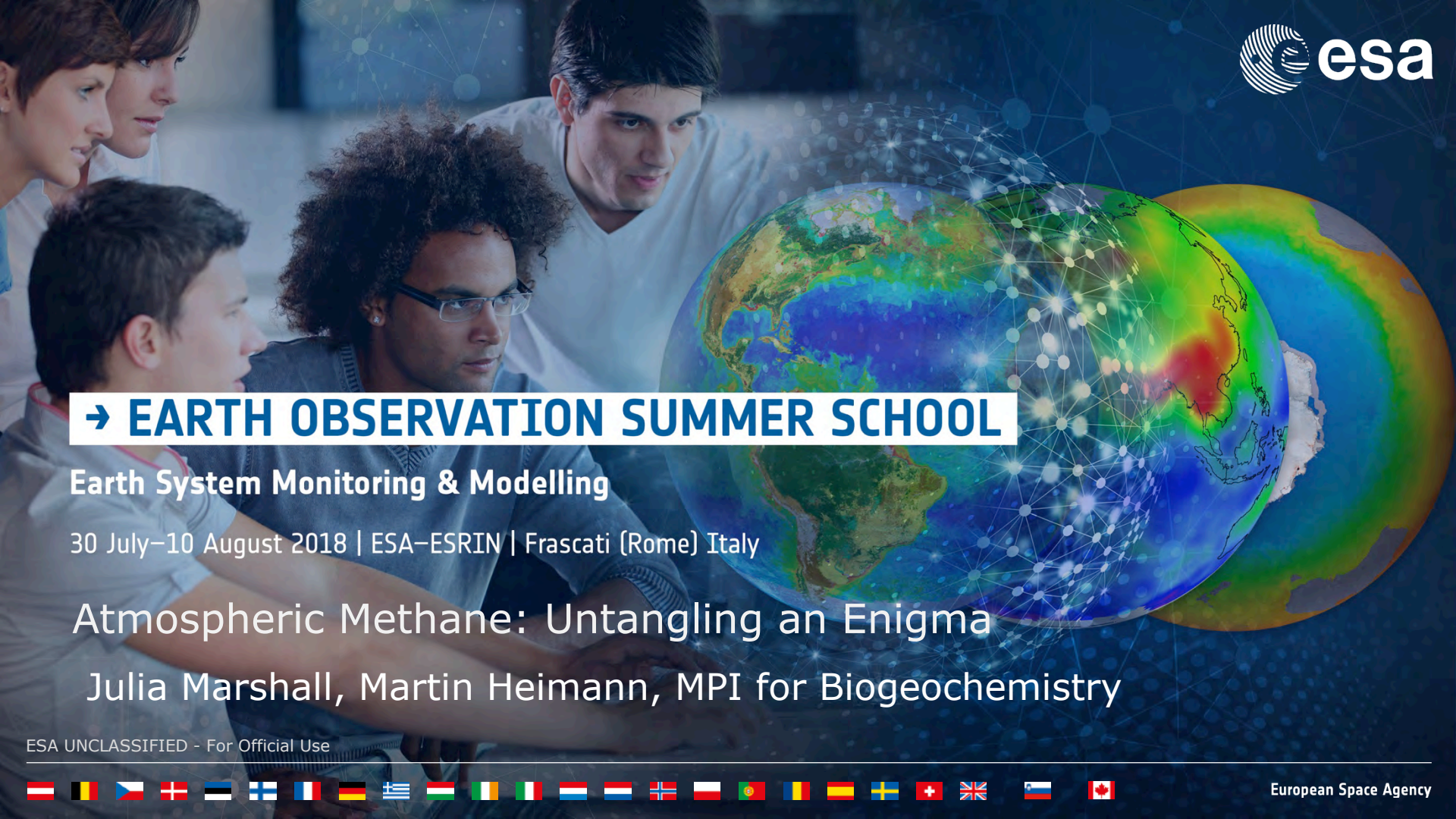


→ EARTH OBSERVATION SUMMER SCHOOL

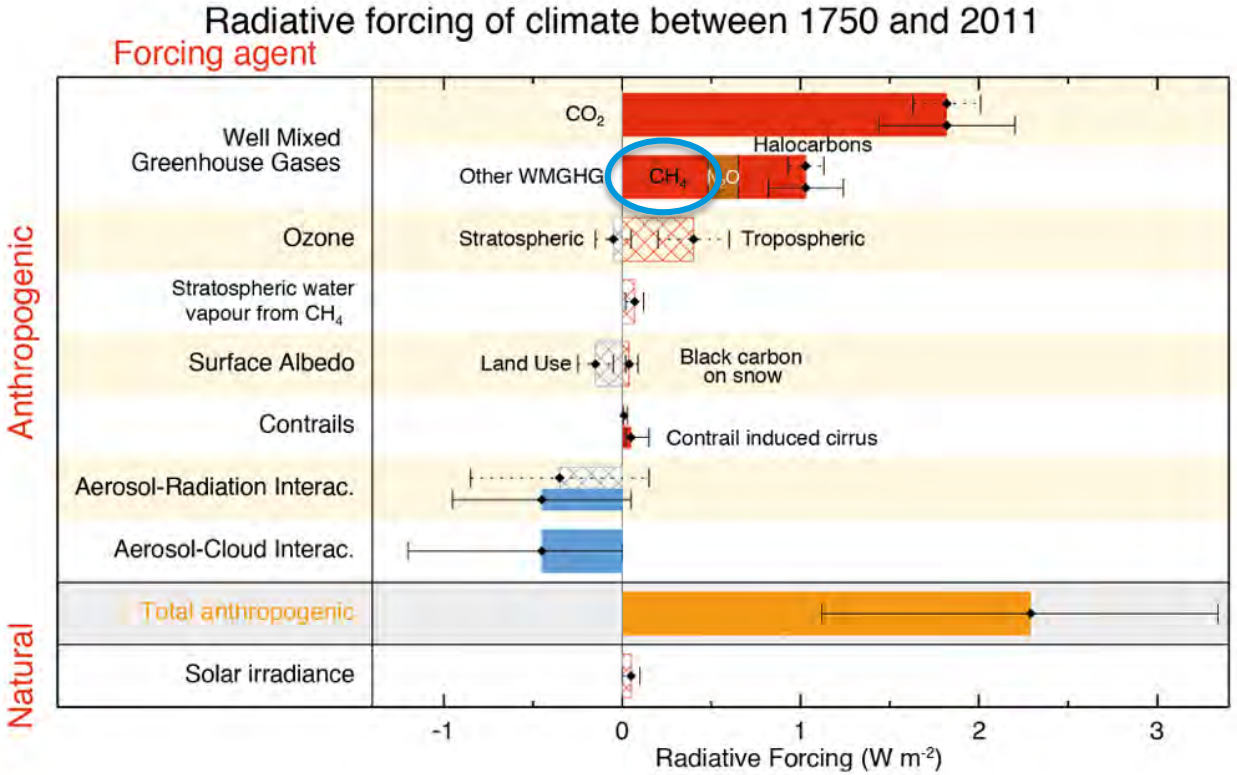
Earth System Monitoring & Modelling

30 July–10 August 2018 | ESA–ESRIN | Frascati (Rome) Italy

Atmospheric Methane: Untangling an Enigma

Julia Marshall, Martin Heimann, MPI for Biogeochemistry

Why are we interested in methane?



- Second-most important well-mixed greenhouse gas influenced by human activity
- Easier to mitigate: we often don't emit it on purpose

Historical context: first documentation of increase in 1980

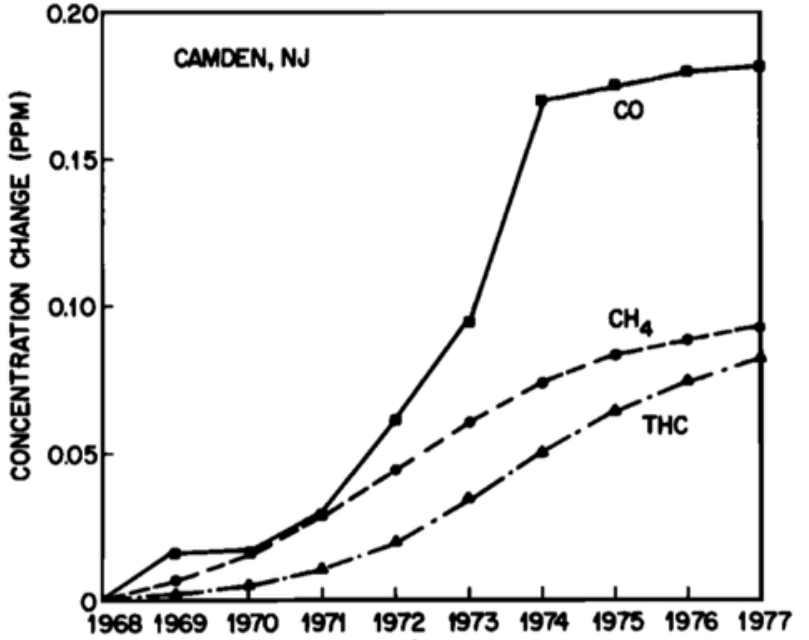


Fig. 1. Changes in annual minima of CO, CH_4, and THC from 1968 through 1977 at Camden, NJ, referenced to 1968 values.

GEOPHYSICAL RESEARCH LETTERS, VOL. 7, NO. 11, PAGES 977-979, NOVEMBER 1980

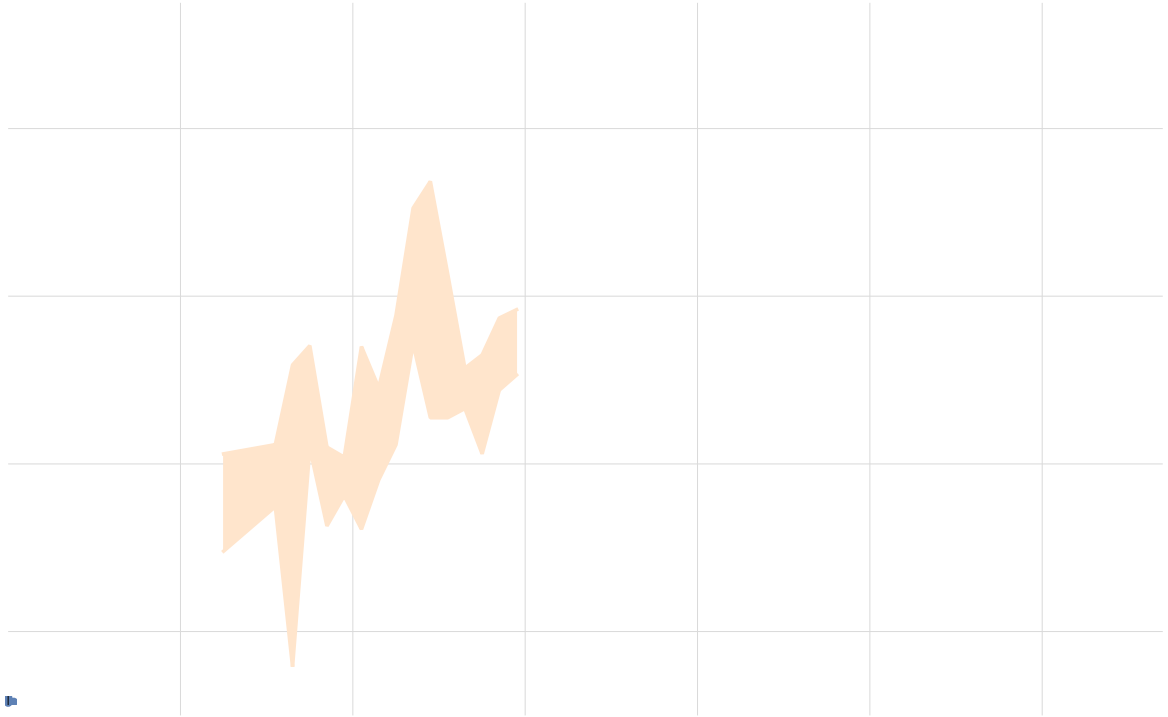
ON THE POSSIBLE INCREASE OF THE ATMOSPHERIC METHANE AND CARBON MONOXIDE CONCENTRATIONS DURING THE LAST DECADE

T. E. Graedel and J. E. McRae

Bell Laboratories, Murray Hill, New Jersey 07974

Graedel and McRae, GRL, 1980

Recent history of methane concentrations



ape Grim, Tasmania (CSIRO)

Global average (NOAA)

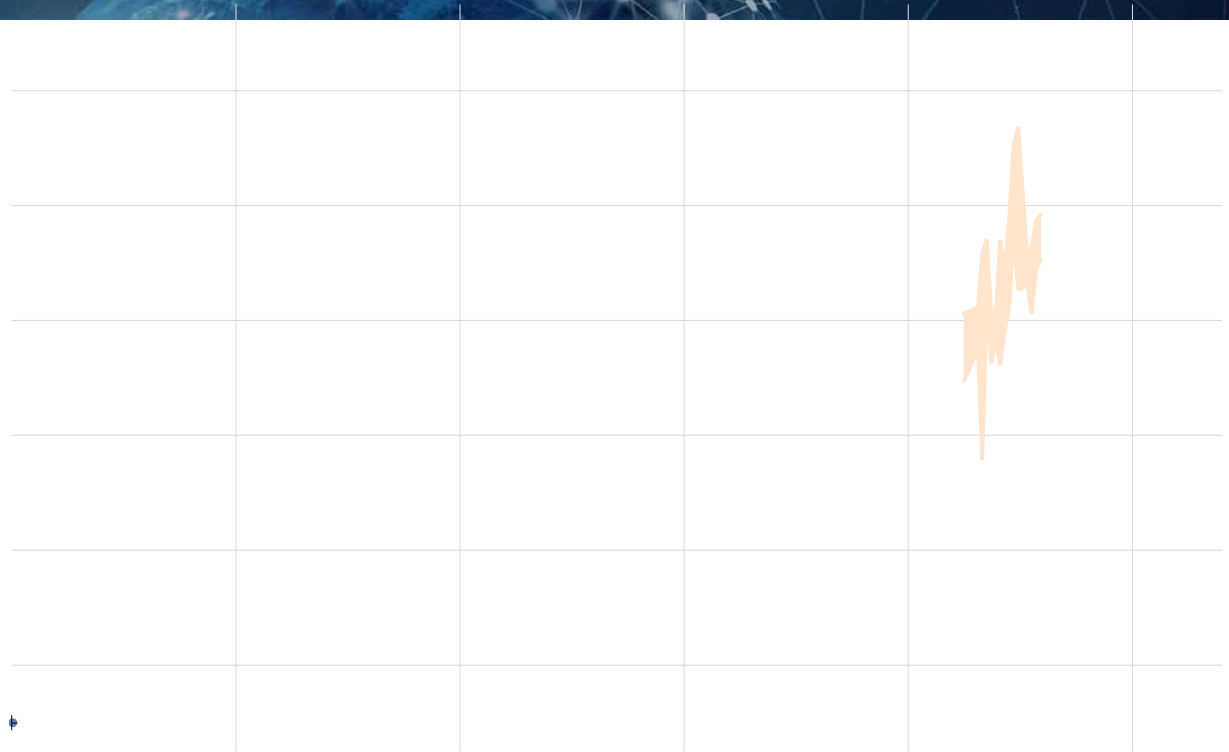
Ice core (NEEM5), Greenland

Pt. Barrow, Alaska (NOAA)

Cape Grim, Tasmania (CSIRO)

Data: Rhodes et al., 2013, MacFarling Meure et al., 2006, NOAA-ESRL, CSIRO
Figure: Martin Heimann

Extension with ice core data



AA)

- Ice core (NEEM5), Greenland
- Pt. Barrow, Alaska (NOAA)
- Cape Grim, Tasmania (CSIRO)

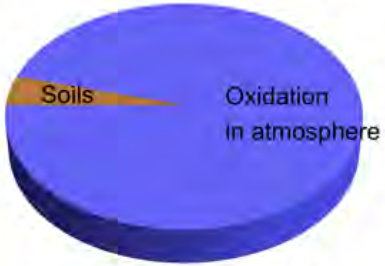
Data: Rhodes et al., 2013,
MacFarling Meure et al., 200
NOAA-ESRL, CSIRO
Figure: Martin Heimann

Global budget, 2000-2009

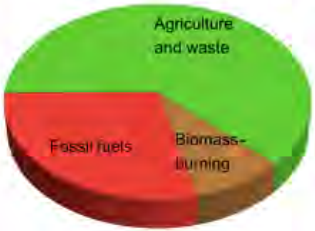
Atmospheric growth rate: ~ 8 $TgCH_4yr^{-1}$

Atmospheric lifetime: ~ 9.14 yr (±10%)
(based on present day budget)

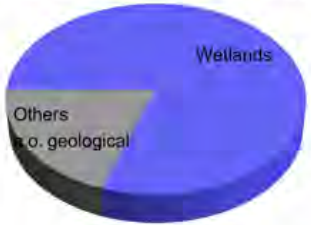
Total sinks: 541 $TgCH_4yr^{-1}$



Total anthropogenic sources: 335 $TgCH_4yr^{-1}$



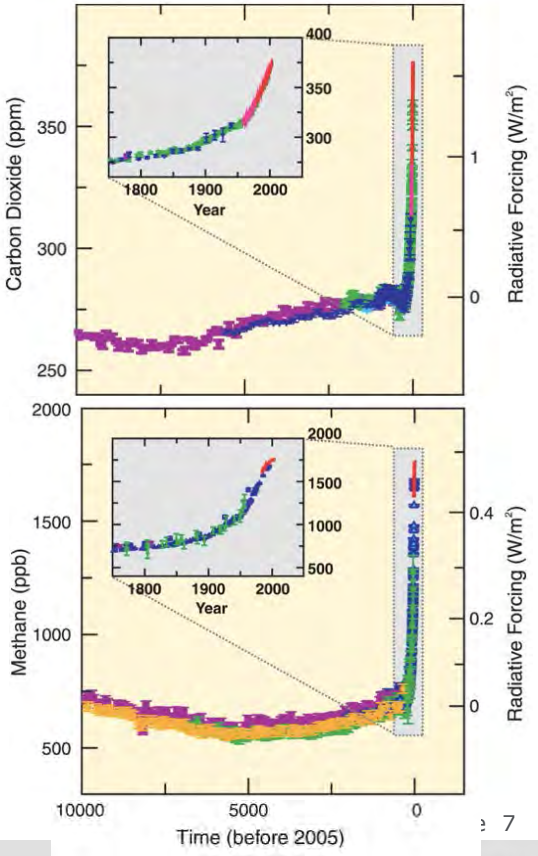
Total natural sources: 218 $TgCH_4yr^{-1}$



Kirschke et al., 2013;
IPCC AR5 Ch. 6

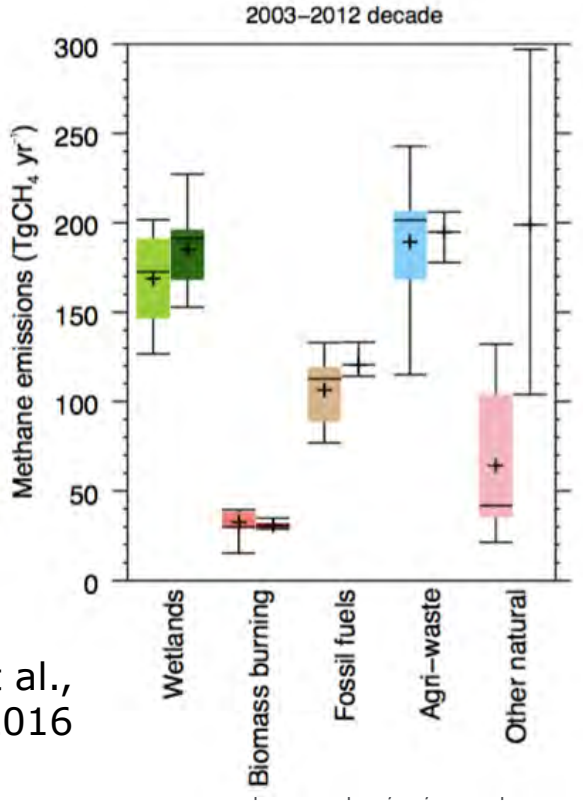
Similarities to the CO_2 problem

- also tackled by top-down or inverse modelling
- also involves combined signals of anthropogenic and biogenic fluxes
- also requires a challengingly high measurement precision and accuracy



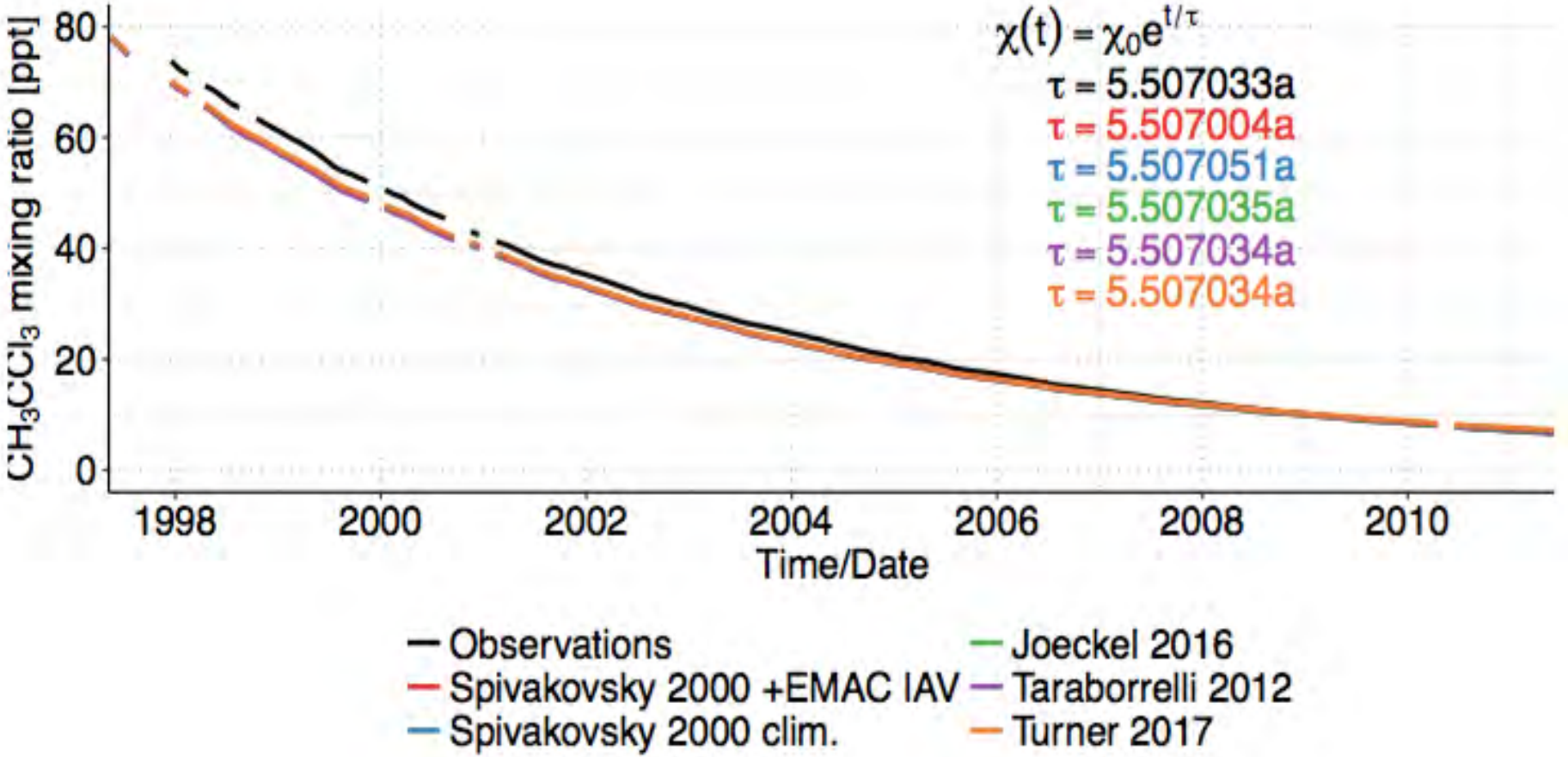
Differences to CO_2

- Significant uncertainties in all contributing processes
- Generally easier to solve for the total CH4 budget, and divide into processes based on bottom-up share per pixel
- Separating the processes directly introduces more unknowns, and requires more constraints

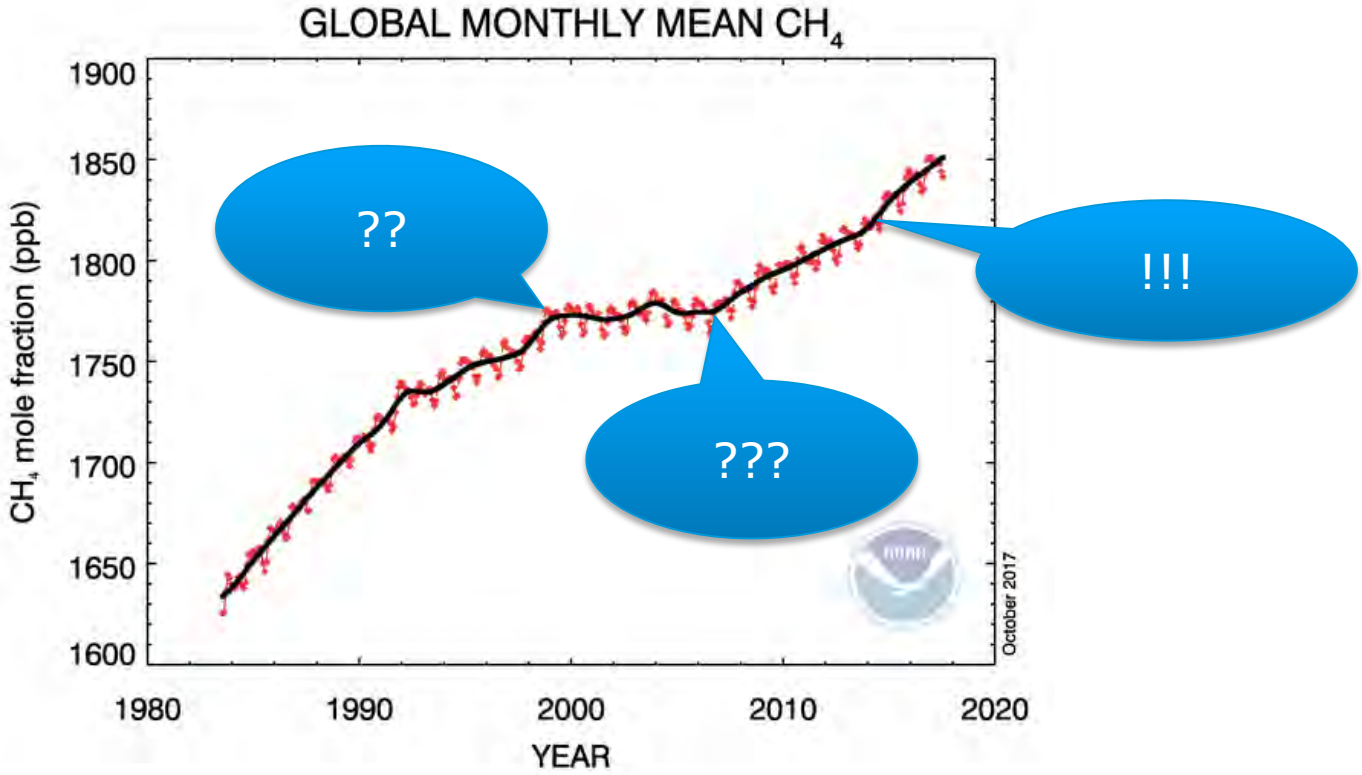


from synthesis of Saunois et al., ESSD, 2016

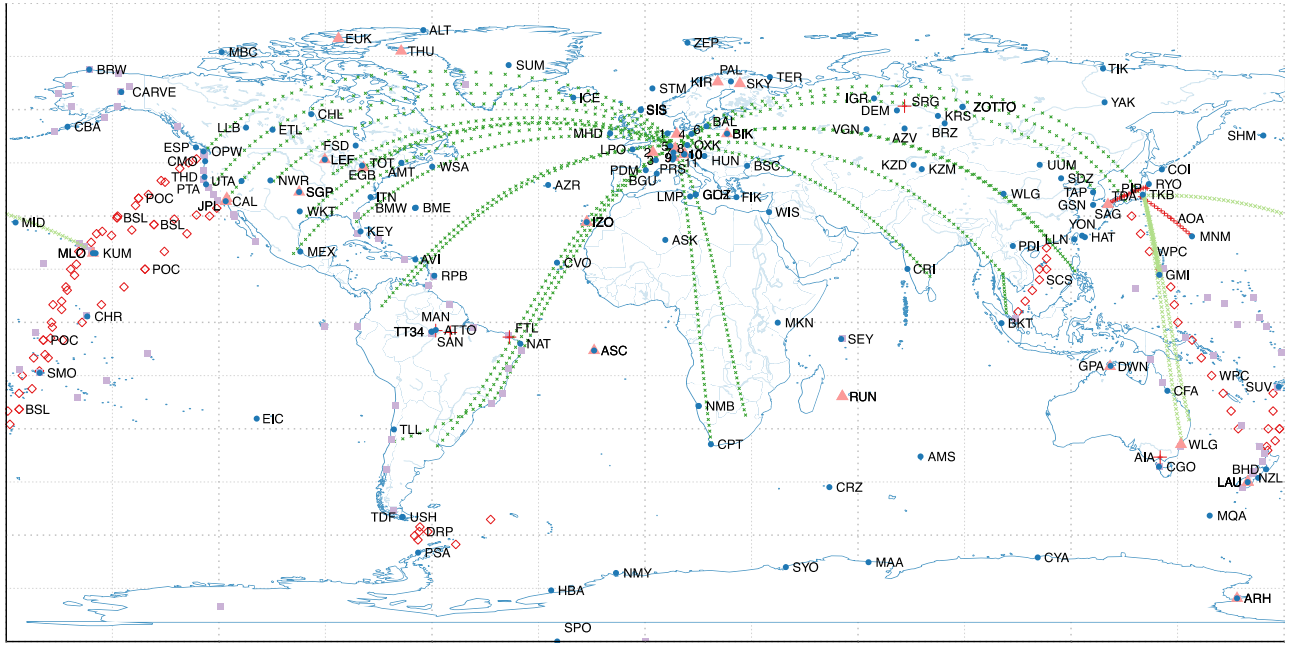
Complications due to chemical sink



Also: enigmatic recent changes in the growth rate

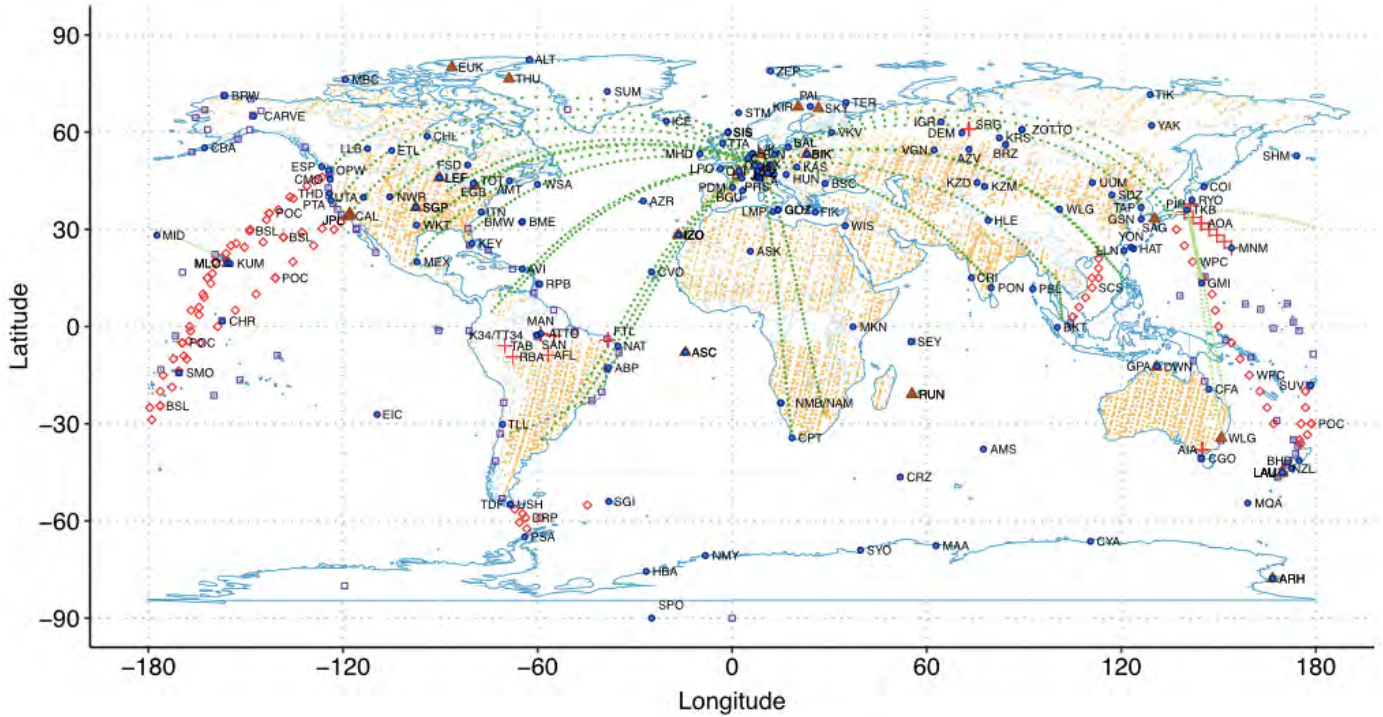


The measurement constraint



ation Ship transect UCI network
Total Column

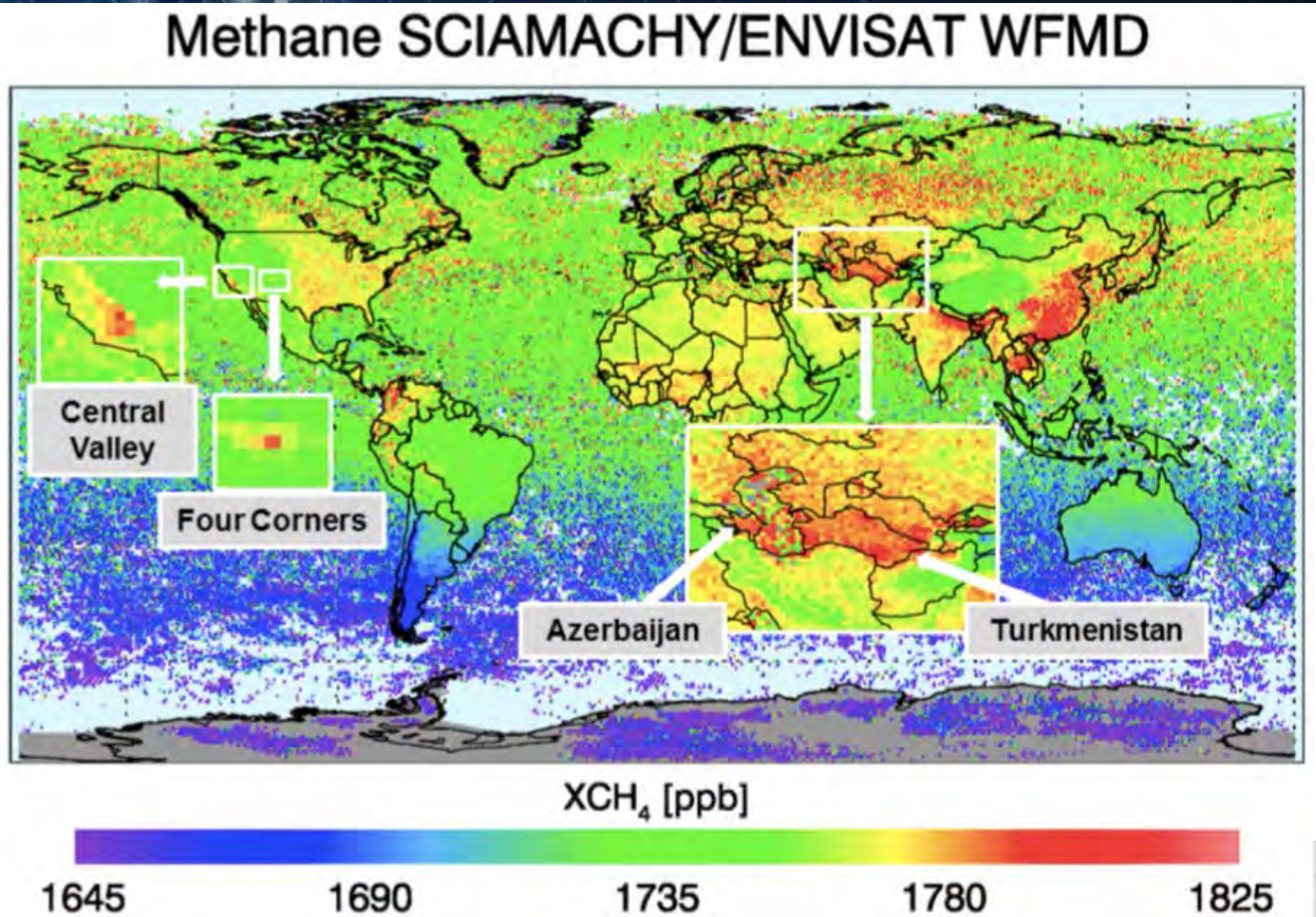
The measurement constraint



Back to SCIAMACHY

- Despite poor precision and sensor degradation, provided new insights into methane fluxes
- Could detect hotspots with sufficient averaging…

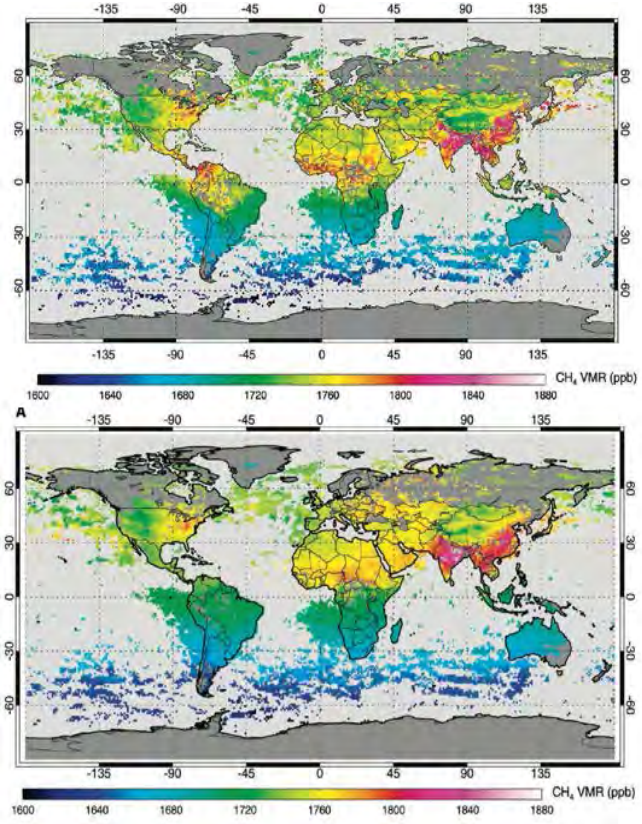
data from 2004, 0.5° binning,
Buchwitz et al., ACP, 2017



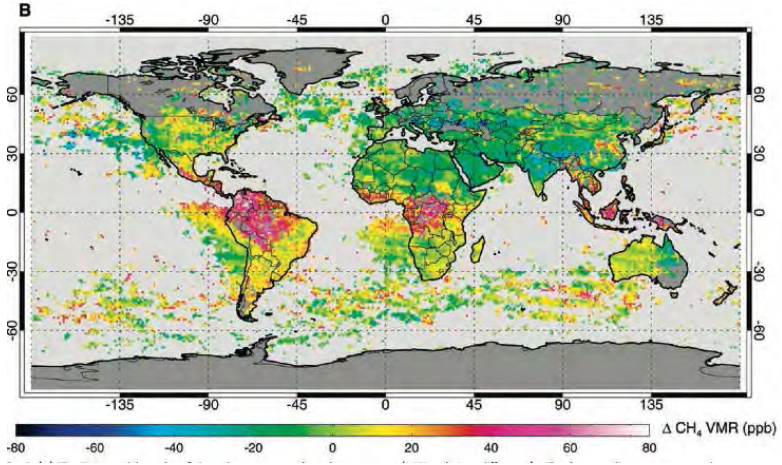
And there were bumps along the way:

SCIAMACHY

TM3



difference



Frankenberg et al., Science, 2005

Is it the plants?!?

Vol 439|12 January 2006|doi:10.1038/nature04420 nature

LETTERS

Methane emissions from terrestrial plants under aerobic conditions

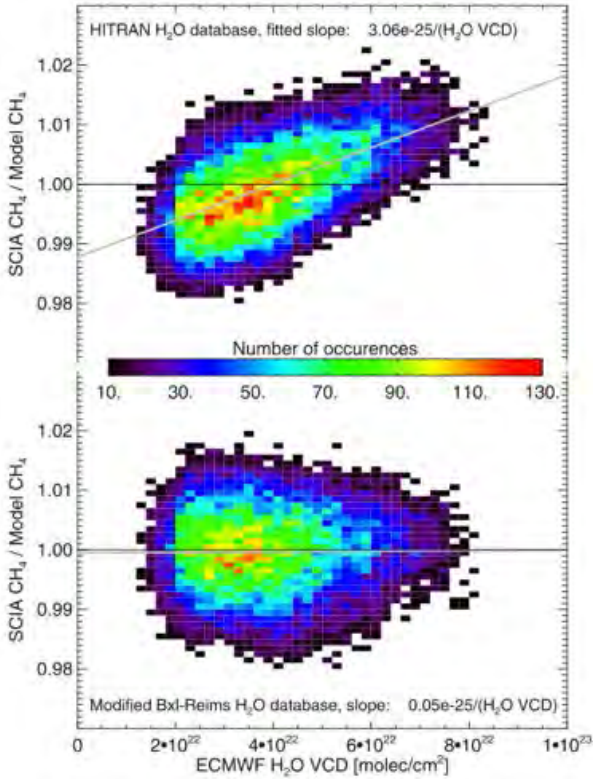
Frank Keppler[1], John T. G. Hamilton[2], Marc Braß[1,3] & Thomas Röckmann[1,3]

Methane is an important greenhouse gas and its atmospheric concentration has almost tripled since pre-industrial times[1,2]. It plays a central role in atmospheric oxidation chemistry and affects stratospheric ozone and water vapour levels. Most of the methane from natural sources in Earth's atmosphere is thought to originate from biological processes in anoxic environments[2]. Here we demonstrate using stable carbon isotopes that methane is readily formed *in situ* in terrestrial plants under oxic conditions by a hitherto unrecognized process. Significant methane emissions from both intact plants and detached leaves were observed during

(dry weight) h^{-1} at 30 °C (see Supplementary Table S1). Release of CH_4 was very temperature sensitive—concentrations approximately doubled with every 10 °C increase over the range 30–70 °C (Fig. 1a), suggesting a non-enzymic rather than an enzyme-mediated process. $\delta^{13}C$ of the emitted CH_4 ranged from −51.8‰ to −68.4‰ (mean = −58.2‰, $n = 61$) and −46.9‰ to −53.1 (mean = −49.5‰, $n = 13$) for C_3 and C_4 plants, respectively. The mean value determined for C_3 plant emissions is comparable with the average $\delta^{13}C$ value for CH_4 emitted from wetlands and rice paddies (approximately −60‰; ref. 8) and thus would be generally regarded

No, it was just spectroscopy.

- HITRAN database had problems with water vapour in some lines
- new line shapes resolved the anomaly



Frankenberg et al., GRL, 2008

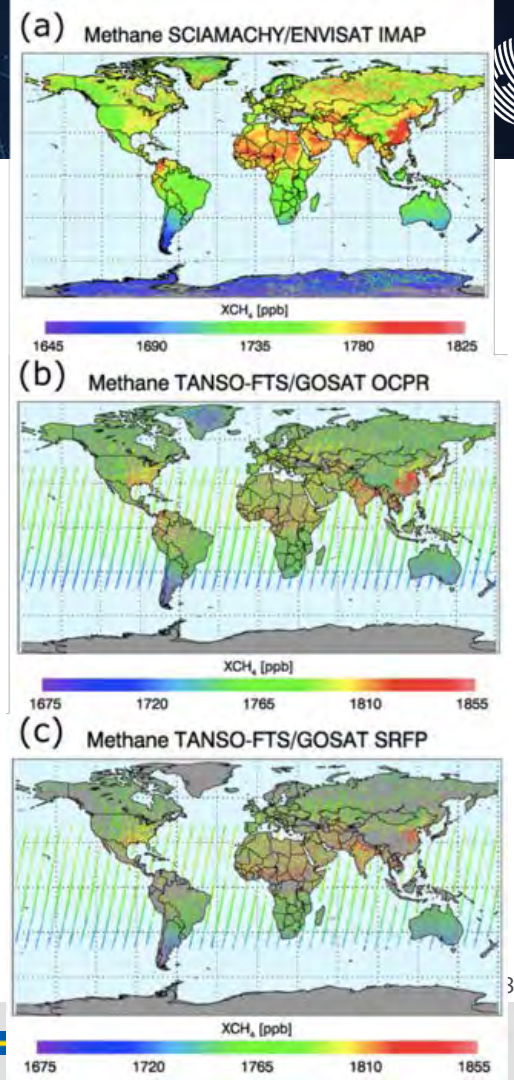
GOSAT: better precision, poorer coverage

so-called "proxy" retrieval

solves for the ratio of XCH_4:XCO_2, and multiplies it by a (better known) modelled XCO_2 value

"full physics" retrieval

has lots of gaps in regions with high cloud cover, aerosol load, and solar zenith angles



Problems with bias in the measurements:

- Modellers usually estimate a model-specific bias based on surface-data-only inversions of methane data, compared to the satellite abundances
- Might actually be correcting for model errors…

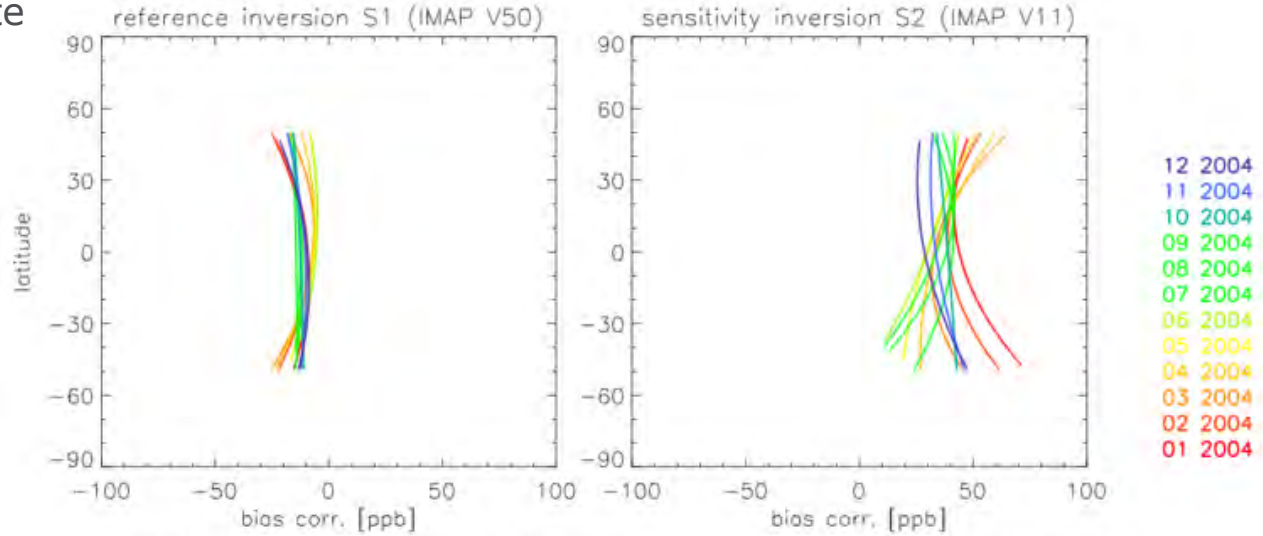
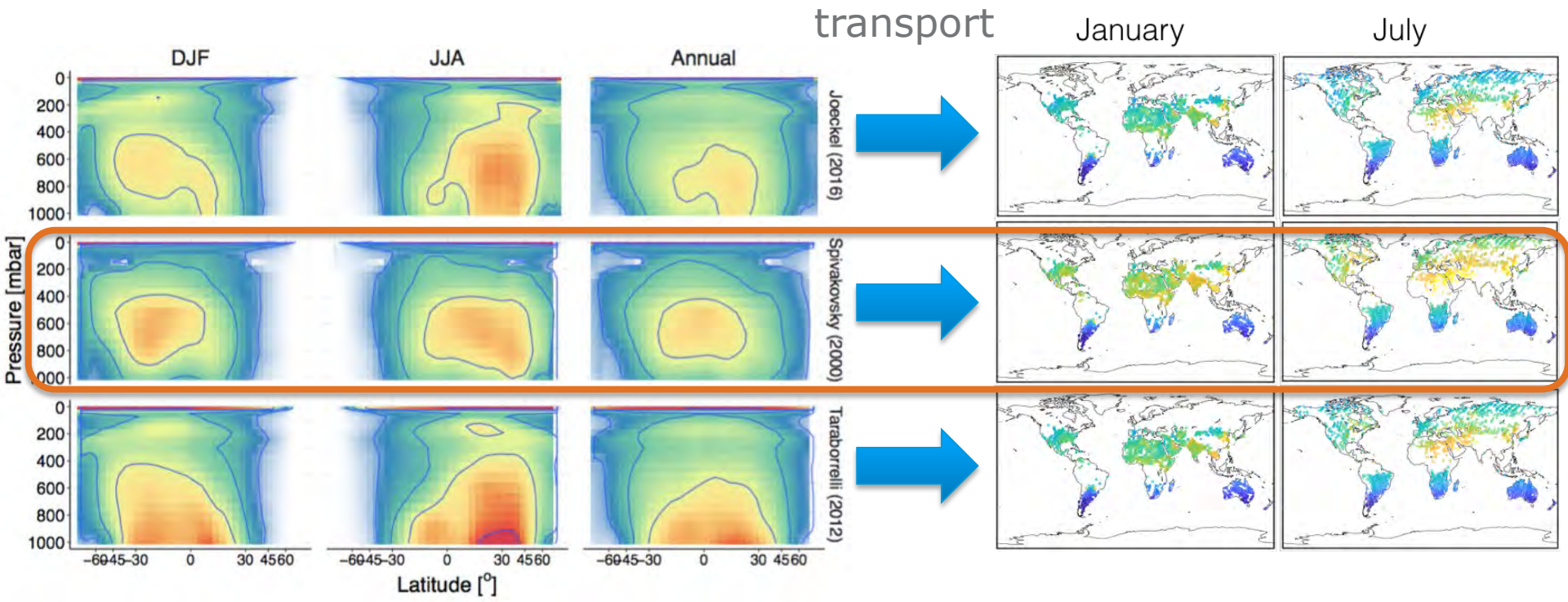


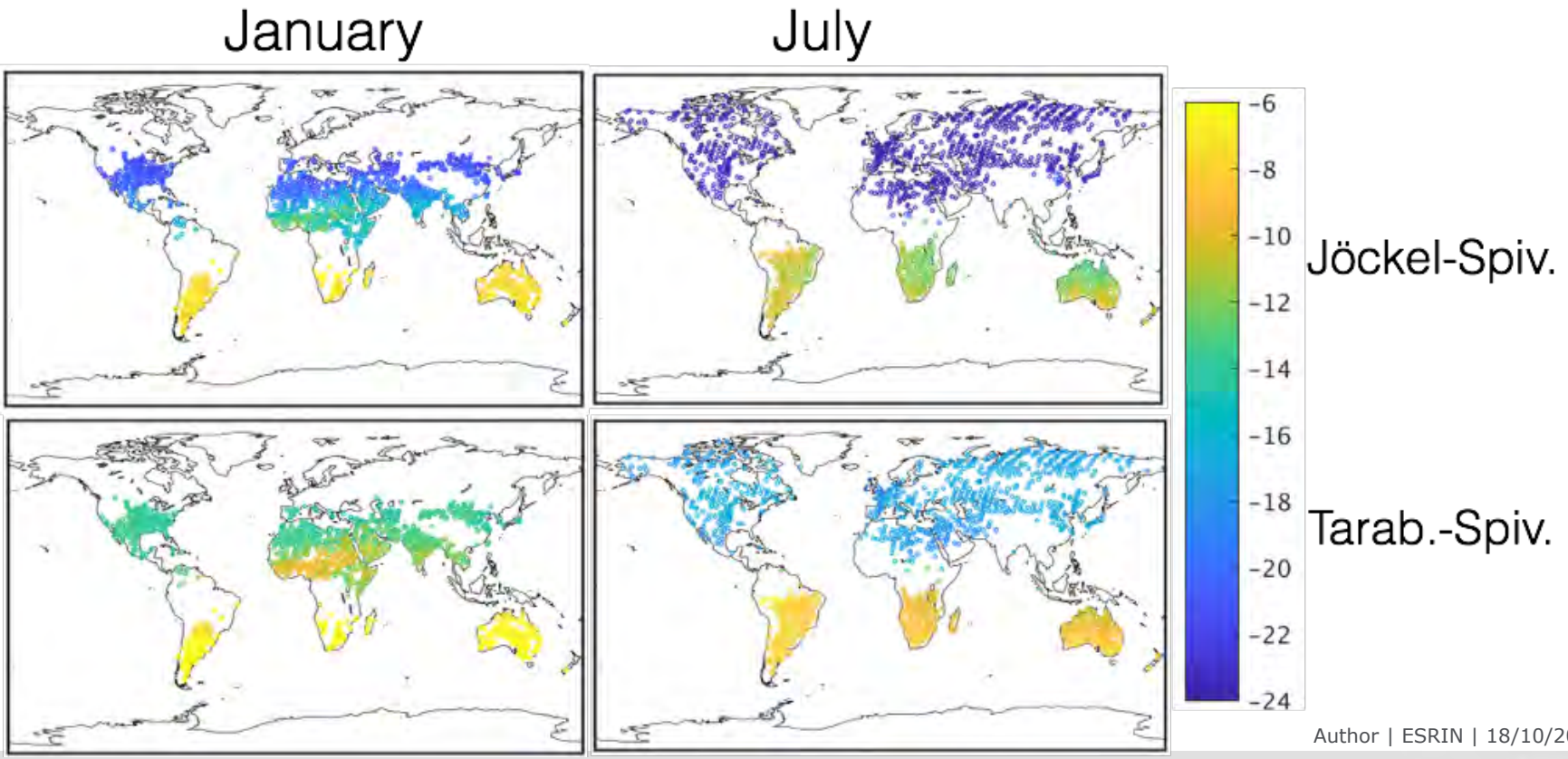
Figure 5. Derived latitudinal/monthly bias correction. (left) IMAP V5.0 (reference inversion S1). (right) IMAP V1.1 (sensitivity inversion S2).

Bergamaschi et al., JGR, 2009

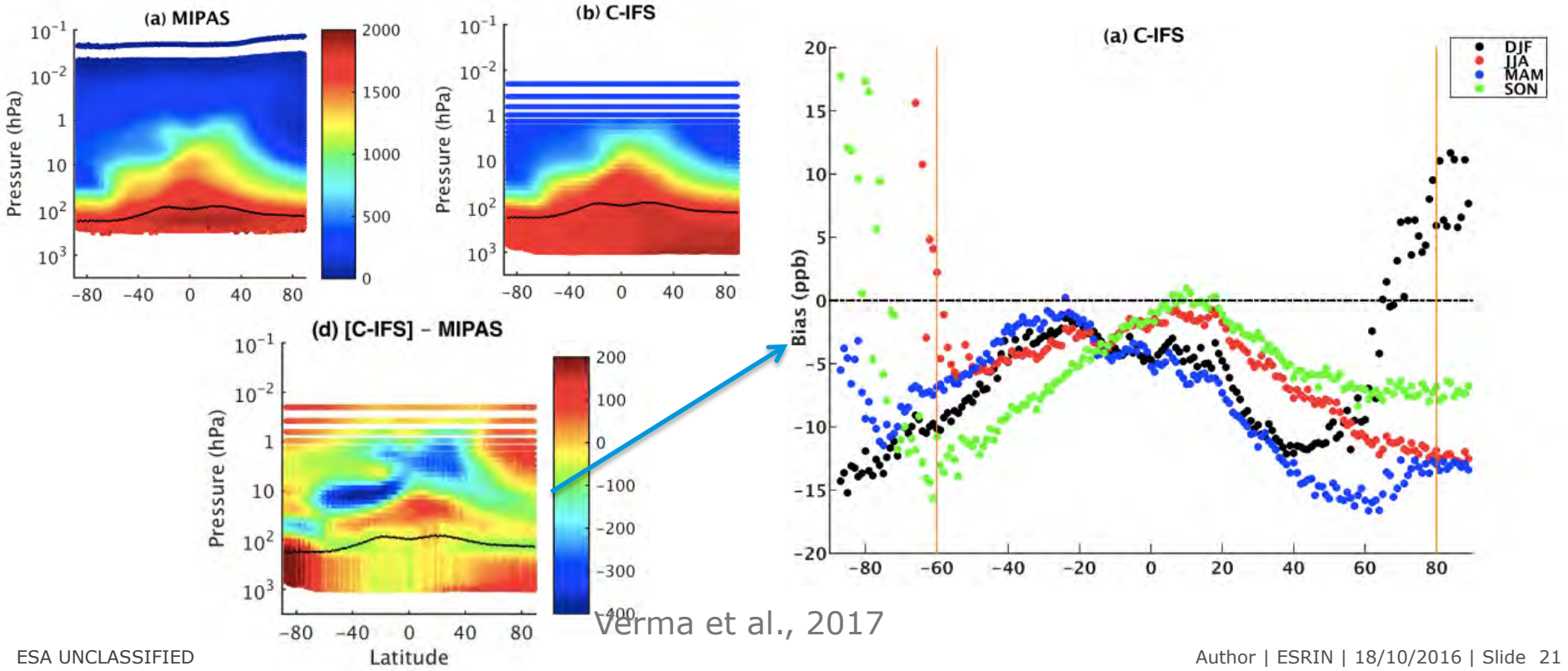
This often looks a bit like the uncertainty in the OH sink:



This often looks a bit like the uncertainty in the OH sink:

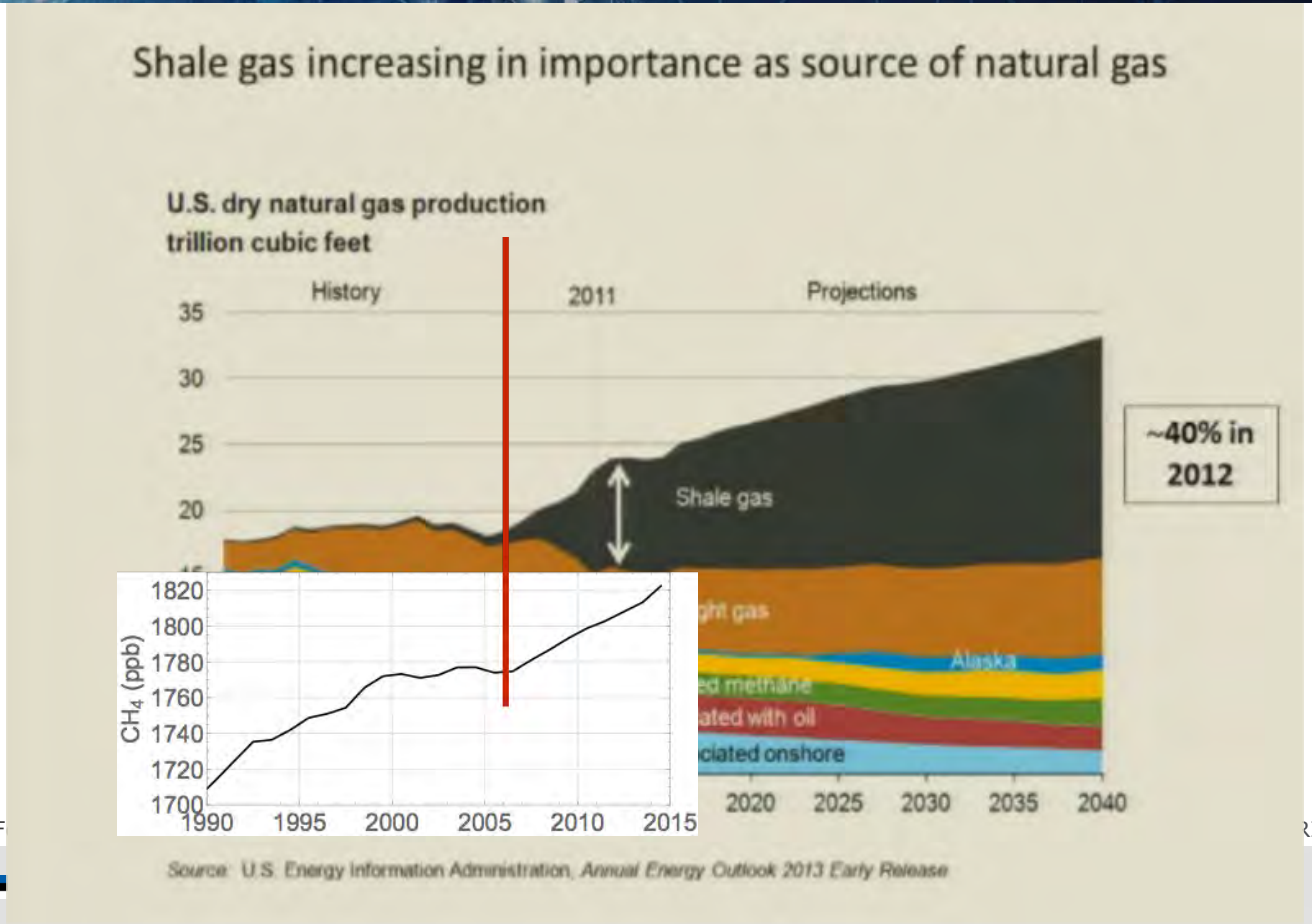


Or even like errors in the stratospheric component



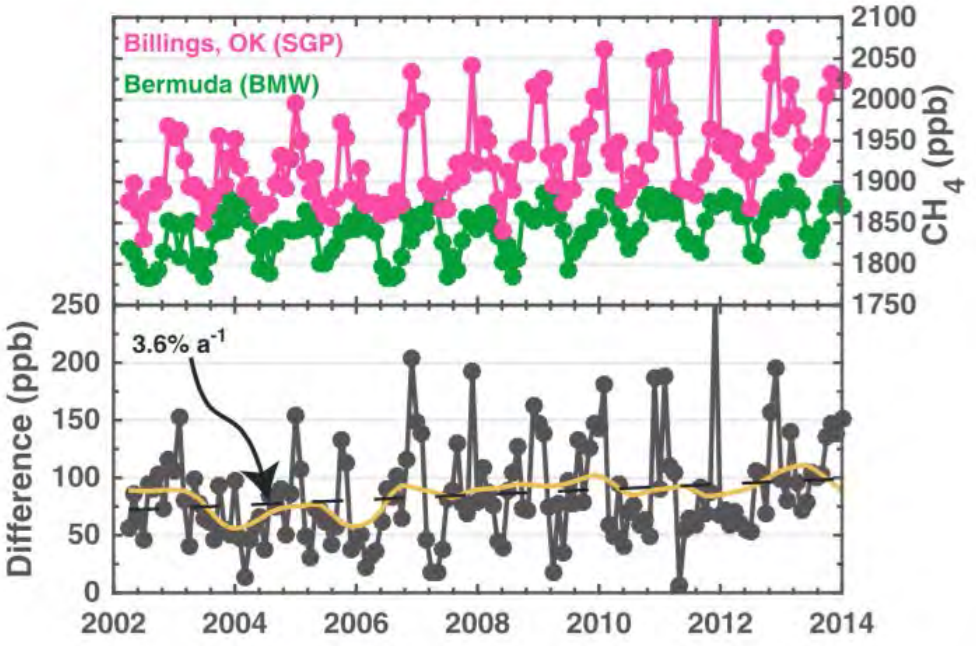
Verma et al., 2017

Trying to understand the growth rate: leaks from shale gas production?



Trying to understand the growth rate: leaks from shale gas production?

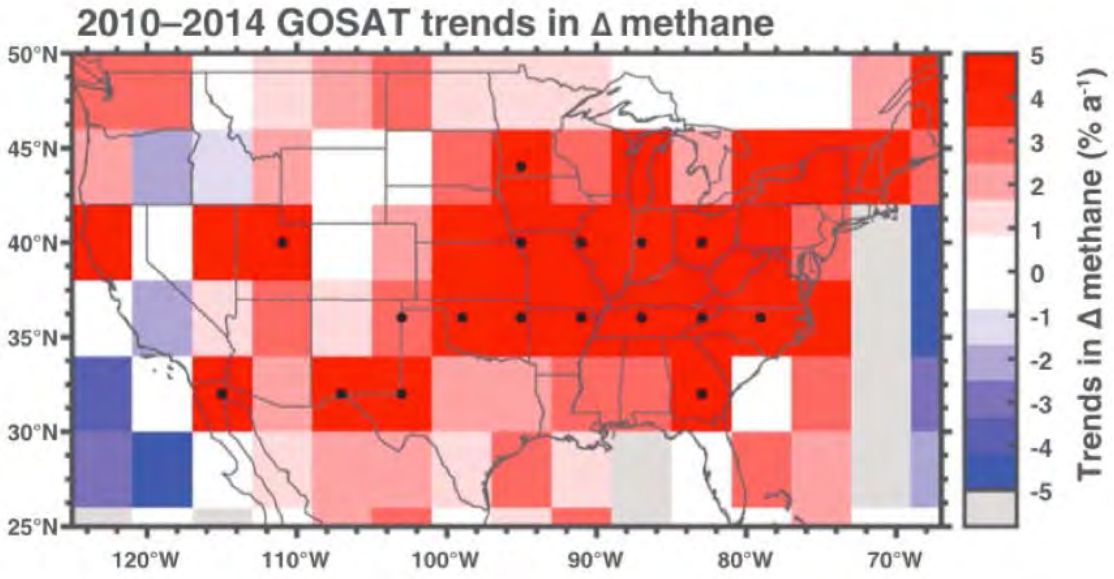
There is an atmospheric signature of increasing emissions over the US



Turner et al., 2016

Trying to understand the growth rate: leaks from shale gas production?

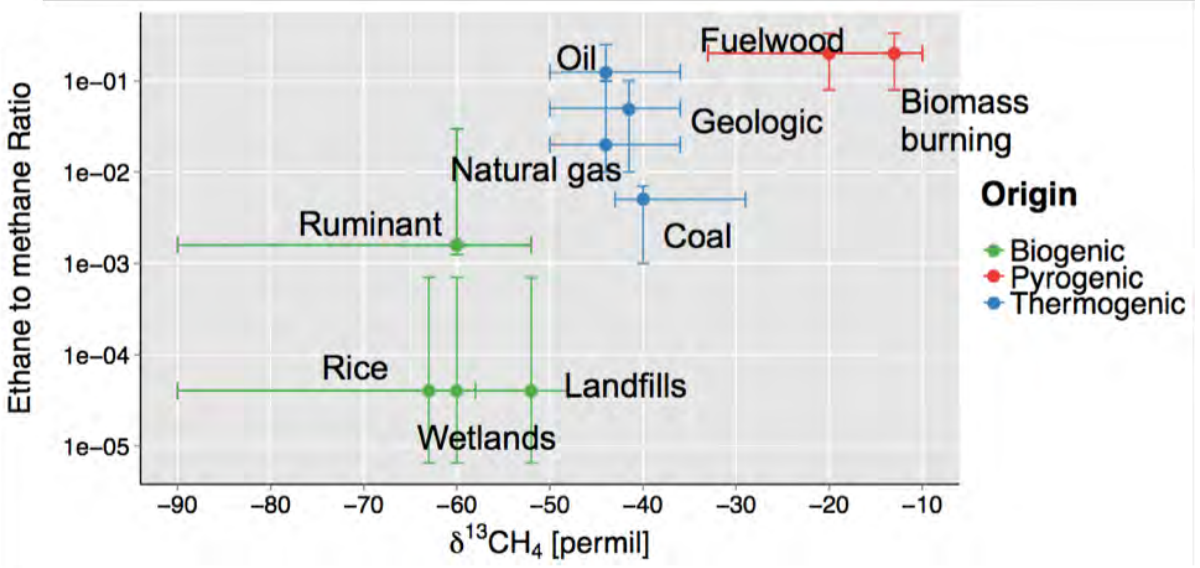
This is also evident in the GOSAT data: a "bulge" in the methane trend over the US (Turner et al., 2016):



Trying to understand the growth rate: leaks from shale gas production?

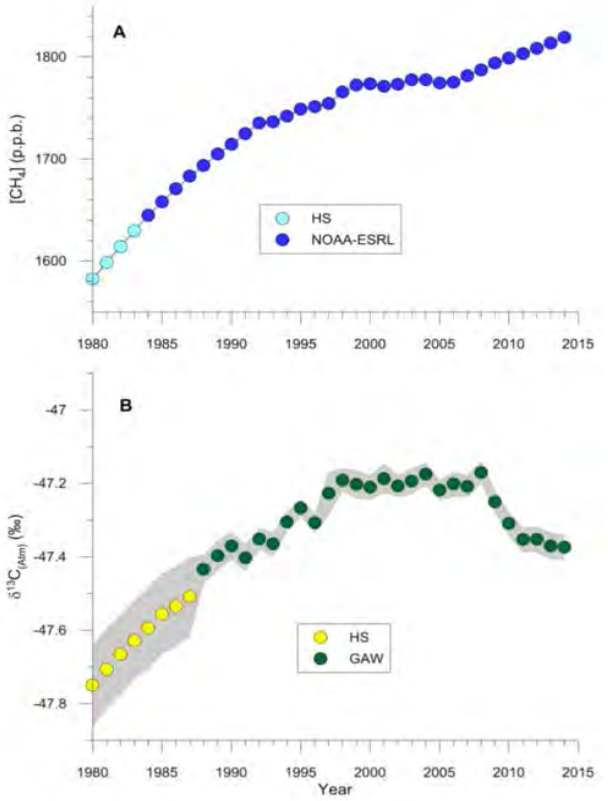
Consider what the stable isotopes tell us:

- Biogenic sources are isotopically depleted
- Pyrogenic sources are isotopically enriched
- Thermogenic sources (like shale gas) are in the middle



Trying to understand the growth rate: leaks from shale gas production?

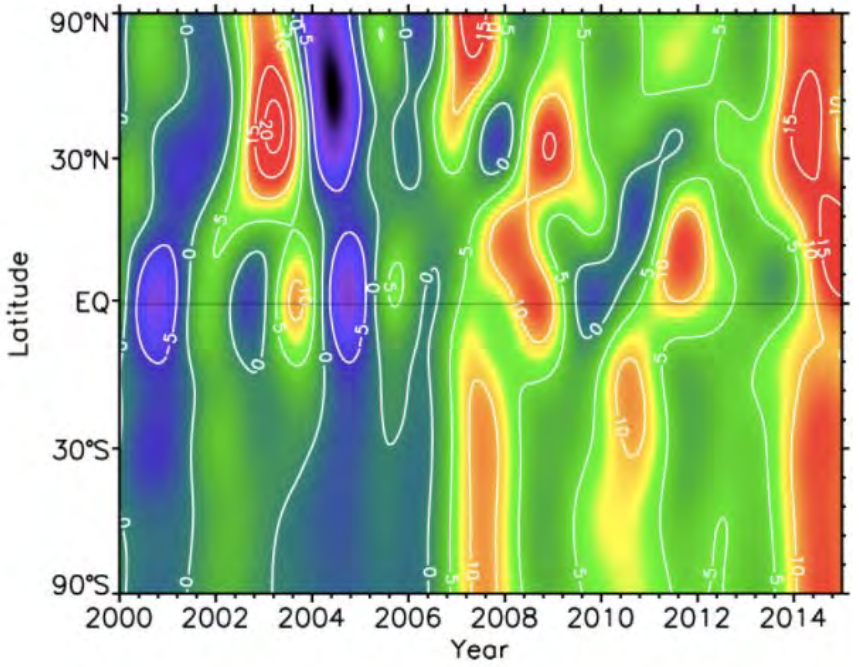
- As methane goes up, the global isotopes went down
- This indicates a larger biogenic source (perhaps combined with a smaller pyrogenic source)
- This was interpreted as an increase in agriculture (ruminants, manure management)



Schaefer et al., Science, 2016

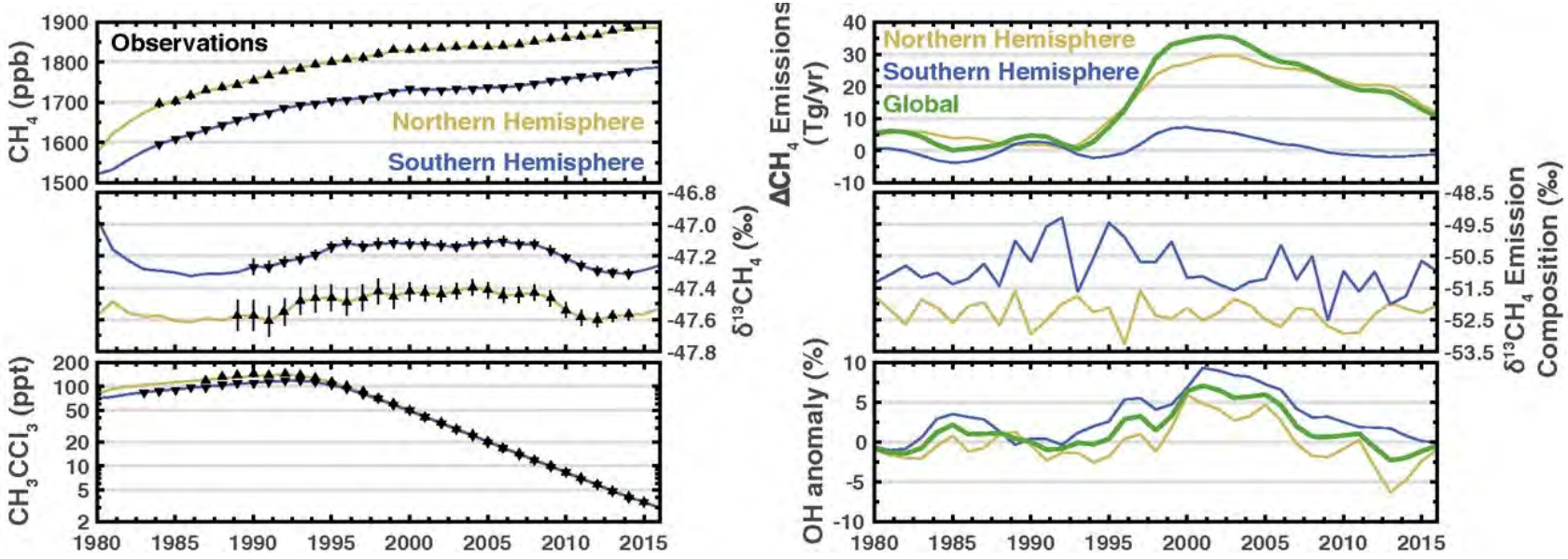
Trying to understand the growth rate: leaks from shale gas production?

- The same data were simultaneously published as being indicative of climate-related increases in tropical wetland emissions
- A cow's stomach is a bit like a wetland, isotopically speaking



Nisbet et al., GBC, 2016

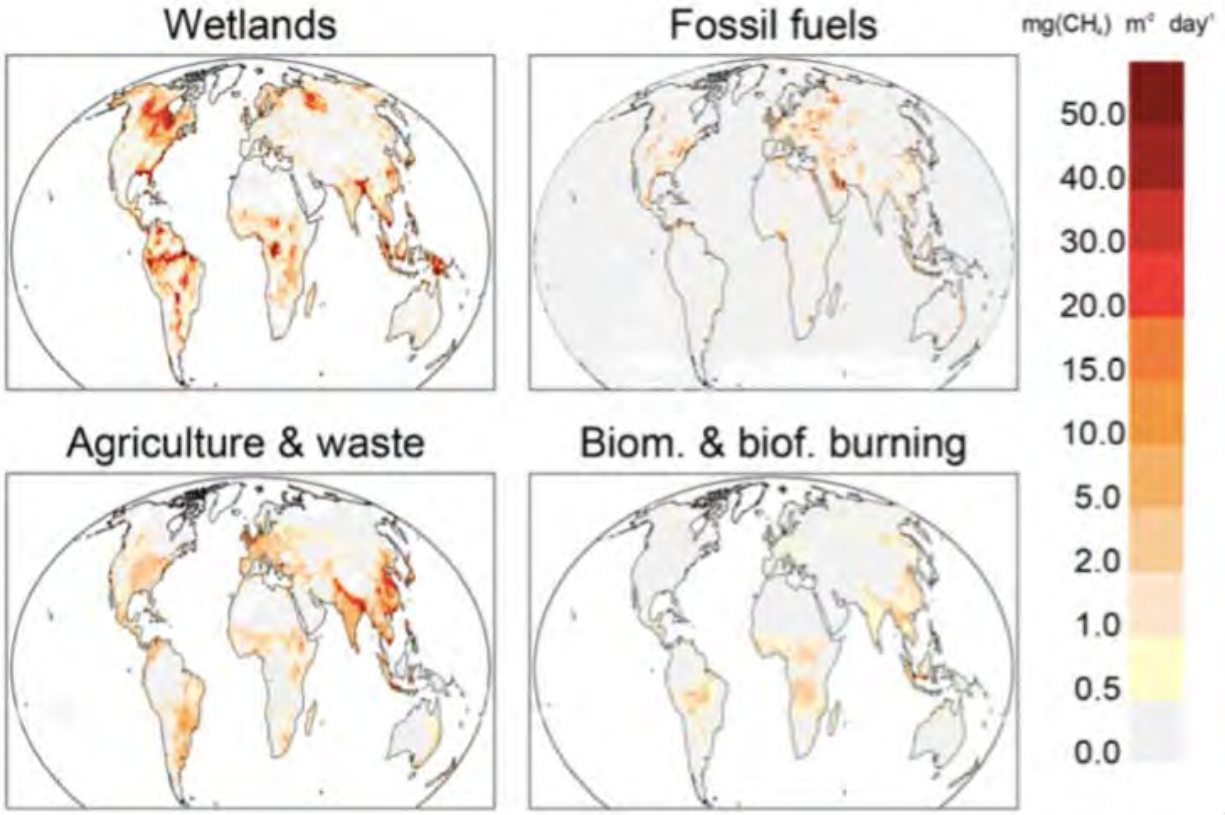
Trying to understand the growth rate: or maybe it's the sink?



Turner et al., 2017

What might help:

Greater spatial resolution better facilitates the separation of distinct source regions:



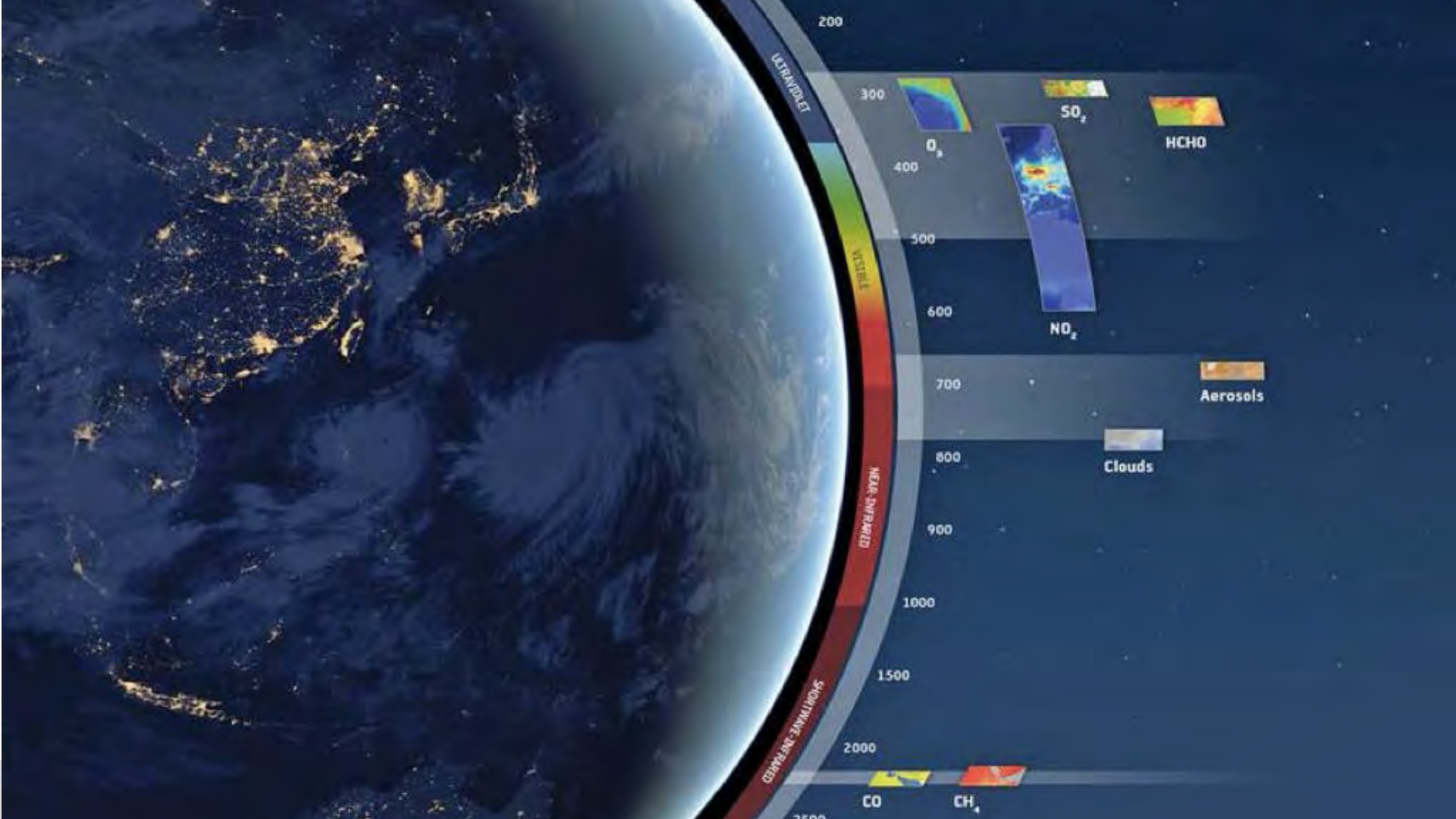
Saunois et al., 2016

Enter TROPOMI on Sentinel-5P

- Launched in October last year
- 7 km x 3.5 km resolution, 2600 km swath
- Similar measurement concept, but uses novel slit homogenizer to deal with stray light issues
- Preliminary data look amazing
- Not yet public for methane, but for other species!

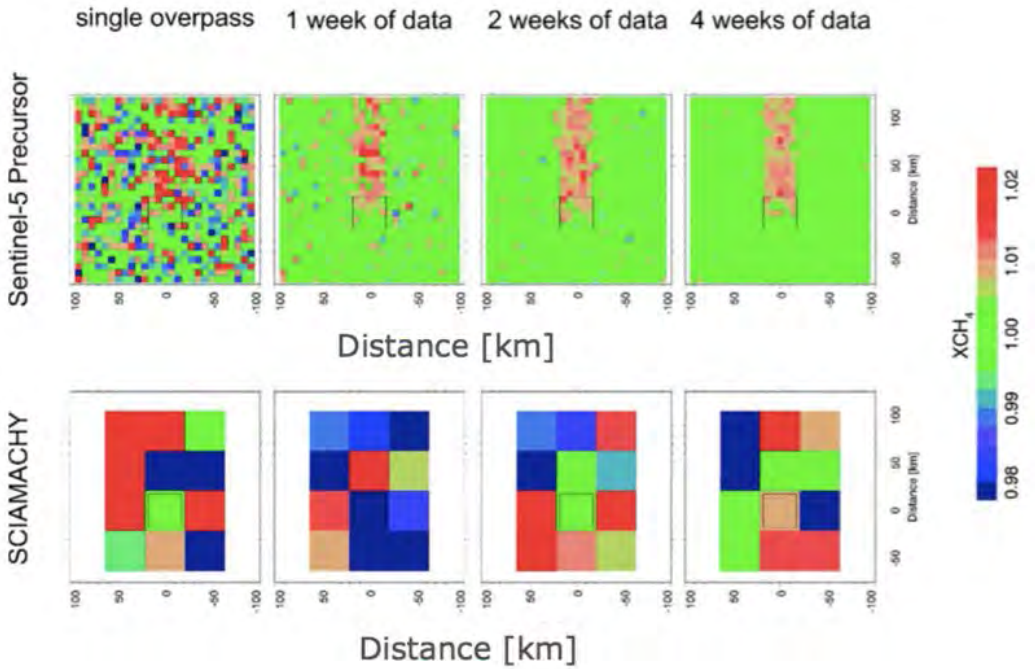
Product	Main Parameter	Staggered Product Releases to the Public
UV Aerosol Index	Aerosol index	
Cloud Properties	Fraction, optical depth, top height	
Nitrogen Dioxide (NO_2)	Total and tropospheric columns	June 2018
Total Ozone (O_3)	NRT total column	
Carbon Monoxide (CO)	NTC total column	
NPP_CLOUD	Cloud mask from VIIRS	
Sulphur Dioxide (SO2)	Total column	
Formaldehyde (HCHO)	Total column	August 2018
Tropospheric Ozone	Tropospheric column	
Methane (CH4)	Total column	
Carbon Monoxide (CO)	NRT total column	October 2018
Total Ozone (O_3)	NTC total column	
Aerosol Layer Height	Mid-level pressure	
Ozone Profiles	Total and tropospheric profiles	December 2018
UV	UV dose	

From Claus Zehner, ESA

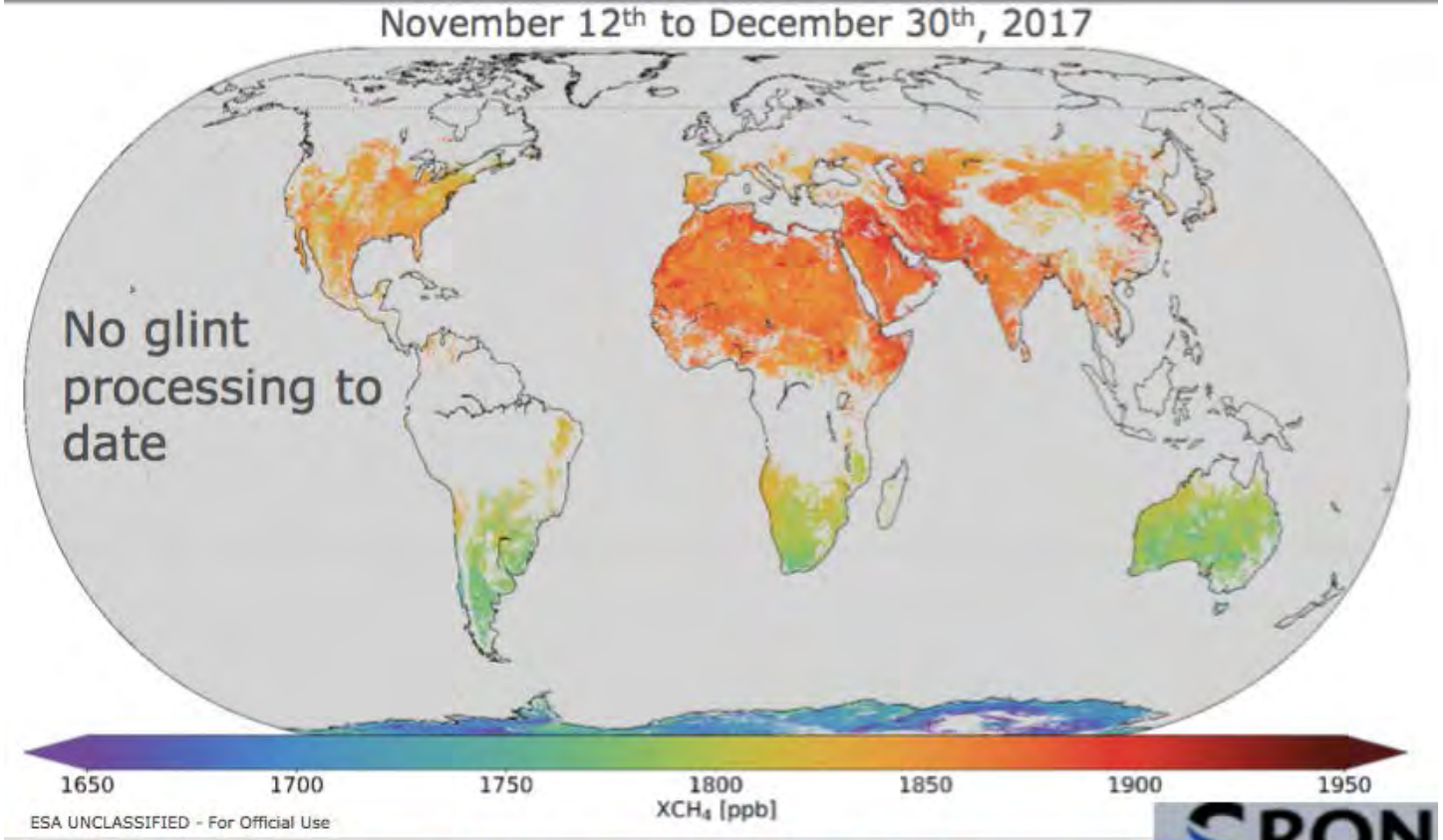

200
300
400
500
600
700
800
900
1000
1500
2000
ULTRAVIOLET
VISIBLE
NEAR INFRARED
SHORTWAVE-INFRARED
O_3
SO_2
HCHO
NO_2
Aerosols
Clouds
CO
CH_4

TROPOMI: the importance of data resolution

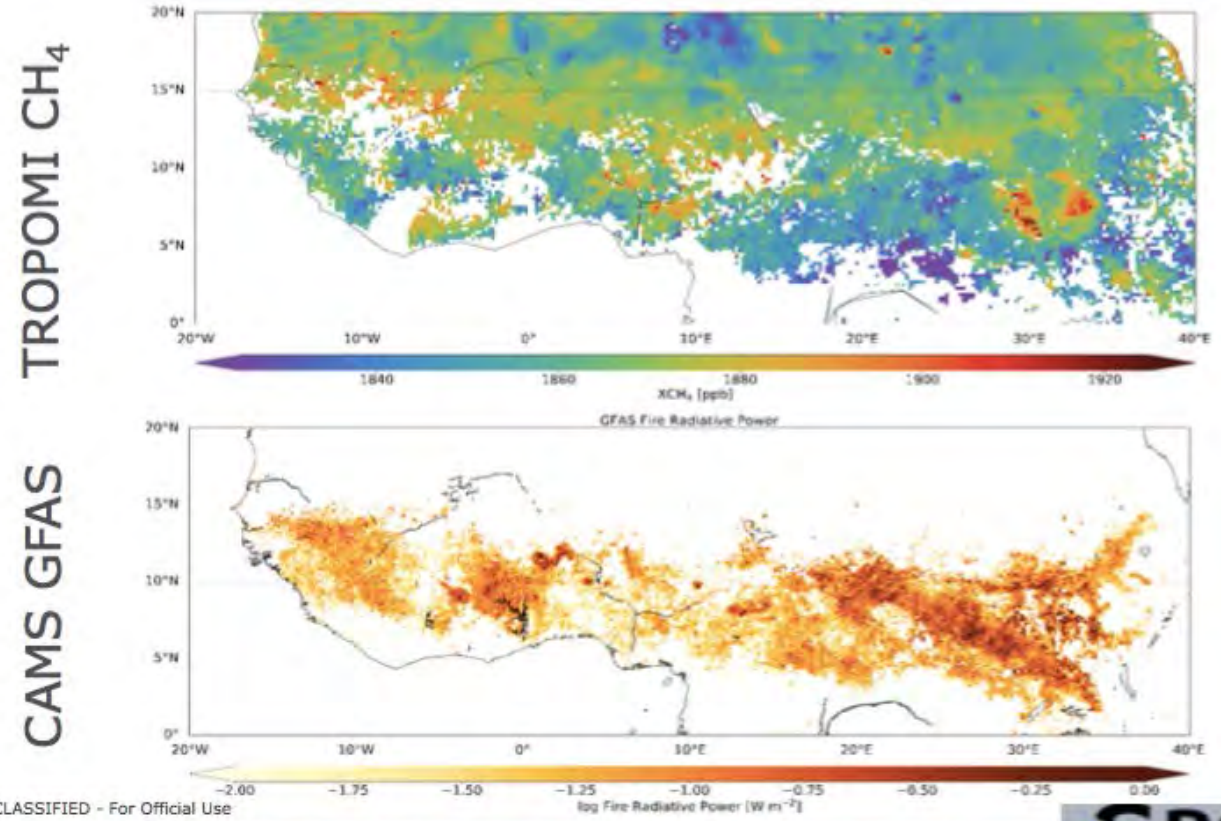
Modelled plume of 500 kt CH_4 point source:



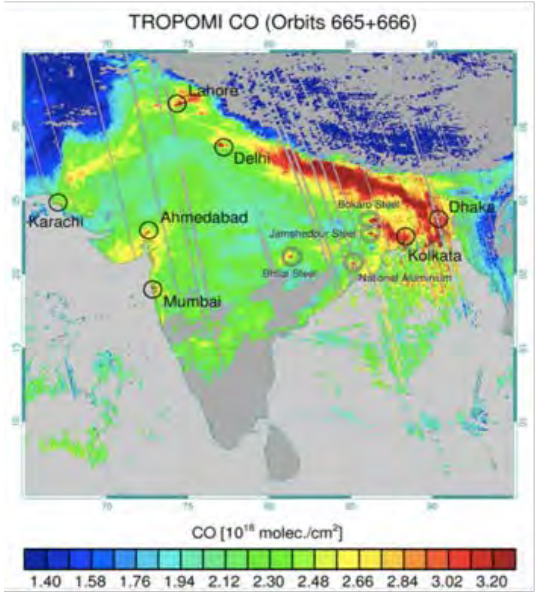
TROPOMI Methane – preliminary results

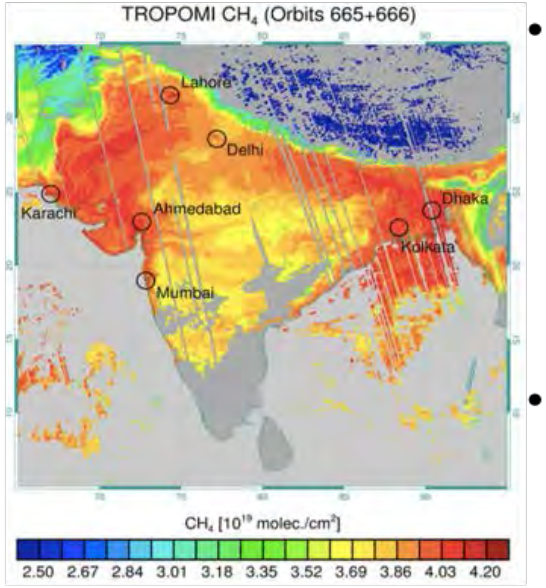


TROPOMI Methane – preliminary results



Very preliminary results





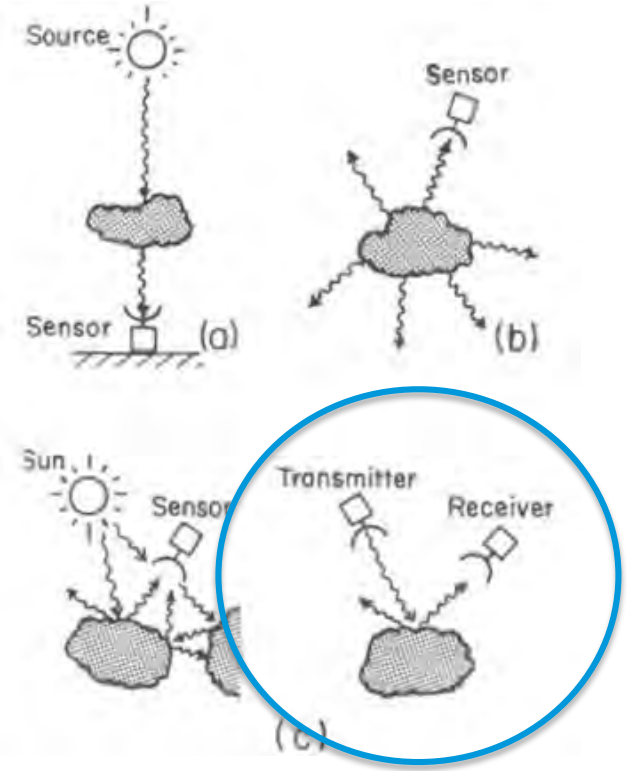
- one day shows as many (or more) features as averaging of multiple years of SCIAMACHY!
- cities "pop out" in CO fields the way they usually/used to do in NO_2

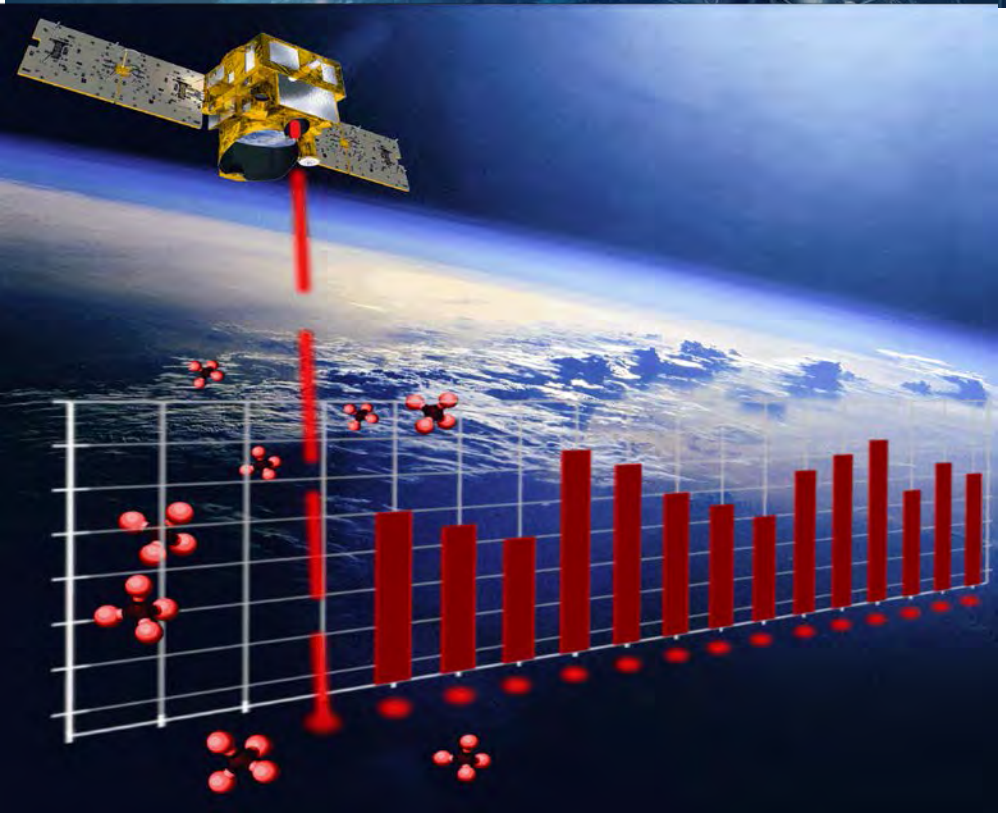
Universität Bremen

Difficulties can still arise when processes are co-located…

A look forward:

Coming back to the active sensor concept…



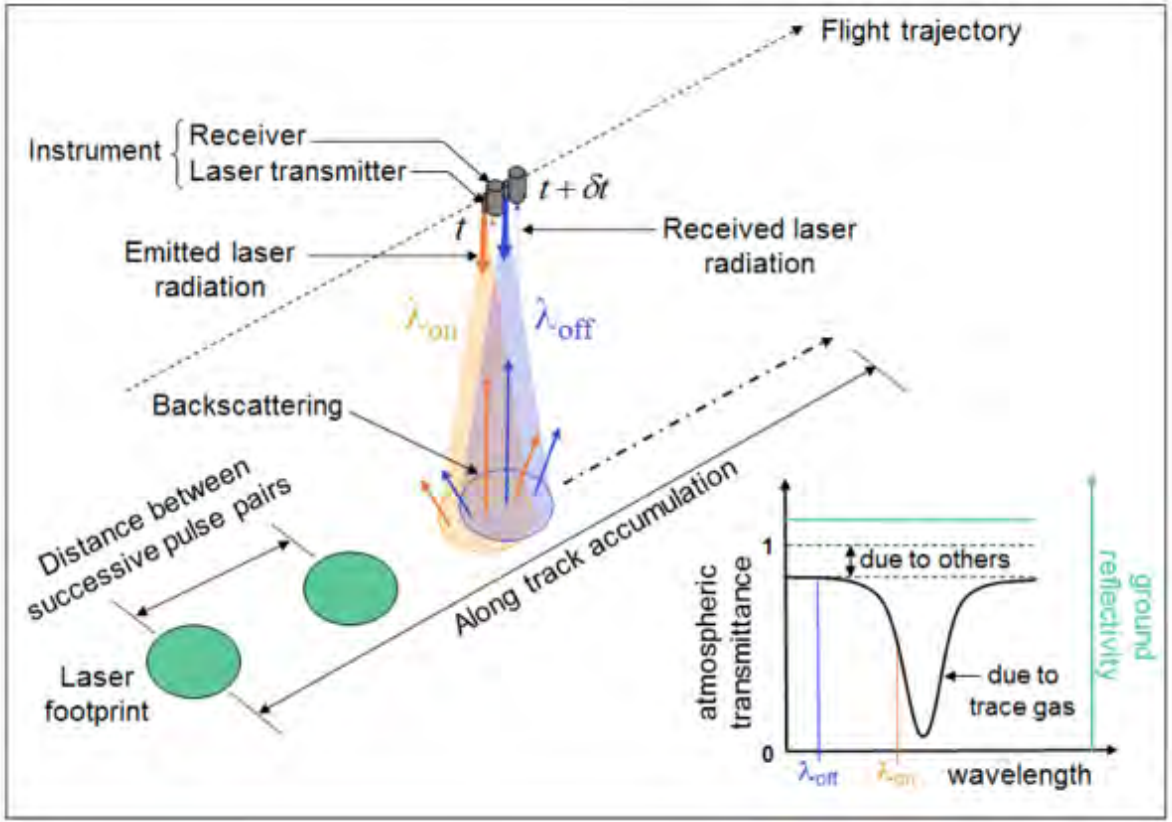


MERLIN
Atmospheric Methane Lidar Mission

- Can measure day and night, winter and summer

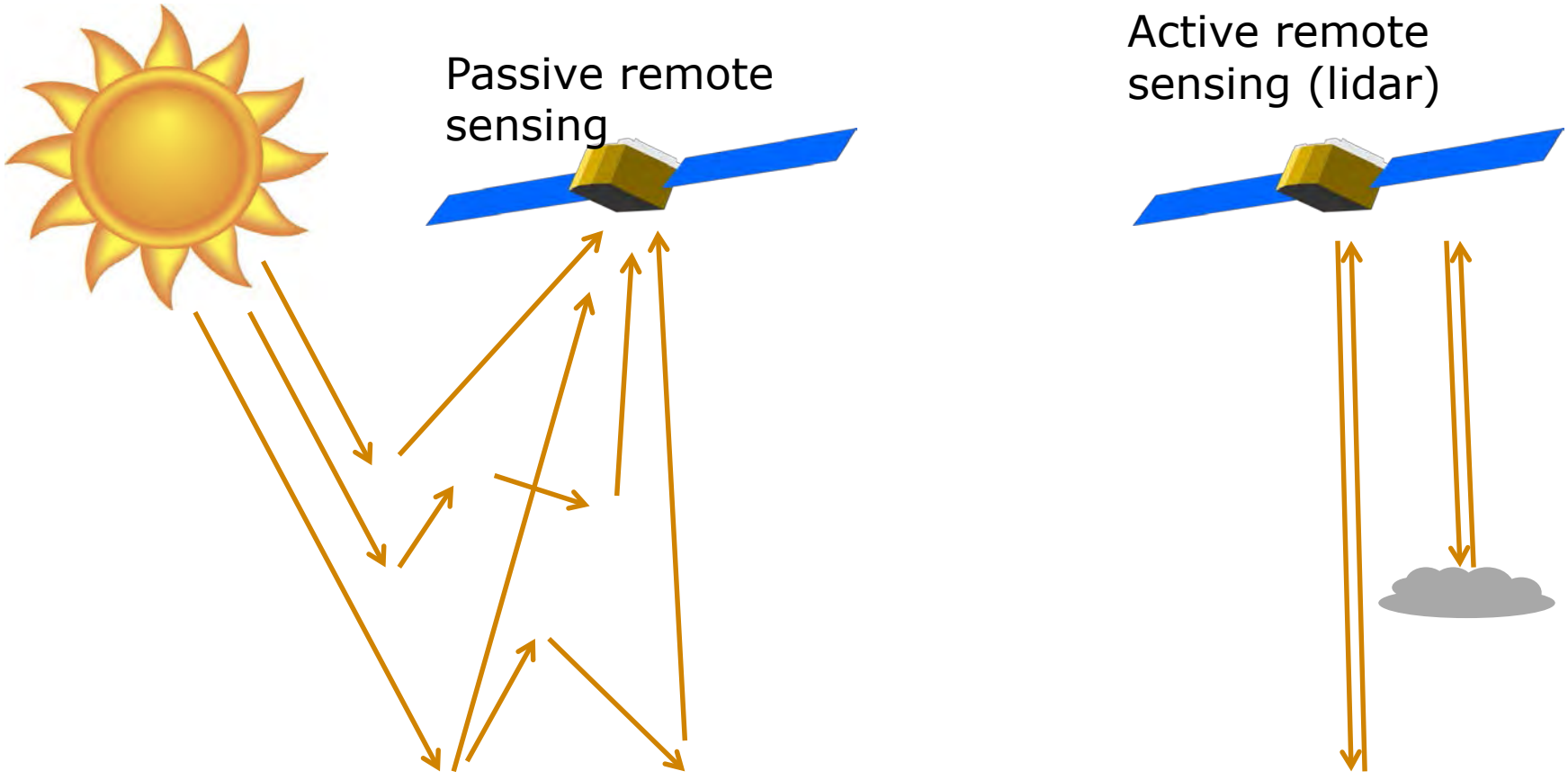
cnes DLR

MERLIN: measurement concept

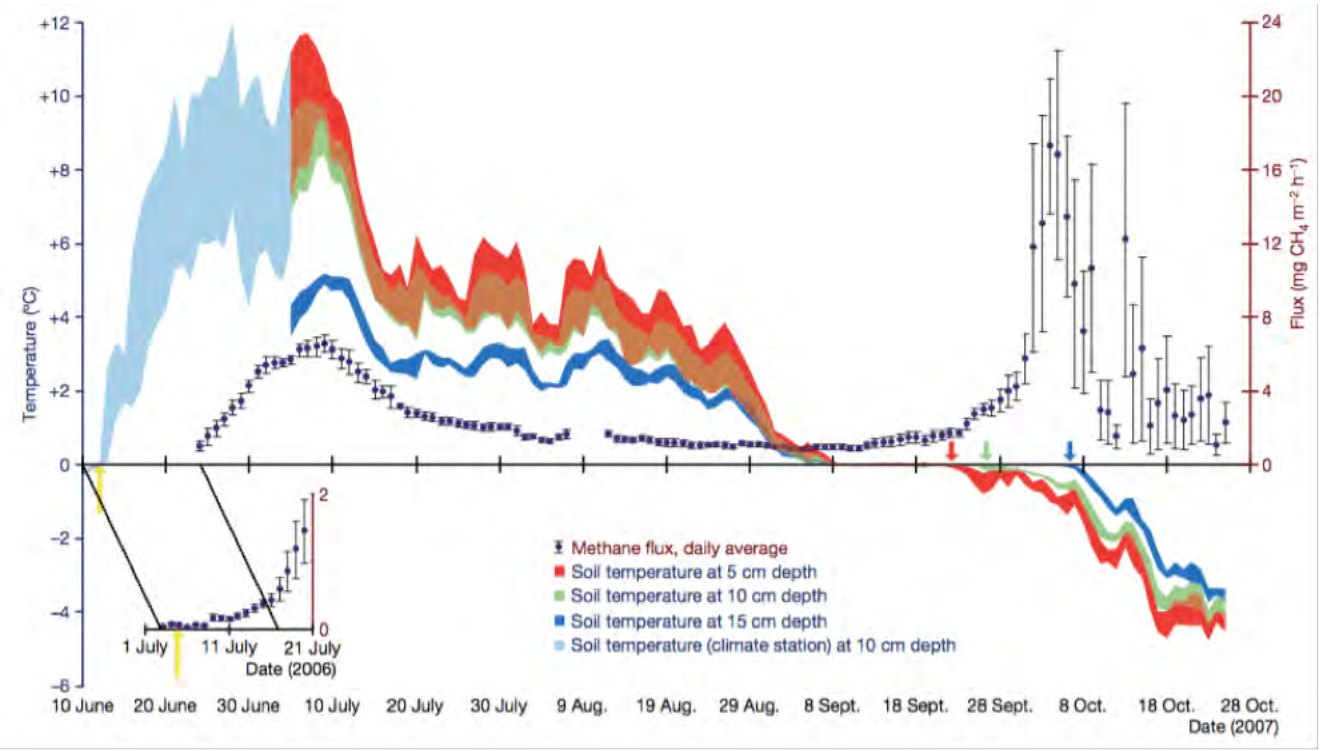


- Differential absorption of laser pulses at two very close wavelengths: one on a methane line, one just off it
- Results in very low bias (good!) but poorer precision (okay)
- Averaging of along-track measurements helps

Ehret et al., 2017


Passive remote sensing
Active remote sensing (lidar)

MERLIN: benefit of high latitude/winter measurements



- Able to measure things like wetland emissions after the zero curtain, potential East Siberian Arctic Shelf methane fluxes

Mastepanov et al., Nature, 2008

Also different from CO_2

- Methane emissions are easier to mitigate: low-hanging fruit
- Reducing CO_2 usually means greatly increasing efficiency, or shifting fuel sources completely
- We don't emit CO_2 by accident!
- Sometimes reducing methane just means finding a leak and fixing it…
- It's a "fat tail" problem
- As such, broader interest exists in finding methane hotspots

Commercial/private satellites focussing on methane: GHG-Sat

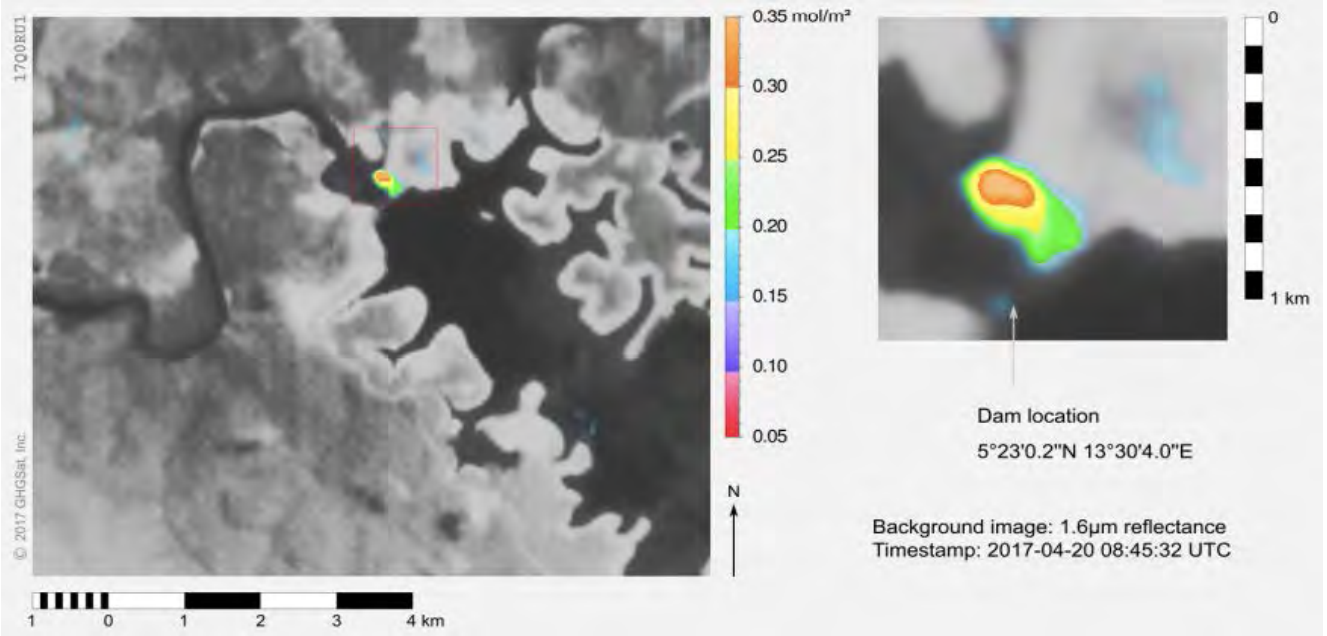
- Canadian company, targeting industrial clients
- Using an imaging Fabry-Perot spectrometer
- 23 m resolution, 12 km x 12 km field of view
- Much higher uncertainty, but solving a different problem…
- One nanosatellite (15 kg) in space since 2016, more on the way

GHGSat
GLOBAL EMISSIONS MONITORING

Application	Spatial	Column	Coverage
CH_4 emissions	$20 - 50$ m	$< 10\%$ bg	Targeted
CO_2 emissions	$20 - 50$ m	$< 20\%$ bg	Targeted
Global models	$1 - 10$ km	0.5% bg	Continuous

Commercial/private satellites focussing on methane: GHG-Sat

Example from the Lom Pangar Dam in Cameroon, April 20th, 2017



Commercial/private satellites focussing on methane: Bluefield

- Using Gas Filter Correlation Radiometry (GFCR)
- Differences images measured in a continuous push-frame configuration through a methane spectral filtering gas cell
- Claim a sensitivity of less than 1% natural abundance
- Not launched yet!

Commercial/private satellites focussing on methane: MethaneSat

- With support of EDF and several private donors
- Aims for 1-km resolution and global weekly coverage
- Plans a launch in 2020-2021…
- Very ambitious!

www.edf.org

Conclusions

- The methane budget is a badly underconstrained problem
- Anthropogenic and natural sources and the sink are uncertain
- S5P will change our knowledge substantially
- Innovative types of remote sensing measurements are on the horizon