



Universität
Bremen



Institut für
Umweltphysik

Fachbereich 01
Physik/Elektrotechnik

Methane controlled releases 2024/2025:

Stanford | Doerr
School of Sustainability

M UNIVERSITY OF
MICHIGAN



Methane retrievals from Sentinel-5 Precursor, PRISMA, EnMAP and EMIT and corresponding emission estimates of localized sources

Michael Buchwitz, Oliver Schneising-Weigel, Stefan Noël, Maximilian Reuter, Michael Hilker,
Jonas Hachmeister, Heinrich Bovensmann, John P. Burrows and Hartmut Boesch

University of Bremen, Institute of Environmental Physics, Germany

Frances Reuland, Adam Brandt

Department of Energy Science and Engineering Doerr School of Sustainability, Stanford University, CA, USA

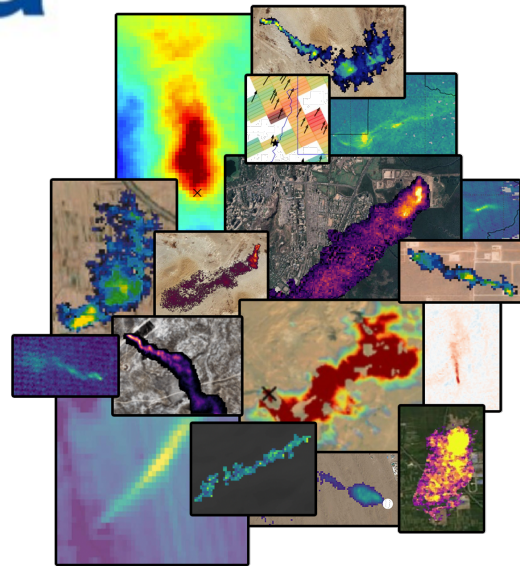
Taylor Adams, Eric A. Kort

Department of Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, MI, USA

IUP-UB: Funding through various projects



**Methane
Emissions
Detection
Using
Satellites
Assessment (MEDUSA)**

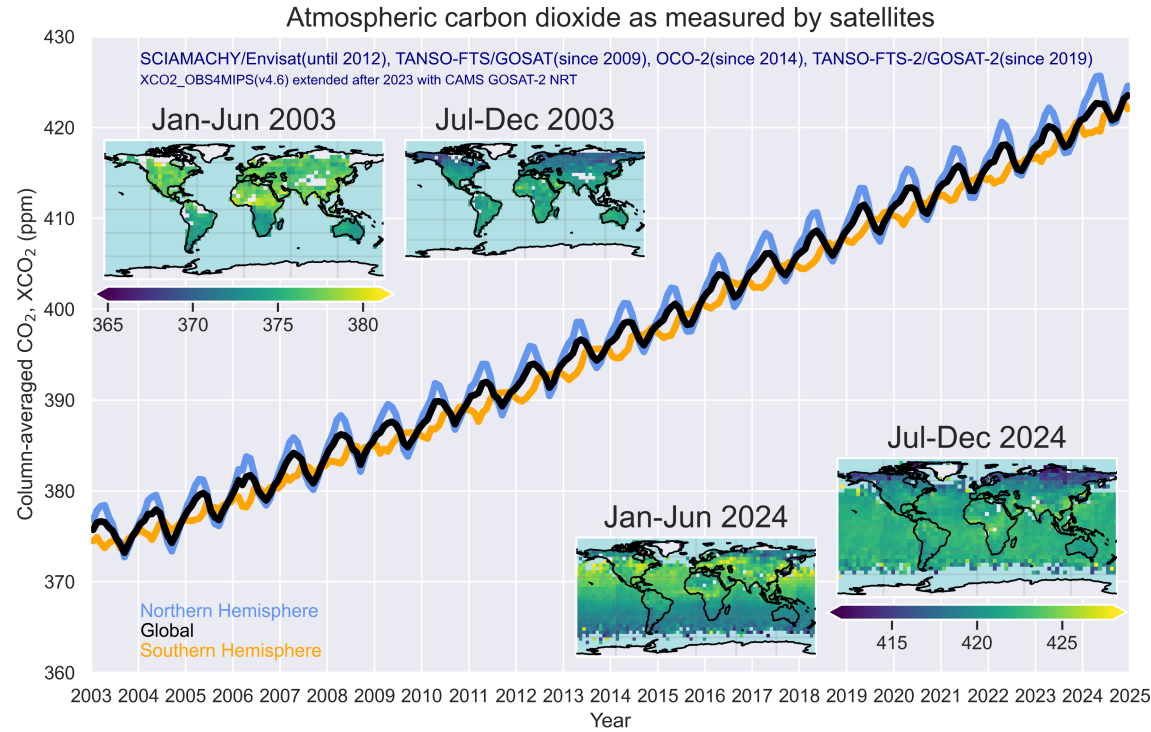


Bundesministerium
für Forschung, Technologie
und Raumfahrt

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

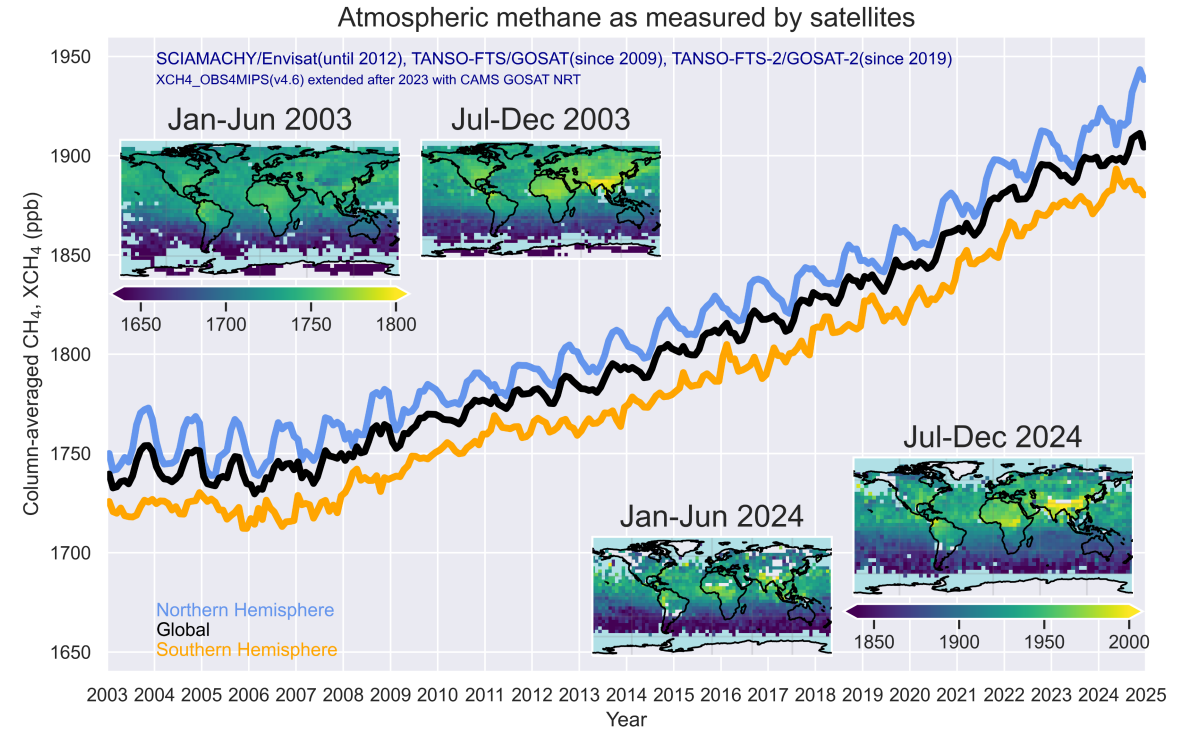


Satellite XCO₂ and XCH₄ retrievals ...



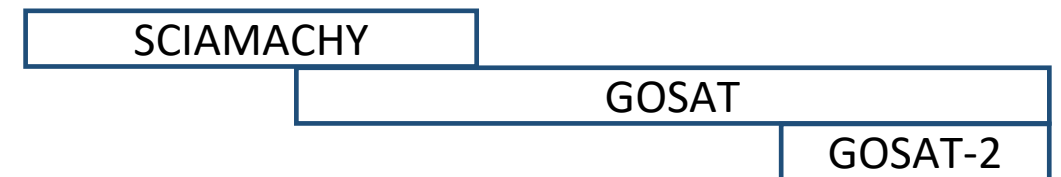
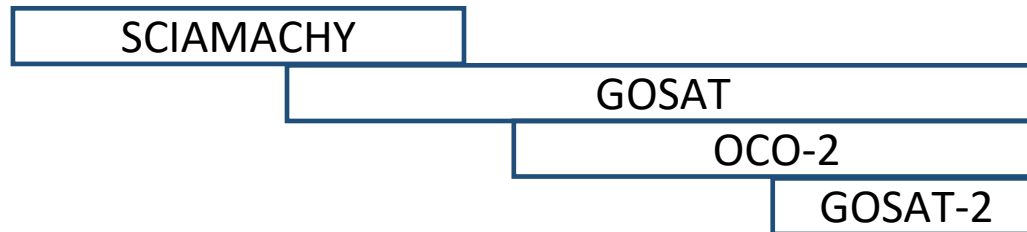
Michael.Buchwitz@iup.physik.uni-bremen.de, 22-Jan-2025 - ts1_XCO2_OBS4MIPS_v4.6_60S-60N_land_v1_CO2_GO2_FOCA_NRT_v3.1_latbands_MB20250122.csv

ts1yo:0



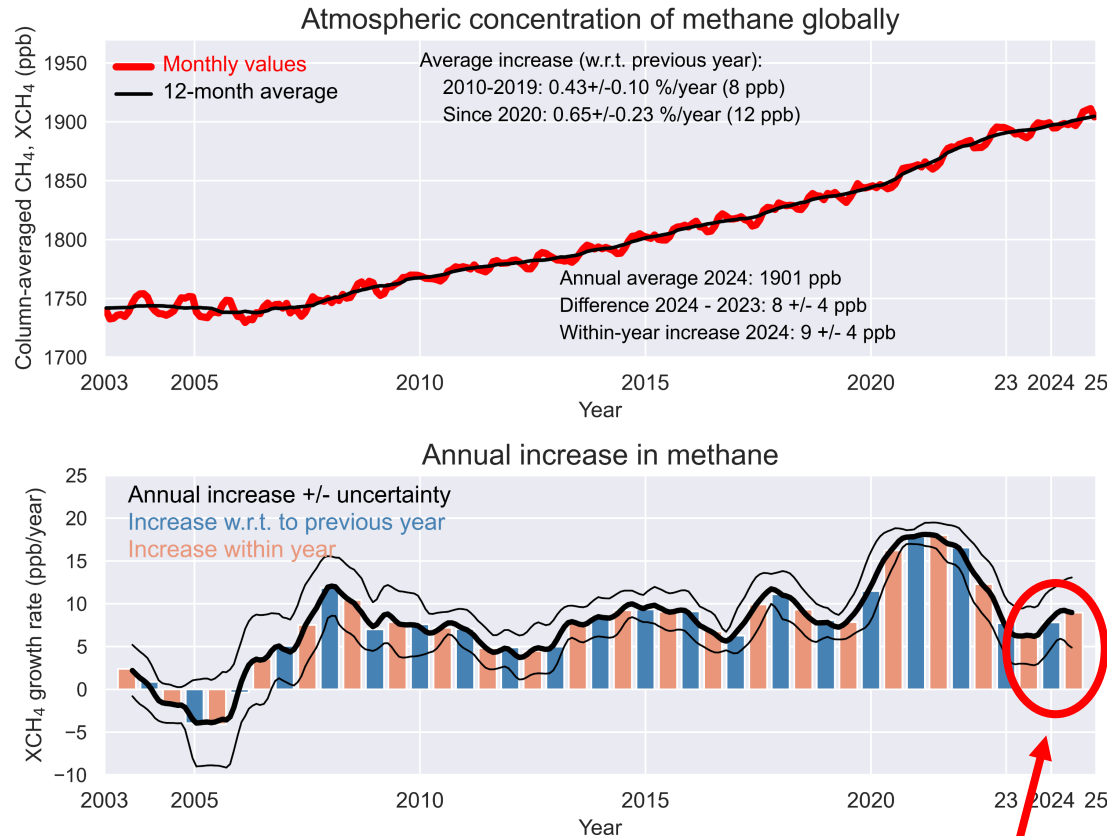
Michael.Buchwitz@iup.physik.uni-bremen.de, 22-Jan-2025 - ts1_XCH4_OBS4MIPS_v4.6_60S-60N_land_v1_CH4_GO2_SRFP_NRT_latbands_MB20250122.csv

ts1yo:0



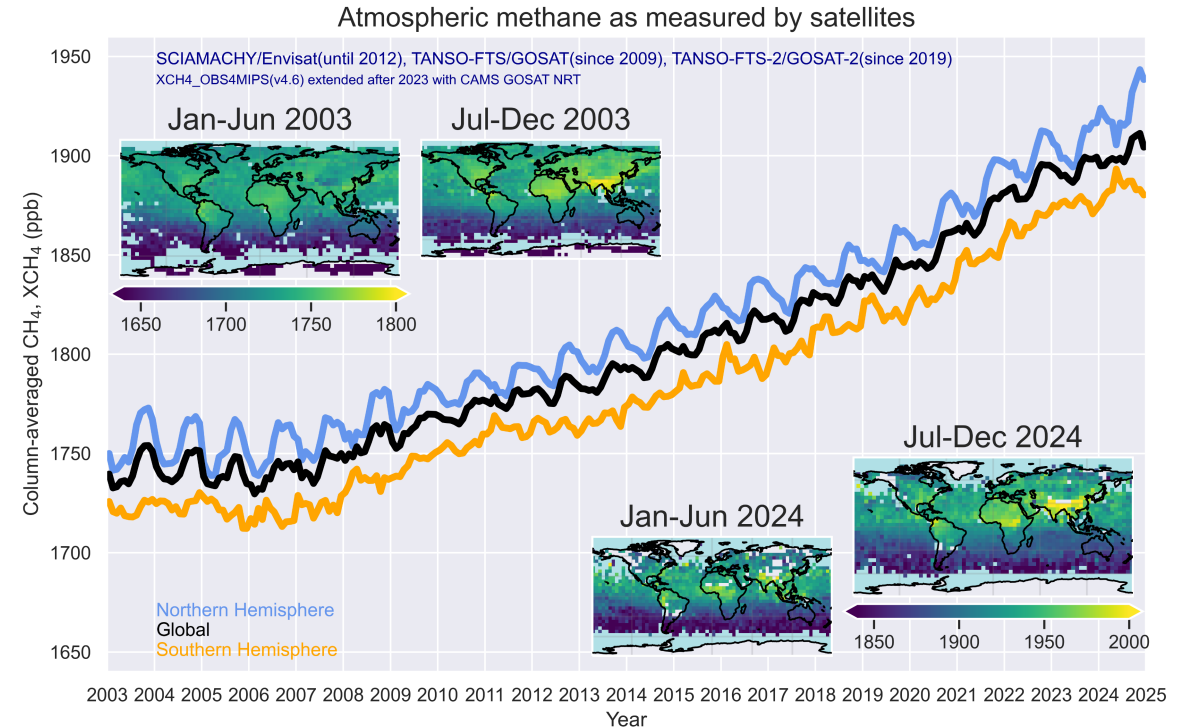
+ TROPOMI/S5P, PRISMA, EnMAP, EMIT, ...
+ future S5, GOSAT-GW, CO2M, ...

Satellite XCH₄ retrievals ...



Michael.Buchwitz@iup.physik.uni-bremen.de, 22-Jan-2025 - ts06c_OBS4MIPS_v4p6_CAMS-NRT_MB20250122

**Methane growth rate in 2024
high (~ 8 ppb) but not record high**



Michael.Buchwitz@iup.physik.uni-bremen.de, 22-Jan-2025 - ts1_XCH₄_OBS4MIPS_v4.6_60S-60N_land_v1_CH4_GO2_SRFP_NRT_latbands_MB20250122.csv telyo:0

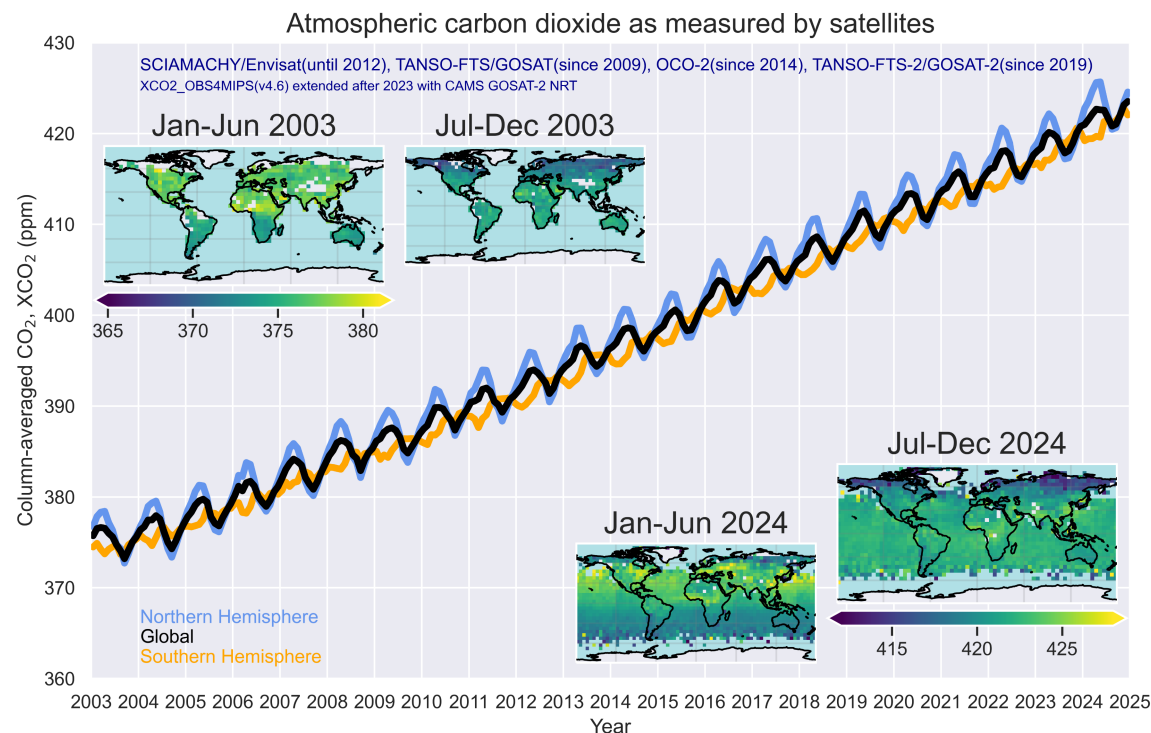
SCIAMACHY

GOSAT

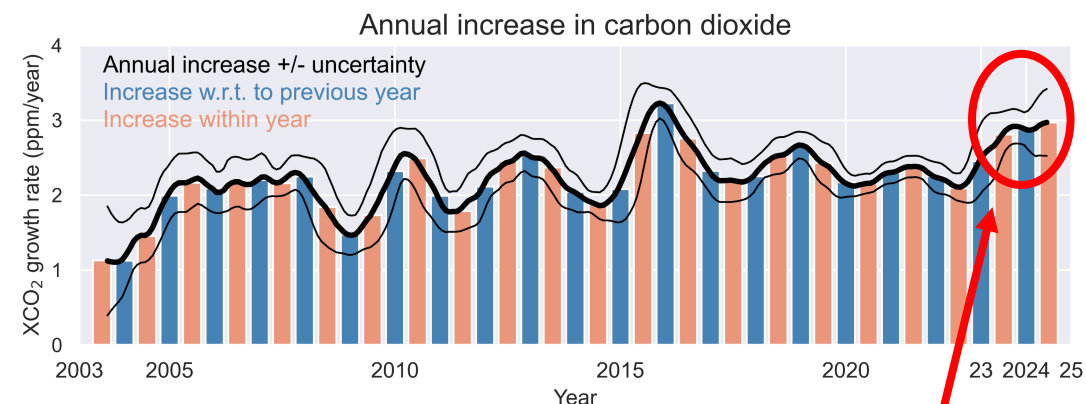
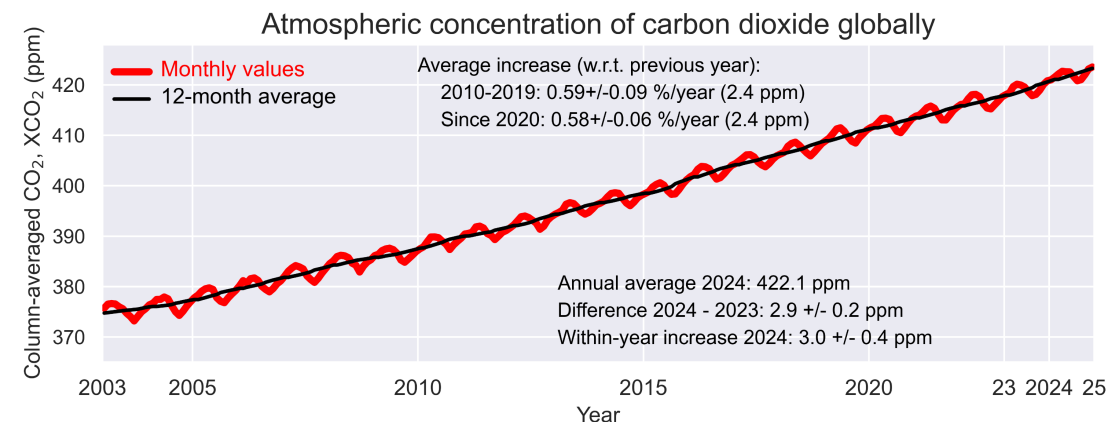
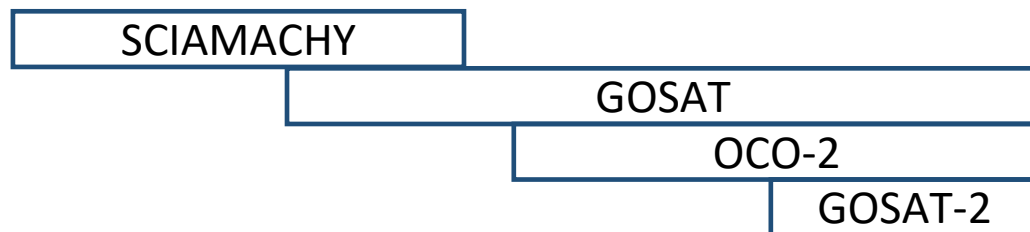
GOSAT-2

+ TROPOMI/S5P, PRISMA, EnMAP, EMIT, ...
+ future S5, GOSAT-GW, CO2M, ...

Satellite XCO₂ retrievals ...



Michael.Buchwitz@iup.physik.uni-bremen.de, 22-Jan-2025 - ts1_XCO2_OBS4MIPS_v4.6_60S-60N_land_v1_CO2_GO2_FOCA_NRT_v3.1_latbands_MB20250122.csv tsiyo:0



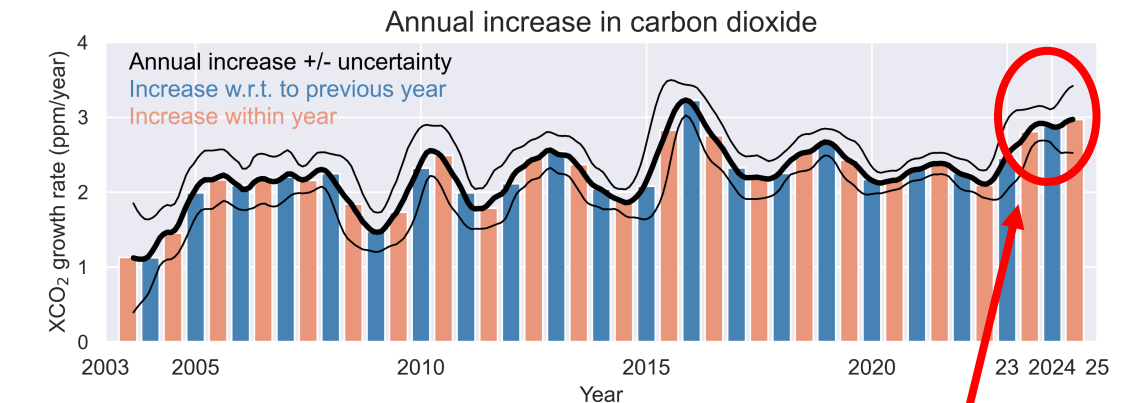
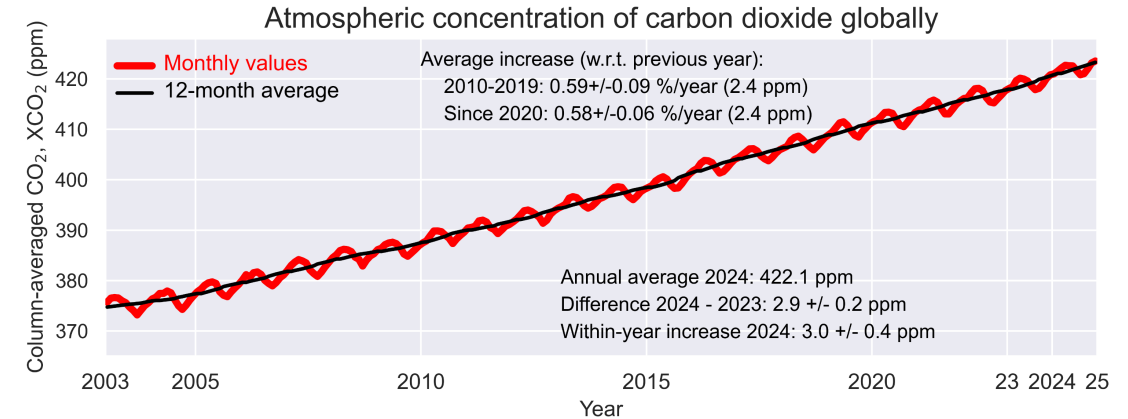
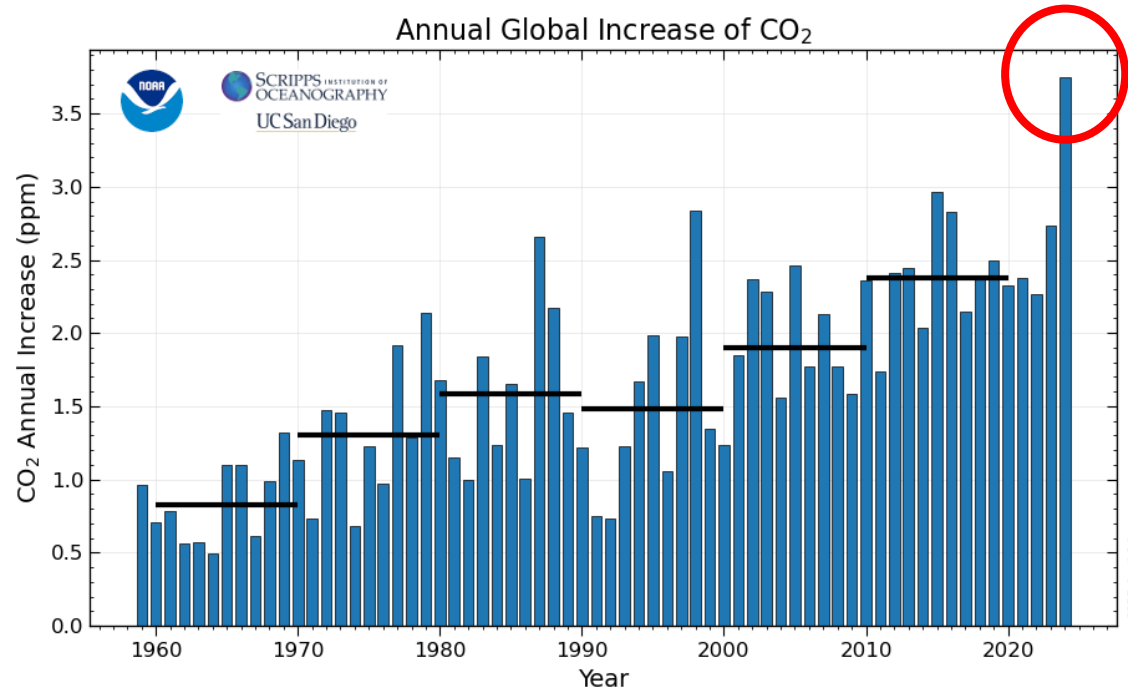
Michael.Buchwitz@iup.physik.uni-bremen.de, 22-Jan-2025 - ts06c_OBS4MIPS_v4p6_CAMS-NRT_MB20250122

XCO₂ growth rate very high in 2024: ~ 3 ppm !

XCO₂ and surface CO₂ growth rates ...

**CO₂ surface
data:**

3.75 ppm (global)
3.33 ppm (Mauna Loa)



Michael.Buchwitz@iup.physik.uni-bremen.de, 22-Jan-2025 - ts06c_OBS4MIPS_v4p6_CAMS-NRT_MB20250_22

**XCO₂ growth rate very high in
2024: ~ 3 ppm !**

Emission estim. algos for localized sources

NIST Interagency Report
NIST IR 8575

Common Practices for Quantifying Methane Emissions from Plumes Detected by Remote Sensing

Collaborative report of CEOS, NPL, NIST, and LBNL

John Worden
National Aeronautics and Space Administration (NASA)

Annmarie Eldering
Special Programs Office
Laboratory Programs, NIST

Paul Green
Earth Observations & Climate Group
National Physics Laboratory, UK
CEOS GHG Task Team

Evan Sherwin
Energy Analysis & Env. Impacts Division
Lawrence Berkeley National Laboratory

This publication is available free of charge from:
<https://doi.org/10.6028/NIST.IR.8575>

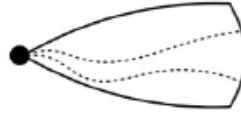
May 2025



U.S. Department of Commerce
Howard Lutnick, Secretary

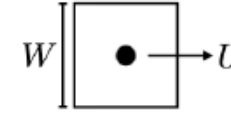
National Institute of Standards and Technology
Craig Burkhardt, Acting Under Secretary of Commerce for Standards and Technology and Acting NIST Director

Gaussian Plume



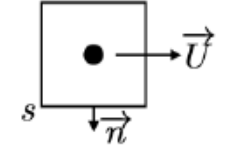
$$Q = U \Delta \Omega(x, y) \left(\sqrt{2\pi} \sigma_y(x) e^{-\frac{y^2}{2\sigma_y(x)^2}} \right)$$

Local mass balance



$$Q = UW \Delta \Omega$$

Gauss's theorem



$$Q = \oint_s \Omega(s) \vec{U} \cdot \vec{n} ds$$

Integrated mass enhancement (IME)



$$Q = U_{\text{eff}} \text{IME} / L$$

Cross-sectional flux (CSF)



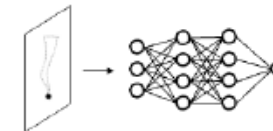
$$Q = U \int_a^b \Delta \Omega(x, y) dy$$

Angular width



$$Q = f(\text{IME}, \theta)$$

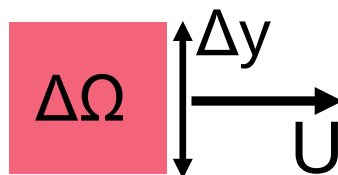
Computer vision



$$Q = \text{NN}(\text{Plume image})$$

<https://doi.org/10.6028/NIST.IR.8575>

Integration of column enhancements times wind speed along transects perpendicular to wind / plume direction



$$Q[\text{t/h}] = \Delta \Omega[\text{t/km}^2] * \Delta y[\text{km}] * U[\text{km/h}]$$

Emission ~ Column enhancement * Wind speed

Schneising et al., AMT, 2023

Advances in retrieving XCH₄ and XCO from Sentinel-5 Precursor: improvements in the scientific TROPOMI/WFMD algorithm

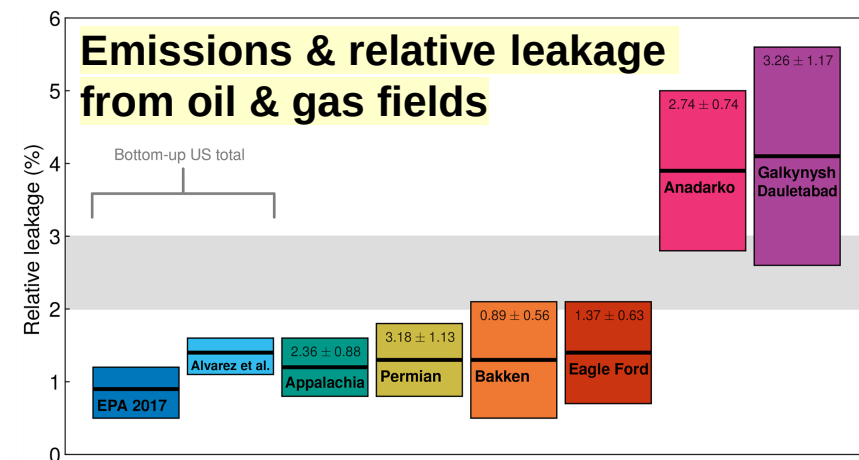
Oliver Schneising, Michael Buchwitz, Jonas Hachmeister, Steffen Vanselow, Maximilian Reuter, Matthias Buschmann, Heinrich Bovensmann, and John P. Burrows

Schneising et al., ACP, 2020

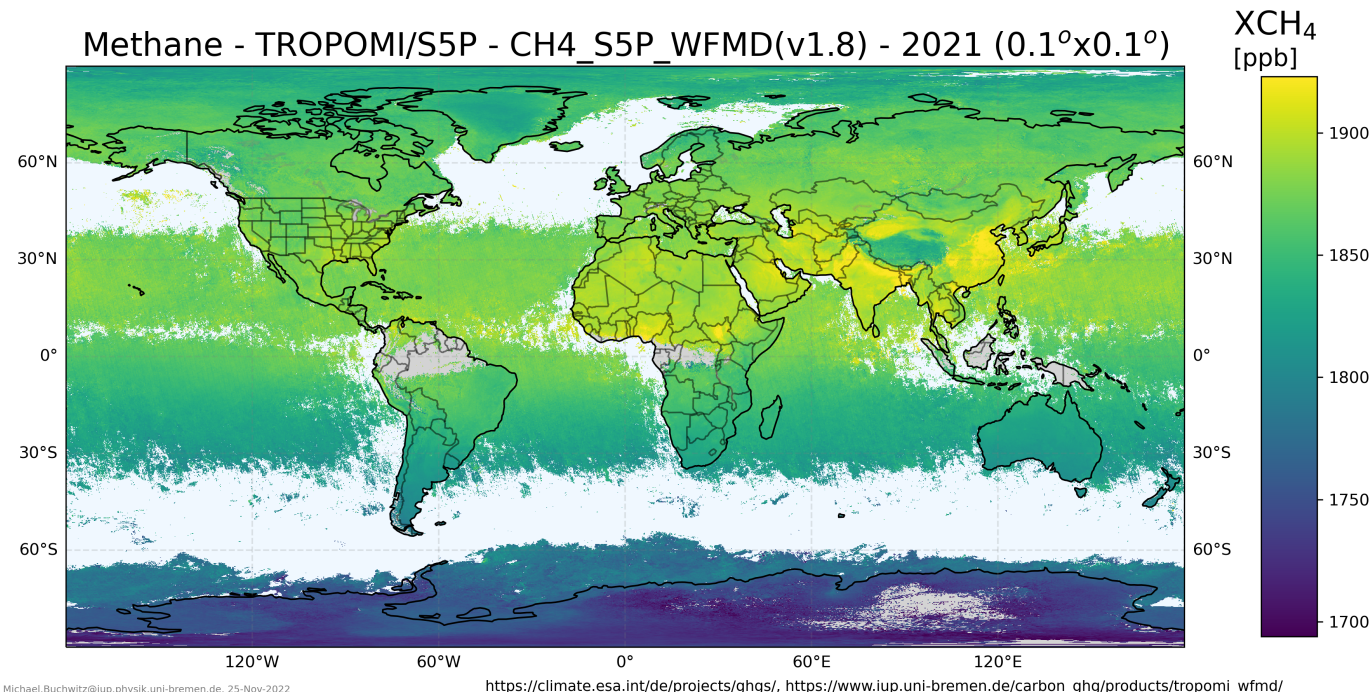
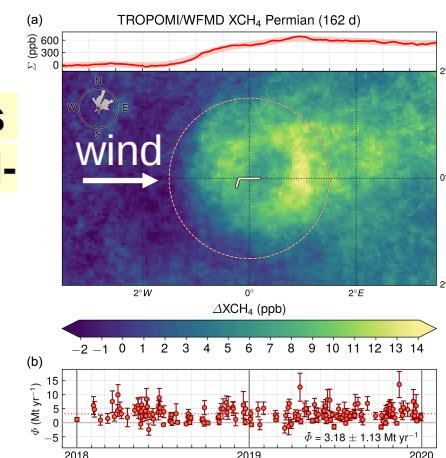
Remote sensing of methane leakage from natural gas and petroleum systems revisited

Oliver Schneising, Michael Buchwitz, Maximilian Reuter, Steffen Vanselow, Heinrich Bovensmann, and John P. Burrows

Institute of Environmental Physics (IUP), University of Bremen FB1, Bremen, Germany



Emission estimates via Cross-Sectional-Flux (CSF) method for 2018-2019



Available from:

https://www.iup.uni-bremen.de/carbon_ghg/products/tropomi_wfmd/

<https://climate.esa.int/en/projects/ghgs/>

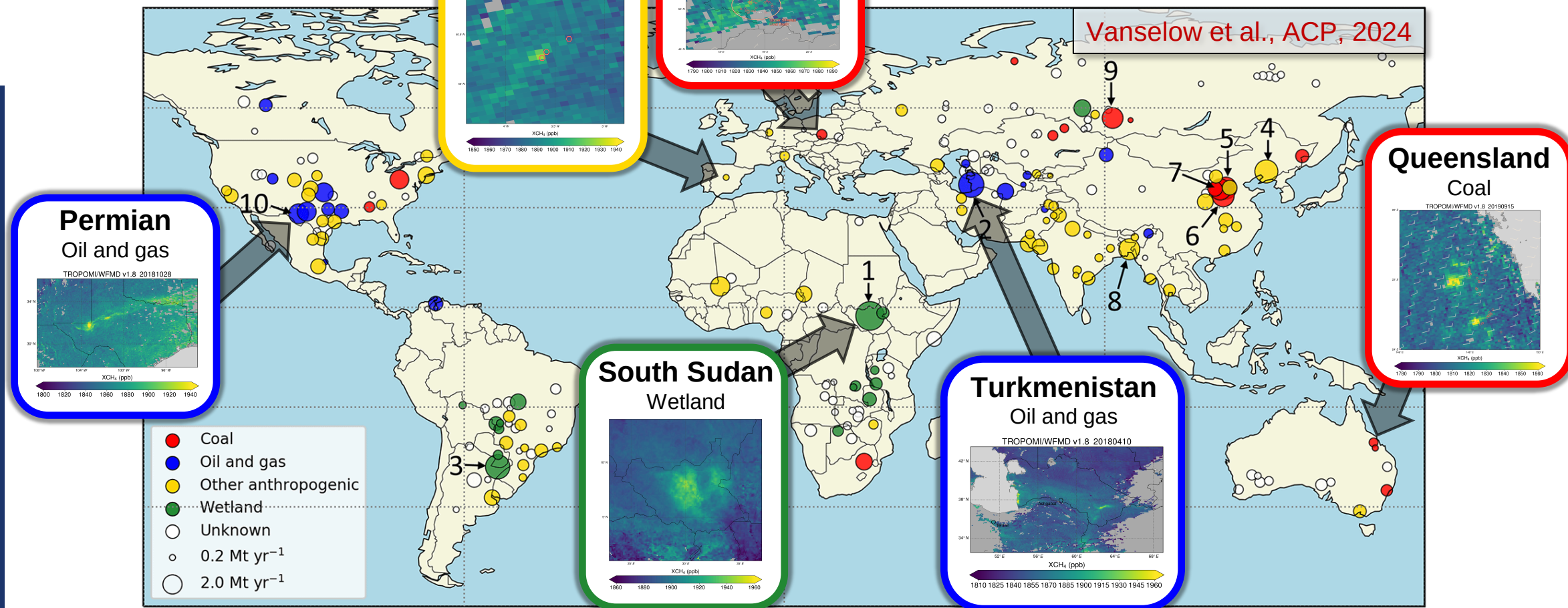
<https://catalogue.ceda.ac.uk/>

Potential persistent emission hotspots

Emission estimates based
on TROPOMI/S5P WFMD
v1.8 XCH₄ retrievals & mass
balance method:

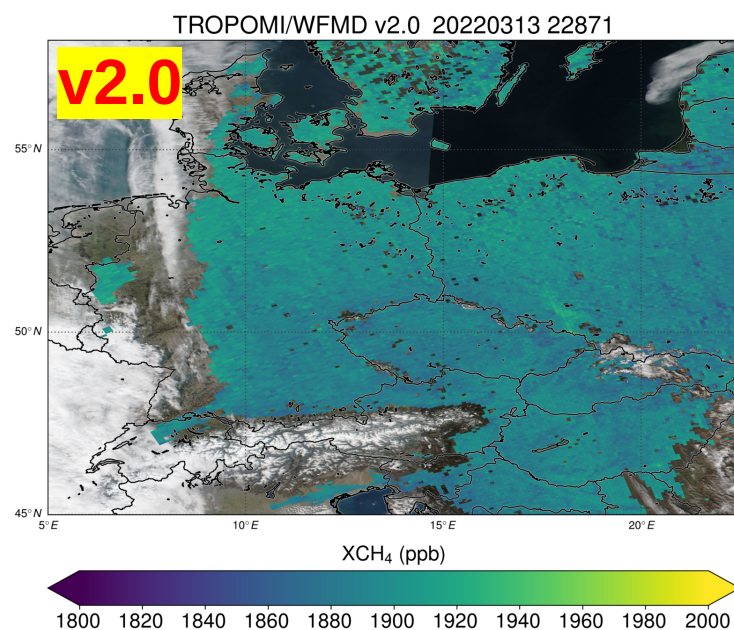
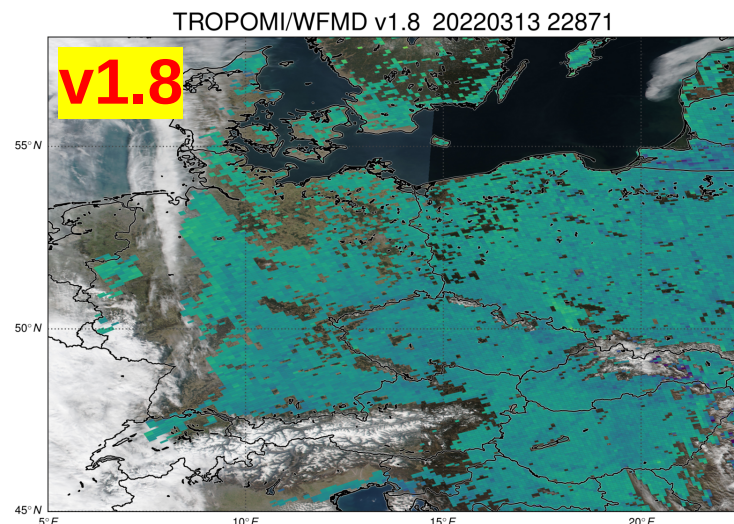
Automated persistent hotspot detection, quantification,
and source type assignment based on monthly data

Vanselow et al., ACP, 2024



217 Potential Persistent Source Regions (PPSRs) detected (2018 - 2021)

TROPOMI/S5P XCH₄ WFMD v2.0



Filesize:

Random Forest

XGBoost

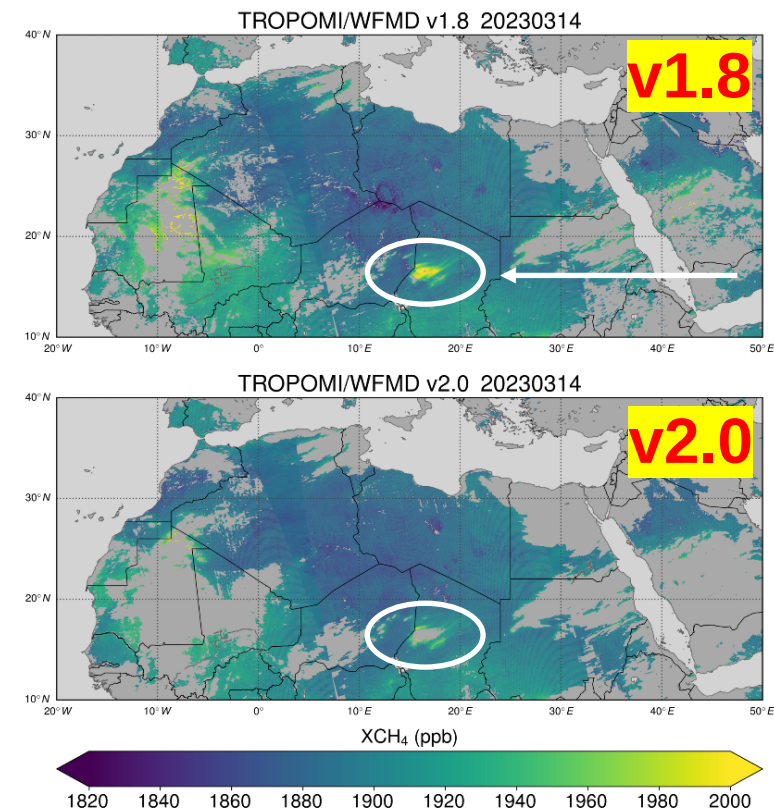


0.23 GB

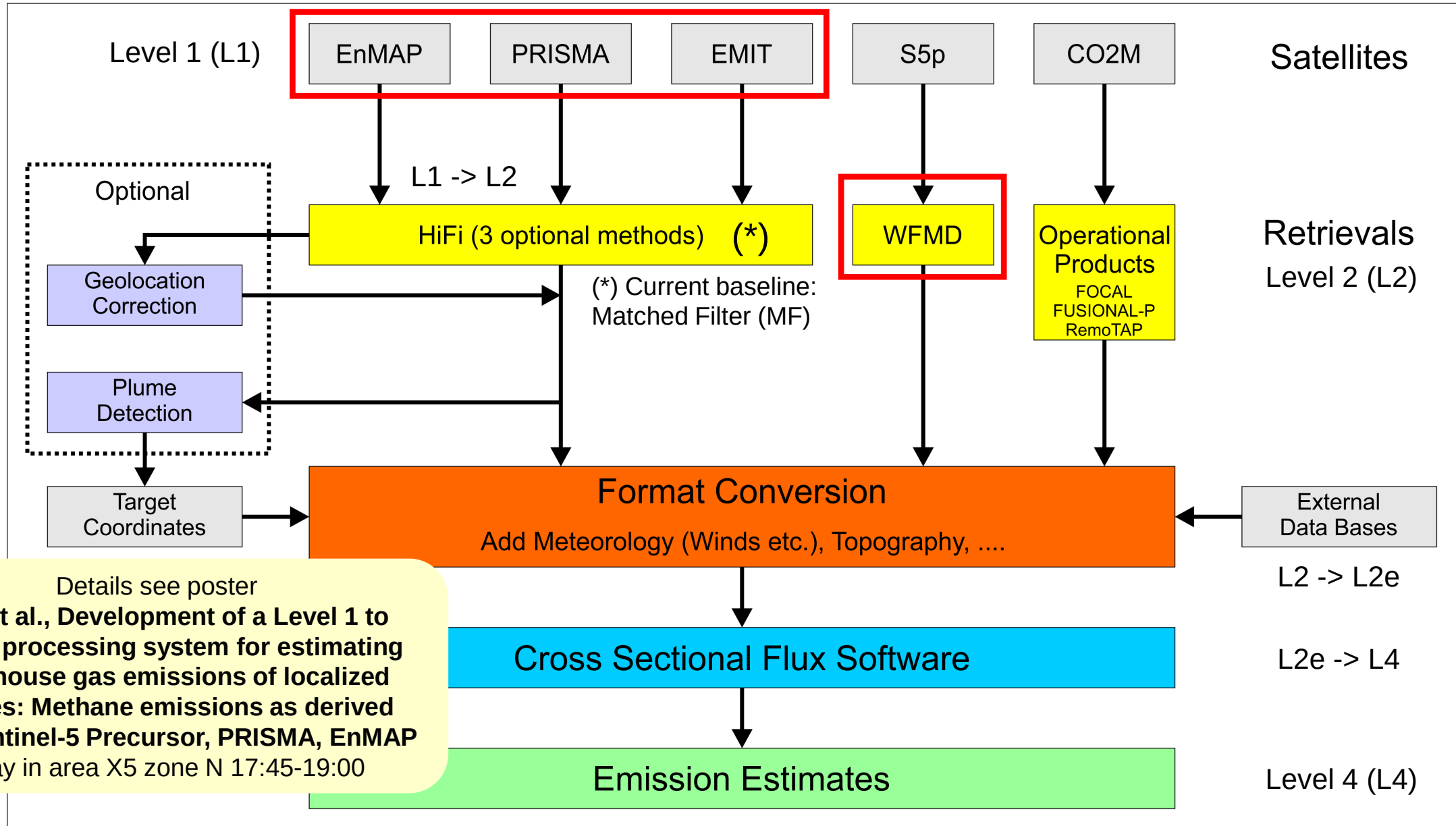
v1.8
v2.0

TROPOMI/WFMD v2.0

- Better resource efficiency due to reduced memory consumption of machine learning quality filter
- Improved accuracy and precision according to validation with TCCON
- More rigorous filtering of specific aerosol events over bright surfaces
- Otherwise, higher data yield, especially for mid and high latitudes



Emissions: Cross-Sectional-Flux (CSF) algo

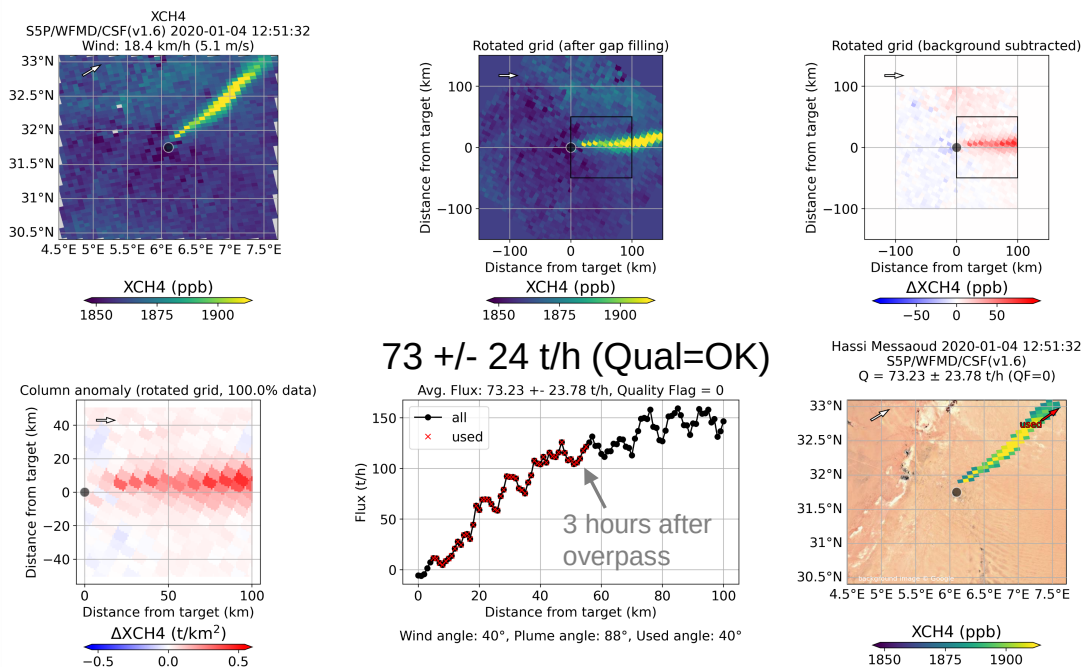


Methane emission estimates: CSF method

TROPOMI/S5P (CSF v1.6)

Input: Level 2: XCH4 WFMD v1.8

Hassi Messaoud (Lat: 31.7500°, Lon: 6.1000°)
S5P XCH4 2020-01-04 12:51:32 orbit 11536
geolocation correction not done, shift (0,0)
WindFlag OK, NdataFlag OK, NindepFlag OK



Box size (default): 100 x 100 km²
Wind: PBL average (ERA5)

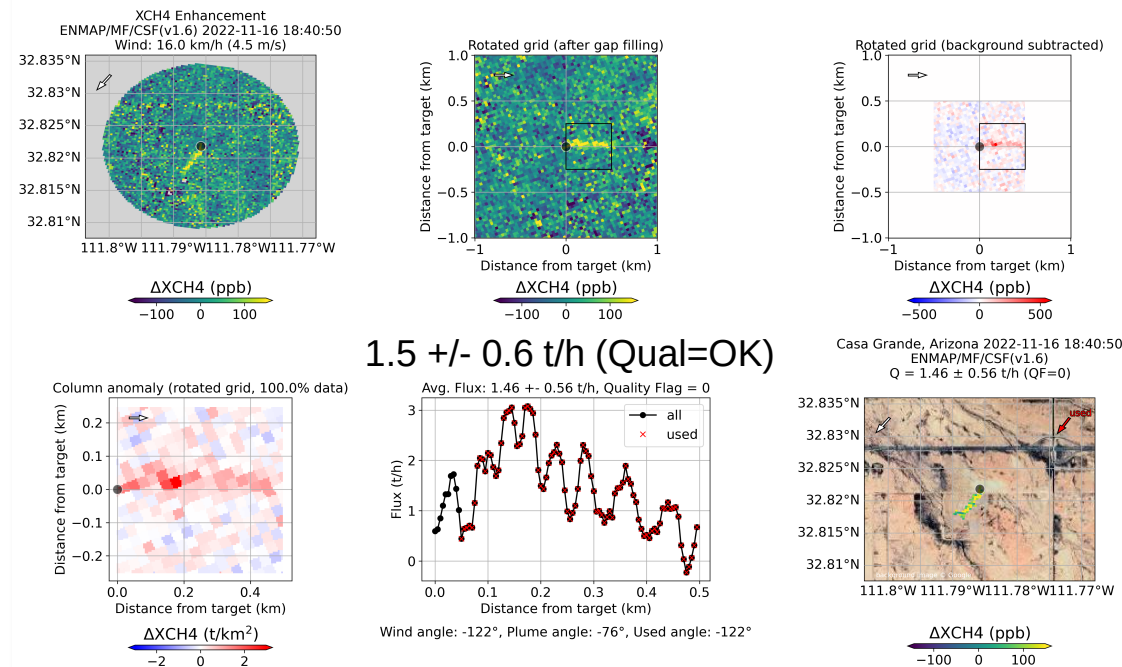
Uncertainty (1-sigma): Several terms added quadratically:

- (i) Stddev of emissions per cross-section,
- (ii) wind (variability + 0.5 m/s), (iii) other (20%)

EnMAP (HiFi-MF & CSF v1.6)

Input: Level 1

Casa Grande, Arizona (Lat: 32.8218°, Lon: -111.7858°)
ENMAP XCH4 2022-11-16 18:40:50
geolocation correction good, shift (-4,-24)
WindFlag OK, NdataFlag OK, NindepFlag OK



Box size (default): 0.5 x 0.5 km²
Wind: 10 m (ERA5)

Quality flag: Qual=OK (QF=0) means:

- Enough data in box (e.g., > 90% of area covered)
- Wind not too low (wind speed > 1 m/s)

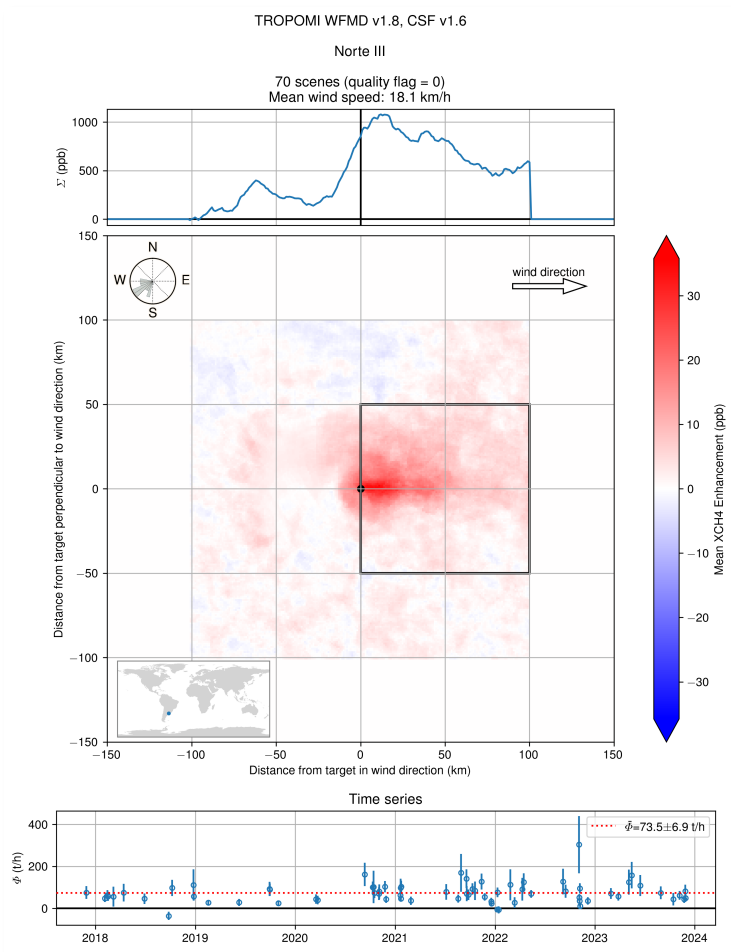
Released: 1.1 t/h
(Sherwin et al., 2022)

Methane: S5P/WFMD: ΔXCH_4 rotat. & avg.

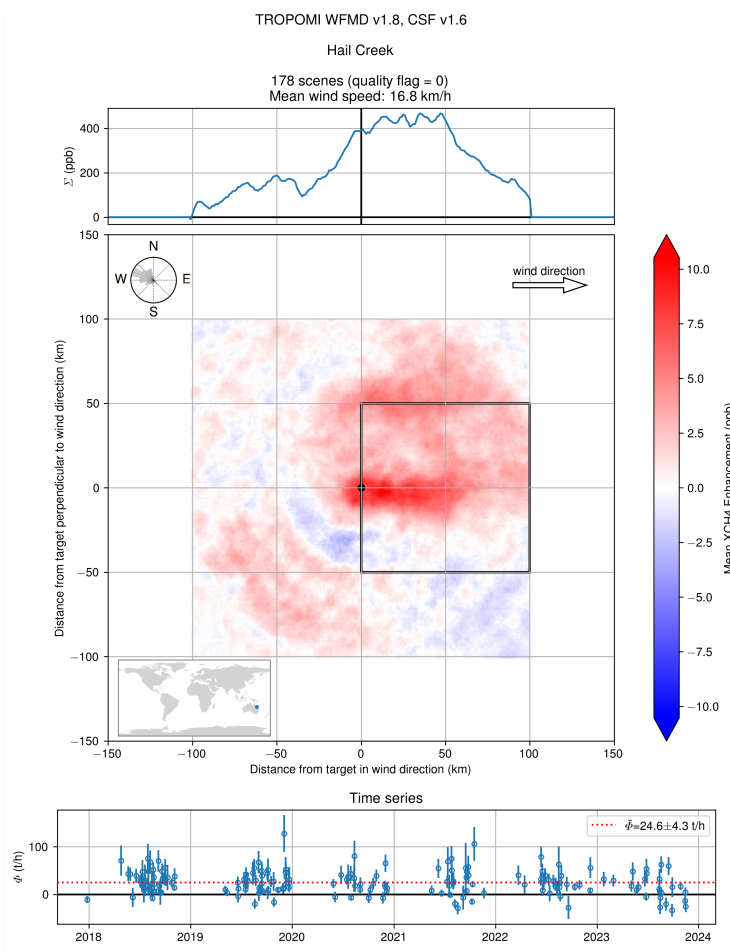
Norte III landfill
Buenos Aires, Argentina

Open coal mine
around Hail Creek, Australia

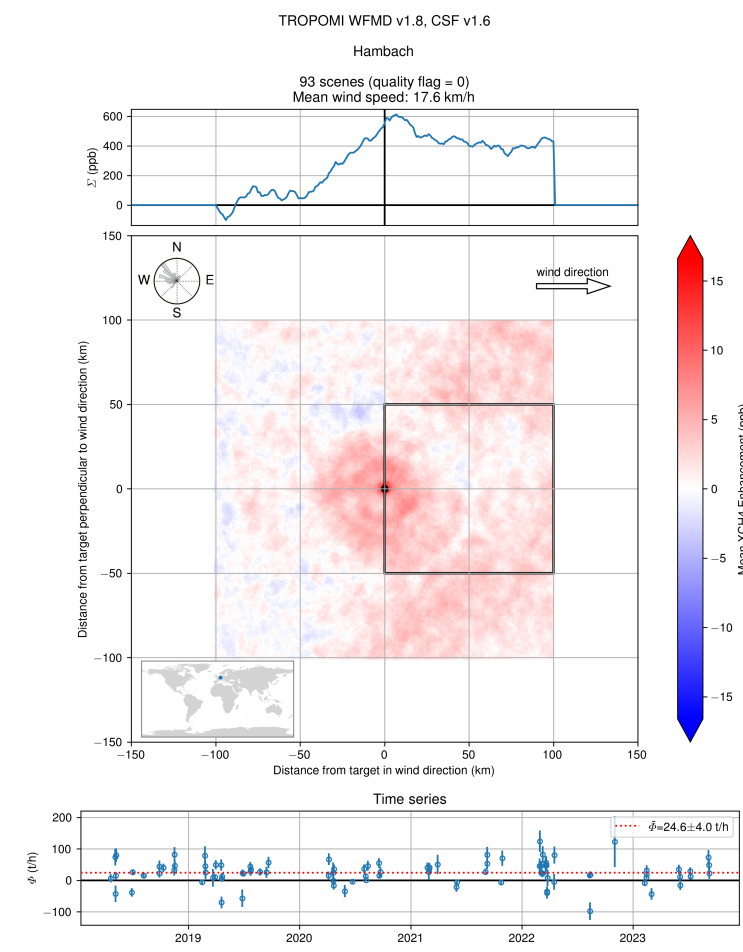
Open coal mine
around Hambach, Germany



Clear average plume
indicating strong isolated source



Average plume but also strong
near-by sources

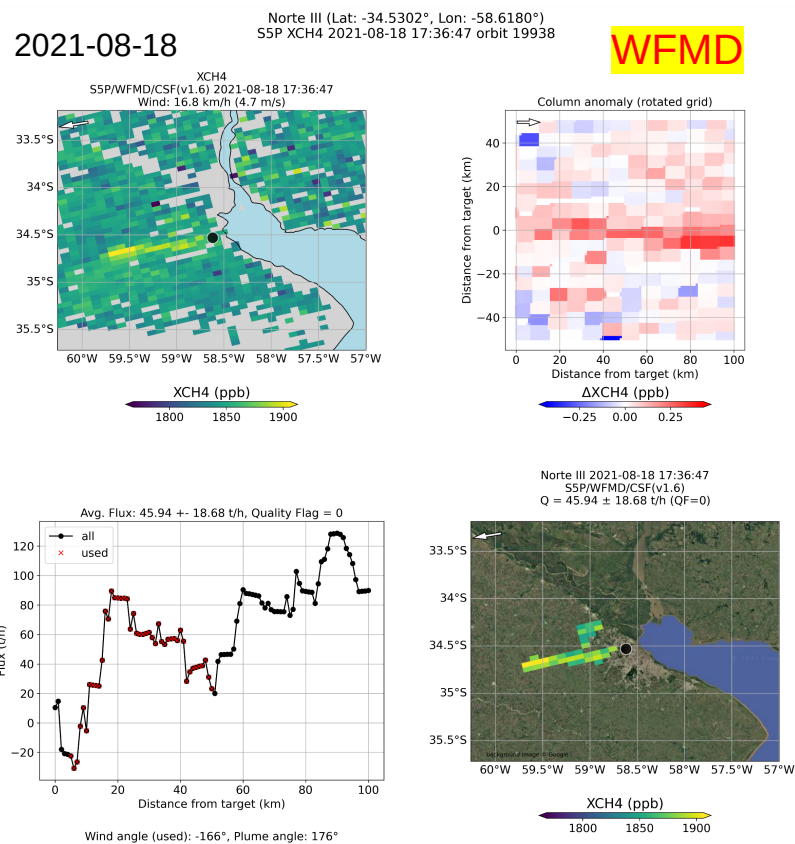


No average plume but local
enhancement (challenging conditions)

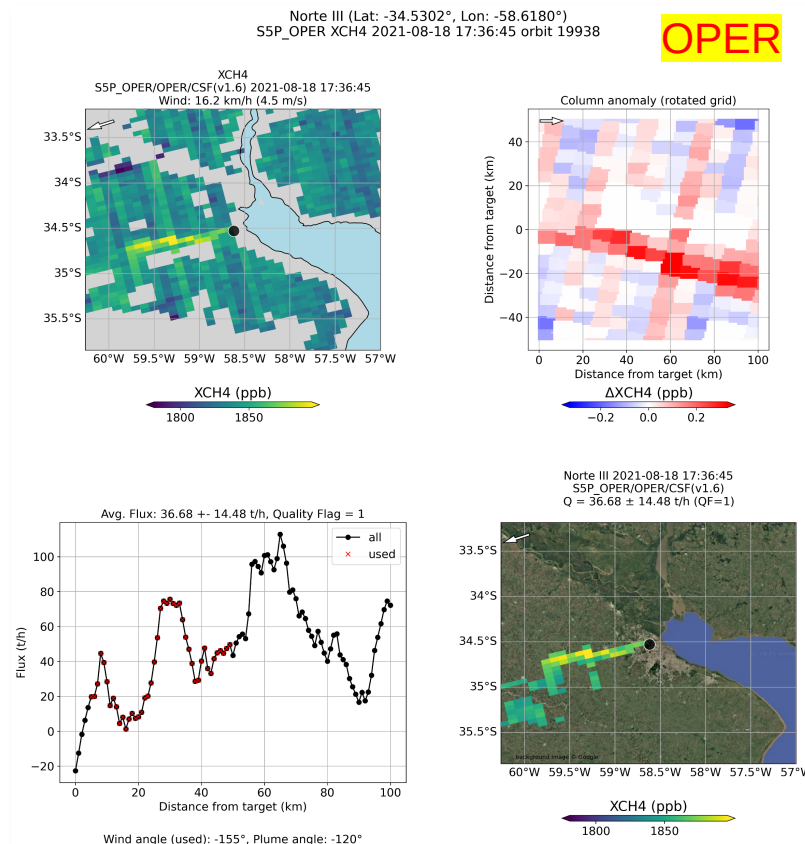
Methane: S5P/WFMD&OPER/CSF: Norte III

IUP-UB CSF (v1.6) algorithm applied to 2 different XCH4 data products:

- Scientific **WFMD** v1.8
- **OPER**ational v02

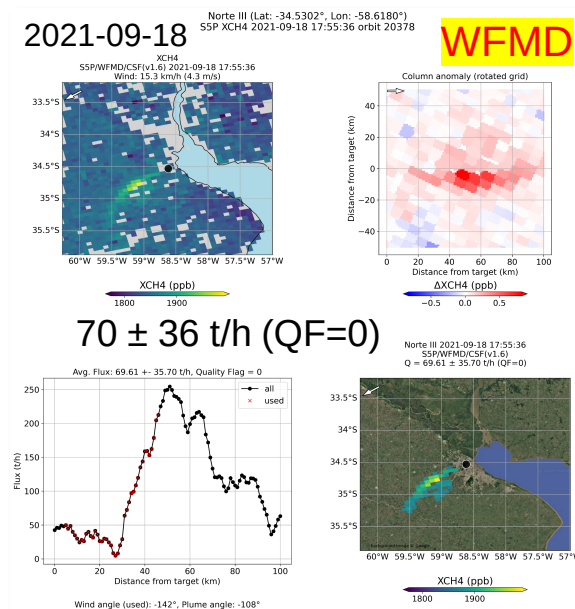


46 ± 19 t/h (QF=0)

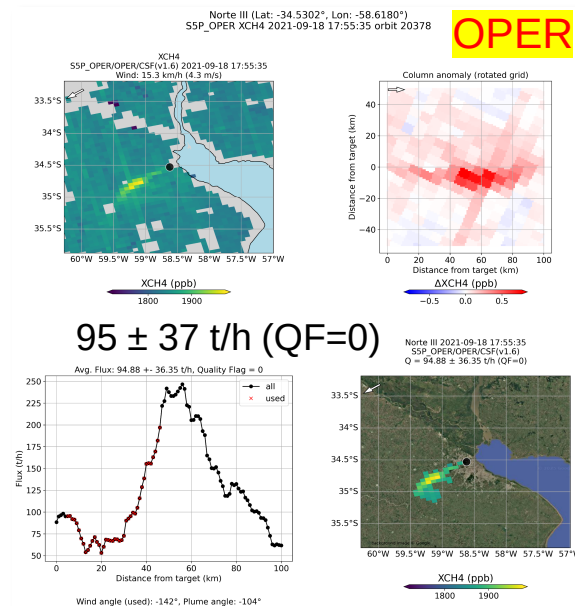


37 ± 15 t/h (QF=1)

OPER product used as is, i.e.,
without correction for striping, etc.

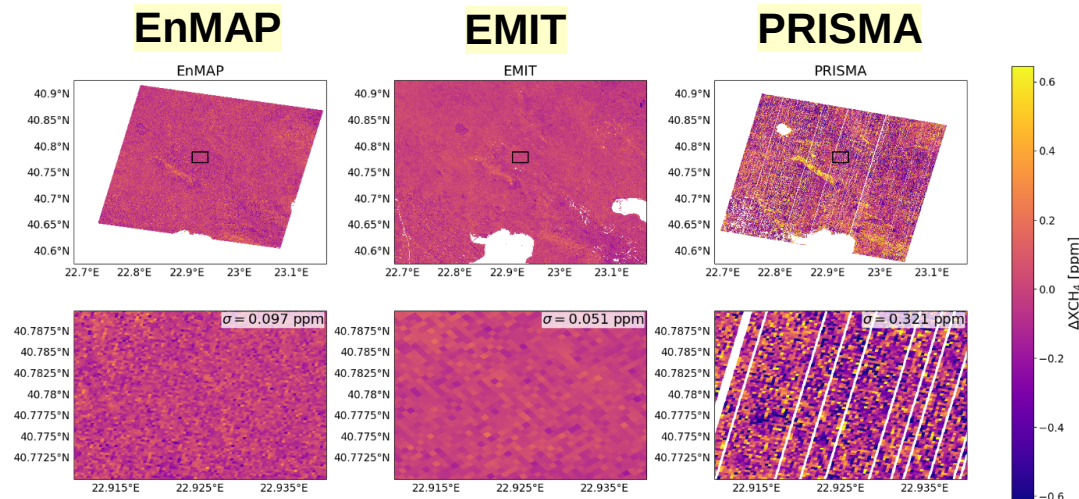
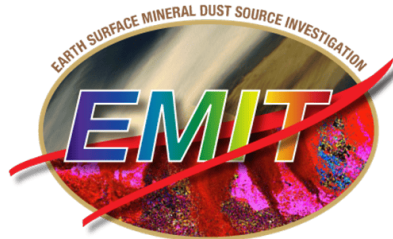
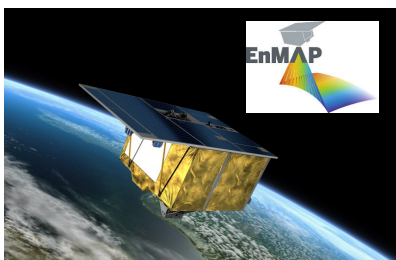


70 ± 36 t/h (QF=0)



95 ± 37 t/h (QF=0)

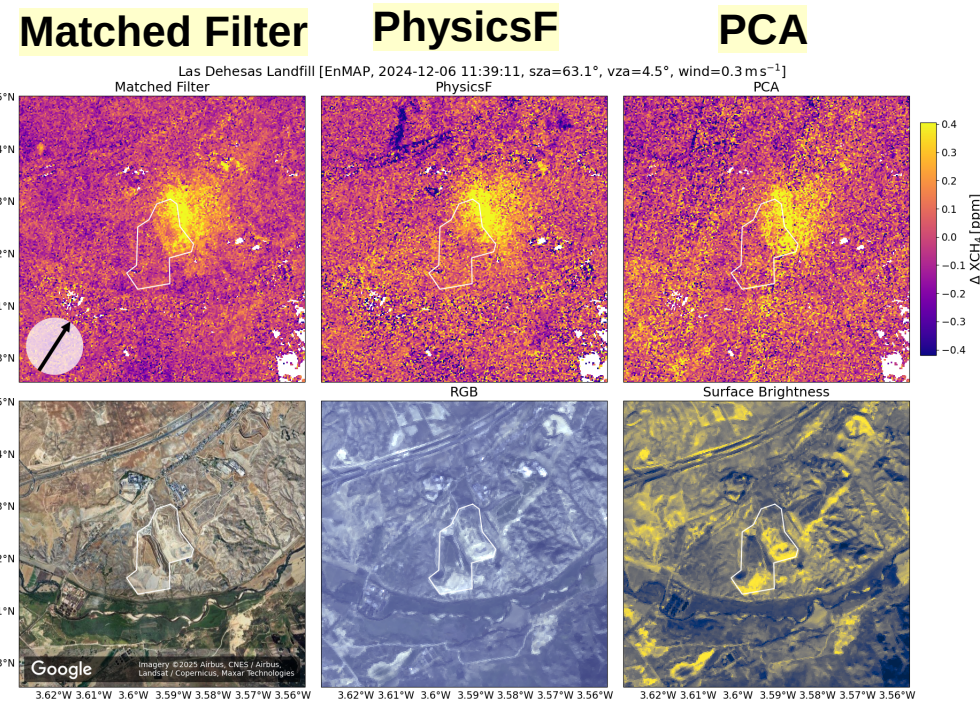
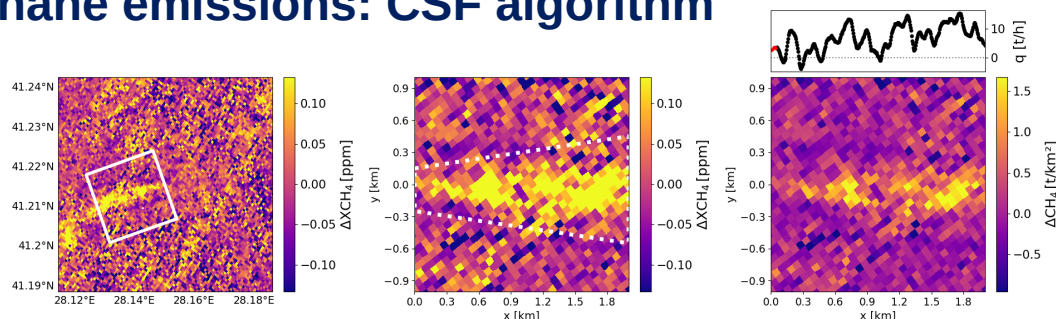
Hyperspectral Imager (HI) @ 30m/60m res.



Methane enhancement retrievals:

- Three methods under development („HiFi“)
 - Differ primarily w.r.t. forward model F & measurement error covariance matrix S_e
 - PhysicsF** (PF) (low order „DOAS polynomial“ e.g. for surface reflectivity, ...)
 - Principal Components Analysis (**PCA**) (PCs instead of polynomial)
 - Matched Filter** (MF) (e.g., no polynomial but S_e from image)

Methane emissions: CSF algorithm



European localized emission sources

CSF method applied
to EnMAP and EMIT



**Inventory of point source
emissions of CH₄
estimated from high-
resolution satellite data**

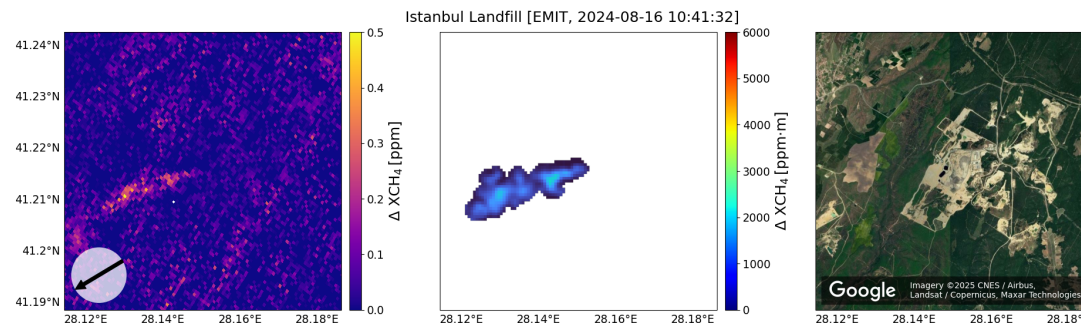
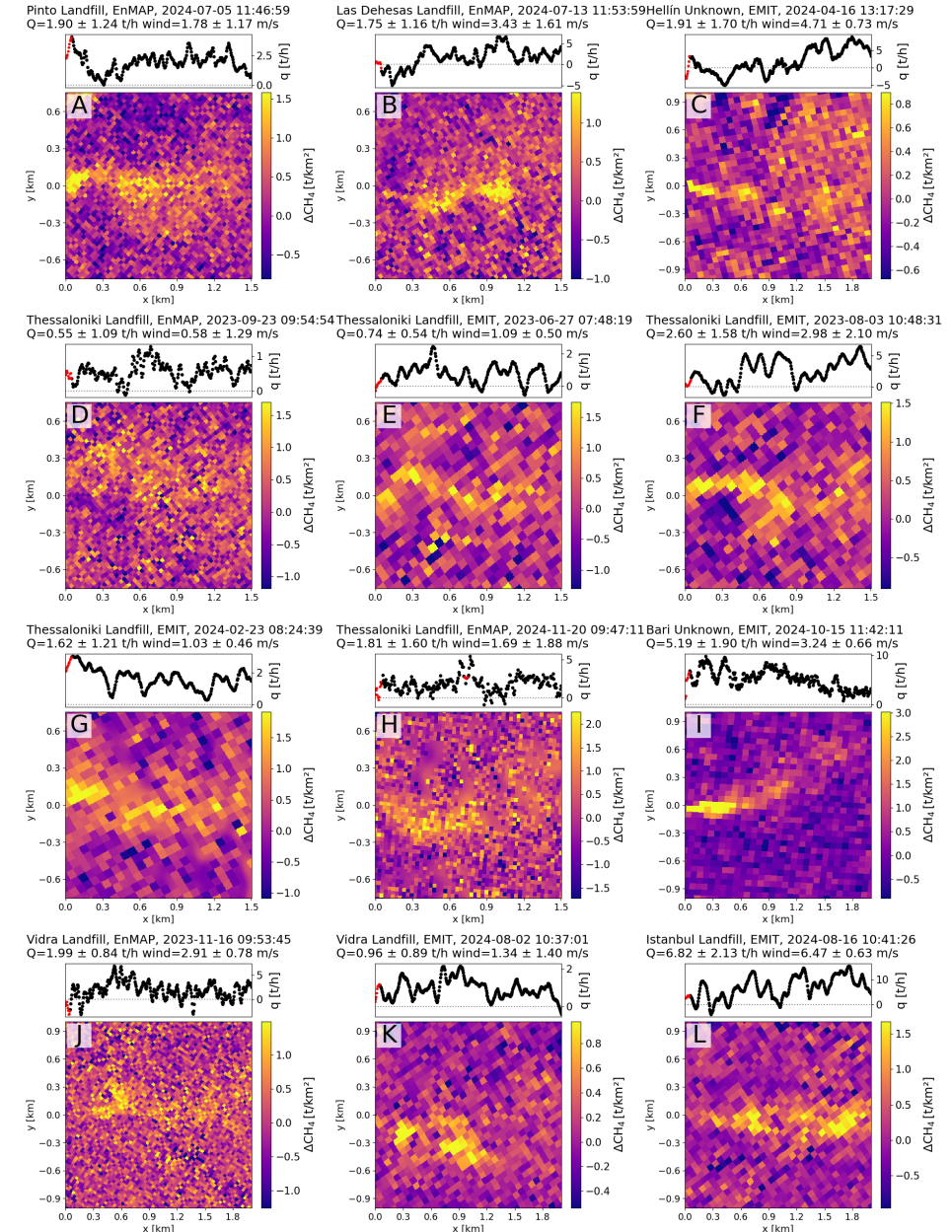
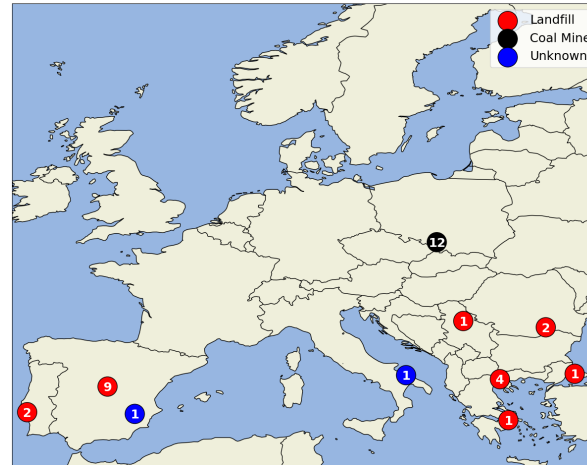
DELIVERABLE 1.4

Author(s): Hartmut Bösch, Michael Hilker
Date of submission: 11-03-2025
Version: 1.0
Responsible partner: University of Bremen
Deliverable due date: 31-12-2024
Dissemination level: Public

Call: HORIZON-CL5-2022-D1-02
Topic: Climate Sciences and Responses
Project Type: Research and Innovation Action
Lead Beneficiary: NILU - Norsk Institutt for Luftforskning

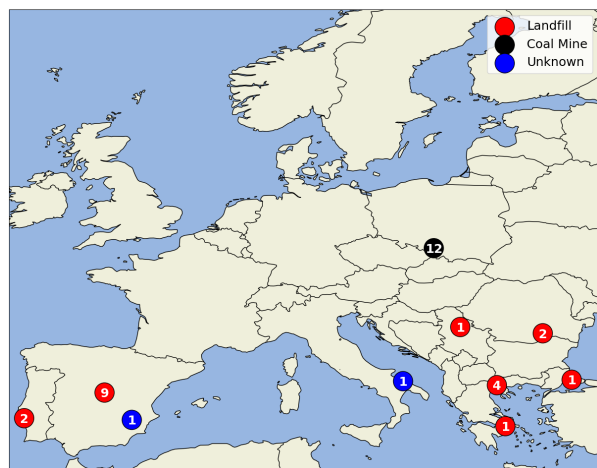
This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101011395

<https://eyeclima.eu/>



European localized emission sources

CSF method applied
to EnMAP and EMIT



Inventory of point source
emissions of CH₄
estimated from high-
resolution satellite data

DELIVERABLE 1.4

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<https://eyeclima.eu/>

Details see talk

**Bösch et al., Assessment of European localized
CH₄ Emission Sources with hyperspectral sensors**
Today in Session A.04.01 14:00-15:30

Comparisons of landfill emission estimates:

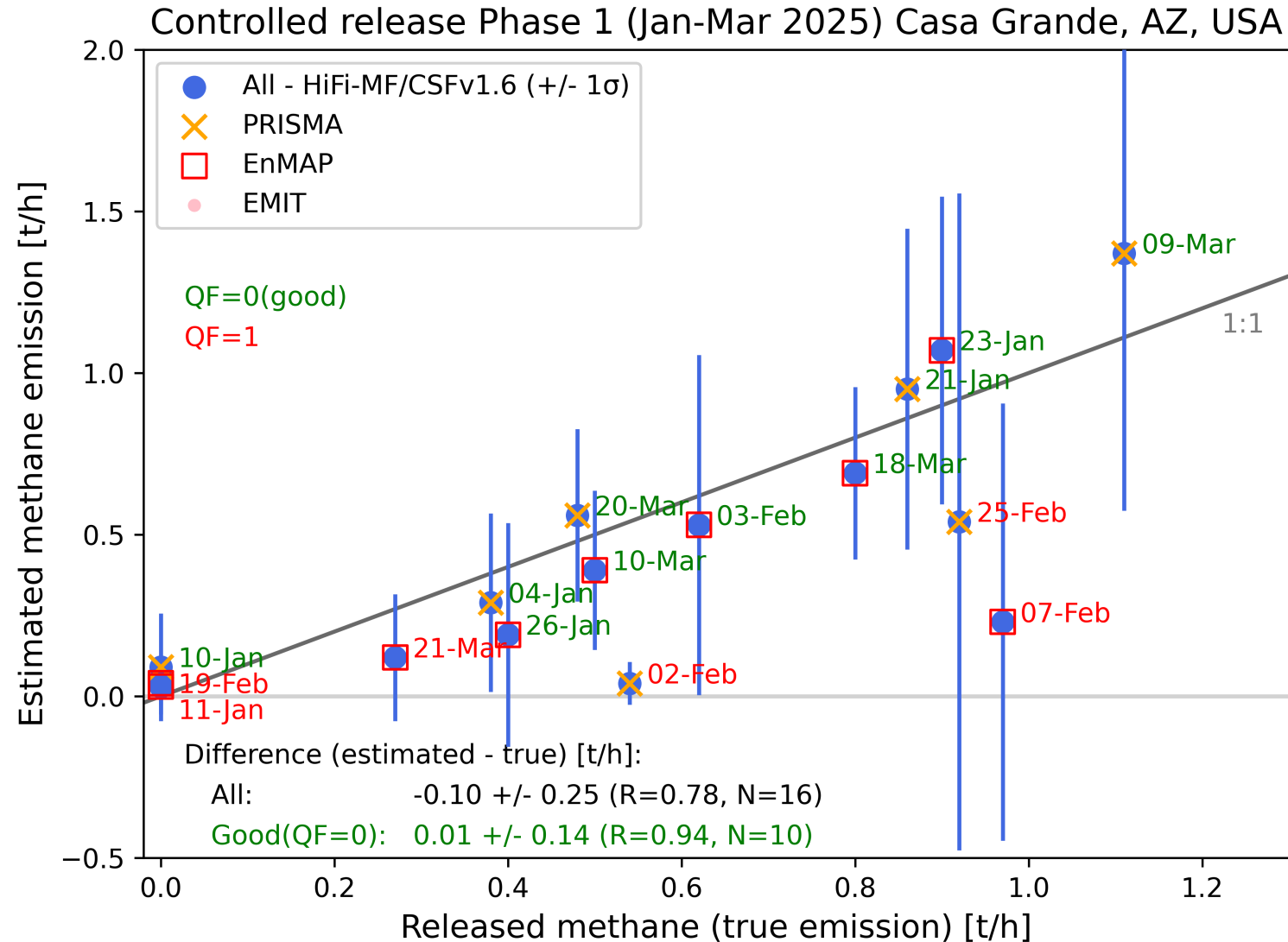
Location	Scene	Emission rate [t/h]				
		HiFi (Our study)	Carbon Mapper (EMIT) (S)	Carbon Mapper (Tanager)	GHGSat (2021 - 2022)	E-PRTR 2022
Pinto Landfill	EnMAP_20240705T114659	1.90±1.24 (0.44)	-	1.28±0.37	4.48±0.57	0.04
Las Dehezas Landfill	EnMAP_20240713T115359	1.75±1.16 (0.94)	-	1.77±0.74	2.98±0.42	0.17
Hellin Unknown	EMIT_20240416T131729	1.91±1.70 (1.66)	2.09±0.15	-	-	-
Thessaloniki Landfill	EnMAP_20230923T095454	0.55±1.09 (0.13)	-	1.83±0.56	2.91±0.99	0.68
	EMIT_20230627T074819	0.74±0.54 (0.20)	-			
	EMIT_20230803T104831	2.60±1.58 (0.82)	2.31±0.61			
	EMIT_20240223T082439	1.62±1.21 (0.38)	1.62±0.32			
	EnMAP_20241120T094711	1.81±1.60 (0.43)	-			
Bari Unknown	EMIT_20241015T114211	5.19±1.90 (1.35)	4.93±0.42	-	-	-
Vidra Landfill	EnMAP_20231116T095345	1.99±0.84 (0.58)	-	-	2.15±0.58	0.05
	EMIT_20240802T103701	0.96±0.89 (0.23)	0.62±0.06			
Istanbul Landfill	EMIT_20240816T104126	6.82±2.13 (1.94)	3.57±0.49	-	7.21±0.99	-

(S) <https://data.carbonmapper.org/>

□ Same EMIT scene

Stanford-Michigan Controlled Releases

2024 – 2025 Methane
Controlled Releases



Single-blind test:

- Satellite-derived emissions submitted in April 2025
- „True emission“ information provided in May 2025



- **TROPOMI/S5P WFMD XCH₄ data product:**
 - WFMD v1.8 product (Schneising et al., 2023) used to identify emission hotspots (Vanselow et al., 2024)
 - Improved WFMD v2.0 XCH₄ and XCO product available (https://www.iup.uni-bremen.de/carbon_ghg/products/tropomi_wfmd/)
- **Methane emission estimates via S5P and Hyperspectral Imagers:**
 - Cross-Sectional-Flux (CSF) algorithm
 - First results from S5P, PRISMA, EnMAP, EMIT
 - Emission estimates European localized sources (EYE-CLIMA)
 - Detailed comparisons within MEDUSA (ongoing)
 - Participation Stanford-Michigan Controlled Releases 2024/25