# Satellite remote sensing of methane
## from GOSAT to TROPOMI measurements

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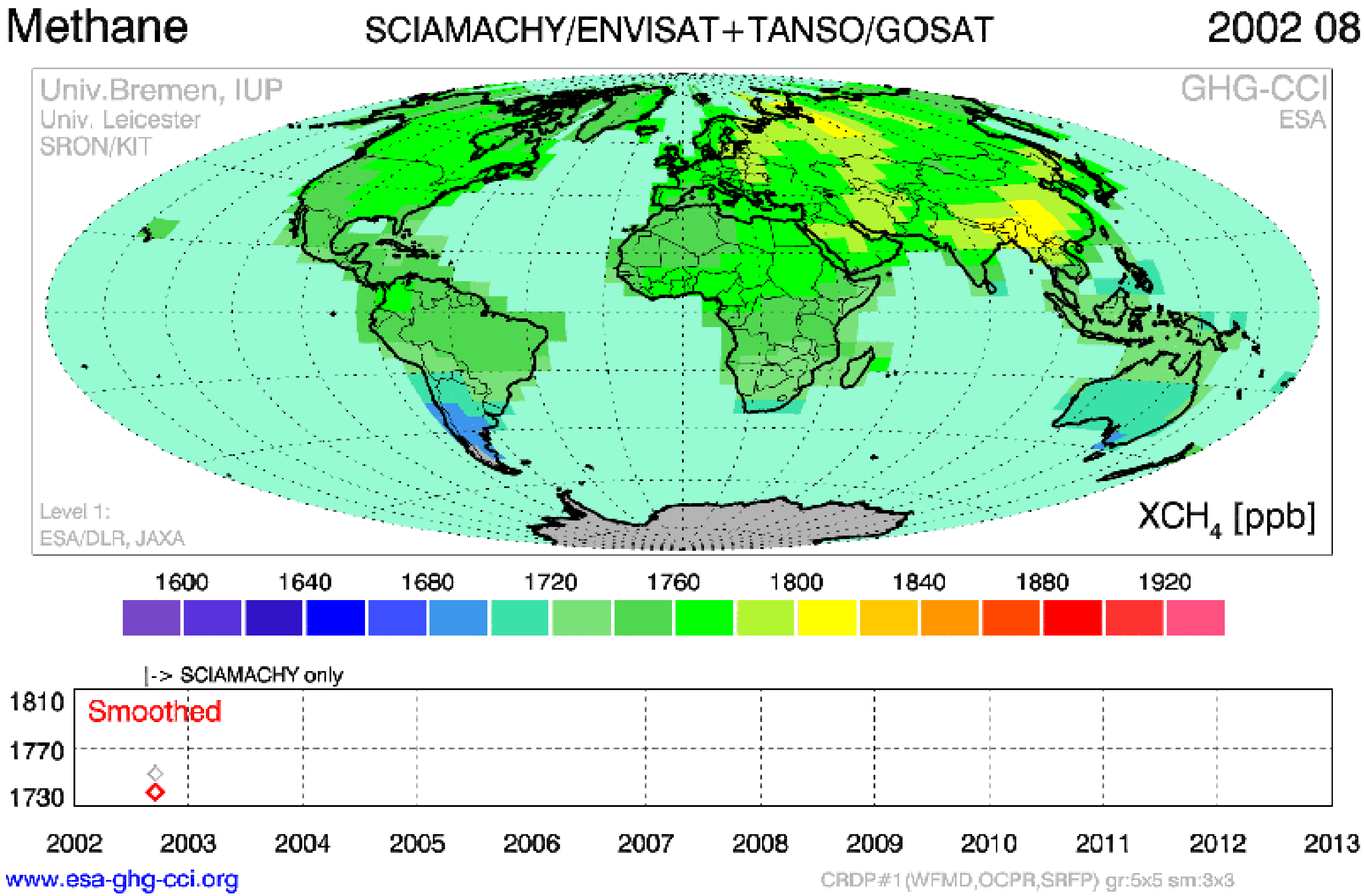
Netherlands Institute for Space Research

Netherlands Organisation for Scientific Research

# CH4 measurements from space




# CH4 measurements from space




Sentinel-5 Precursor
2016 – (2023)

2020 - …

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# Spatial sampling –TROPOMI versus SCIAMACHY

MODIS resolution
500x500 m

SCIAMACHY resolution
120x30 km (channel 8)
60x30 km (channel 6)

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# Spatial sampling –TROPOMI versus SCIAMACHY

MODIS resolution
500x500 m

TROPOMI resolution
7x7km (SWIR)

TROPOMI will observe as many cloud-free pixels in one day as SCIAMACHY in one year.

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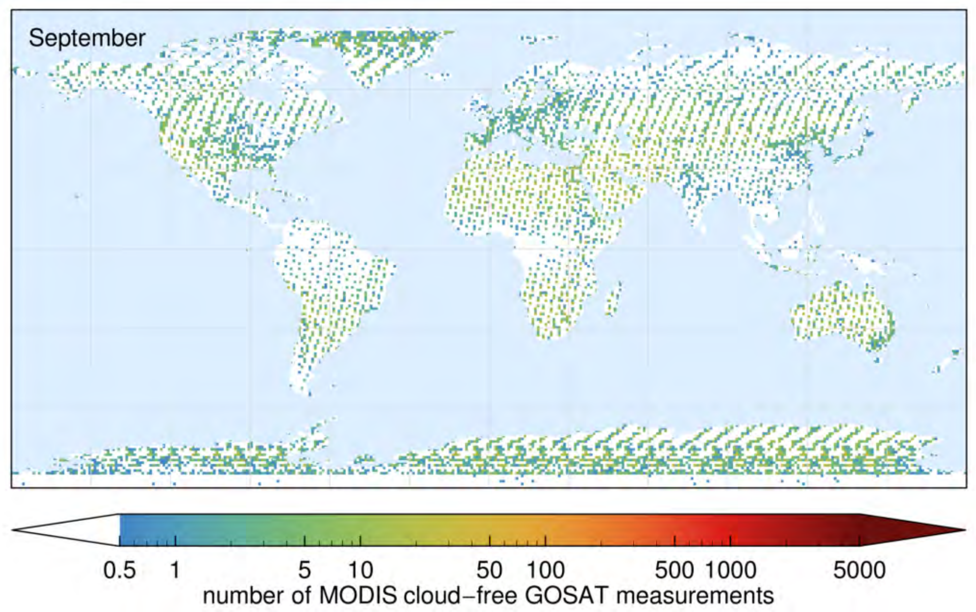
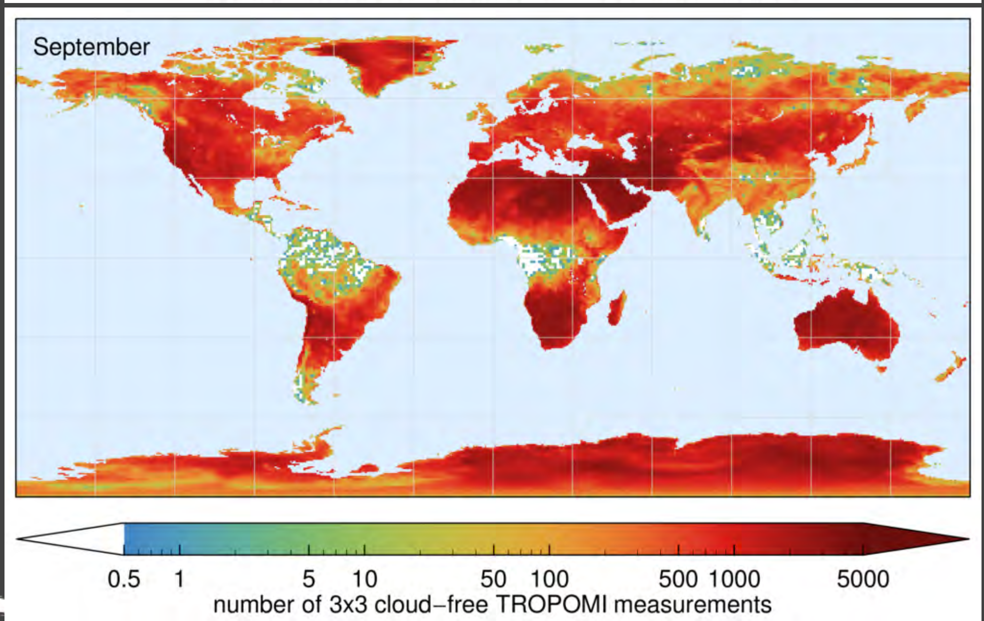
# Spatial sampling –TROPOMI versus GOSAT

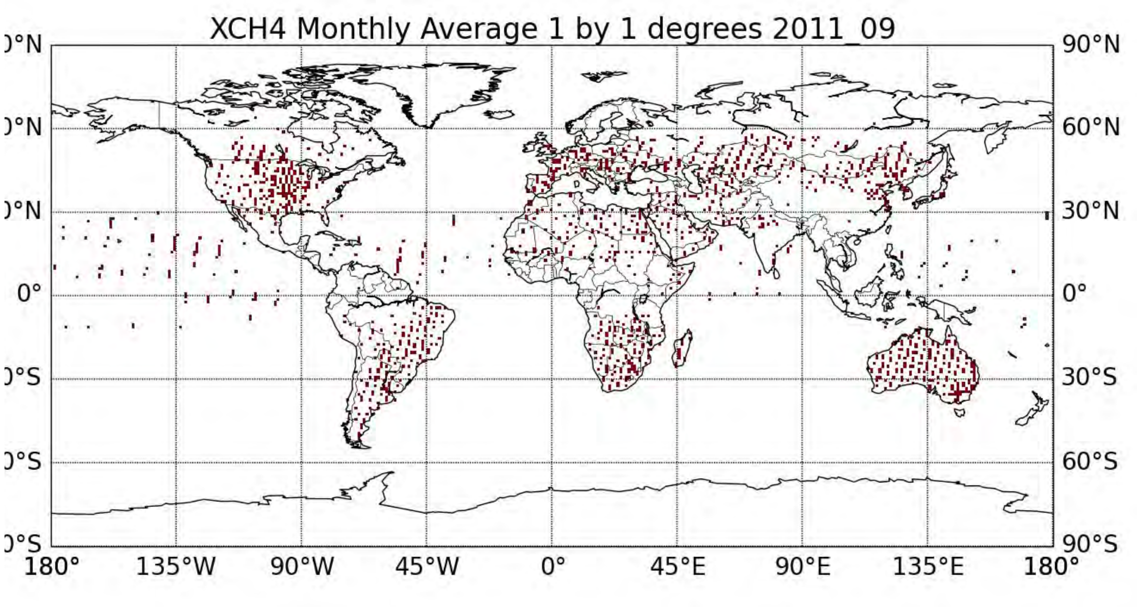



GOSAT (0.22 meas/sec)

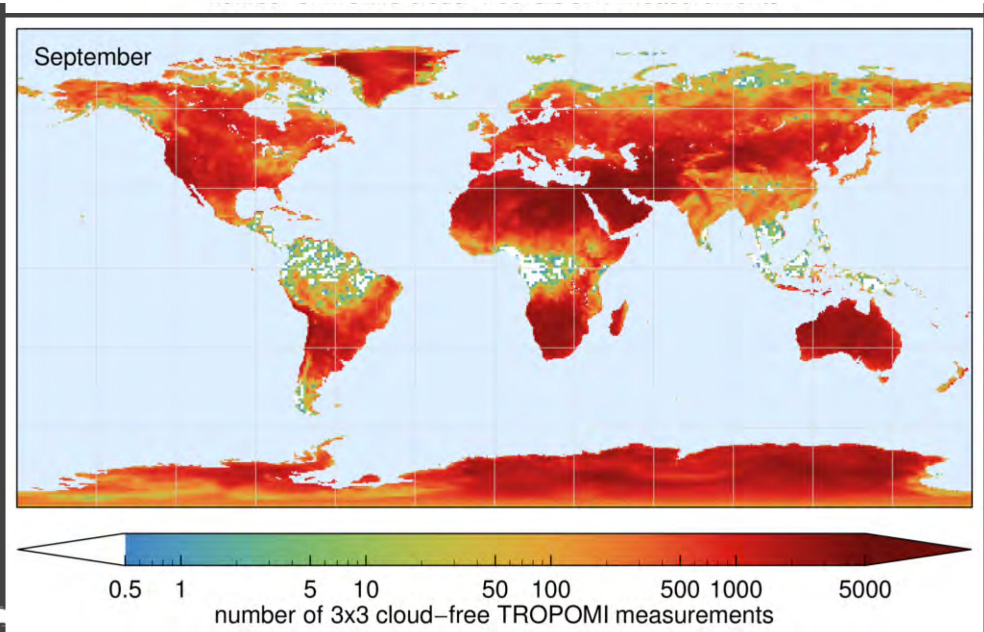



TROPOMI (216 meas/sec)
1000x more measurements

# Spatial sampling –TROPOMI versus GOSAT




GOSAT (0.22 meas/sec)
CH4 product for only
1/3 of cloud-free data,
due to retrieval filtering




TROPOMI (216 meas/sec)
1000x more measurements

# Comparing different satellites

| Satellite/instrument | Satellite type | Instrument type | Footprint size | # meas. per second | Sensitivity per meas. (XCH4 %) |
|---|---|---|---|---|---|
| SCIAMACHY | scanning (960 km swath) | grating spectrometer | ~60x30 km (1800 $km^2$) | 1.35 | 1.5–4.5% |
| GOSAT | pointing | Fourier transform spectrometer | ~10 km diameter (80 $km^2$) | 0.22 | 0.25-0.5% |
| TROPOMI | pushbroom (2600 km swath) | (immersed)grating spectrometer | ~7x7 km (50 $km^2$) | 216 | <0.1-0.3% |

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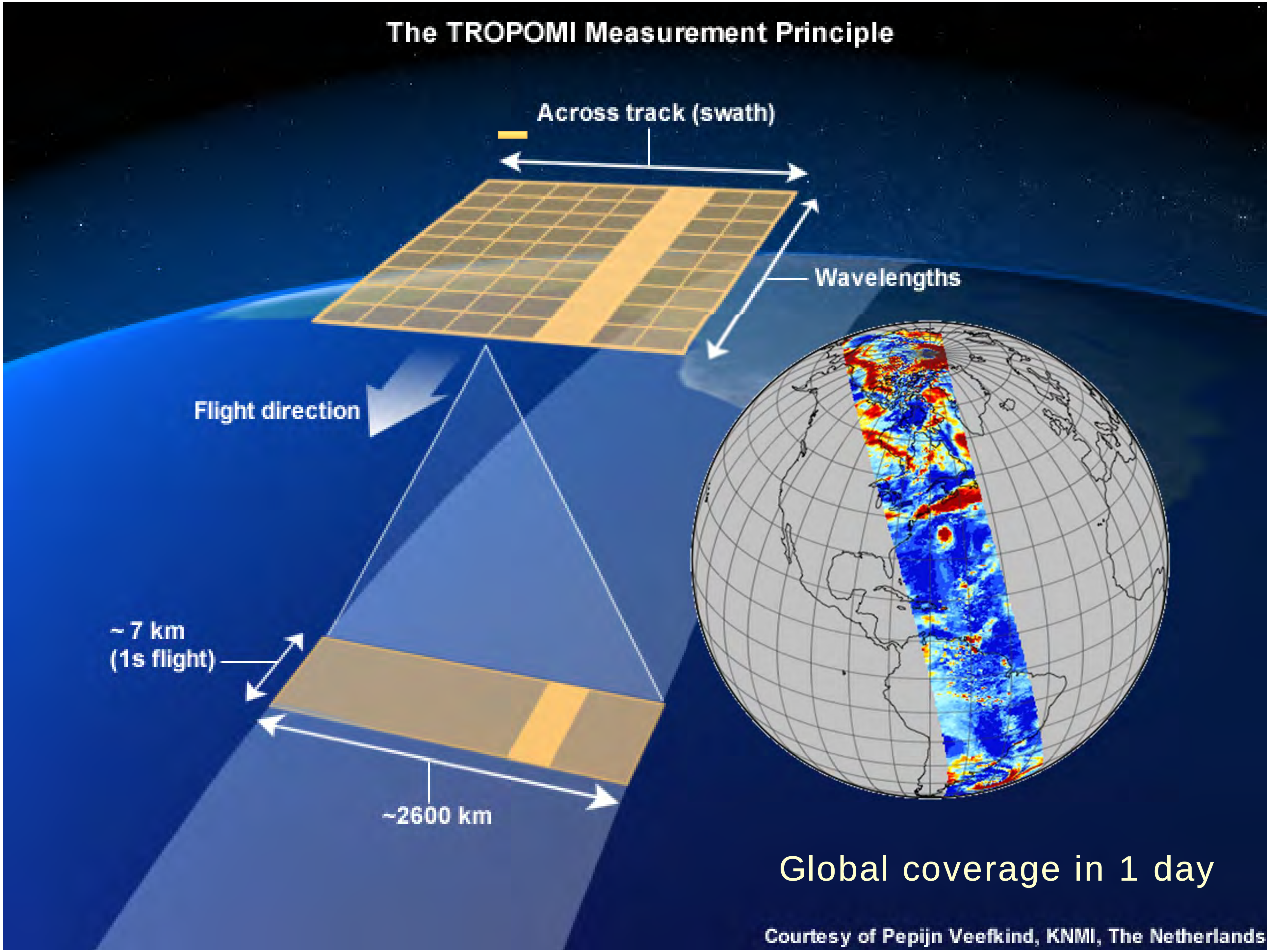
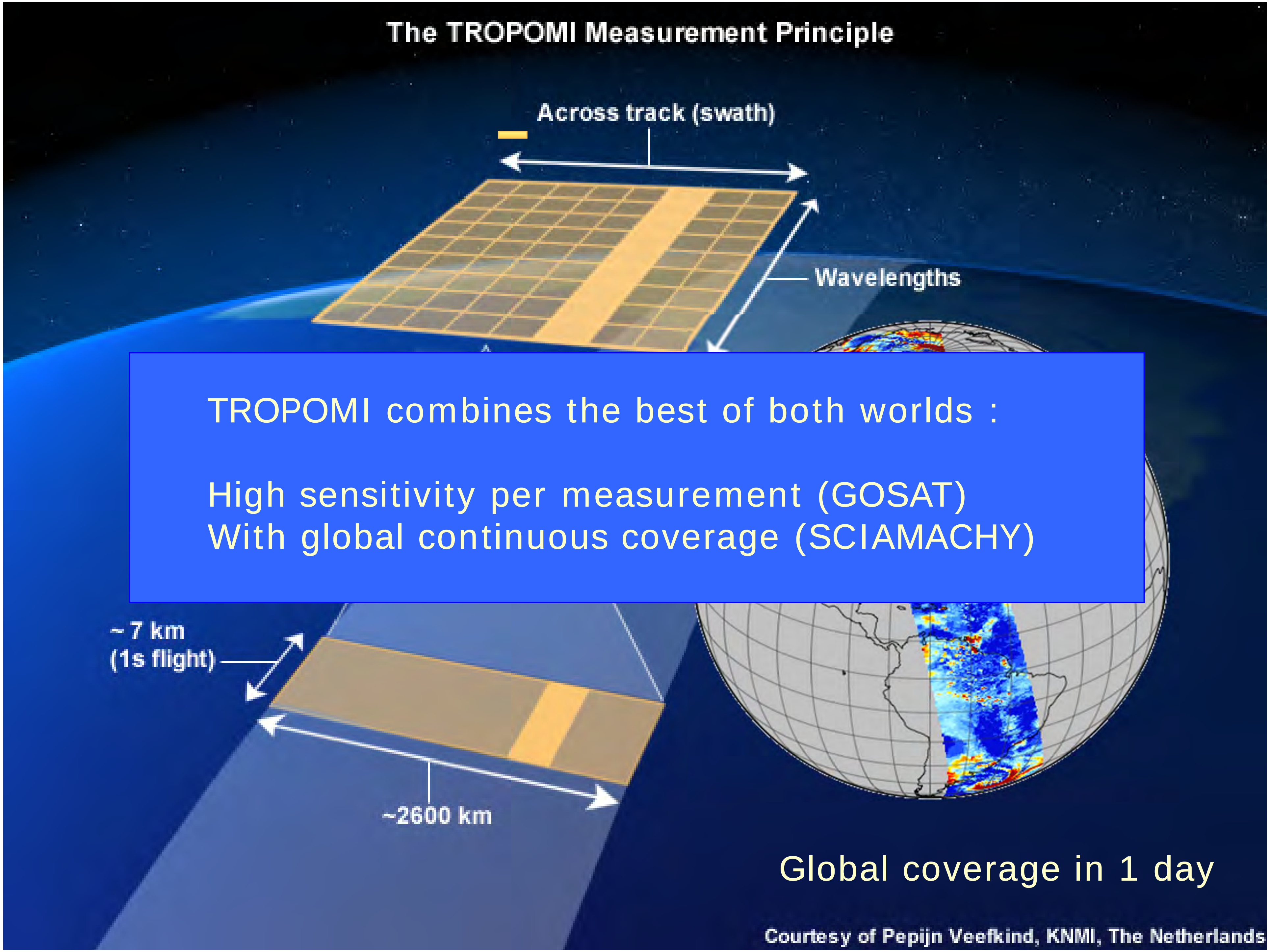

The TROPOMI Measurement Principle
Across track (swath)
Wavelengths
Flight direction
~ 7 km
(1s flight)
~2600 km
Global coverage in 1 day
Courtesy of Pepijn Veefkind, KNMI, The Netherlands


The TROPOMI Measurement Principle
Across track (swath)
Wavelengths
TROPOMI combines the best of both worlds :
High sensitivity per measurement (GOSAT)
With global continuous coverage (SCIAMACHY)
~ 7 km
(1s flight)
~2600 km
Global coverage in 1 day
Courtesy of Pepijn Veefkind, KNMI, The Netherlands

# Sentinel 5 precursor

COPERNICUS ATMOSPHERE MISSION IN POLAR ORBIT

TROPOMI

- The ESA Sentinel-5 Precursor (S-5P) is a pre-operational mission focussing on global observations of the atmospheric composition for air quality and climate.
- The TROPOspheric Monitoring Instrument (**TROPOMI**) is the payload of the S-5P mission and is jointly developed by The Netherlands and ESA.
- The planned launch date for S-5P is 2016 with a 7 year design lifetime.

Copernicus
The European Earth Observation Programme

esa

Netherlands Space Office

**TROPOMI**

- UV-VIS-NIR-SWIR nadir view grating spectrometer.
- Spectral range: 270-500, 675-775, 2305-2385 nm
- Spectral Resolution: 0.25-1.1 nm
- Spatial Resolution: 7x7km2
- Global daily coverage at 13:30 local solar time.

**Contribution to Copernicus**

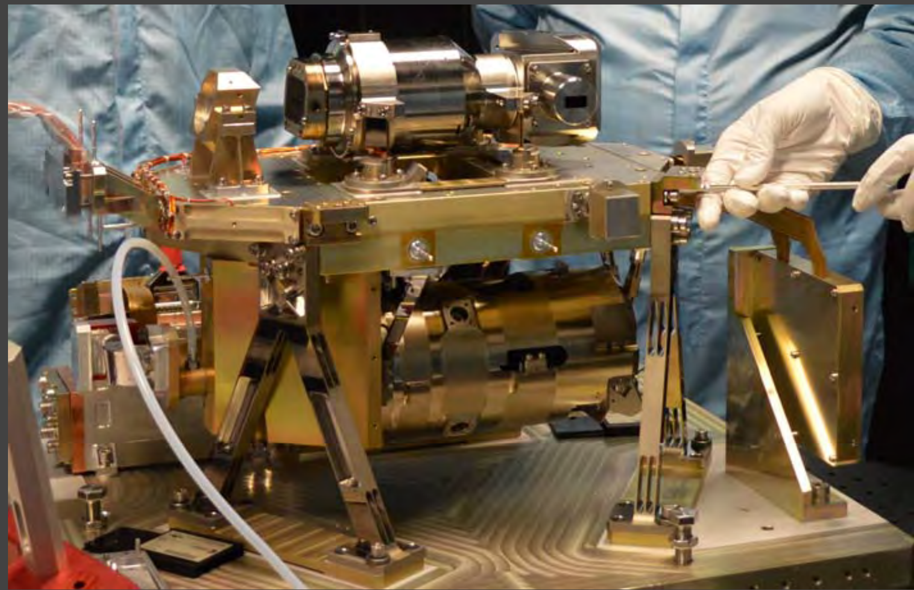
- Total column $O_3$, $NO_2$,$SO_2$, CO, $CH_4$, $CH_2O$,$H_2O$,BrO
- Tropospheric column $O_3$, $NO_2$
- $O_3$ profile
- Aerosol absorbing index & layer height

Loose formation flying with Suomi-NPP

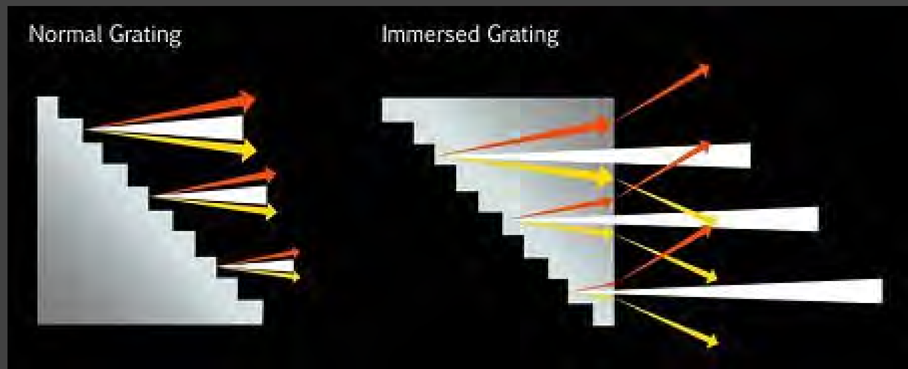
# The TROPOMI instrument

## Assembled TROPOMI instrument

## The SWIR module



Reduced size thanks to new immersed grating technology. This technology will also be used for Sentinel-5.

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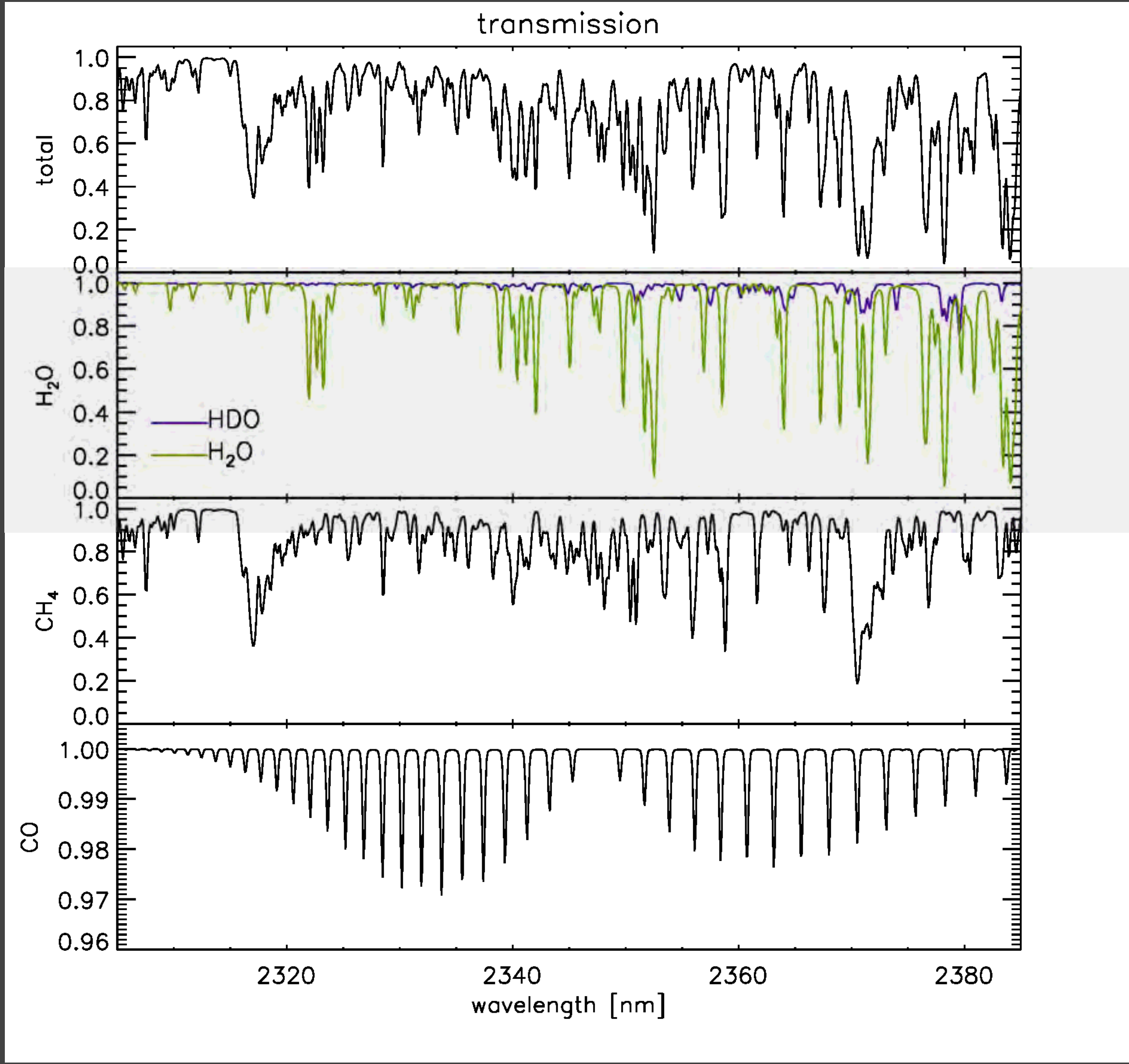
# The 2.3 µm spectral range (SWIR)

Spectral range contains information on:
- •Methane
- •Carbon monoxide
- •(HDO/$H_2O$)

Quality requirement for operational data product:

CO: 10 % precision /
15 % bias

$CH_4$: 1 % precision /
1 % bias

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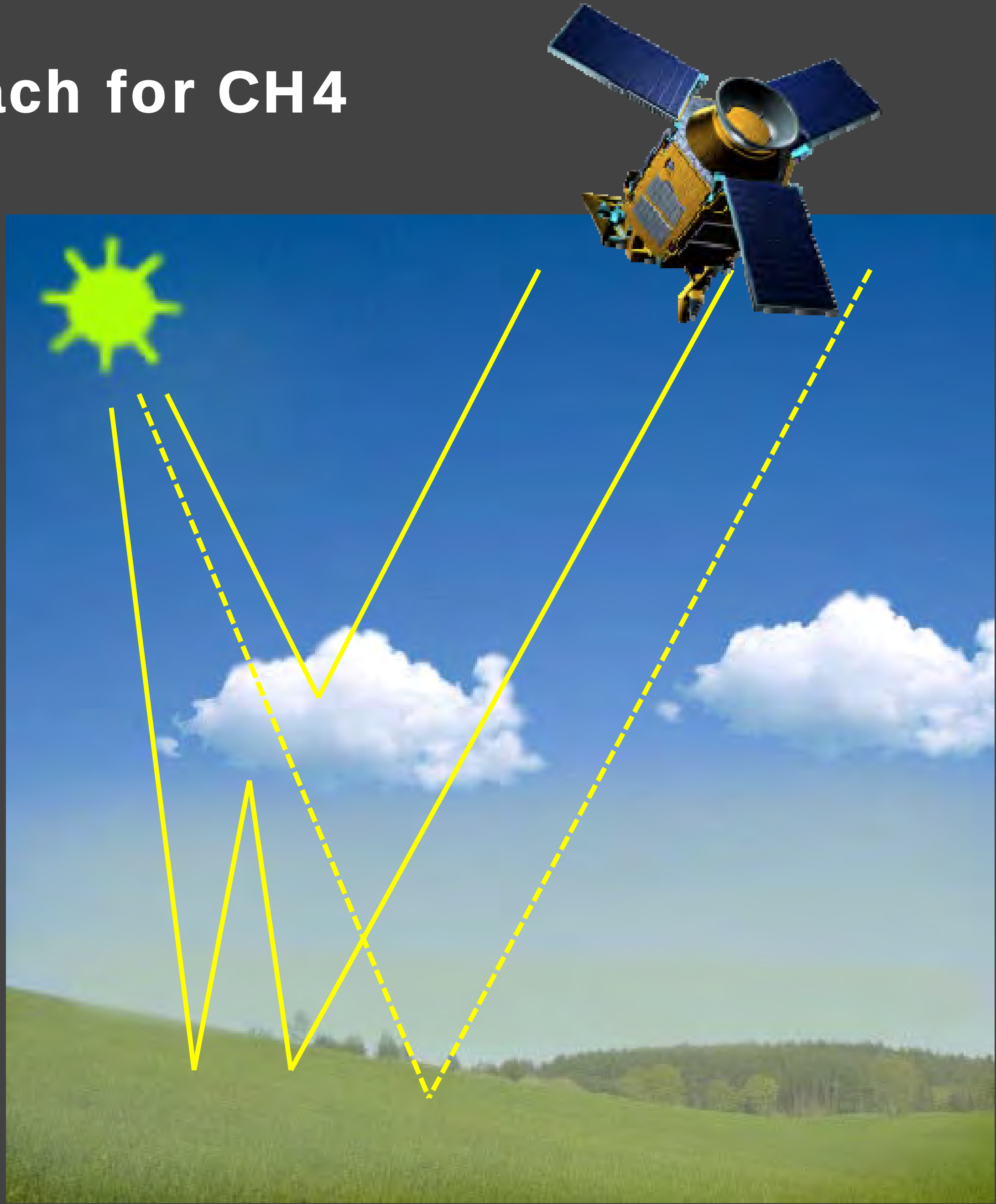
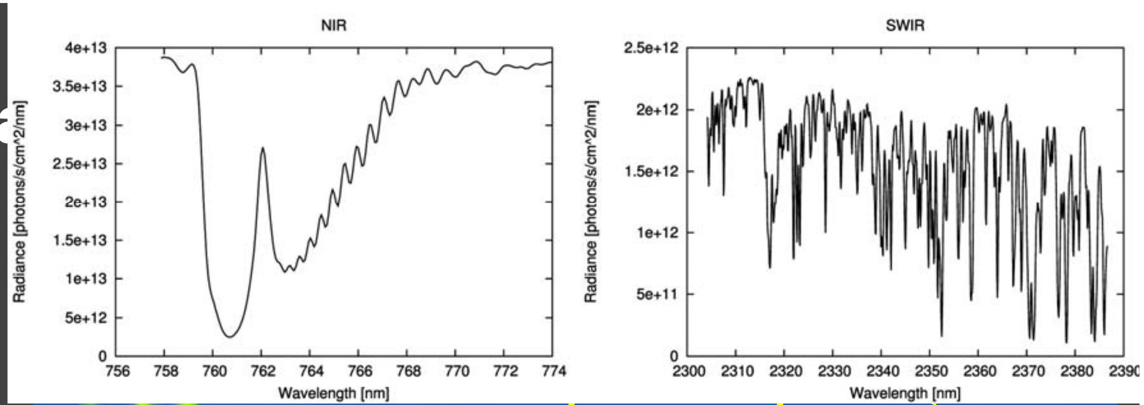
# Retrieval approach for CH4

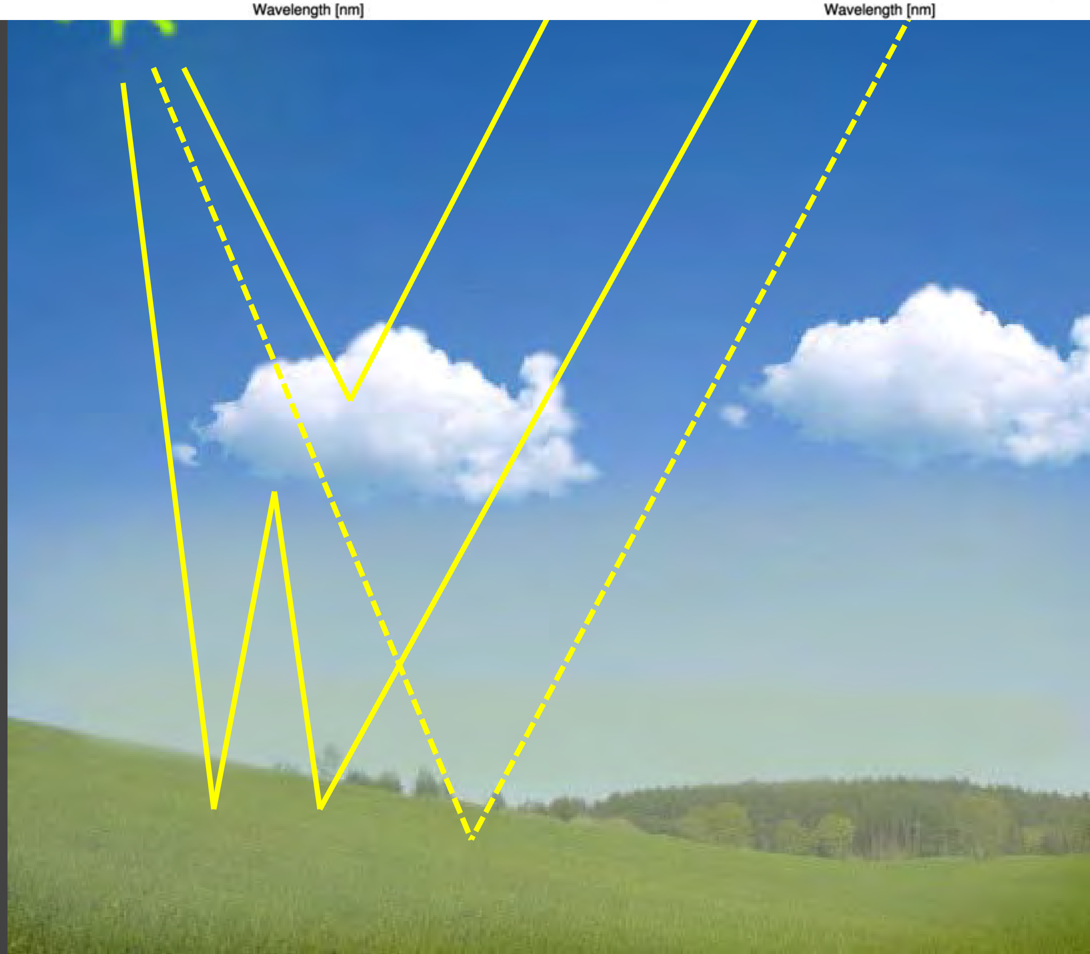
Light path can be shortened or enhanced due to atmospheric scattering.

Our retrieval algorithm (RemoTeC) infers information an trace gases and atmospheric scattering simultaneously from the measurement
-> full physics method



# Retrieval approa



Light path can be shortened or enhanced due to atmospheric scattering.

Our retrieval algorithm (RemoTeC) infers information an trace gases and atmospheric scattering simultaneously from the measurement
-> full physics method

Solve non-linear ill-posed inverse problem using iterative regularized Gauss-Newton method

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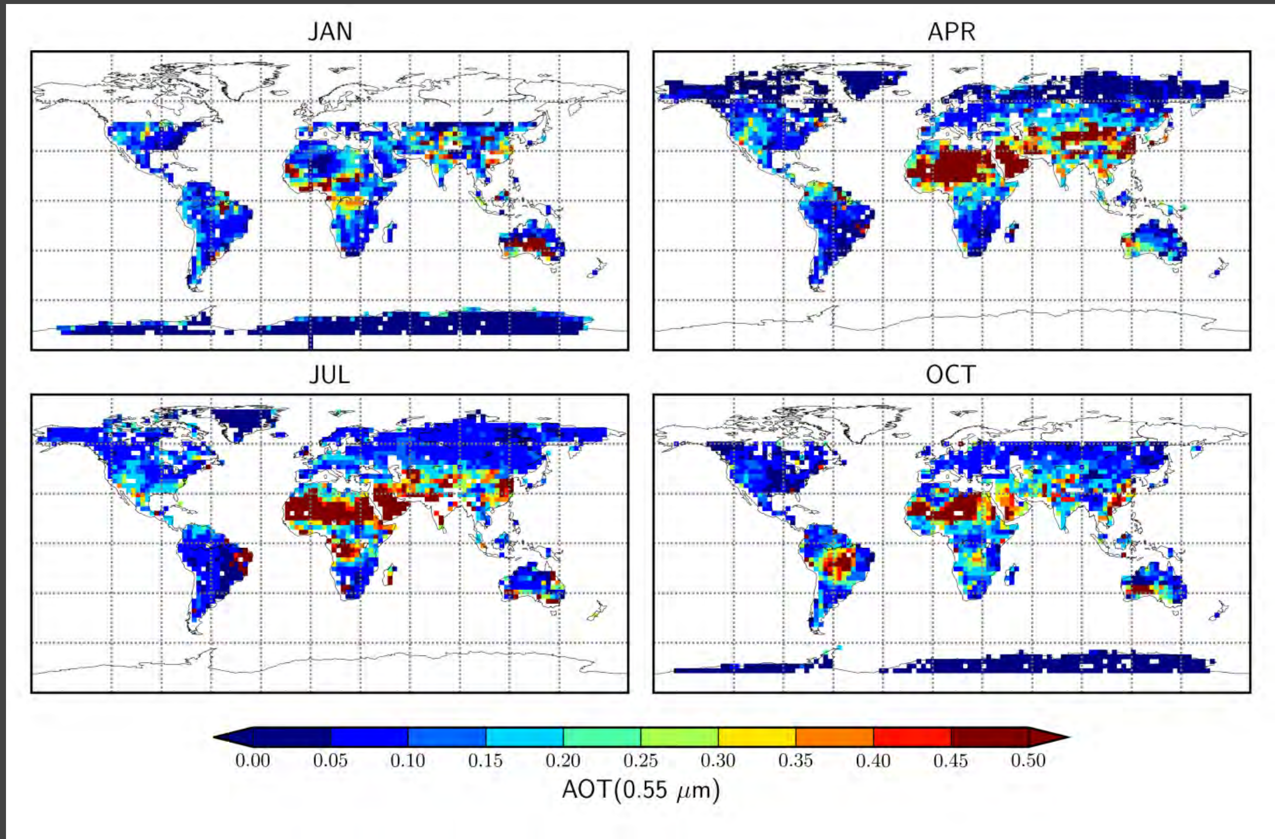
# Performance evaluation on synthetic global ensemble of TROPOMI measurements

Input simulations:

- AOT from MODIS
- Realistic aerosol type, size, height from ECHAM5-HAM
- Cirrus optical thickness, height from CALIPSO
- Surface albedo from SCIAMACHY
- $CH_4$ and CO profiles from TM5




Ensemble of 9030 simulations (cloud-free, land only)

*Butz et al., JGR, 2010*

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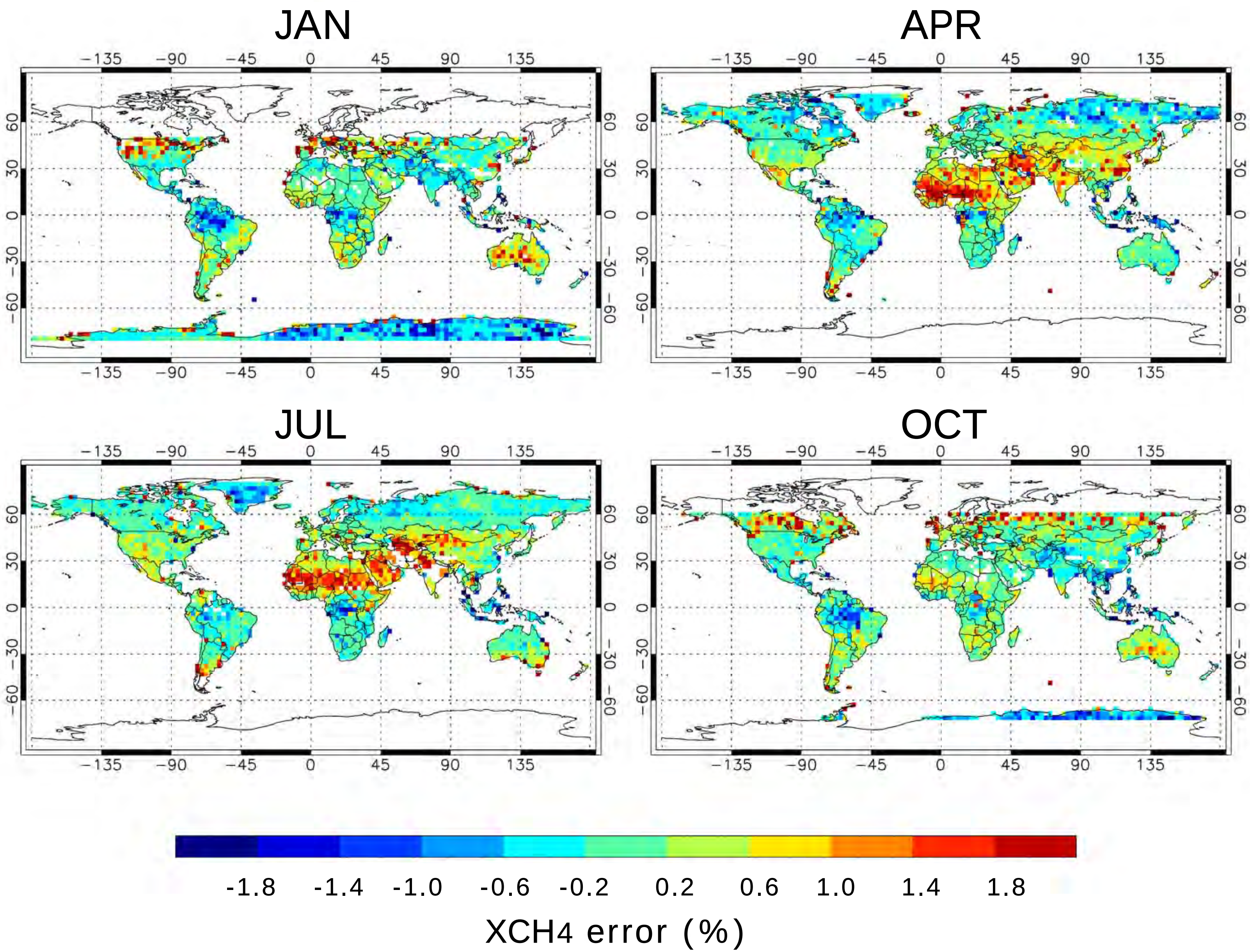
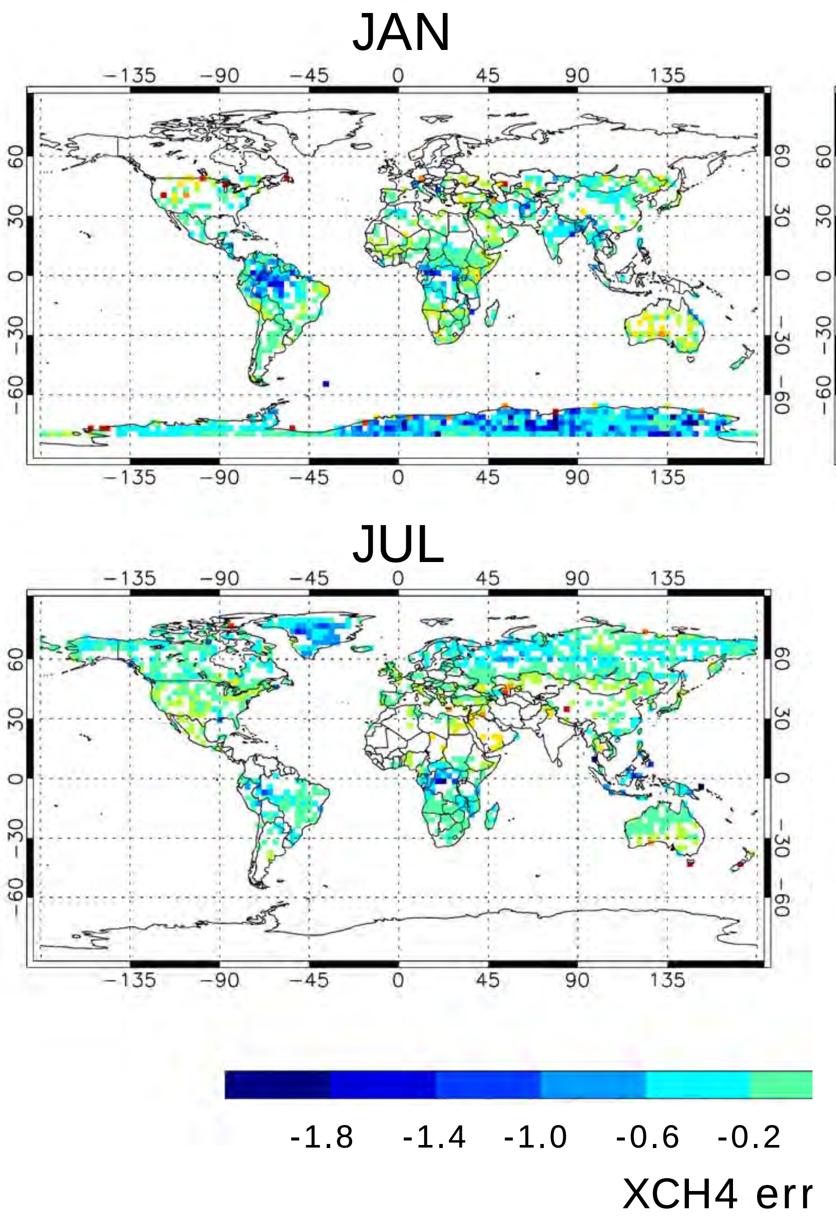
# TROPOMI ensemble

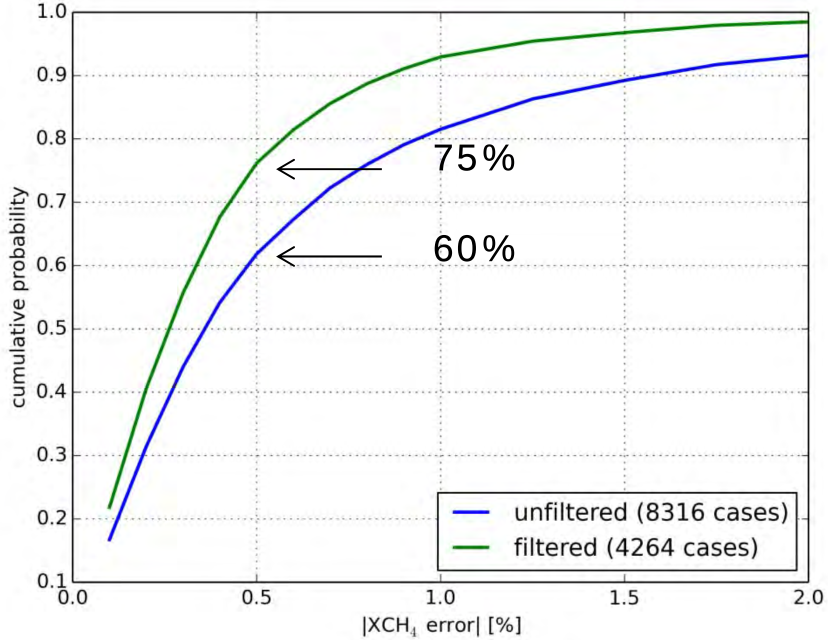



due to scattering by aerosols and cirrus

8316 cases

# TROPOMI ensemble after aerosol filtering

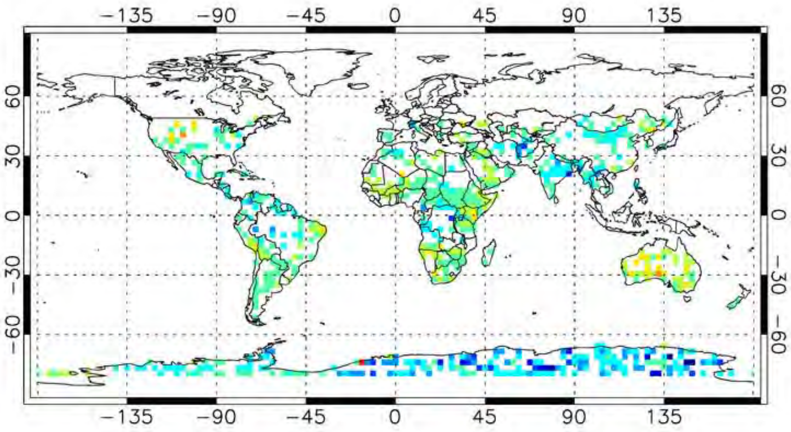


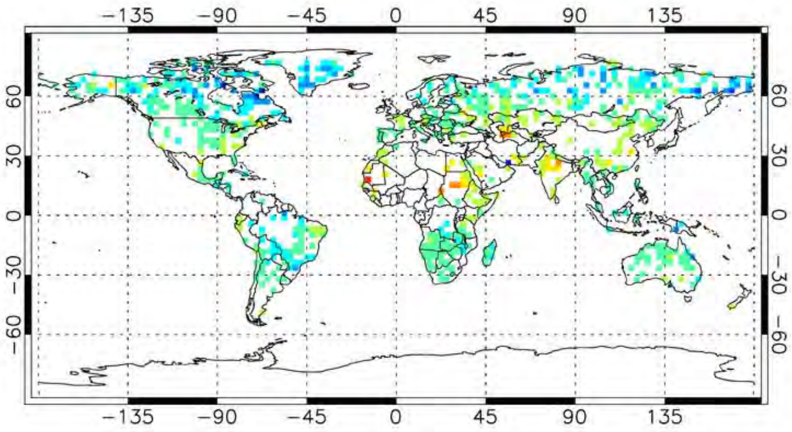

4264 cases (50%)

# TROPOMI ensemble after cirrus filtering

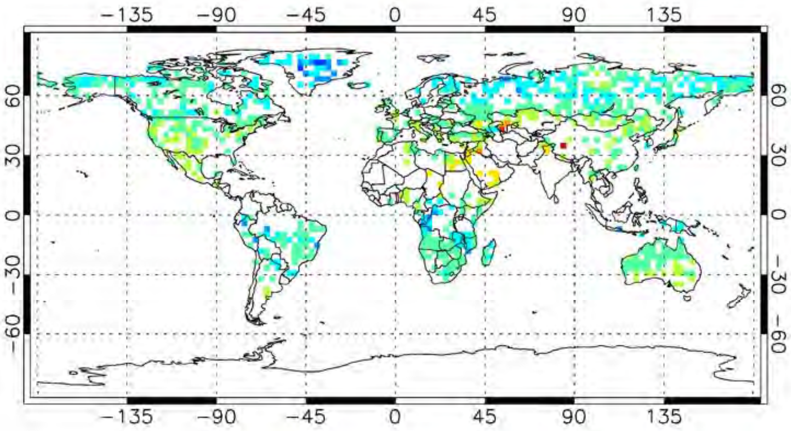
JAN

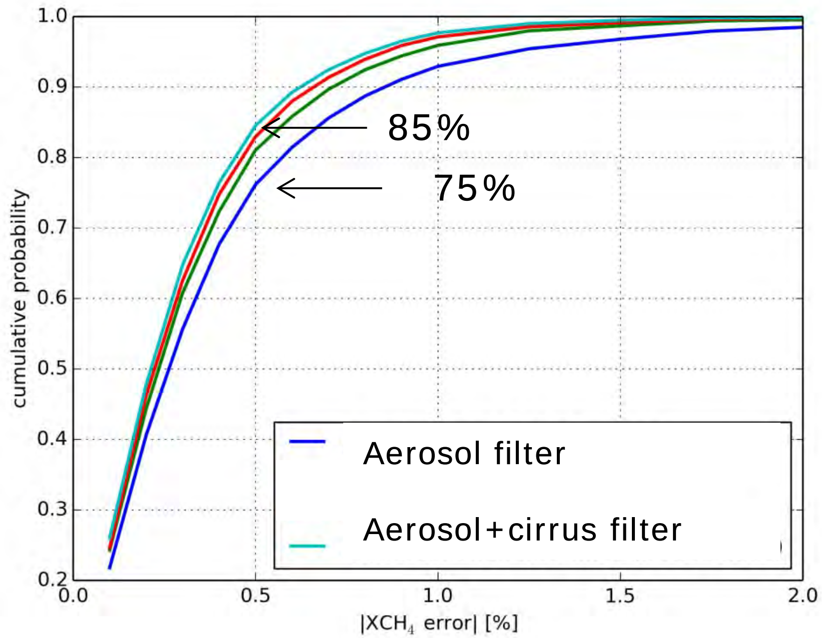


APR



JUL

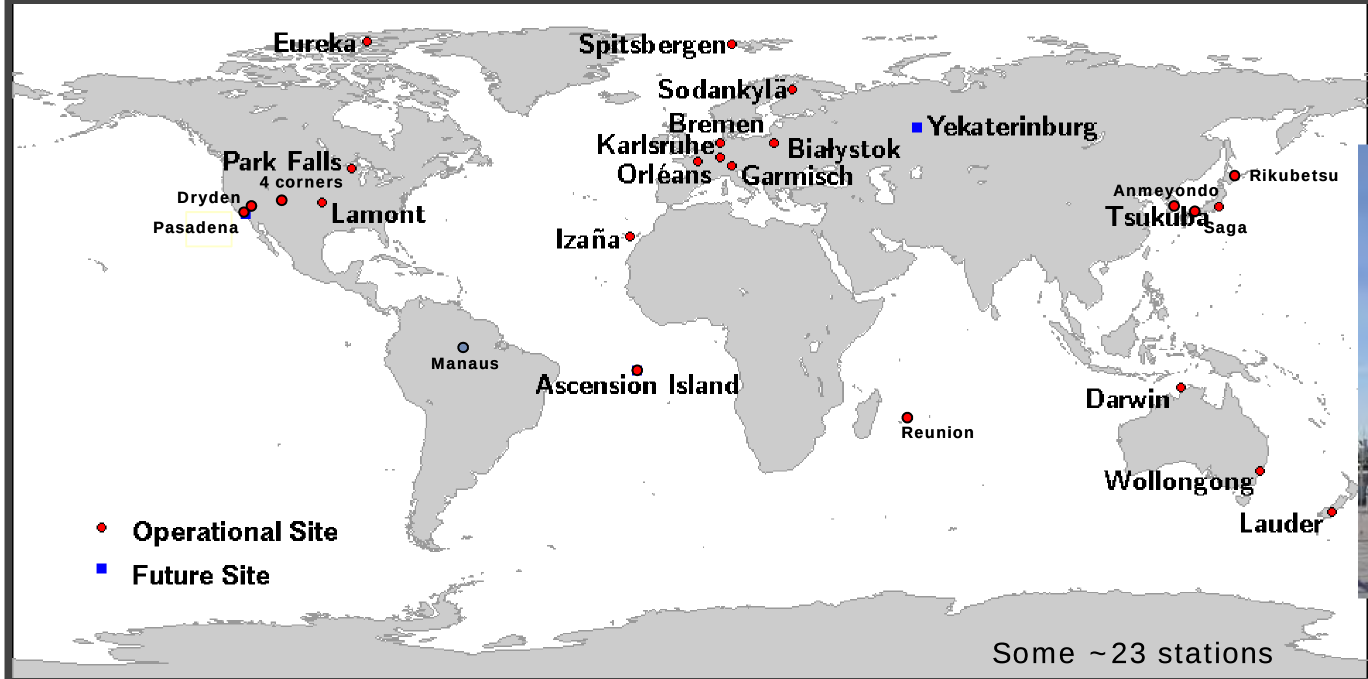



2981 cases (35%)

# Performance evaluation with real GOSAT data:

## Validation with Total Carbon Column Observing Network (TCCON)




Ground-based network of spectrometers set up for the validation of satellite measurements of $CO_2$, $CH_4$, $N_2O$, HF, CO, $H_2O$ and HDO columns

We used 12 stations for validation of GOSAT $CH_4$ columns

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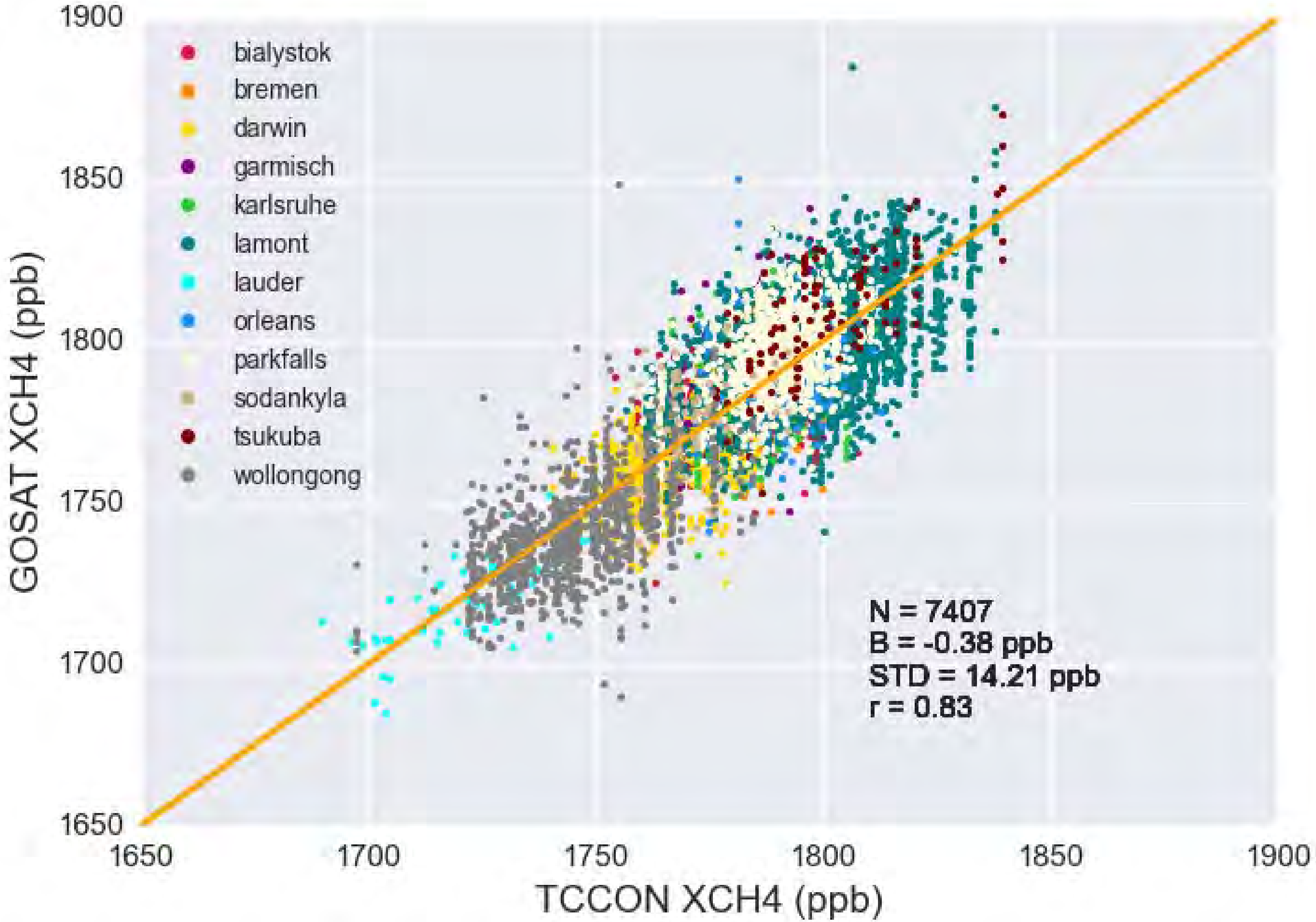
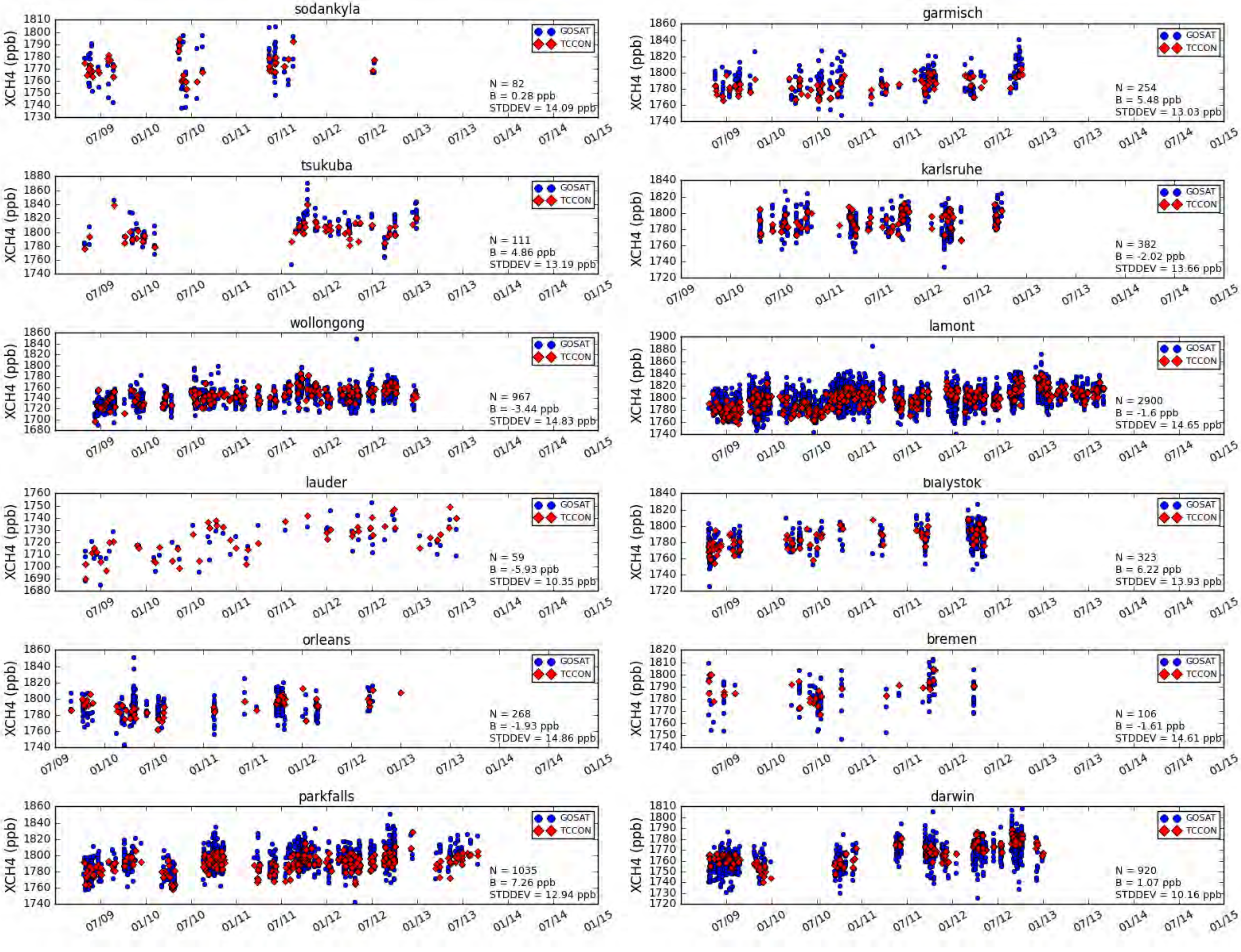
# GOSAT-TCCON XCH4 correlation (2009-2014)





sodankyla
N = 82
B = 0.28 ppb
STDDEV = 14.09 ppb
garmisch
N = 254
B = 5.48 ppb
STDDEV = 13.03 ppb
tsukuba
N = 111
B = 4.86 ppb
STDDEV = 13.19 ppb
karlsruhe
N = 382
B = -2.02 ppb
STDDEV = 13.66 ppb
wollongong
N = 967
B = -3.44 ppb
STDDEV = 14.83 ppb
lamont
N = 2900
B = -1.6 ppb
STDDEV = 14.65 ppb
lauder
N = 59
B = -5.93 ppb
STDDEV = 10.35 ppb
bialystok
N = 323
B = 6.22 ppb
STDDEV = 13.93 ppb
orleans
N = 268
B = -1.93 ppb
STDDEV = 14.86 ppb
bremen
N = 106
B = -1.61 ppb
STDDEV = 14.61 ppb
parkfalls
N = 1035
B = 7.26 ppb
STDDEV = 12.94 ppb
darwin
N = 920
B = 1.07 ppb
STDDEV = 10.16 ppb
GOSAT
TCCON
XCH4 (ppb)

# Interesting science

Science
AAAS

## Assessing Methane Emissions from Global Space-Borne Observations

C. Frankenberg,[1] J. F. Meirink,[2] M. van Weele,[2] U. Platt,[1] T. Wagner[1]

Atmos. Chem. Phys., 14, 3991–4012, 2014
www.atmos-chem-phys.net/14/3991/2014/
doi:10.5194/acp-14-3991-2014

Atmospheric Chemistry and Physics

## A multi-year methane inversion using SCIAMACHY, accounting for systematic errors using TCCON measurements

S. Houweling[1,2], M. Krol[1,2,3], P. Bergamaschi[4], C. Frankenberg[5], E. J. Dlugokencky[6], I. Morino[7], J. Notholt[8], V. Sherlock[9], D. Wunch[10], V. Beck[11], C. Gerbig[11], H. Chen[12,13], E. A. Kort[14], T. Röckmann[2], and I. Aben[1]

Geophysical Research Letters
AN AGU JOURNAL

Research Letter

## Four corners: The largest US methane anomaly viewed from space

Eric A. Kort, Christian Frankenberg, Keeley R. Costigan, Rodica Lindenmaier, Manvendra K. Dubey, Debra Wunch

Atmos. Meas. Tech. Discuss., 8, 3851–3882, 2015
www.atmos-meas-tech-discuss.net/8/3851/2015/
doi:10.5194/amtd-8-3851-2015

Atmospheric Measurement Techniques Discussions

This discussion paper is/has been under review for the journal Atmospheric Measurement Techniques (AMT). Please refer to the corresponding final paper in AMT if available.

## Quantifying lower tropospheric methane concentrations using near-IR and thermal IR satellite measurements: comparison to the GEOS-Chem model

J. R. Worden[1], A. J. Turner[2], A. A. Bloom[1], S. S. Kulawik[3], J. Liu[1], M. Lee[1], R. Weidner[1], K. Bowman[1], C. Frankenberg[1], R. Parker[4], and V. H. Payne[1]

Atmos. Chem. Phys., 15, 7049–7069, 2015
www.atmos-chem-phys.net/15/7049/2015/
doi:10.5194/acp-15-7049-2015

Atmospheric Chemistry and Physics

## Estimating global and North American methane emissions with high spatial resolution using GOSAT satellite data

A. J. Turner[1], D. J. Jacob[1,2], K. J. Wecht[2], J. D. Maasakkers[1], E. Lundgren[1], A. E. Andrews[3], S. C. Biraud[4], H. Boesch[5,6], K. W. Bowman[7], N. M. Deutscher[8,9], M. K. Dubey[10], D. W. T. Griffith[8], F. Hase[11], A. Kuze[12], J. Notholt[9], H. Ohyama[12,13], R. Parker[5,6], V. H. Payne[7], R. Sussmann[14], C. Sweeney[3,15], V. A. Velazco[8], T. Warneke[9], P. O. Wennberg[16], and D. Wunch[16]

Atmos. Chem. Phys., 15, 113–133, 2015
www.atmos-chem-phys.net/15/113/2015/
doi:10.5194/acp-15-113-2015

Atmospheric Chemistry and Physics

## Inverse modelling of $CH_4$ emissions for 2010–2011 using different satellite retrieval products from GOSAT and SCIAMACHY

M. Alexe[1], P. Bergamaschi[1], A. Segers[2], R. Detmers[3], A. Butz[9], O. Hasekamp[3], S. Guerlet[3], R. Parker[4], H. Boesch[4], C. Frankenberg[5], R. A. Scheepmaker[3], E. Dlugokencky[6], C. Sweeney[6,7], S. C. Wofsy[8], and E. A. Kort[10]

## Summary

- SCIAMACHY (2002-2012) provided first $CH_4$ and $CO_2$ measurements from space.
- GOSAT (2009) is first dedicated Greenhouse Gas mission ($CH_4$, $CO_2$). Improved accuracy but limited sampling/coverage.
- Sentinel-5 Precursor (2016) will combine high accuracy, high spatial resolution (GOSAT) and good coverage/sampling (SCIAMACHY).
- Long term European continuity through Sentinel-5 (2020+).

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# Summary

- S5P operational data processing will deliver atmospheric key products, such as $CH_4$ and CO.
- Scientific data processing can deliver interesting products, such as HDO, $H_2O$, fluorescence, $CH_4$ retrievals over cloudy ocean.
- RemoTeC as operational CH4 retrieval algorithm.
- Performance tested on synthetic global ensemble and real measurements (GOSAT).
- Validation with ground-based measurements (TCCON).