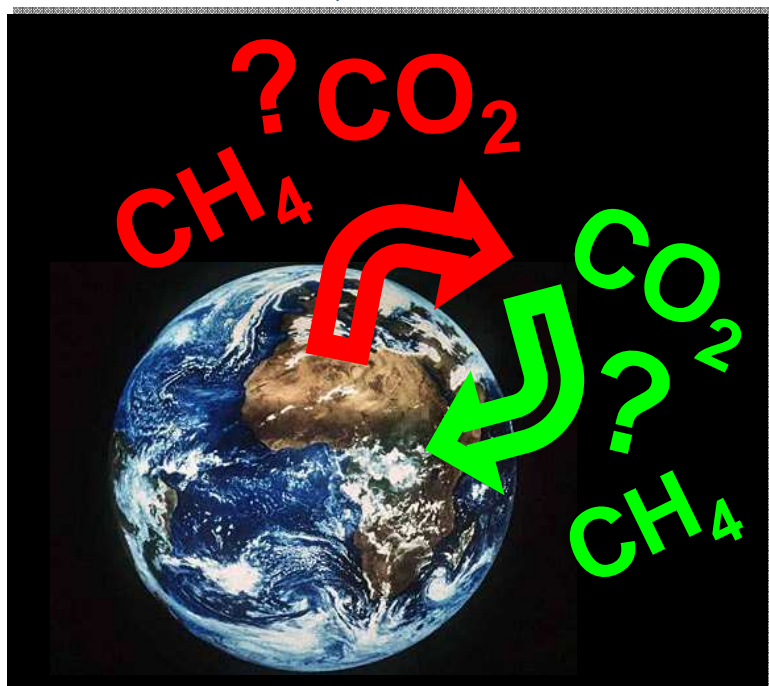


**Retrieval
(L 1-2)**

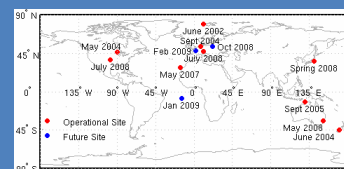
Atmospheric GHG distributions



Global observations

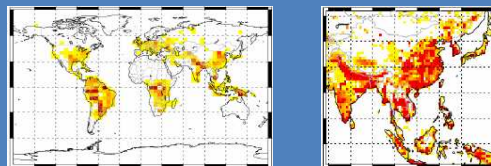


Reference observations



Validation

Improved information on
GHG sources & sinks



**Inverse
modelling,
CCDAS**

Current Satellite Missions

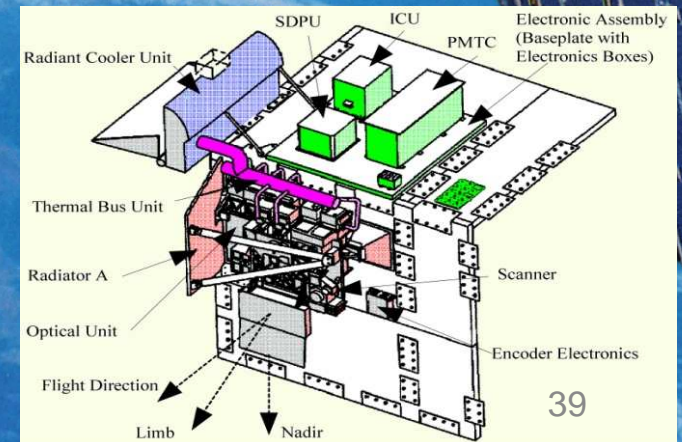
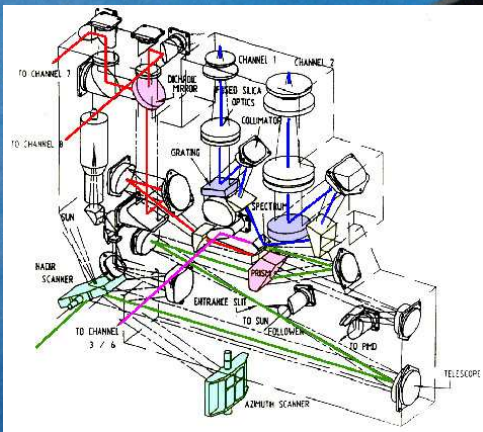
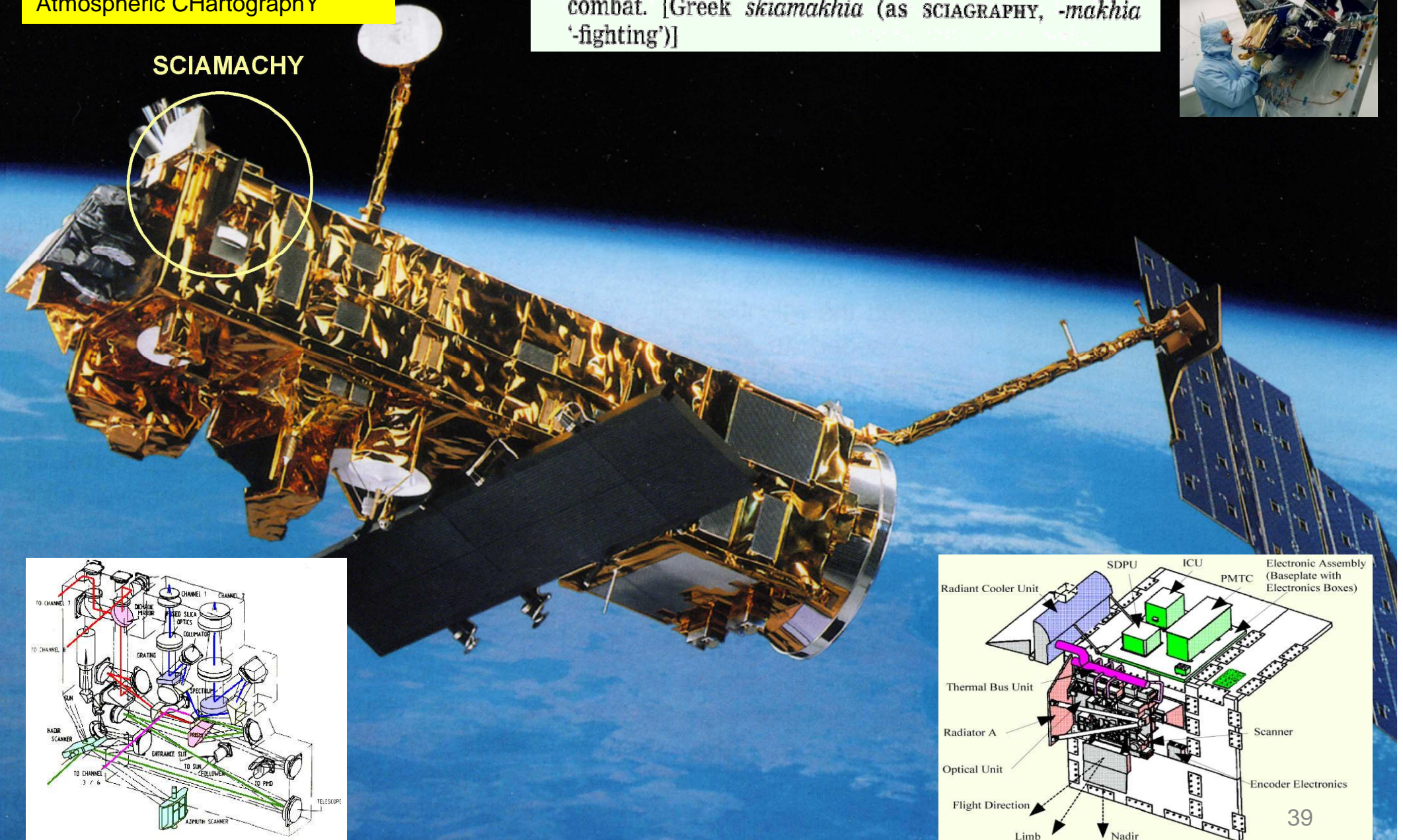
SCIAMACHY on ENVISAT

SCIAMACHY Scanning Imaging
Absorption Spectrometer for
Atmospheric CHartographY

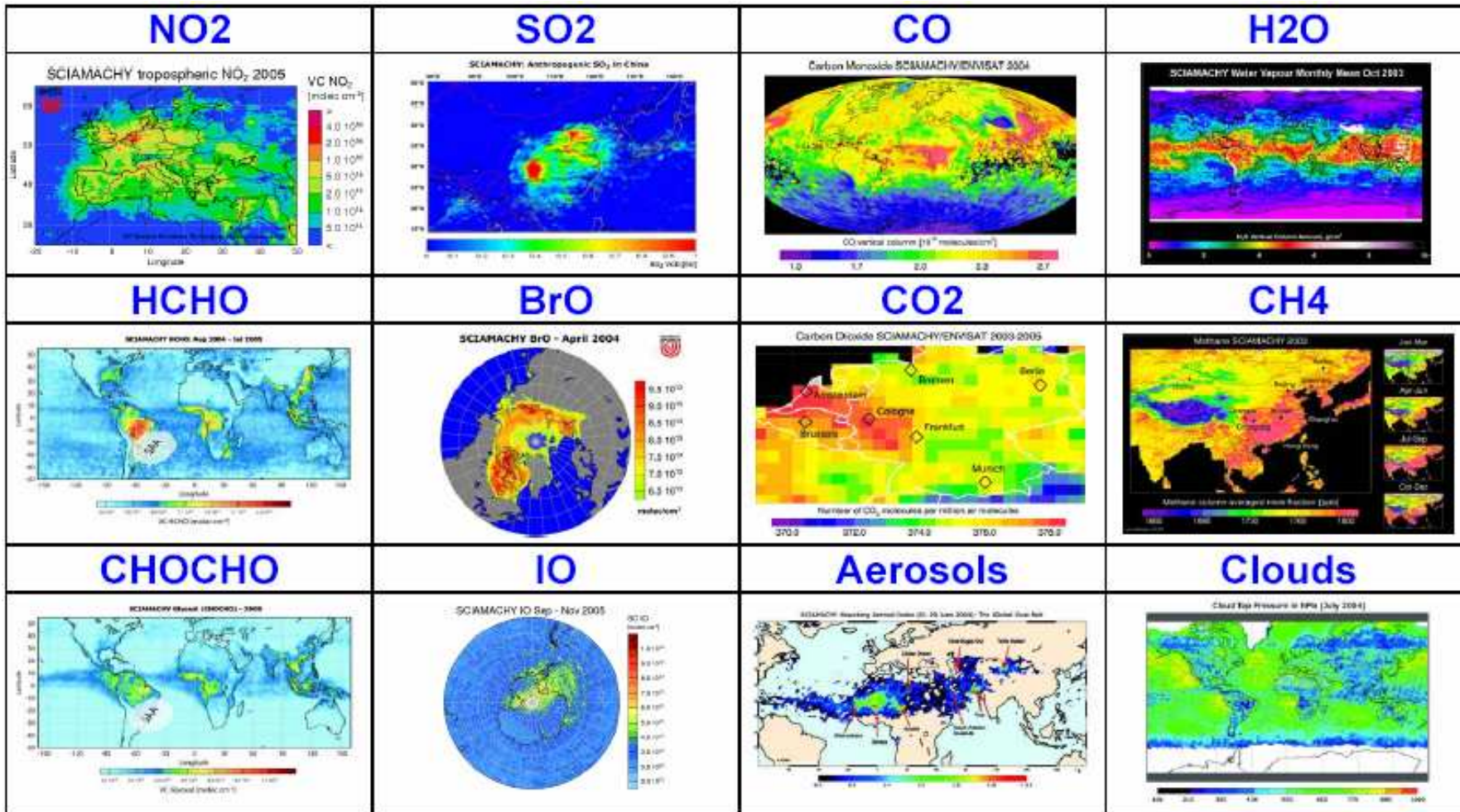
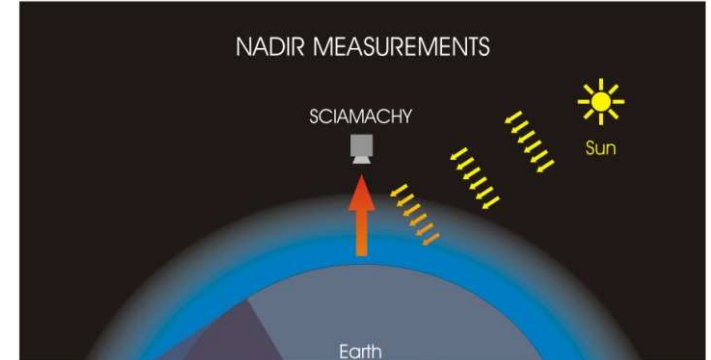
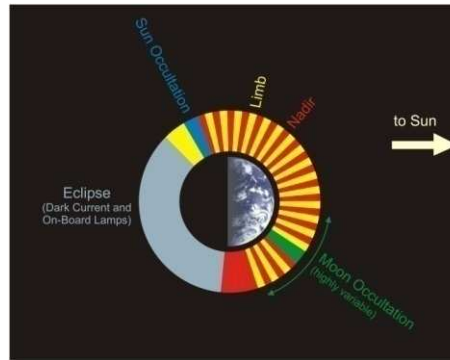
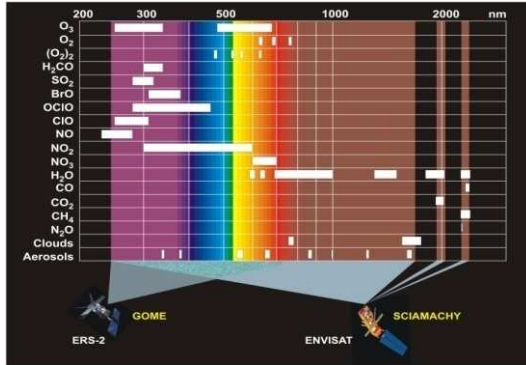
sciamachy /sai'amæki/ *n.* (also **skiamachy** /skai-/)
formal **1** fighting with shadows. **2** imaginary or futile
combat. [Greek *skiamakhia* (as **SCIAGRAPHY**, *-makhia*
'-fighting')]



SCIAMACHY

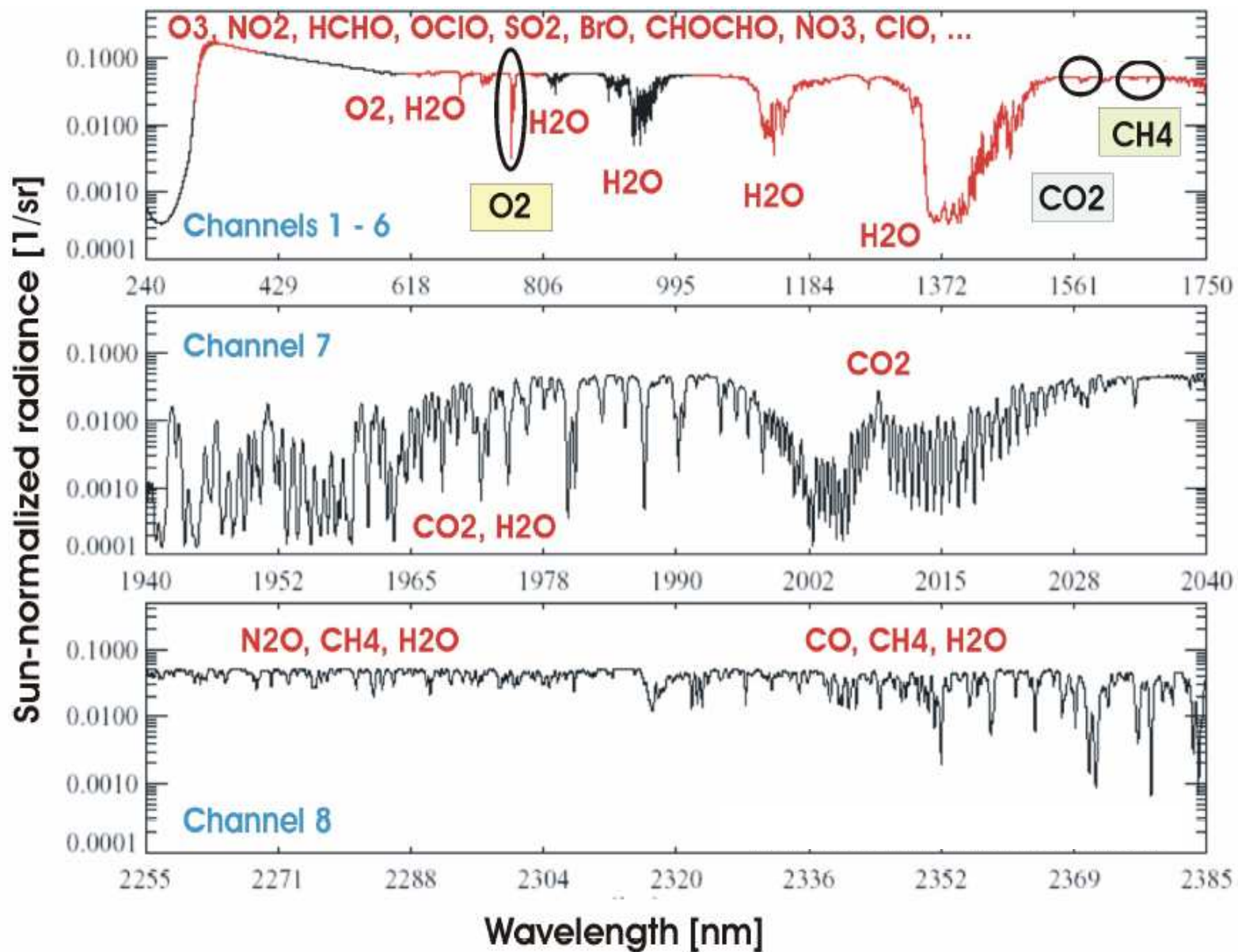


Tropospheric data products from SCIAMACHY/nadir

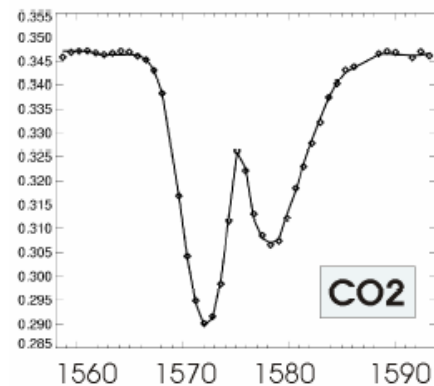


... and more.

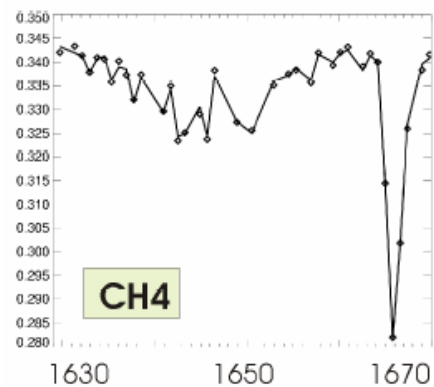
SCIAMACHY nadir spectrum



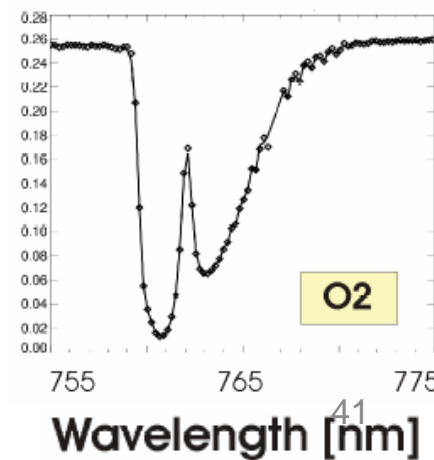
Carbon dioxide fit



Methane fit



Oxygen fit

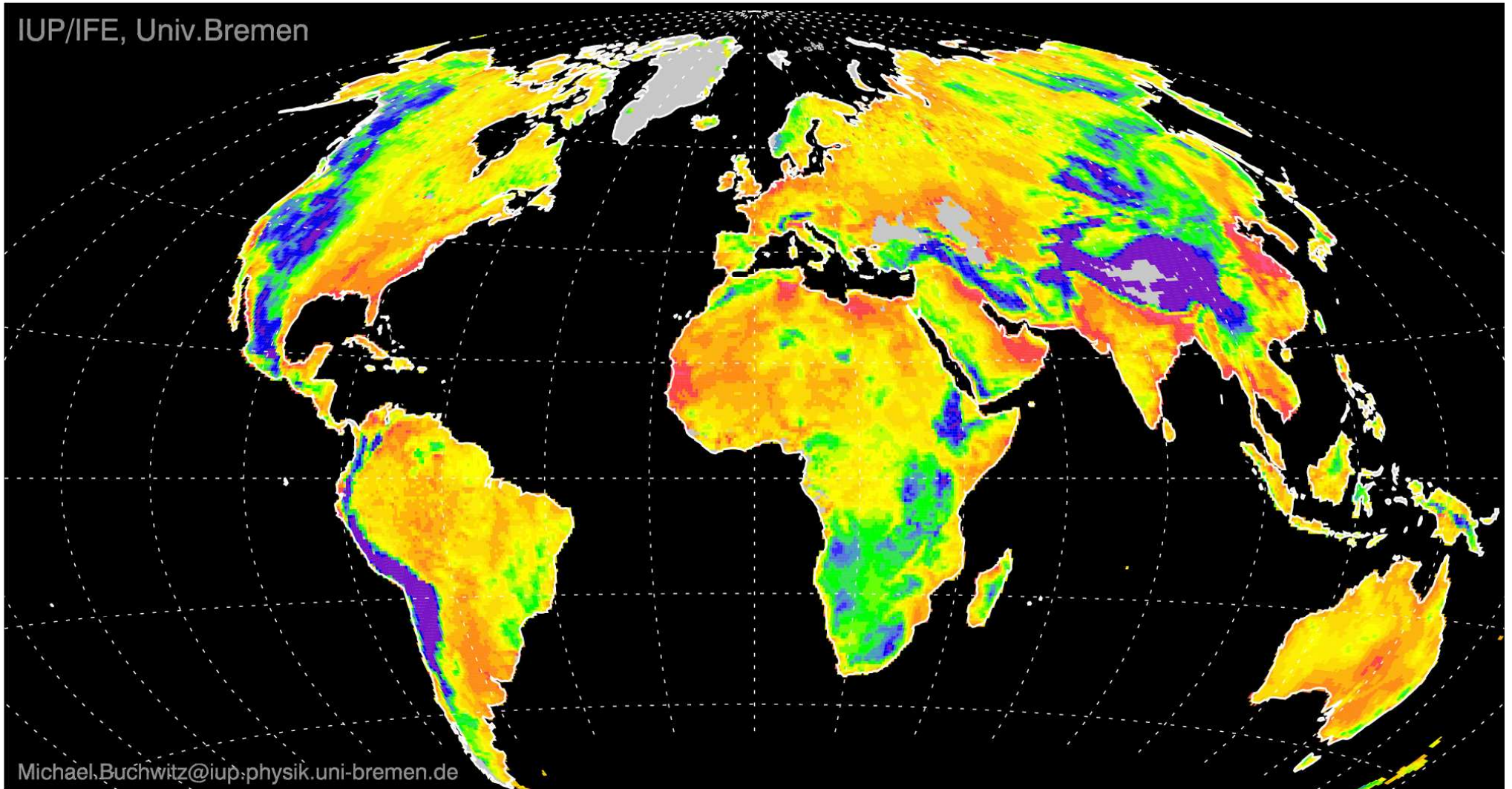


Buchwitz, 2000; Schneising et al., 2008, 2009

CO₂ vertical columns

Carbon Dioxide SCIAMACHY/ENVISAT 2003-2005

IUP/IFE, Univ.Bremen



Michael.Buchwitz@iup.physik.uni-bremen.de

CO₂ vertical column [10^{21} molecules/cm²]



6.1

6.6

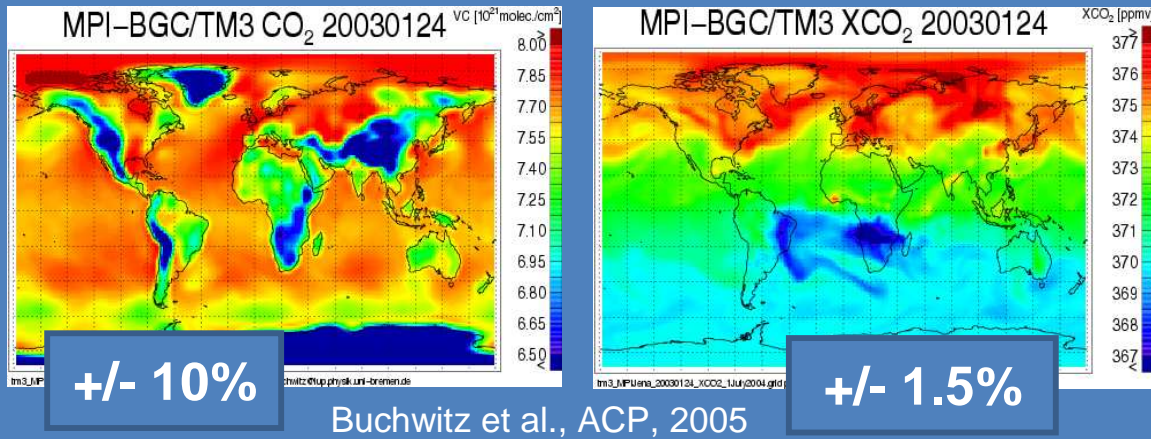
7.1

7.6

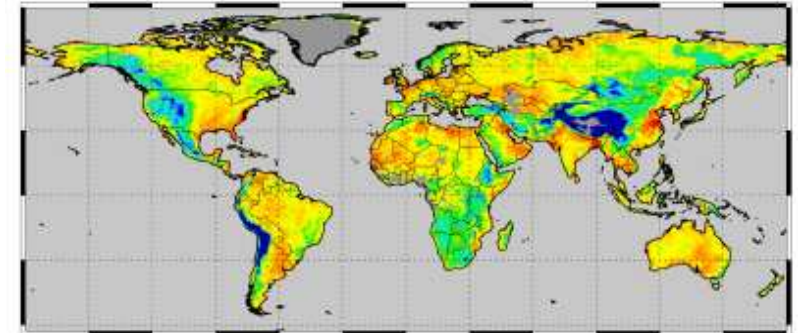
8.1

42

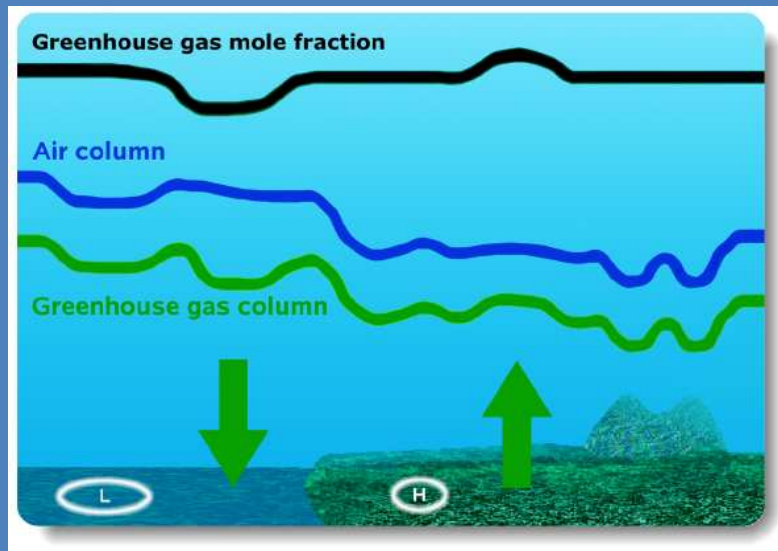
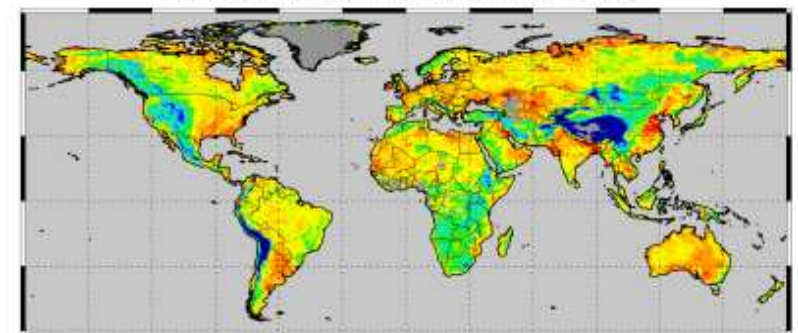
Column-averaged mole fraction: XCO₂ (ppm)



CO2 SCIAMACHY (WFMDv1.0) - 2003



O2 SCIAMACHY (WFMDv1.0) - 2003



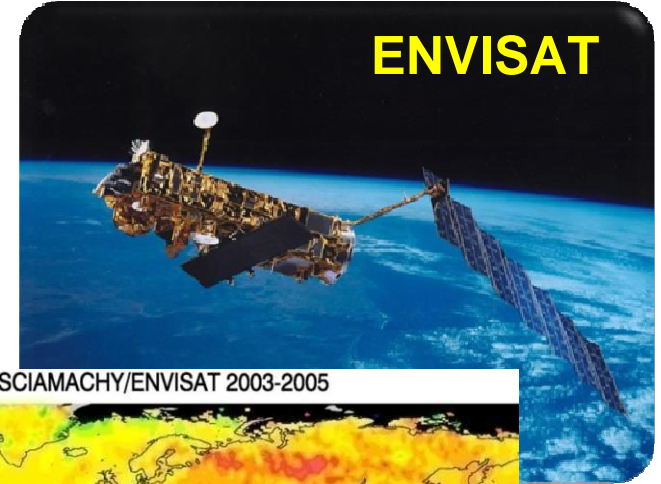
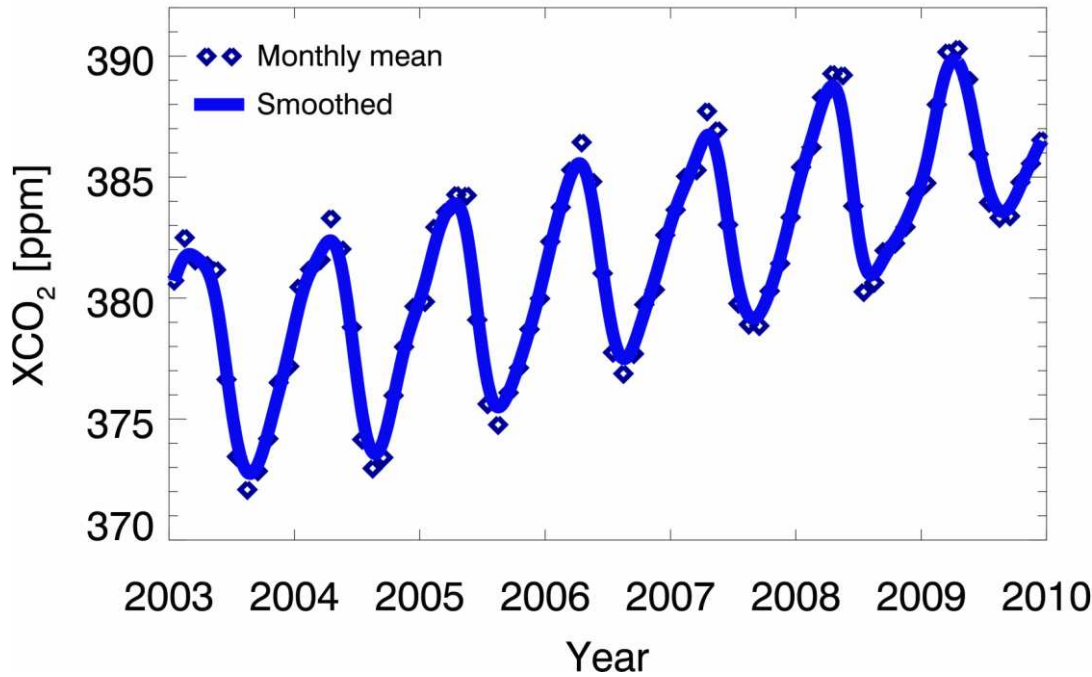
$$XCO_2 \text{ (ppm)} = CO_2\text{-column} / AIR\text{-column} * 10^6$$

$$AIR\text{-column} = O_2\text{-column} / 0.2095$$

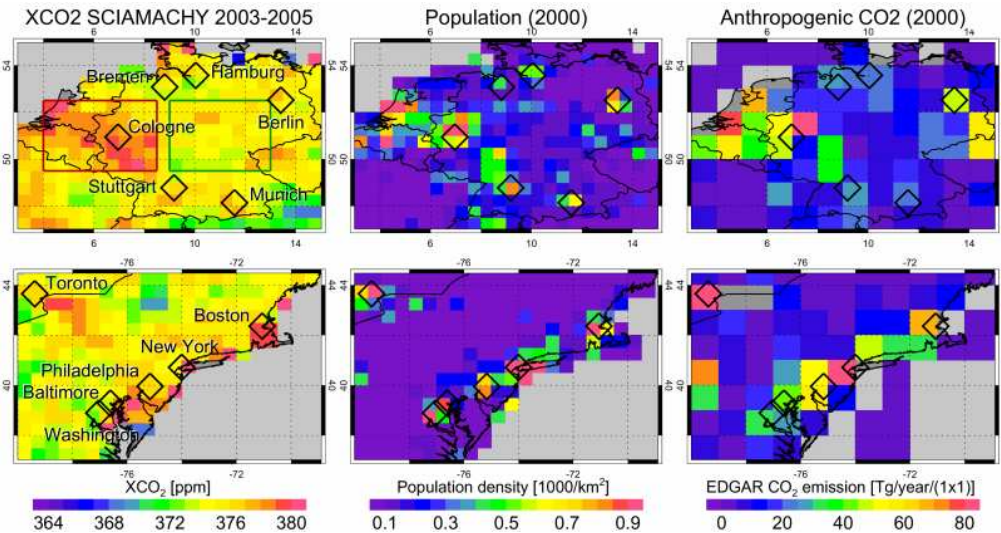
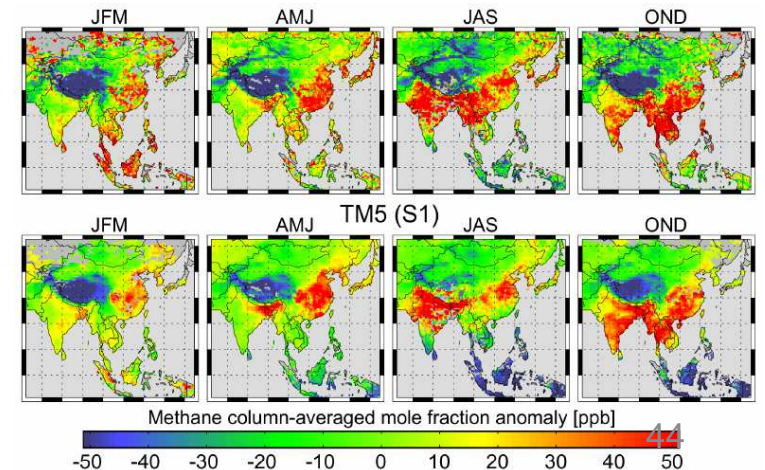
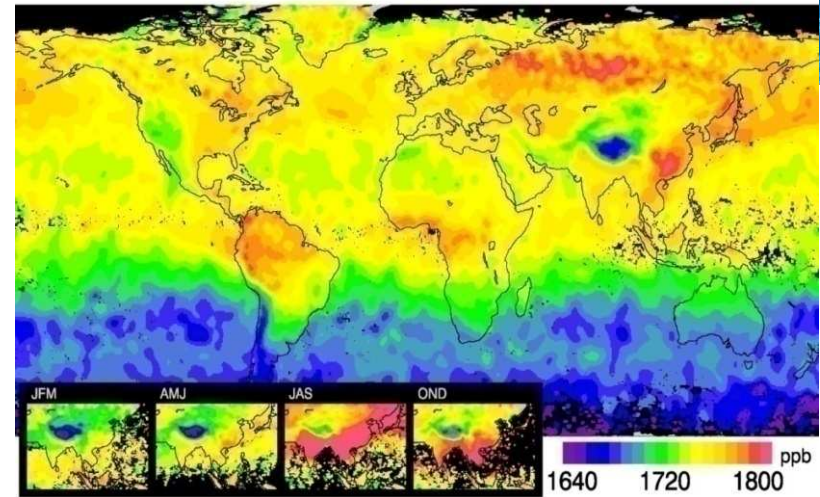
Schneising et al., ACP, 2008

SCIAMACHY Carbon Dioxide & Methane

SCIAMACHY CO₂ Northern Hemisphere



Methane SCIAMACHY/ENVISAT 2003-2005



Buchwitz et al., ACP, 2007; Schneising et al., ACP, 2008, 2009

SCIAMACHY methane & methane emissions

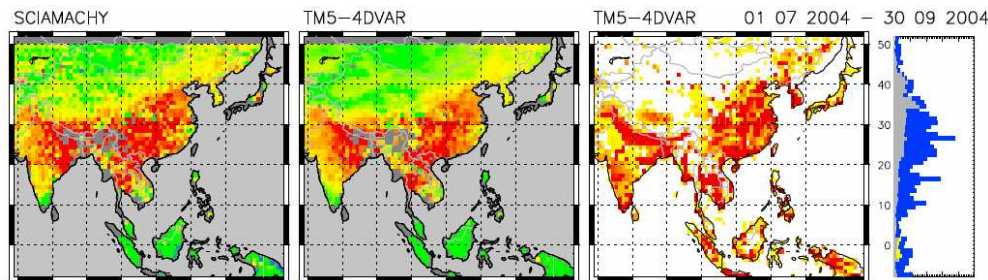
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, D22301, doi:10.1029/2009JD012287, 2009



Bergamaschi et al., JGR, 2009

Inverse modeling of global and regional CH₄ emissions using SCIAMACHY satellite retrievals

... the **SCIAMACHY** data put strong constraints on the smaller-scale spatial distribution of emissions, while remote surface measurements mainly constrain the emissions of larger regions.



Two main application areas:

- **Improved emission inventories** (for different categories, e.g., wetlands, rice, ...)
- **Improved process understanding** (e.g., land biosphere & related emissions)

➔ **Better climate prediction, ...**

Bloom et al., Science, 2010 Large-Scale Controls of Methanogenesis Inferred from Methane and Gravity Spaceborne Data

A. Anthony Bloom,¹ Paul I. Palmer,^{1*} Annemarie Fraser,¹ David S. Reay,¹ Christian Frankenberg²

SCIAMACHY CH₄, groundwater depth, skin T

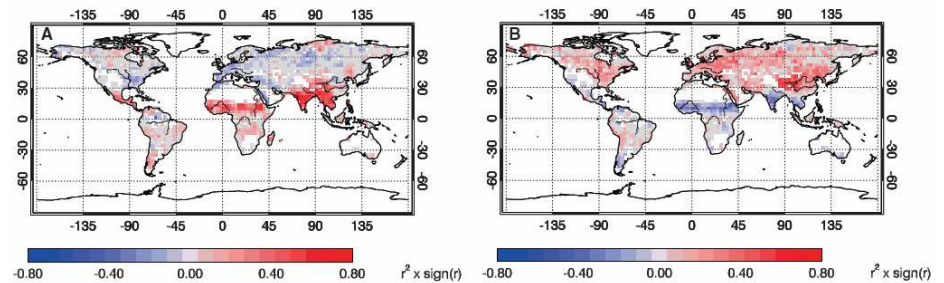
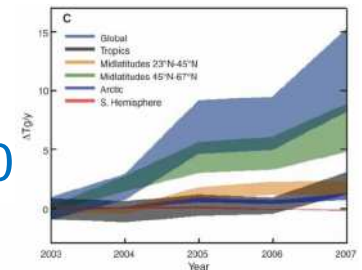
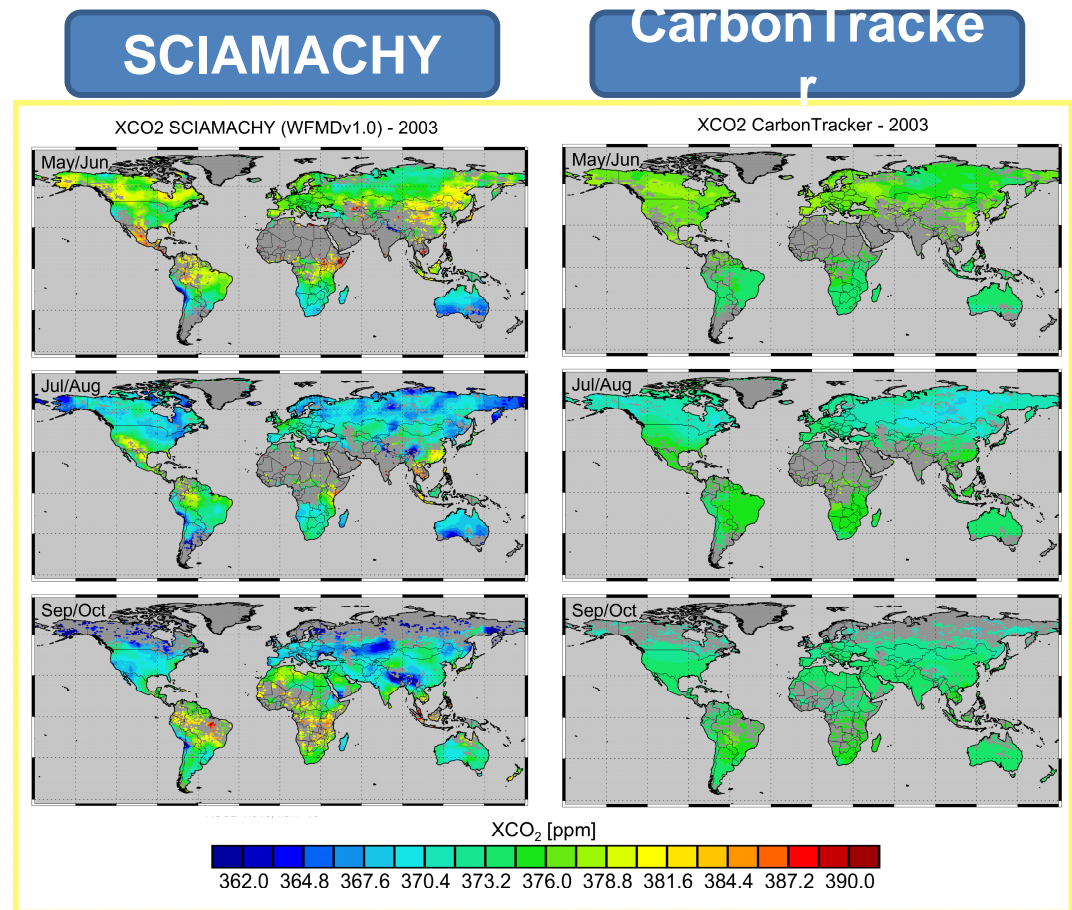


Fig. 1. Correlations (r^2) between cloud-free SCIAMACHY CH₄ column volume mixing ratios (VMRs) (in parts per million) and (A) equivalent groundwater depth (in meters), determined from gravity anomaly measurements from the GRACE satellites (28) and (B) NCEP/NCAR surface skin temperatures (in kelvin), calculated on a 3° × 3° horizontal grid over 2003–2005. The correlation at a given point is determined by at least 15 and typically 60 CH₄ groundwater, and temperature measurements. See SOM for a description of individual data sets.

User Requirements

Challenging !

Inverse modelling:
Observation – Model
differences interpreted as
model surface flux errors.
Model transport errors !?
Biases satellite data !?



Key requirement:

Avoid systematic biases !

Required relative accuracy ^{*)}:

- XCO₂: < 0.3% (1 ppm) (e.g., Chevallier et al., JGR, 2007)
- XCH₄: < 0.6% (10 ppb) (e.g., Meirink et al., ACP, 2006)

^{*)} for spatio-temporal averages, e.g., monthly, few deg x few deg

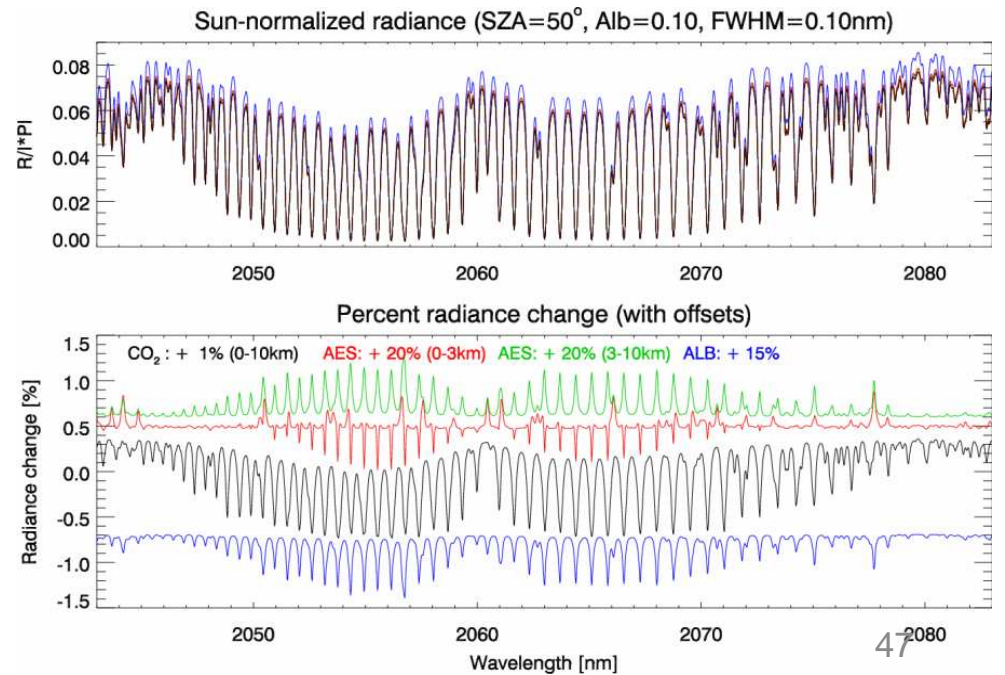
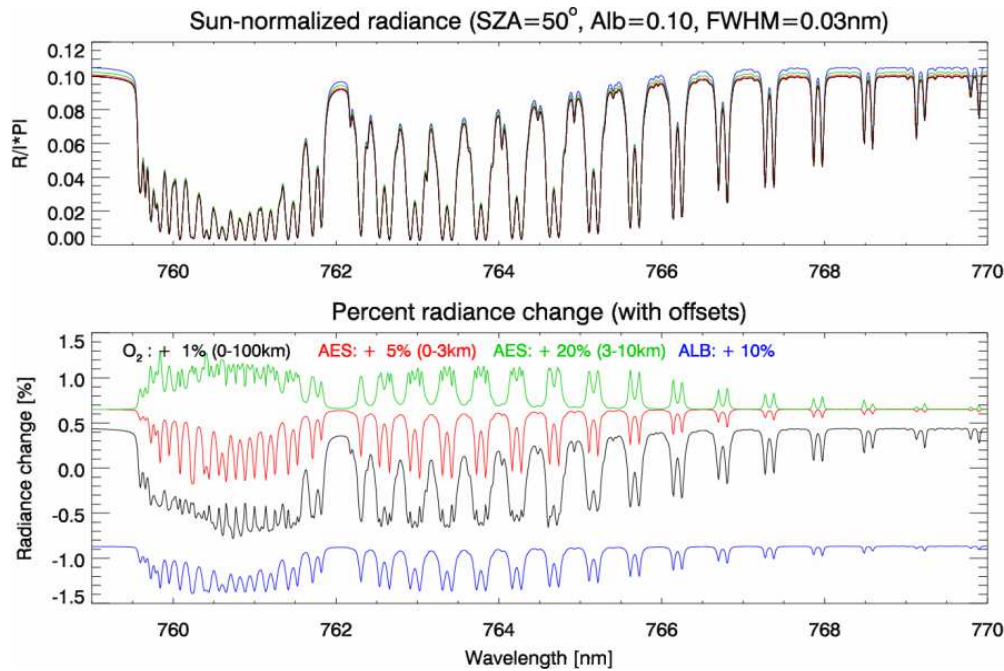
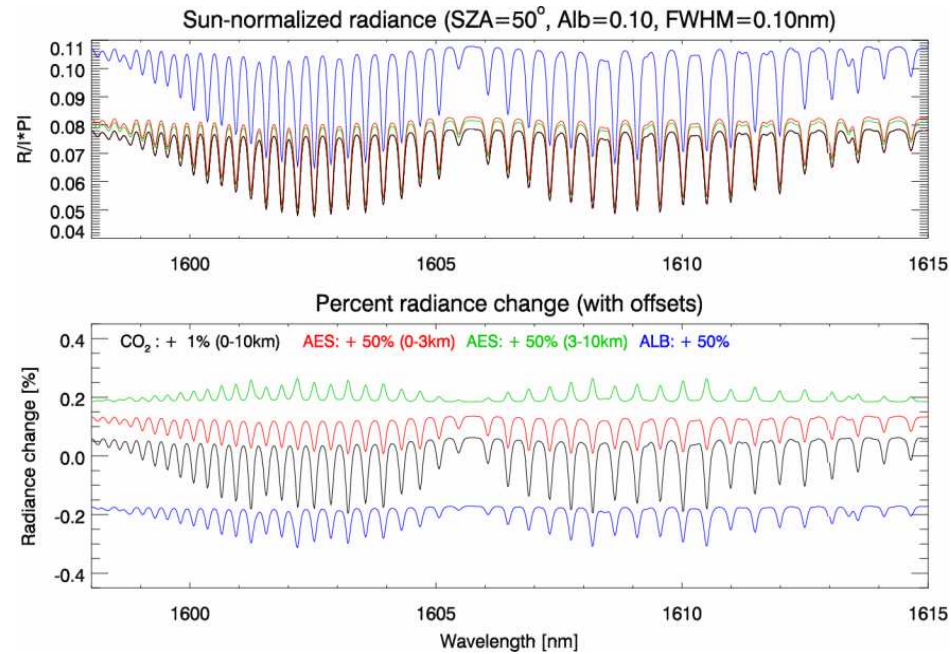
GCOS (accuracy RMS): CO₂ column: < 1%, CH₄ column: < 2%

High resolution nadir spectra & derivatives

Info on CO₂ column
(issue: clouds & aerosols)

Info on clouds & aerosols

Info on clouds & aerosols



GOSAT

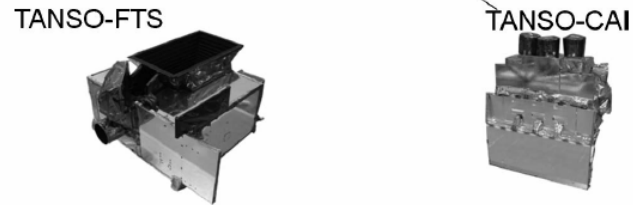
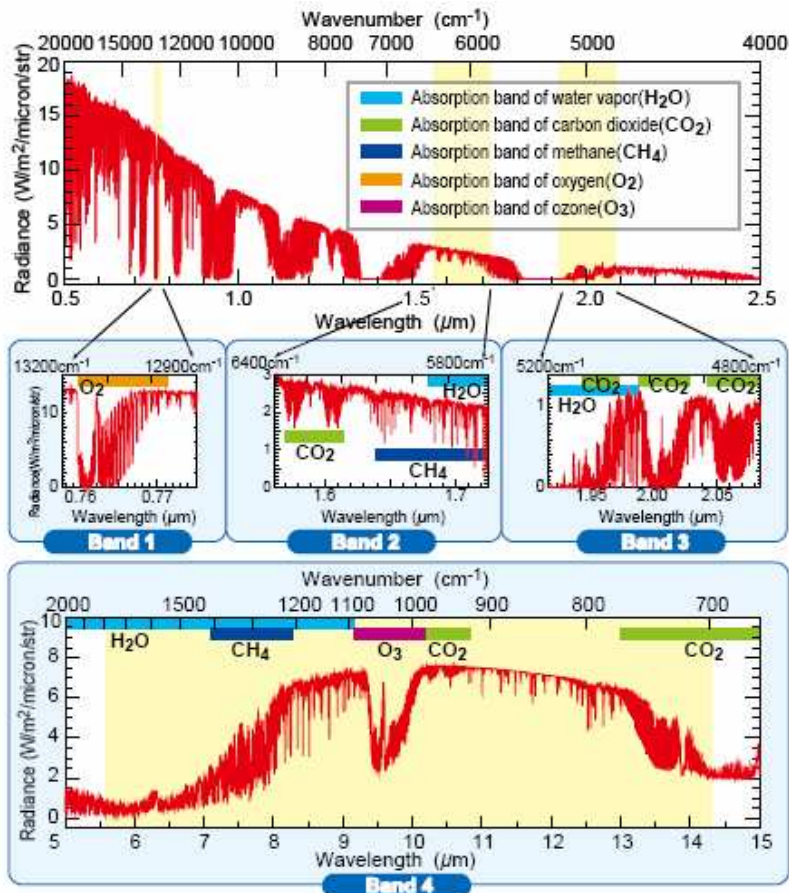
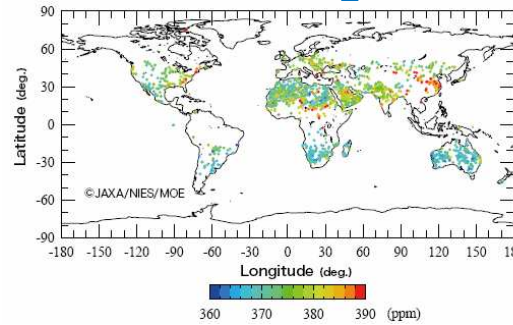


Fig. 1. TANSO-FTS and CAI photos and design view of the GOSAT satellite in orbit.

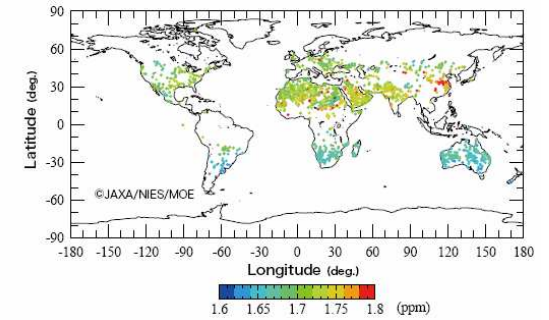
TANSO-FTS Spectra



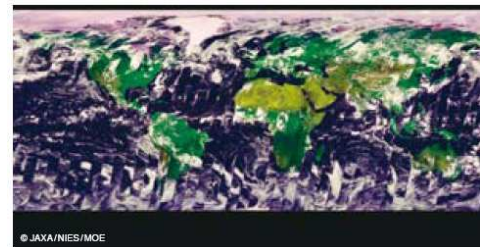
XCO₂



XCH₄



TANSO-CAI Images



TANSO-FTS Scan Pattern

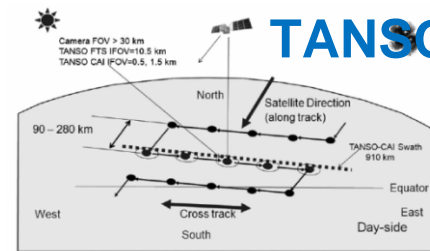


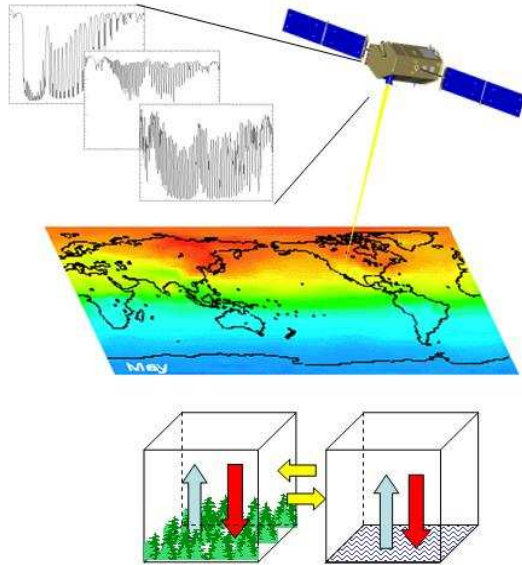
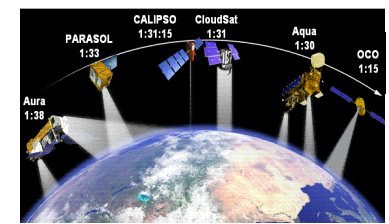
Fig. 7. Observation geometry of TANSO-FTS, CAI, and the monitor camera.

Kuze et al., 2009

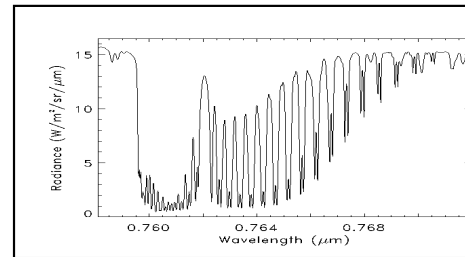
JAXA & NIES GOSAT
web sites

Future Satellite Missions

Orbiting Carbon Observatory (OCO)

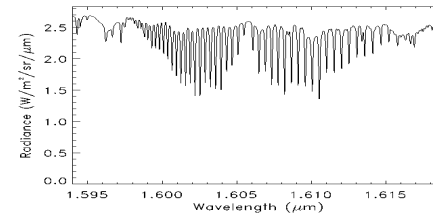


O₂ A-band



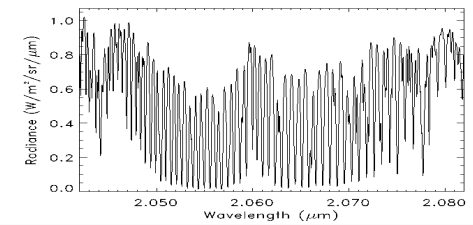
Clouds/Aerosols,
Surface Pressure

CO₂ 1.61 μm

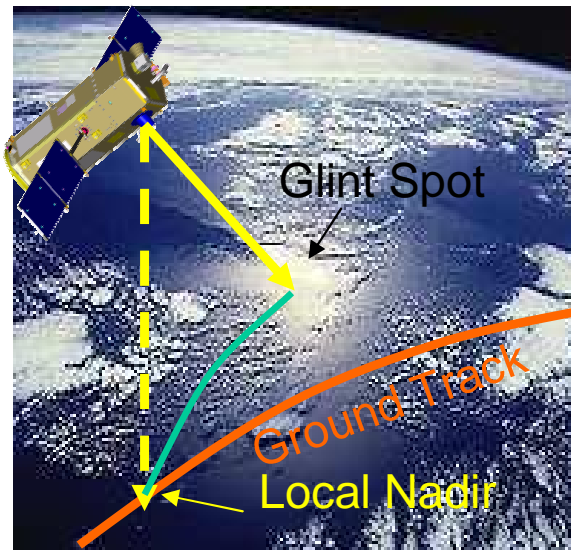
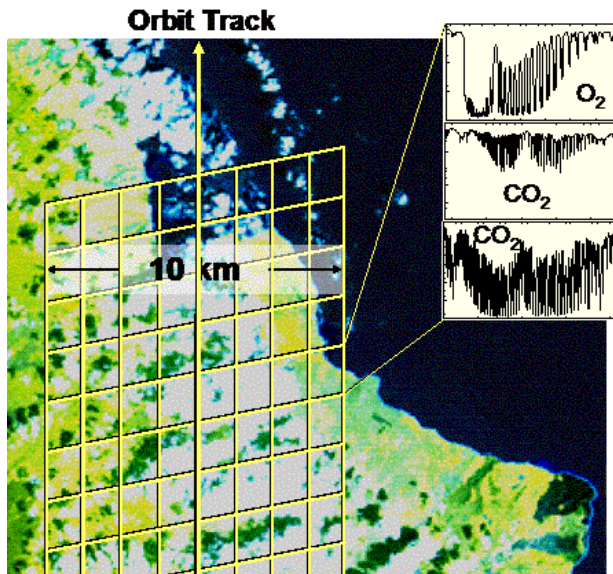


Column CO₂

CO₂ 2.06 μm



Clouds/Aerosols,
H₂O,
Temperature



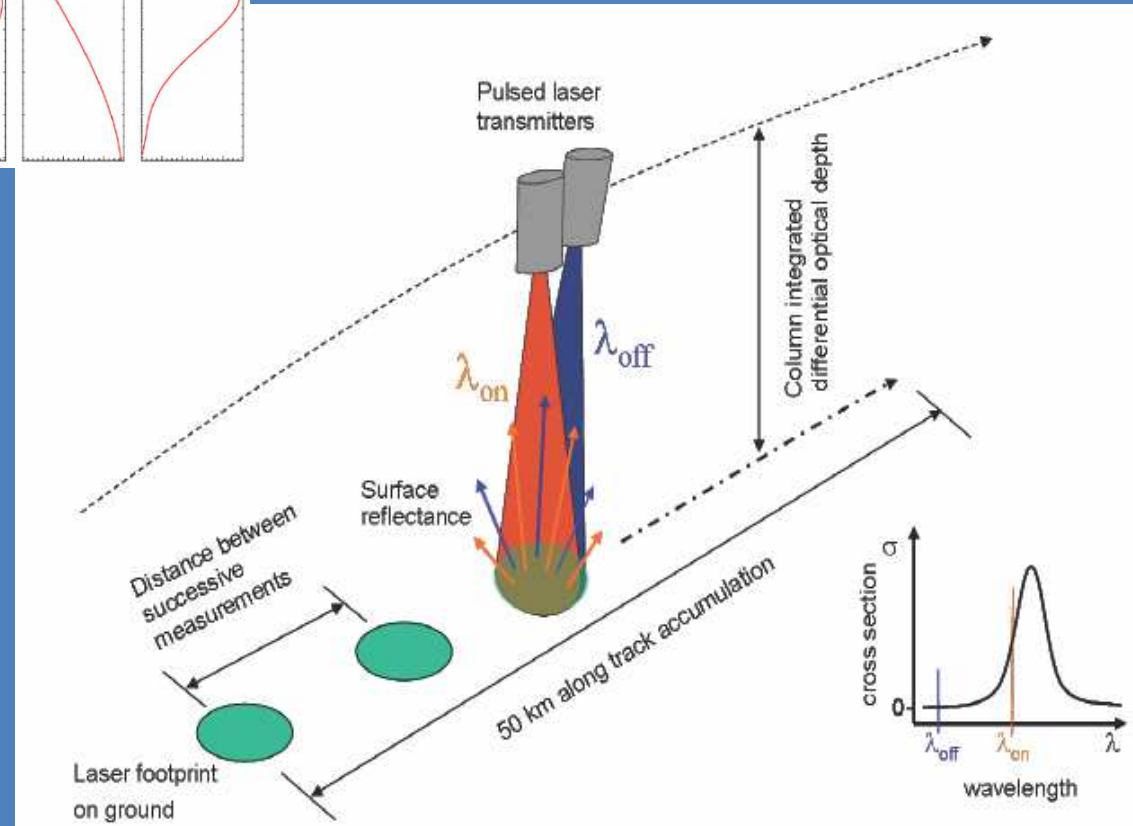
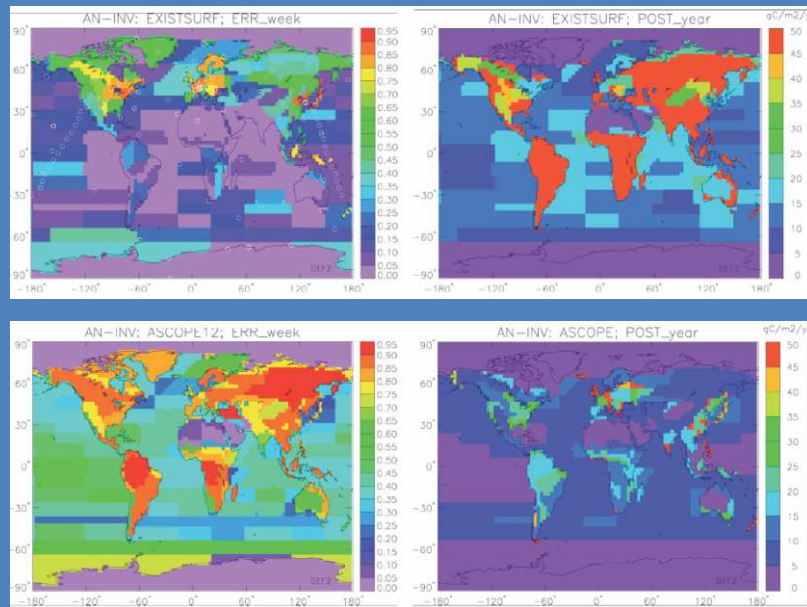
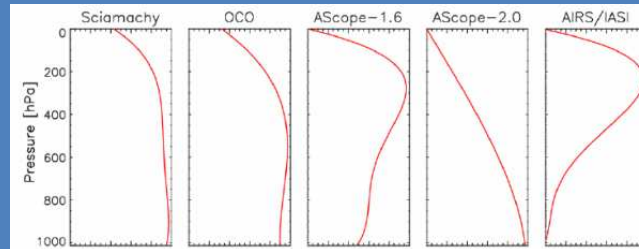
Space-based X_{CO_2} measurements with precisions of 1–2 ppm (0.3–0.5%) on regional scales will:

- Resolve pole to pole X_{CO_2} gradients on regional scales
- Resolve the X_{CO_2} seasonal cycle in the Northern Hemisphere
- Improve constraints on CO₂ fluxes (sources and sinks) compared to the current knowledge
 - Reduce regional scale flux uncertainties from >2000 gC m⁻² yr⁻¹ to < 200 gC m⁻² yr⁻¹
 - Reduce continental scale flux uncertainties below 30 gC m⁻² yr⁻¹

Launch in Feb 2009 failed
Reflight Feb 2013 („OCO-2“, carbon copy of OCO)

Laser: A-SCOPE, ASCENDS, MERLIN, ...

A-SCOPE



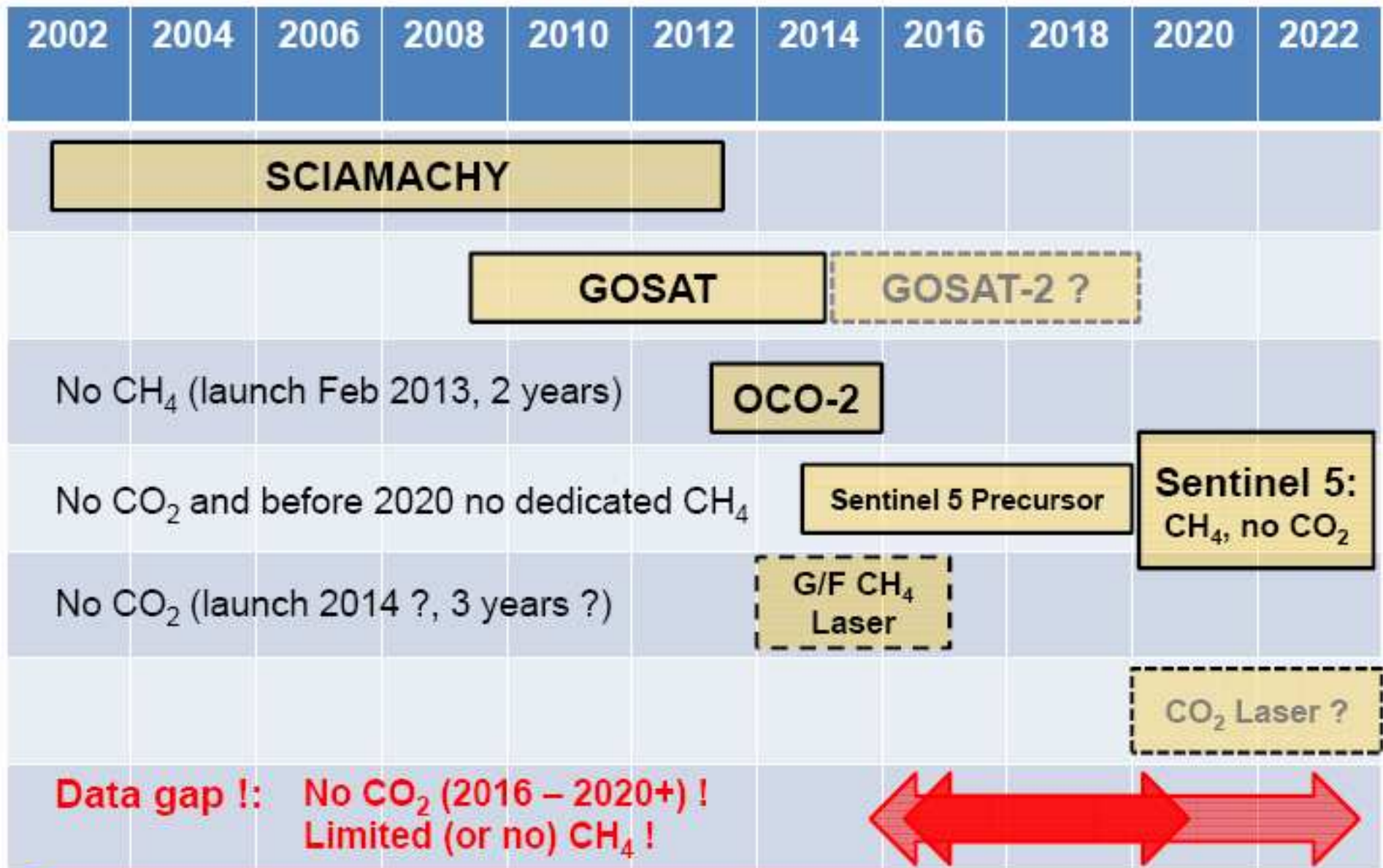
• CO₂:

- A-SCOPE: Proposed to ESA for EE7; not selected because of technical issues
- ASCENDS: Several concepts under study in the US. Launch 2020 ?

• CH₄:

- German-French mission („MERLIN“): In Phase 0. Launch 2014 ? 3 year mission.

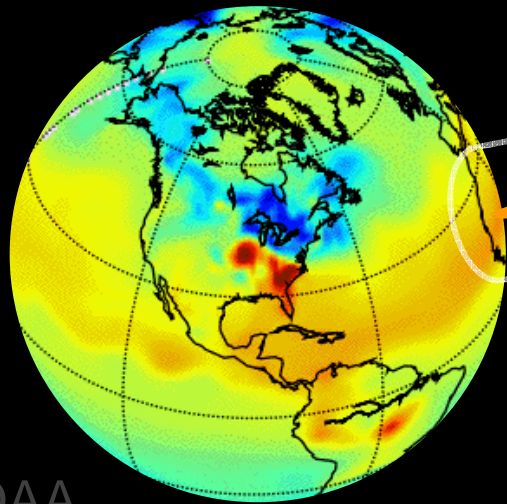
GHG satellite missions with PBL sensitivity



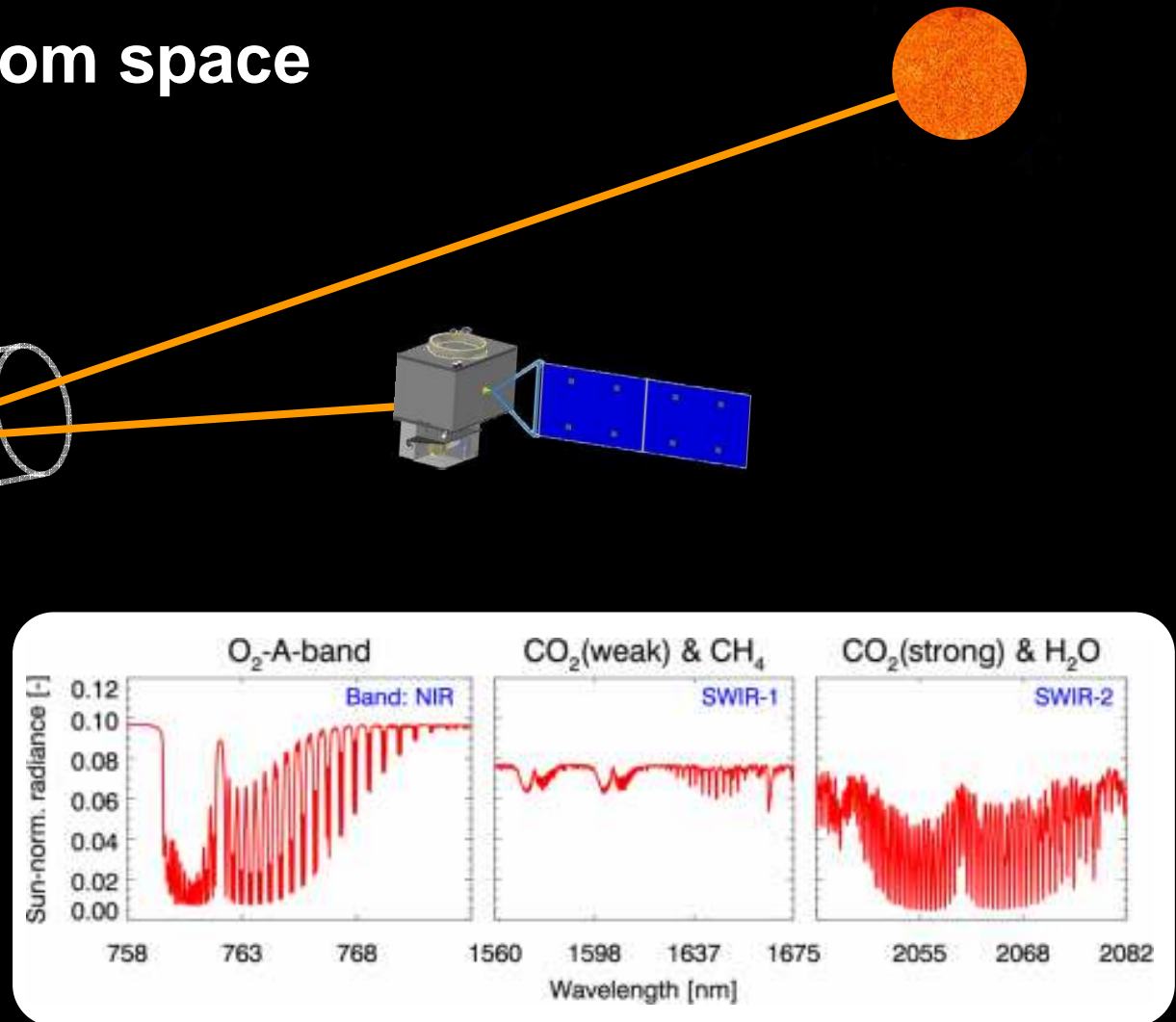
Carbon Monitoring Satellite – Proposed for EE8

CarbonSat

Global CO₂ and CH₄ from space

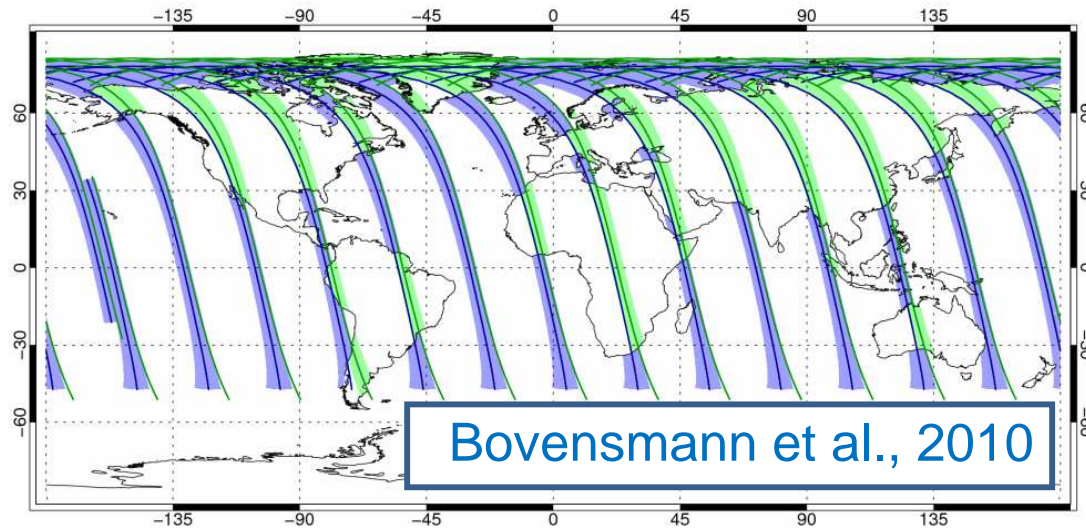


NOAA
CarbonTracker

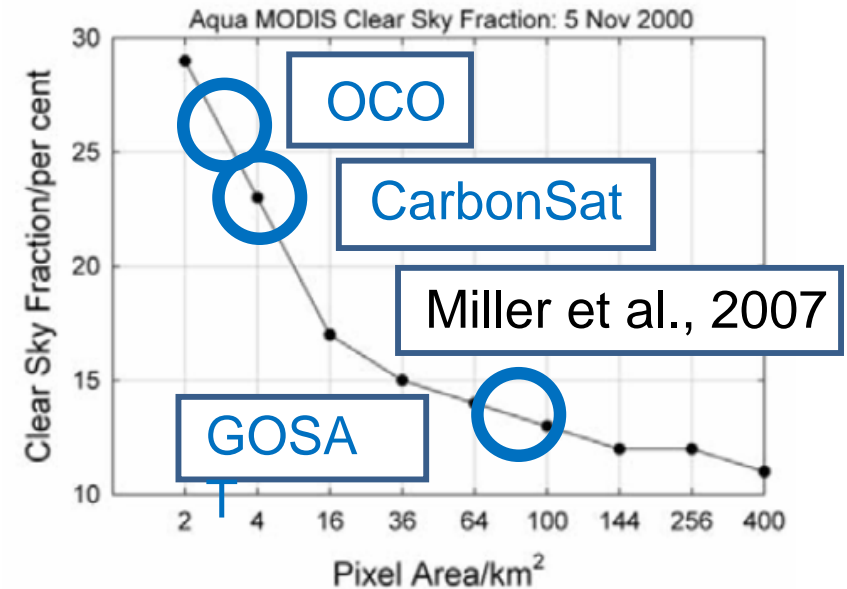




CarbonSat Daily Orbital Coverage



Clear Sky Fraction

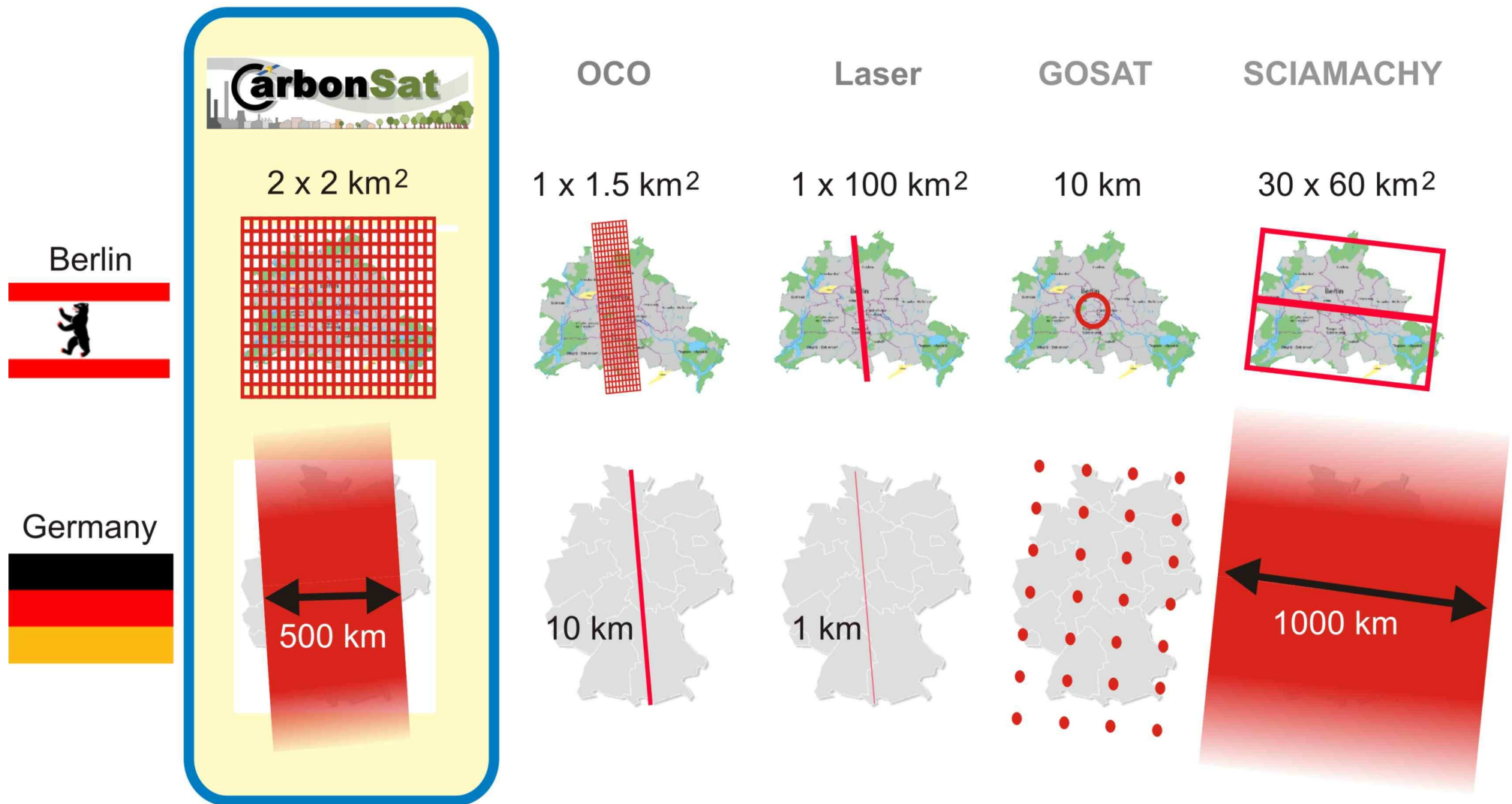


- XCO₂ & XCH₄
 - 500 km swath
 - 2 km x 2 km pixel
 - 250 meas. per 0.3 s
- 6 million cloud free observations / day !

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	28,000,000	23%	6,440,000
OCO	3	1,680,000	27%	453,600
GOSAT	85	10,000	13%	1,300
SCIAMACHY	1800	70,000	5%	3,500

CarbonSat - Spatial resolution & coverage



**CarbonSat enables new important application areas:
CO₂ and CH₄ emission „hot spot“ detection and monitoring (power plants, ...)**

CarbonSat: CO₂ emission hot spot targets

Coal-fired power plants

Belchatov, Poland
(~35 MtCO₂/year)



Kendal, South Africa
(~27 MtCO₂/year)

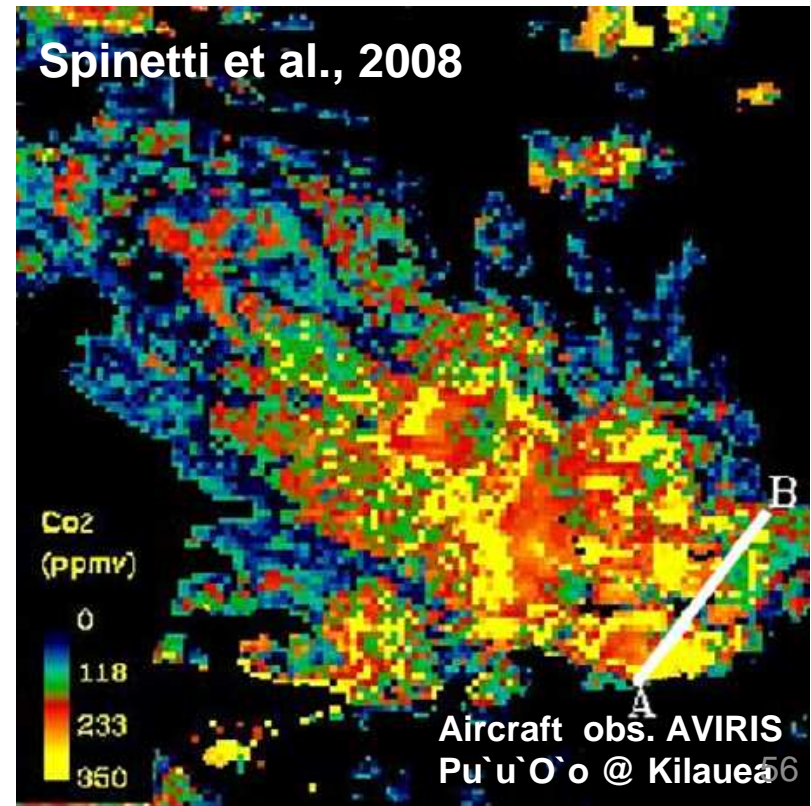


Jämschwalde, Germany
(~27 MtCO₂/year)



Volcanoes

Spinetti et al., 2008



High-resolution CO₂ emission maps



Atmos. Chem. Phys. Discuss., 10, 16307–16344, 2010
www.atmos-chem-phys-discuss.net/10/16307/2010/
doi:10.5194/acpd-10-16307-2010
© Author(s) 2010. CC Attribution 3.0 License.



This discussion paper is/has been under review for the journal Atmospheric Chemistry and Physics (ACP). Please refer to the corresponding final paper in ACP if available.

A very high-resolution global fossil fuel CO₂ emission inventory derived using a point source database and satellite observations of nighttime lights, 1980–2007

T. Oda and S. Maksyutov

Center for Global Environmental Research, National Institute for Environmental Studies,

Discussion Paper | Discussion Paper | Discussion Paper

ACPD
10, 16307–16344, 2010

High resolution global fossil CO₂ inventory
T. Oda and S. Maksyutov

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Printer-friendly Version

Interactive Discussion



CarbonSat: Bovensmann et al., 2010

Atmos. Meas. Tech., 3, 781–811, 2010
www.atmos-meas-tech.net/3/781/2010/
doi:10.5194/amt-3-781-2010
© Author(s) 2010. CC Attribution 3.0 License.



A remote sensing technique for global monitoring of power plant CO₂ emissions from space and related applications

H. Bovensmann¹, M. Buchwitz¹, J. P. Burrows¹, M. Reuter¹, T. Krings¹, K. Gerilowski¹, O. Schneising¹, J. Heymann¹, A. Tretner², and J. Erzinger²

¹Institute of Environmental Physics (IUP), University of Bremen FB1, Otto Hahn Allee 1, 28334 Bremen, Germany

²Helmholtz Centre Potsdam – GFZ German Research Centre for Geosciences, Telegrafenberg, 14473 Potsdam, Germany

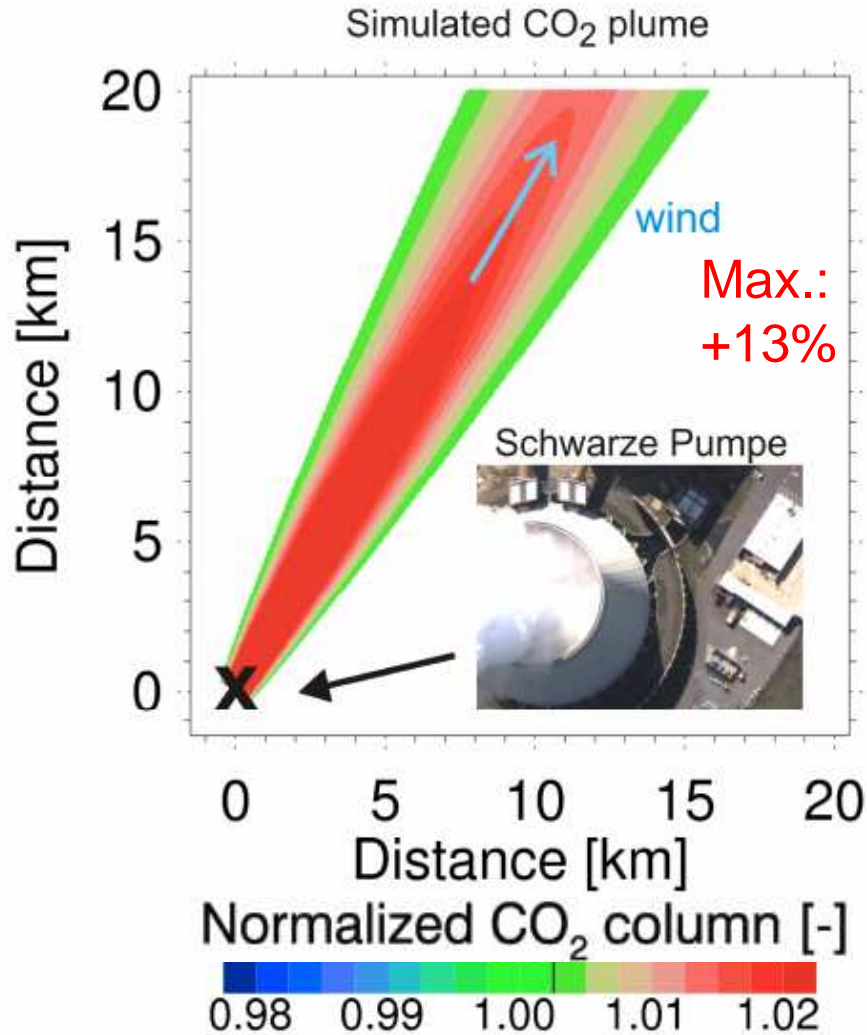
Received: 6 November 2009 – Published in Atmos. Meas. Tech. Discuss.: 7 January 2010

Revised: 14 June 2010 – Accepted: 15 June 2010 – Published: 1 July 2010

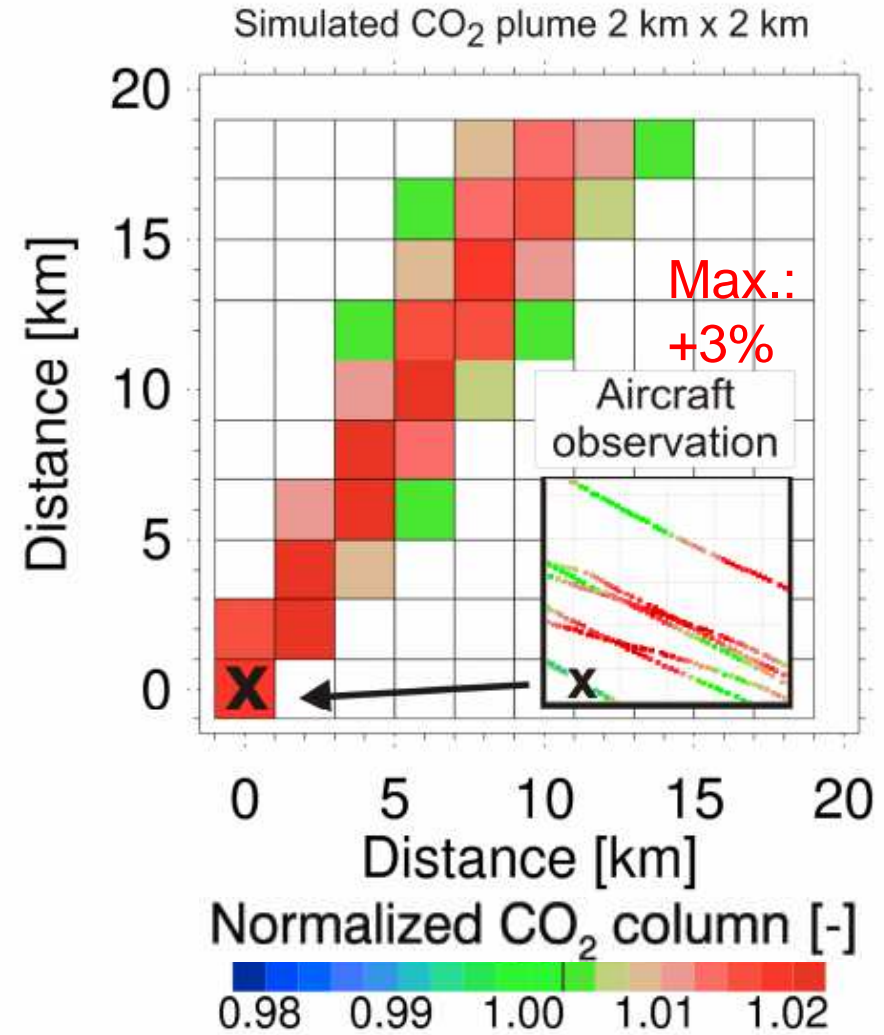
Abstract. Carbon dioxide (CO₂) is the most important anthropogenic greenhouse gas (GHG) causing global warming. The atmospheric CO₂ concentration increased by more than 30% since pre-industrial times – primarily due to burning of fossil fuels – and still continues to increase. Reporting of CO₂ emissions is required by the Kyoto protocol. Independent verification of reported emissions, which are typically not directly measured, by methods such as inverse modeling of measured atmospheric CO₂ concentrations is currently not possible globally due to lack of appropriate observations. Ex-

PP CO₂ emission due to instrument noise is in the range 1.6–4.8 MtCO₂/yr for single overpasses. This corresponds to 12–36% of the emission of a mid-size PP (13 MtCO₂/yr). We have also determined the sensitivity to parameters which may result in systematic errors such as atmospheric transport and aerosol related parameters. We found that the emission error depends linearly on wind speed, i.e., a 10% wind speed error results in a 10% emission error, and that neglecting enhanced aerosol concentrations in the PP plume may result in errors in the range 0.2–2.5 MtCO₂/yr, depending on PP

CarbonSat: Simulation of power plant CO₂ plume

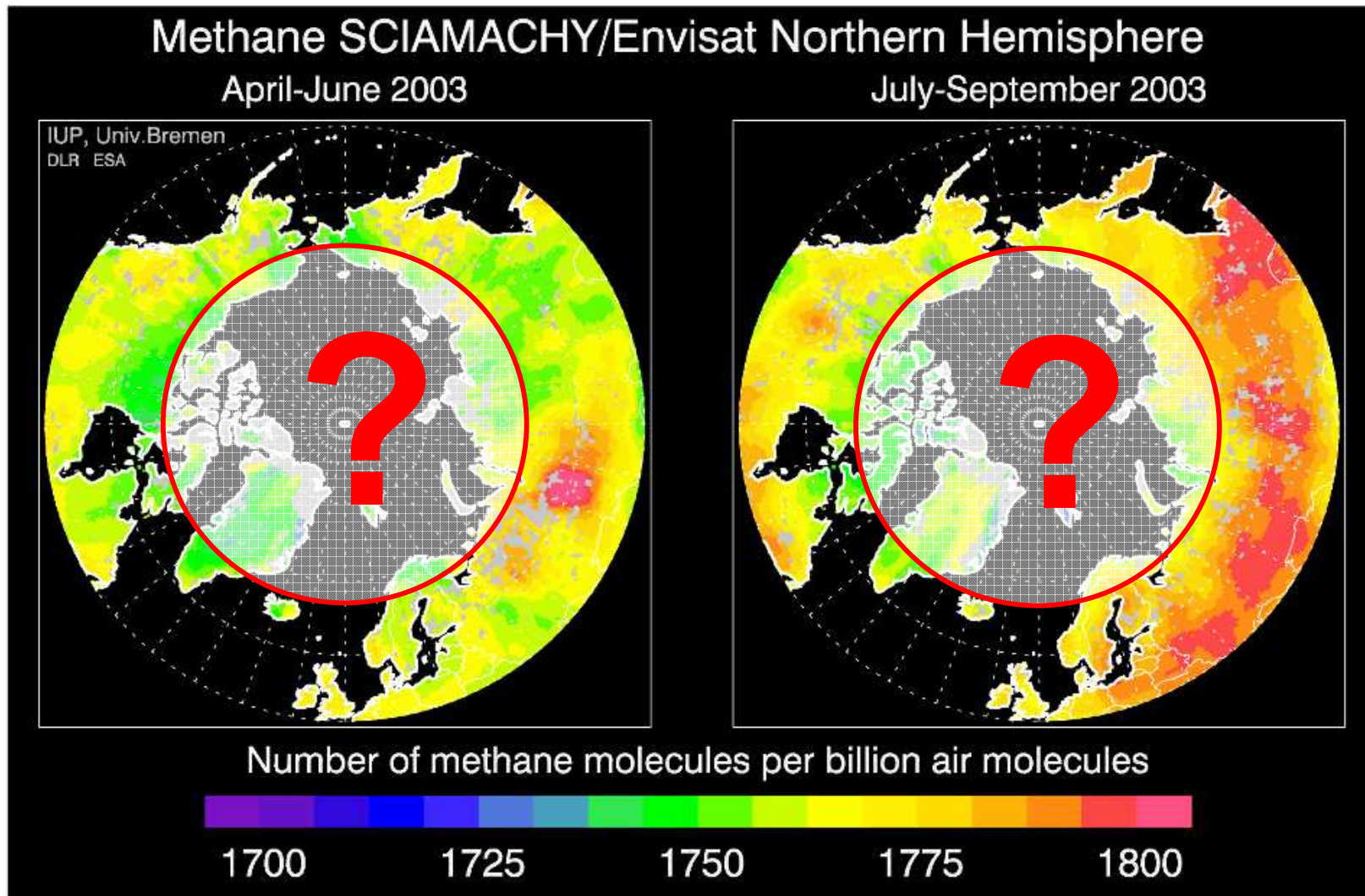


Emission: **13 MtCO₂/year**
 („moderate“; many power plants
 emit 20-35 MtCO₂/year)



Emission uncertainty single overpass
 (+/- 2 ppm XCO₂ error, u = 1 m/s):
+/- 0.8 MtCO₂/year (1-sigma)
 Approx. proportional to wind speed u &
 statistical measurement error

CarbonSat: Methane @ high latitudes



CarbonSat **sun-glint mode** allows observation of methane in vulnerable high latitude regions including Arctic sea and shelf areas. Very difficult with SCIAMACHY & GOSAT. Not possible with OCO.

CarbonSat: CH₄ emission hot spot targets

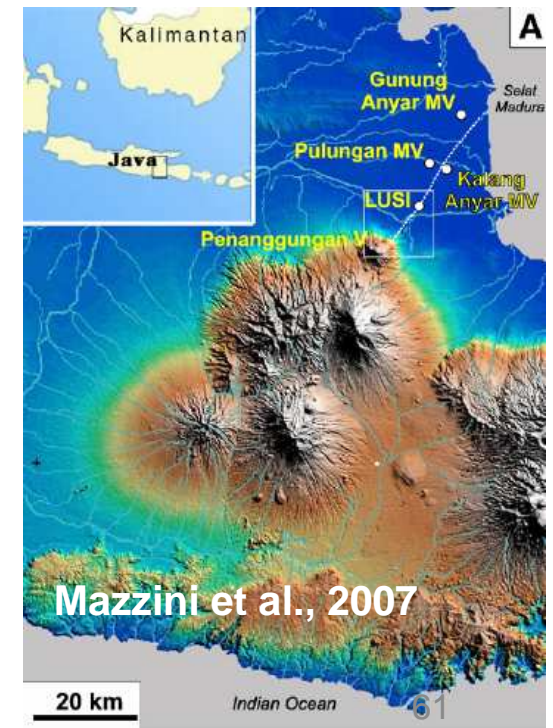
Oil and gas fields Pipelines incl. compressor stations



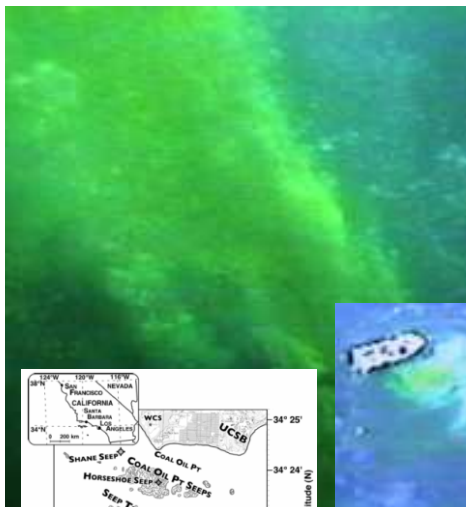
Landfills / Waste



Mud volcanoes



Seeps



Comparison of PBL sensitive GHG satellite missions

Application area & other criteria	SCIAMACHY	GOSAT	OCO	Sentinel 5 Precursor	CH ₄ Laser (MERLIN)	CarbonSat
Regional CO ₂ fluxes	Yellow	Light Green	Bright Green	Red	Red	Bright Green
Regional CH ₄ fluxes	Bright Green	Light Green	Red	Yellow	Bright Green	Bright Green
CO ₂ „hot spots“ (eg power plants)	Red	Red	Yellow	Red	Red	Bright Green
CH ₄ „hot spots“ (eg oil fields)	Red	Red	Red	Red	Yellow	Bright Green
Technical maturity	Bright Green	Bright Green	Bright Green	Bright Green	Red	Bright Green
Daytime	Bright Green	Bright Green	Bright Green	Bright Green	Bright Green	Bright Green
Day & night	Red	Red	Red	Red	Bright Green	Red



CarbonSat Web Site

The screenshot shows a Windows Internet Explorer browser window displaying the CarbonSat website. The address bar shows the URL <http://www.iup.uni-bremen.de/carbonsat/>. The page title is "CarbonSat: Main page - Windows Internet Explorer". The browser's search bar is set to Google. The website content includes a navigation menu on the left with links to "Main page", "Documents", "Presentations", "References", "Media", "Project Team", "Science Team", and "Contact". The main content area features the "CarbonSat" logo and the heading "Carbon Monitoring Satellite - CarbonSat". Below this is an "Introduction" section with the following text:

Carbon dioxide (CO₂) and methane (CH₄) are the two most important anthropogenic ("man-made") greenhouse gases responsible for global warming. Despite their importance our knowledge about their variable natural and anthropogenic sources and sinks has large gaps. An appropriate knowledge about their sources and sinks is a pre-requisite for reliable climate prediction. Satellites can add important missing global information. Currently two satellite instruments are in orbit measuring CO₂ and CH₄ with high sensitivity down the the Earth's surface where the regional source/sink signal is largest: [SCIAMACHY](#) onboard the European ENVISAT satellite and TANSO aboard the Japanese [GOSAT](#) satellite. In order to continue the satellite CO₂ and CH₄ global timeseries after [SCIAMACHY](#) and [GOSAT](#), i.e., after 2014, and to deliver important additional information on CO₂ and CH₄, we propose a new satellite mission: Carbon Monitoring Satellite - CarbonSat.

At the bottom of the page, there is a "CarbonSat" logo with a stylized orange sun or planet icon.

<http://www.iup.uni-bremen.de/carbonsat/>

Good luck with your projects !

Animations showing 7 years of SCIAMACHY CO₂ and CH₄

