ATMOS
1-5 July 2024 | Bologna, Italy

Retrieving atmospheric methane information from Sentinel-5 Precursor, PRISMA and EnMAP within ESA GHG-CCI and related projects

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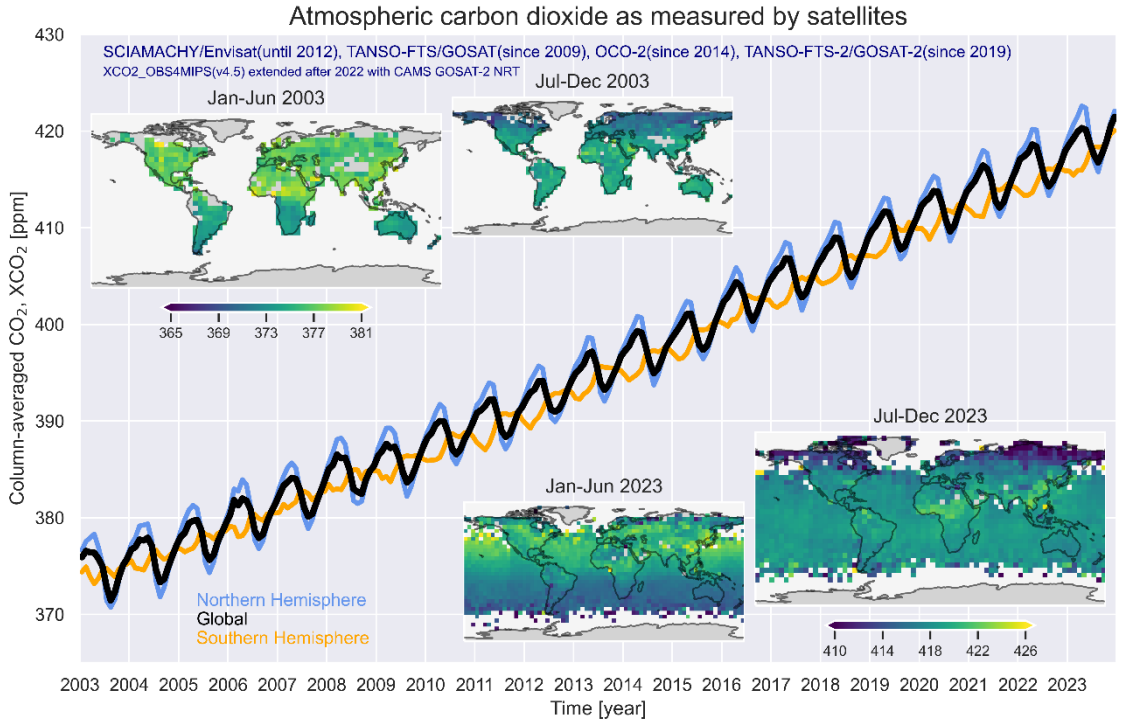
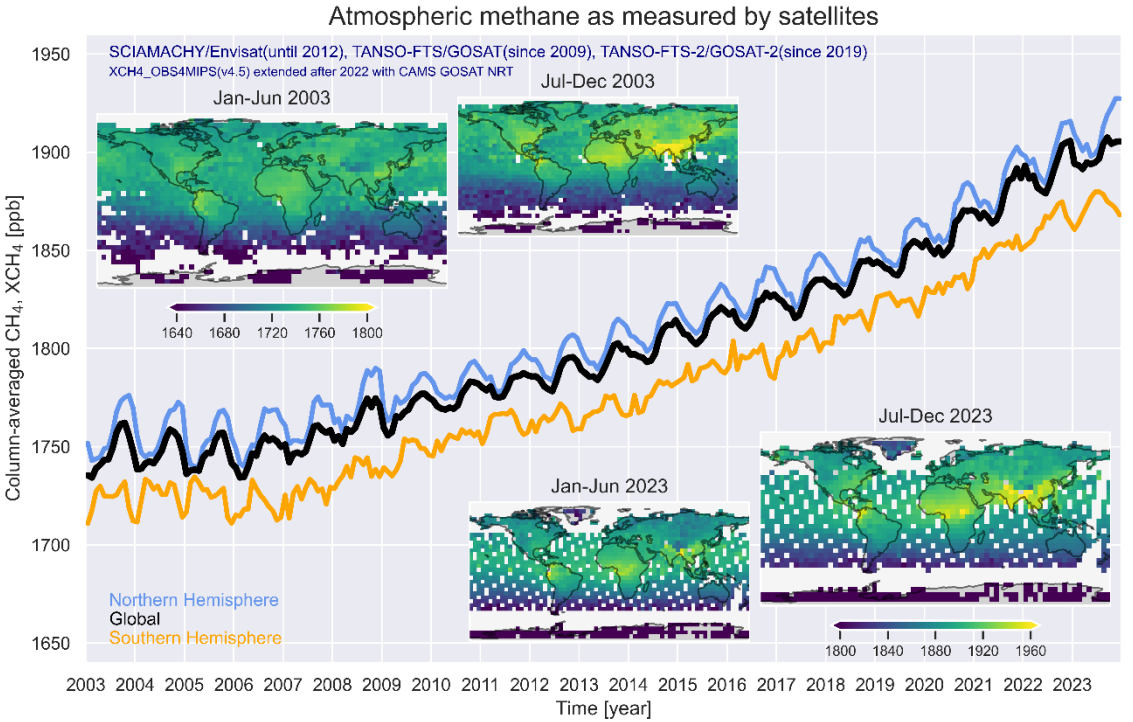
Focus is on selected Univ. Bremen results; for entire GHG-CCI project and team see GHG-CCI website (https://climate.esa.int/en/projects/ghgs/)

Carbon dioxide & methane

Generation of Climate Data Records (CDRs) of Greenhouse Gas (GHG) Essential Climate Variables (ECVs) started via ESA GHG-CCI and is now continued operationally via C3S. Data sets shown here are extended by CAMS NRT XCO_2 and XCH_4.





SCIAMACHY
GOSAT
OCO-2
GOSAT-2

SCIAMACHY
GOSAT
GOSAT-2

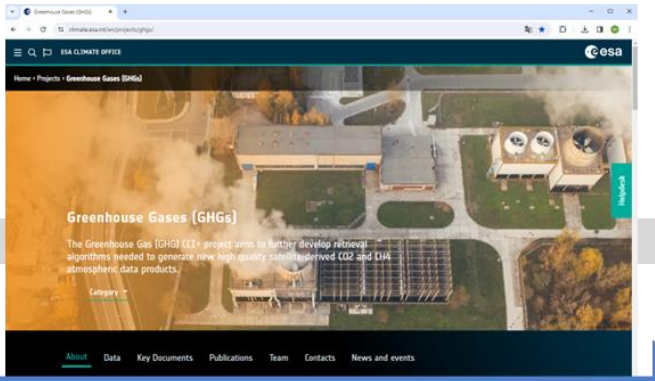
Future: Add S5P, …, CO2M, …

GHG-CCI & related projects

… to generate, assess and use satellite-derived XCH_4 (and XCO_2) products

ESA Methane+: SWIR-TIR combination (S5P+IASI, …), … (ended 2023)
ESA MethaneCAMP: Arctic (ended 5.2024)
ESA SMART-CH4: Non-fossil-fuel CH_4 fluxes (waste, wetlands, …)
ESA MEDUSA: Development prototype for methane emission hotspots
EU: EYE-CLIMA: Emissions of climate forcers
…

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



National, EU, …

EUMETSAT for CO2M

R&D for ECV generation

ESA GHG-CCI

2019

ESA GHG-CCI+

SCIAMACHY/Envisat
GOSAT
IASI
…
Multi-sensor merged
(L2 EMMA, L3 OBS4MIPS)

Sentinel-5 Precursor, OCO-2, GOSAT-2, TanSat, PRISMA, EnMAP

E.g. improved GOSAT-2 XCO2 and XCH4

Operational Climate Data Records (CDR)

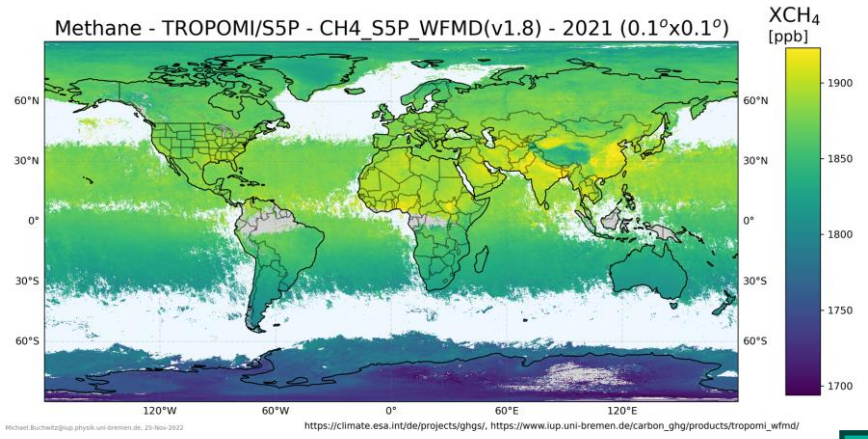
2016

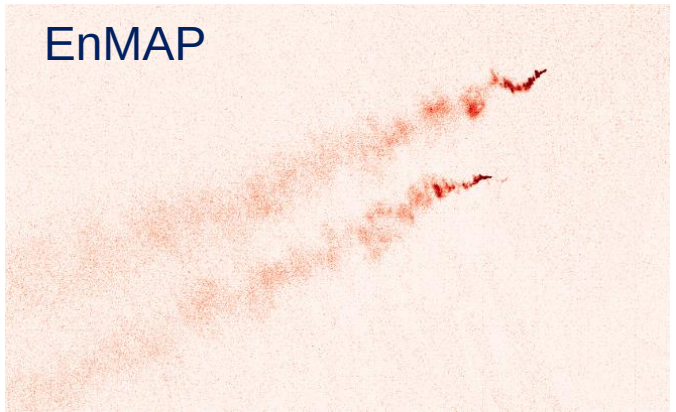
C3S -> Climate Data Store

CAMS / quasi-NRT

GHG-CCI & MEDUSA

ESA GHG-CCI:
Information on atmospheric methane



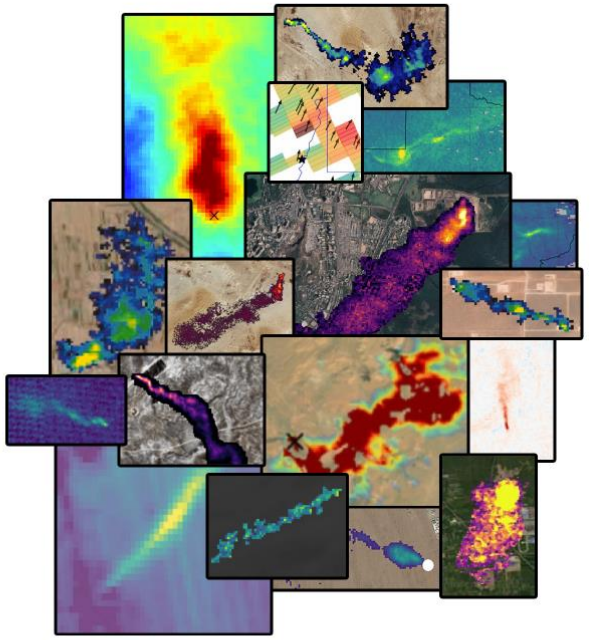


ESA MEDUSA:
Information on methane emissions

Methane Emissions Detection Using Satellites Assessment (MEDUSA)

Authors: SRON, UPV, Kayrros, GHGSat, IUP-UB, and BIRA

Proposal to: AO/1-11905/23/I-NB



SRON Netherlands Institute for Space Research · Universitat Politècnica de València · KAYRROS · GHGSAT · Universität Bremen

In the context of climate change mitigation, Paris Agreement and related GHG monitoring there is the need to develop a system to obtain reliable and actionable information on various methane emission sources.

MEDUSA aims to perform important steps in this direction:

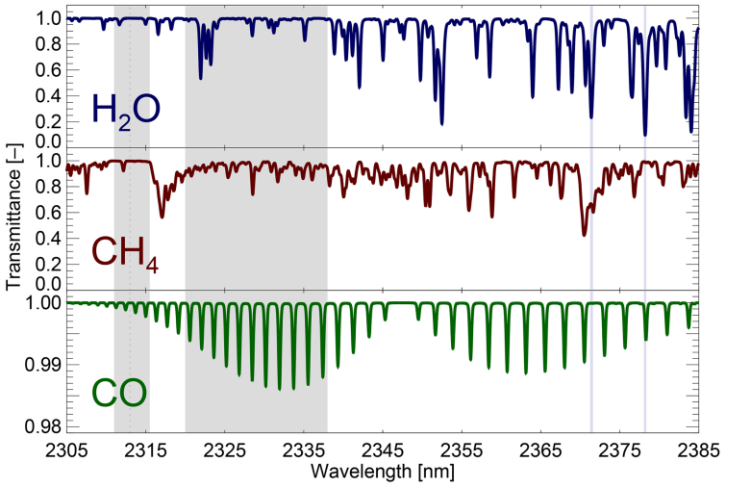
- Use of data from several satellites (S5P, EnMAP, PRISMA, EMIT, S2, S3, L8/9, GOES, GHGSat, …)
- Detailed intercomparison of various algorithms to derive emission information, product comparisons, validation, …
- Integration and synthesis
- User assessments

See also: MEDUSA poster P2.18 presented by Ilse Aben (MEDUSA lead)

TROPOMI/S5P & WFMD algorithm

• TROPOMI/S5P:

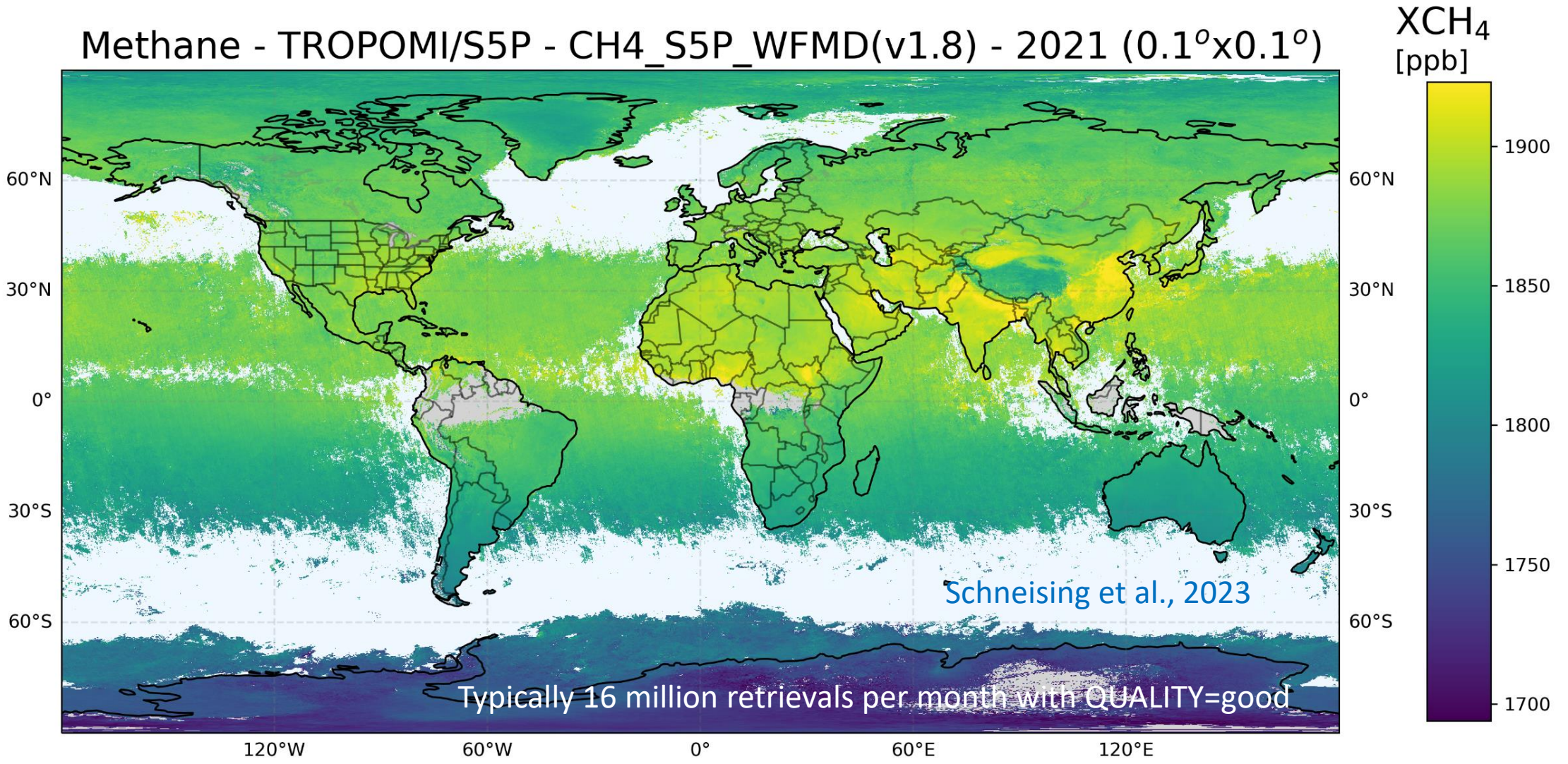
- **Launch: 13-October-2017**; nominal operation started 30-April-2018
- **Spatial resolution & sampling**: 5.5x7 km^2 @ nadir (7x7 km^2 before 6-Aug-2019)
- Covers UV, NIR & SWIR spectral regions; for WFMD we use primarily **2311 – 2338 nm**



• WFMD:

- **Weighting Function Modified DOAS** (Buchwitz et al., JGR, 2000, …, Schneising et al., 2023)
- **Least-squares fit** of vertical column scaling factors for gases (CH_4, CO, H_2O), shift of temperature profile, low-order polynomial, …
- Very fast as based on a **look-up table (LUT)** of pre-computed radiance spectra and corresponding Jacobians, i.e., no online radiative transfer computations (all Level 1 data processed; filtering is part of post-processing)
- **Machine learning (ML)** based post-processing (VIIRS cloud mask & SLIMCH4 model data for training, etc.)
- **Latest version: v1.8** (Schneising et al., AMT, 2023); product available from IUP-Bremen (see https://www.iup.uni-bremen.de/carbon_ghg/) and ESA/CCI (https://climate.esa.int/en/projects/ghgs/).

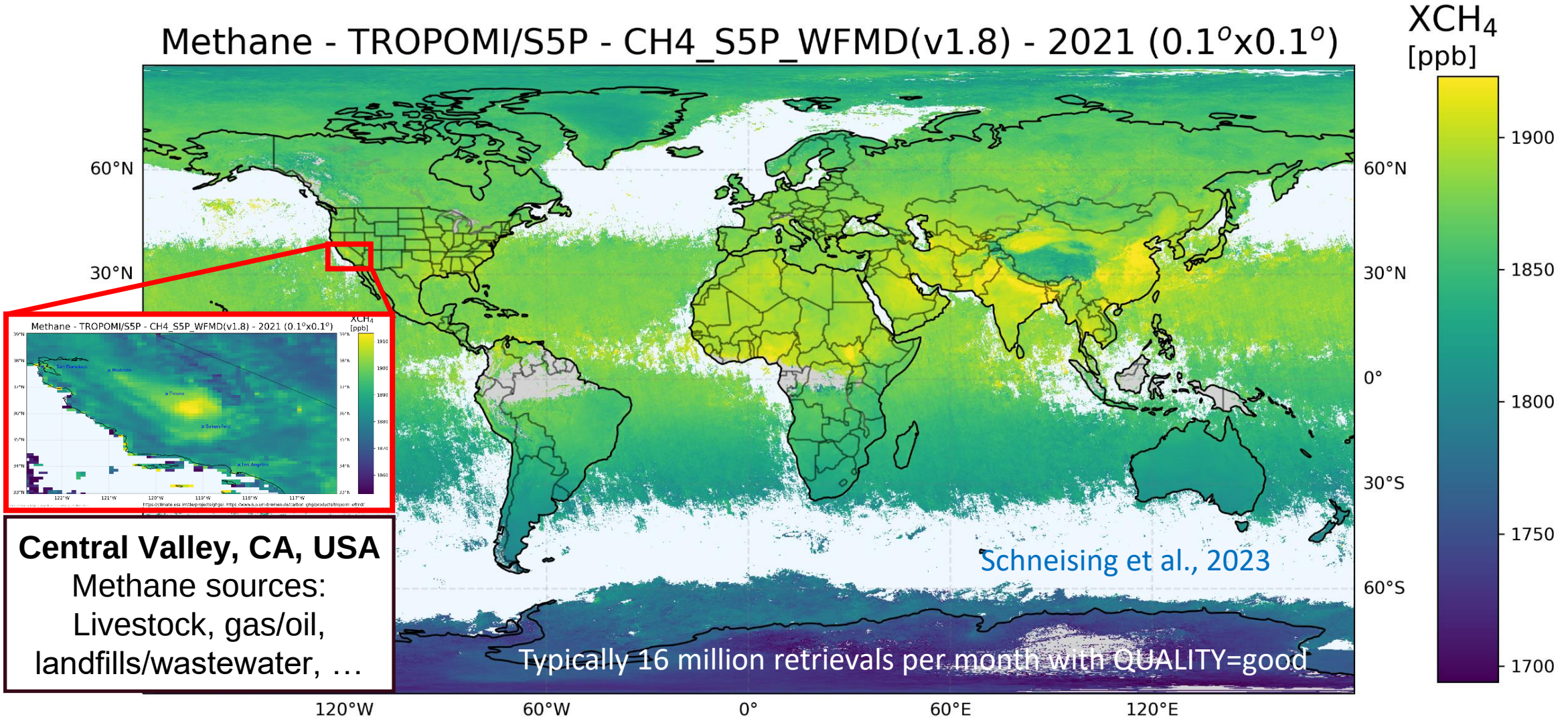
S5P: Methane WFMD(v1.8): 2021



Michael.Buchwitz@iup.physik.uni-bremen.de, 25-Nov-2022

https://climate.esa.int/de/projects/ghgs/, https://www.iup.uni-bremen.de/carbon_ghg/products/tropomi_wfmd/

S5P: Methane WFMD(v1.8): 2021



Central Valley, CA, USA
Methane sources:
Livestock, gas/oil, landfills/wastewater, …

Michael.Buchwitz@iup.physik.uni-bremen.de, 25-Nov-2022

https://climate.esa.int/de/projects/ghgs/, https://www.iup.uni-bremen.de/carbon_ghg/products/tropomi_wfmd/

S5P: Methane WFMD(v1.8): Hotspots

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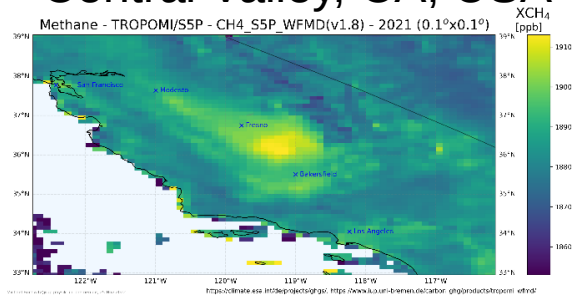
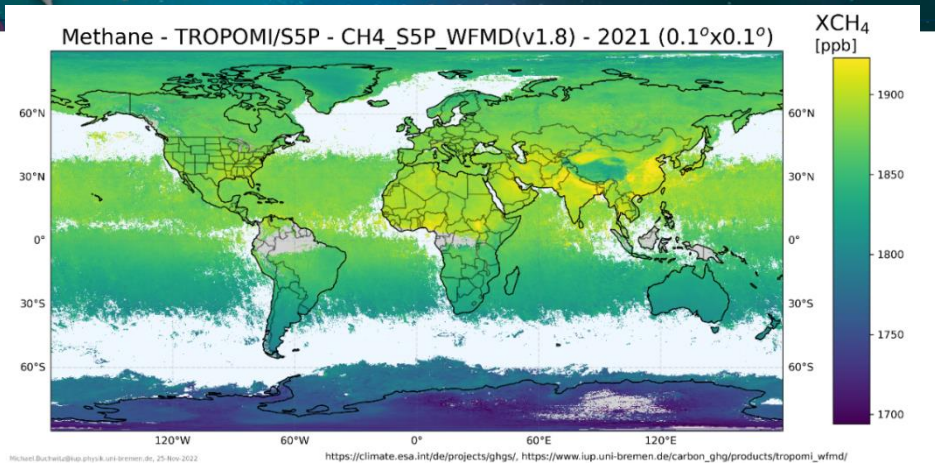
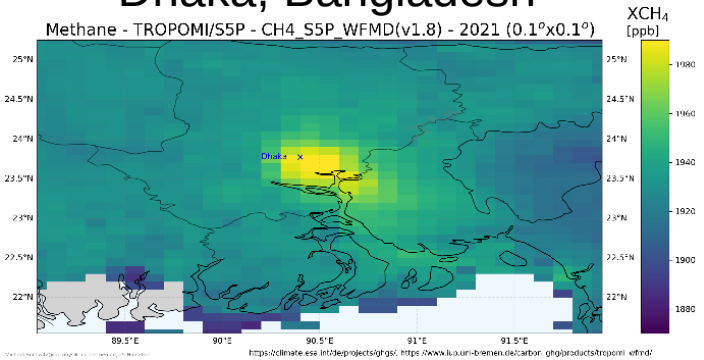
Central Valley, CA, USA

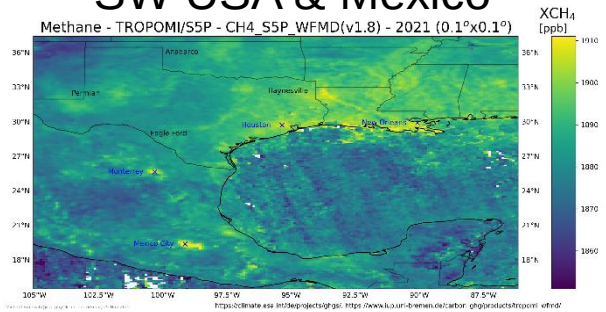




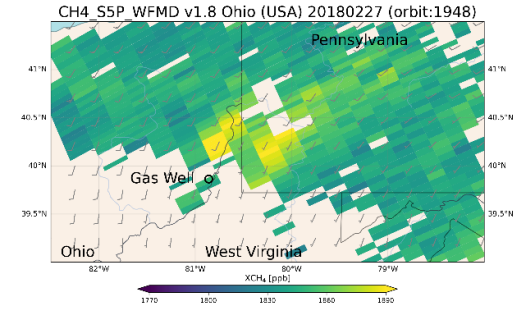
Dhaka, Bangladesh



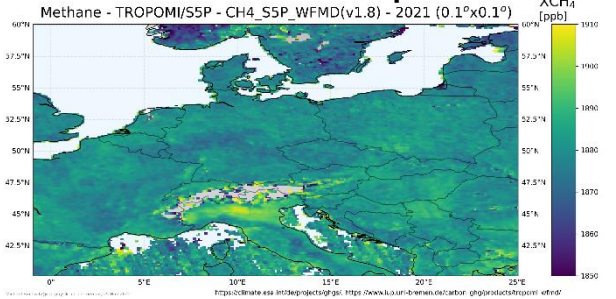
SW USA & Mexico



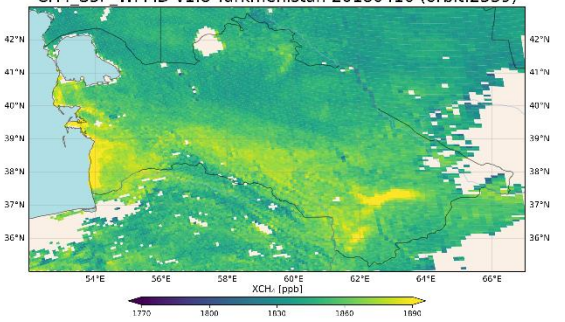
Ohio, USA



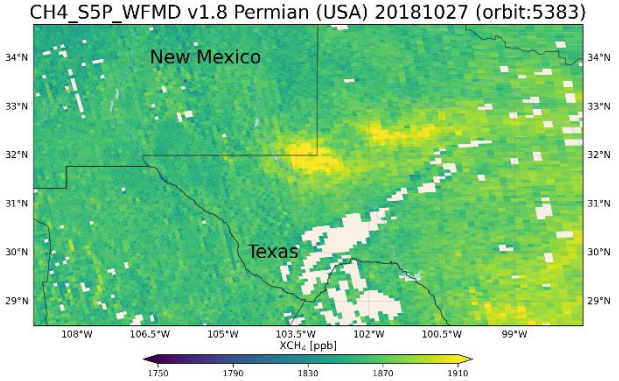
Central Europe



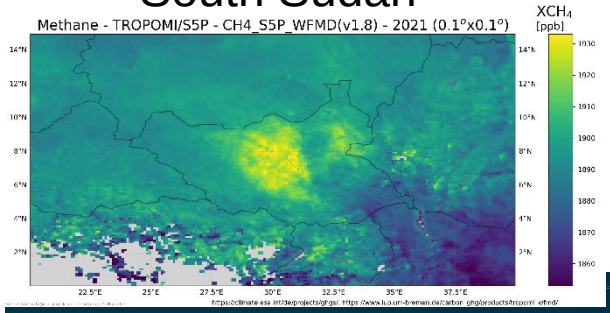
Turkmenistan



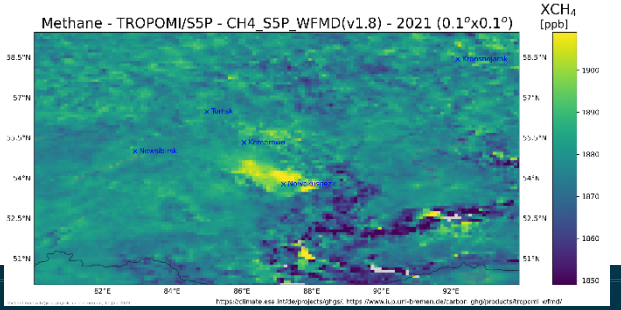
Permian, USA



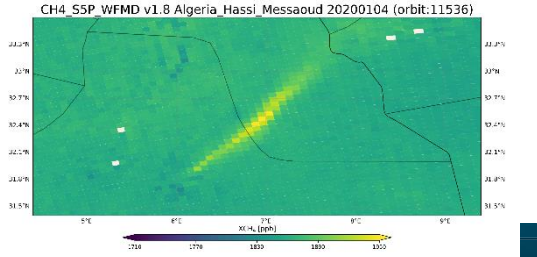
South Sudan



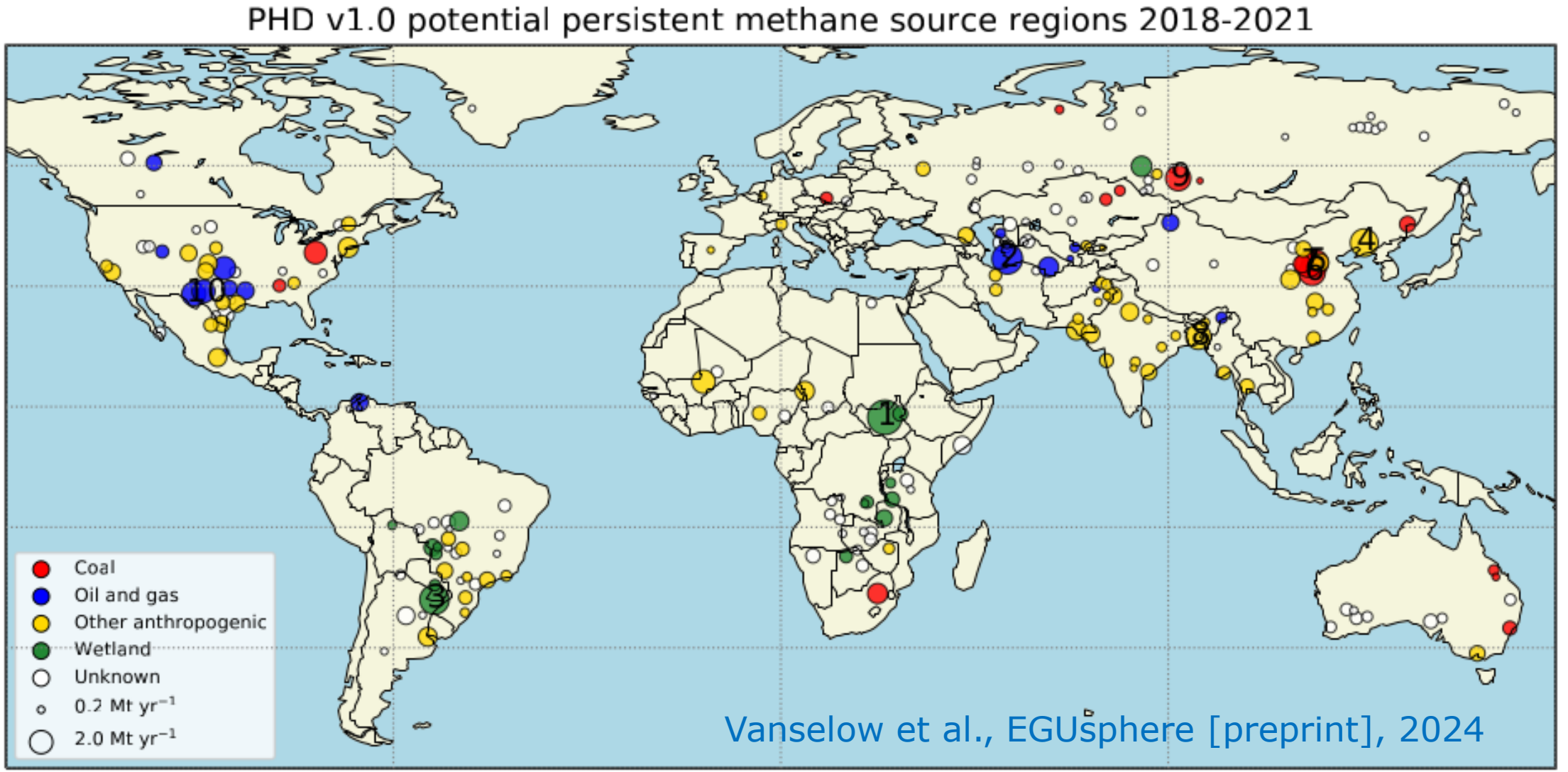
Kuzbass, Russia



Hassi Messaoud, Algeria

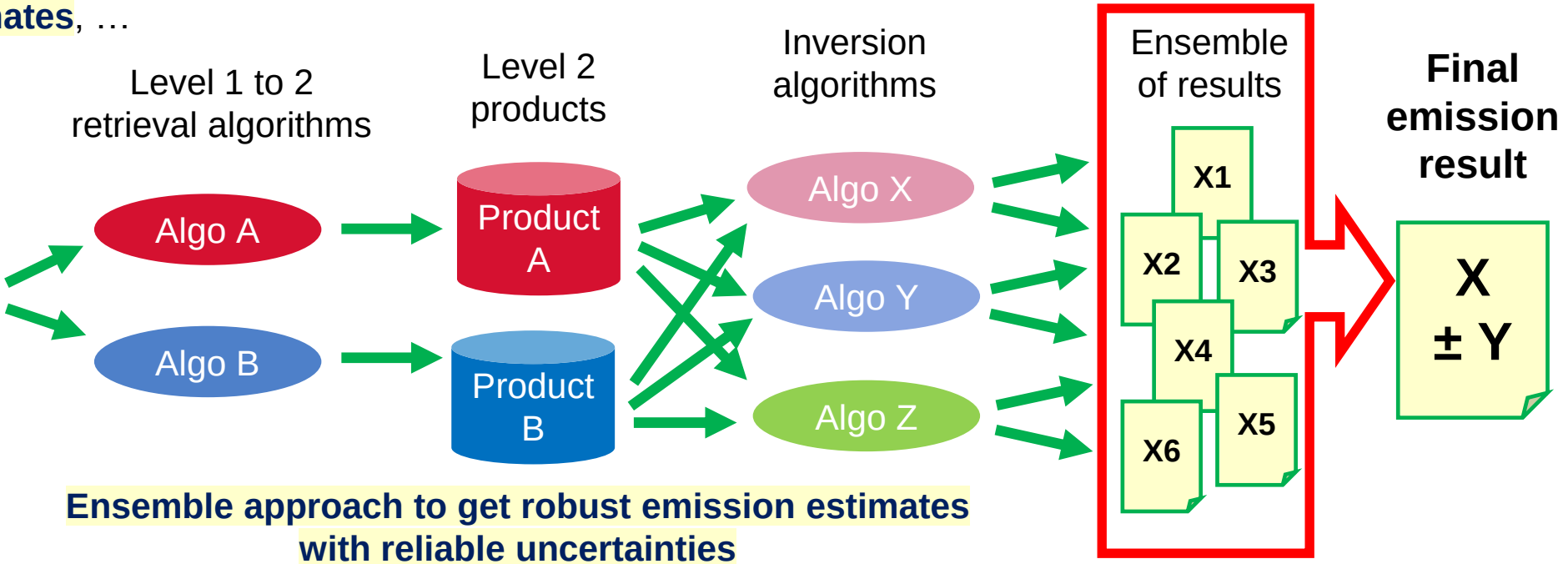


S5P: Methane WFMD(v1.8): Hotspots



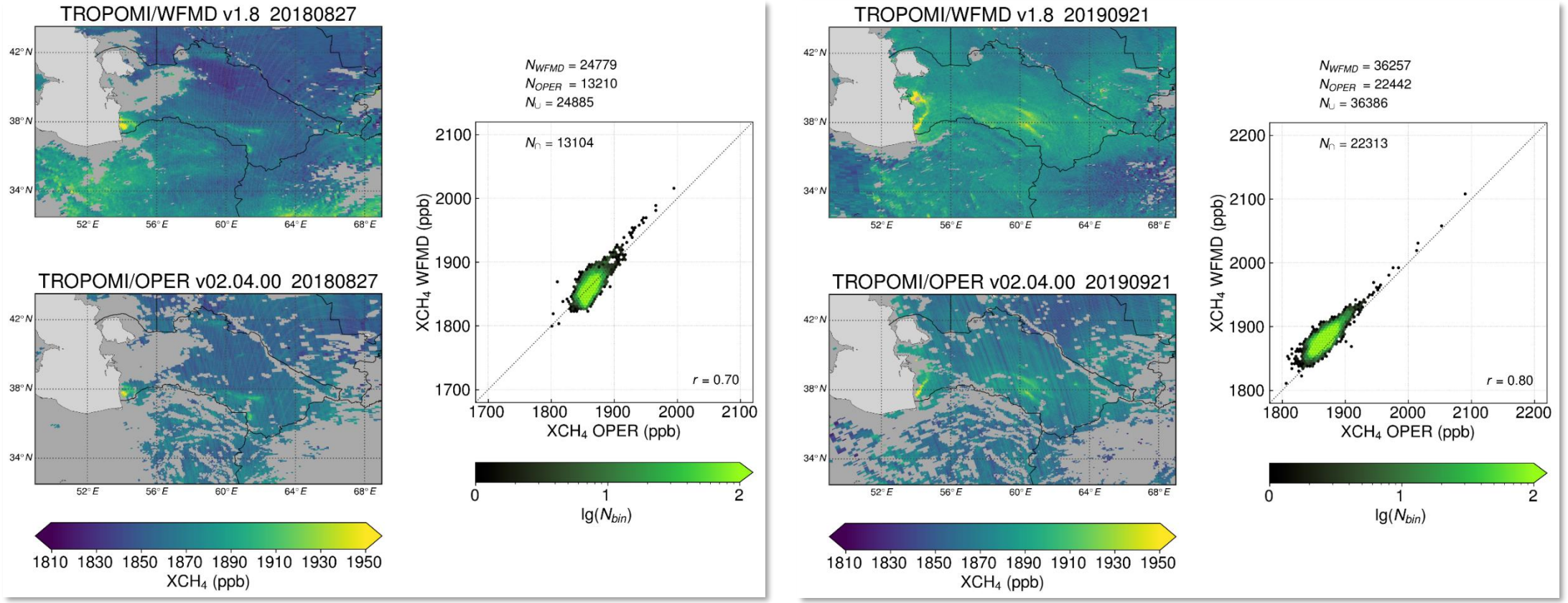
S5P CH4: Multi-algorithm merged product

- Within the ESA GHG-CCI+ project we are developing a **new Level 2 product**, which initially contains both, the scientific WFMD and the OPERational TROPOMI/S5P XCH_4 products (the SRON scientific product is similar as OPER and therefore not included)
- Why?
  - User can easily use both products without worrying about getting large data sets, using different formats etc.; **users can easily switch from one product to another**
  - Different algorithms give different results: Using more that one product enables users to demonstrate that major findings are not due to specific „features“ of a given product/algorithm, **improves robustness of results (e.g., emissions) incl. better error estimates**, …



Ensemble approach to get robust emission estimates with reliable uncertainties

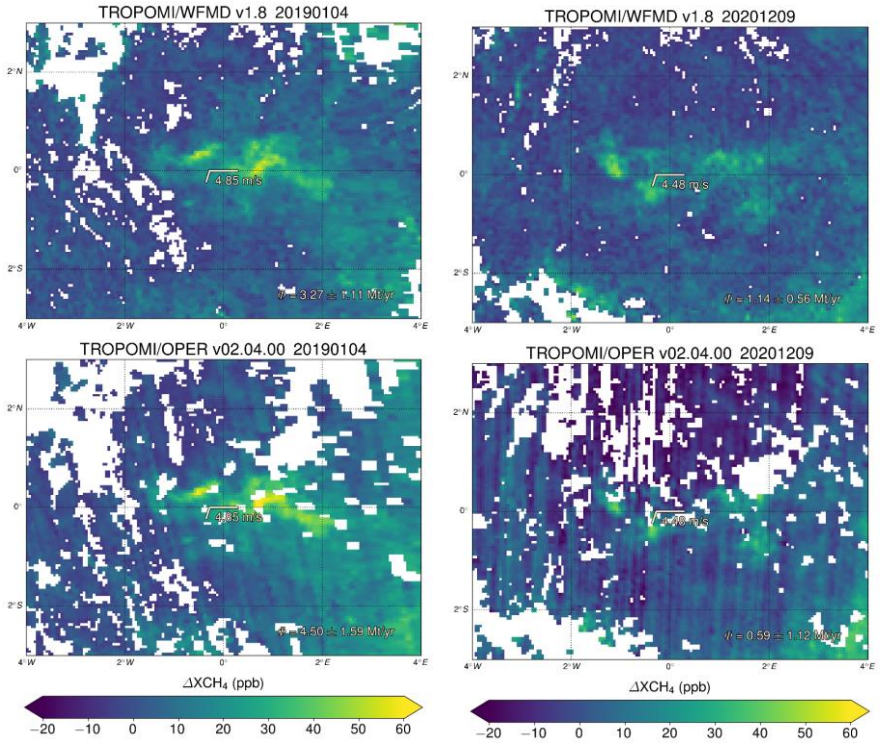
S5P CH4: WFMD vs OPER: Turkmenistan



- Gas & oil fields (see also Schneising et al., ACP, 2020)
- Local methane enhancements: Pattern similar for WFMD and OPER but not identical
- WFMD (v1.8): Typically better coverage & less striping
- OPER (v02.04.00): Next version (v02.07.00) also with striping correction

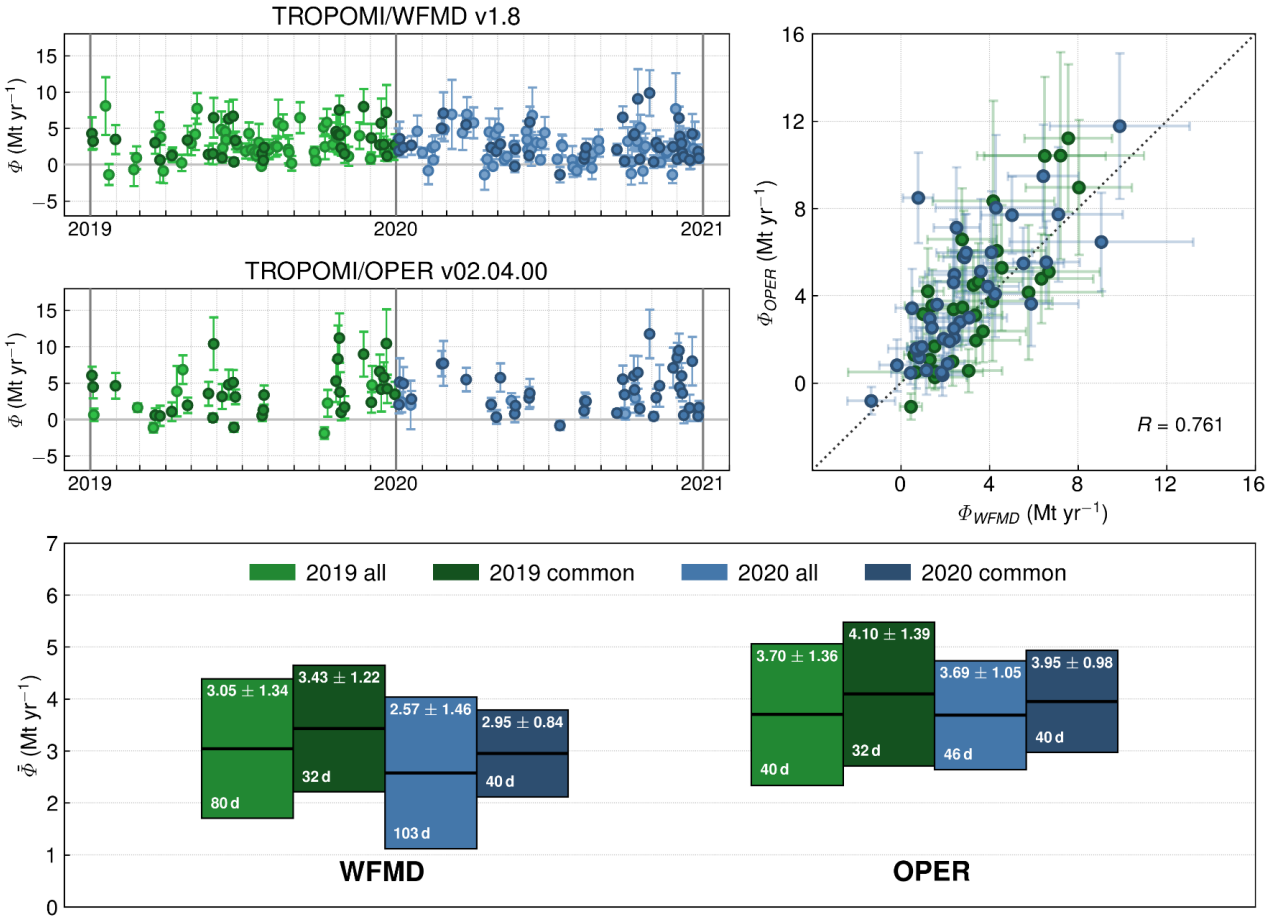
S5P CH4: Comparisons WFMD vs OPER

- Comparisons scientific WFMD v1.8 with OPERational v02.04.00 product



- Differences ΔXCH_4 incl. coverage
- Estimated emissions differ but agree within estimated uncertainty

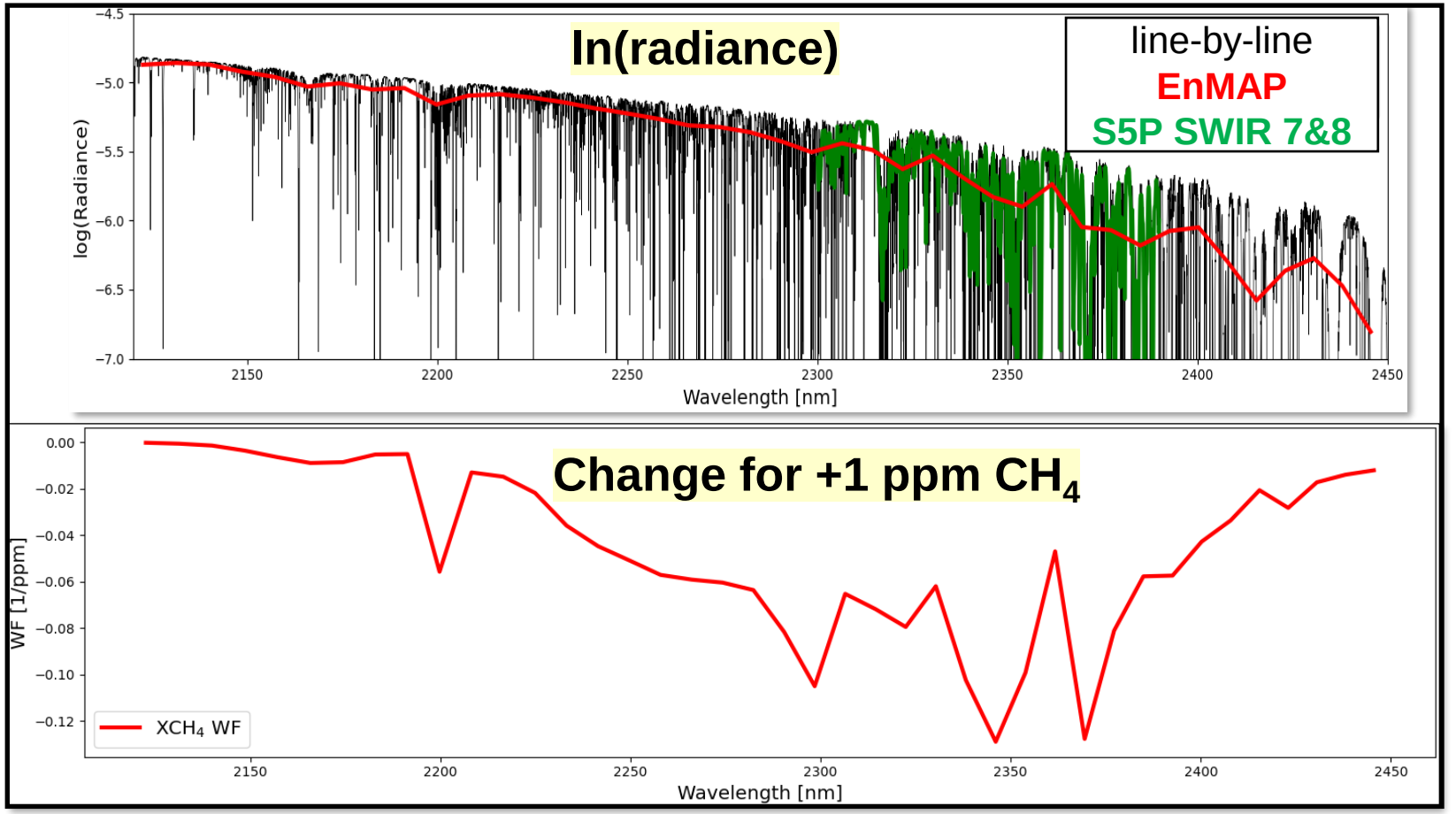
Permian, USA (O&G fields)



Schneising et al., GHG-CCI TN, 2024

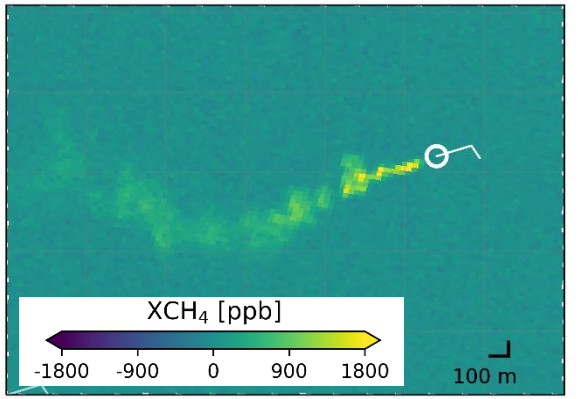
Methane from hyperspectral imagers

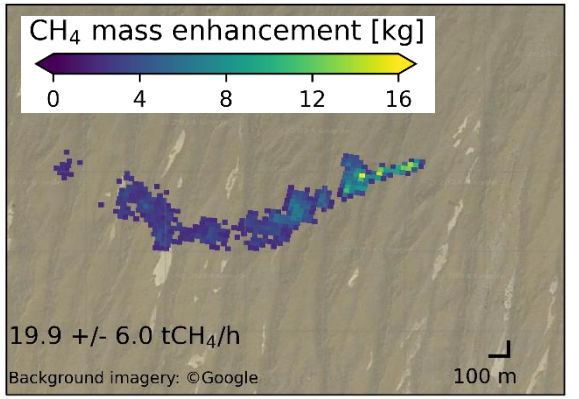
Application of different atmospheric methane enhancement retrieval schemes for point source detection and methane emission quantification from high-spatial-resolution hyperspectral imagers such as **EnMAP & PRISMA**



Methane information

Korpeje O&G field in Turkmenistan via EnMAP

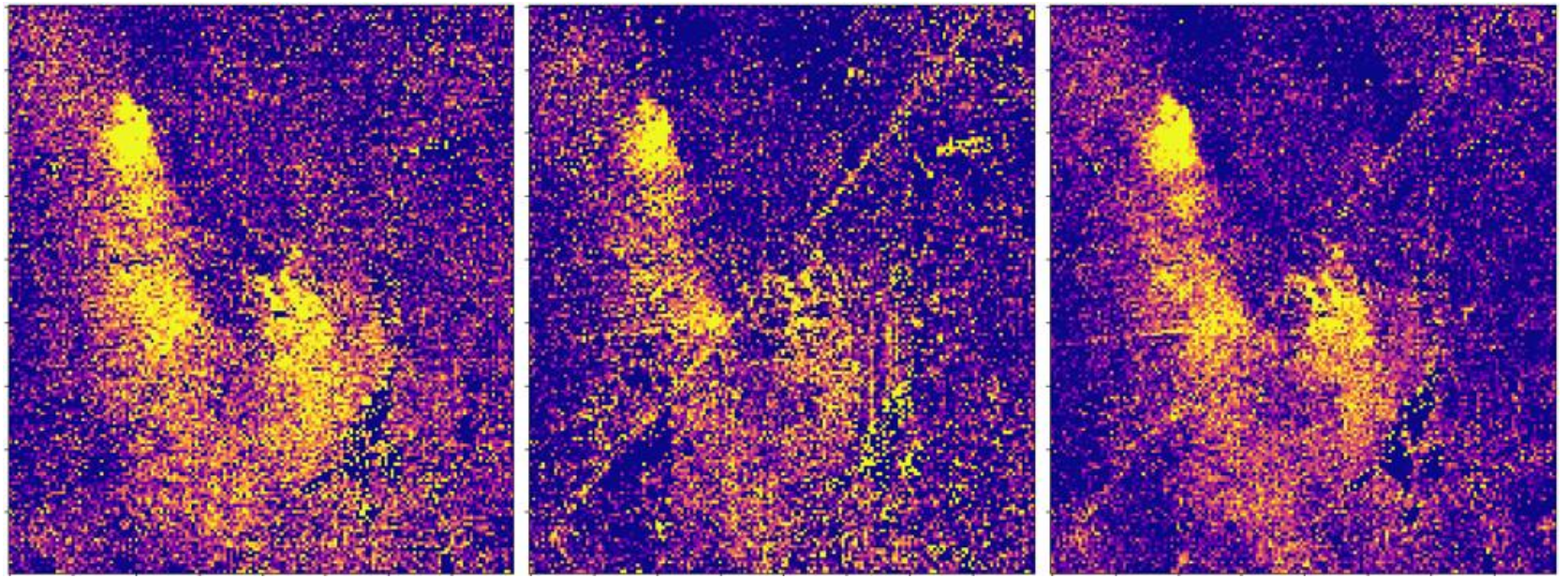




Methane from hyperspectral imagers

- XCH_4 (and XCO_2) retrieval methods for high spatial resolution hyperspectral imagers such as EnMAP & PRISMA:
  - 3 methods under development; they differ primarily w.r.t. forward model F & measurement error covariance matrix S_ε
    - **Physics F (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_ε from image)

3 different methane enhancement images at 30 m resolution (EnMAP)



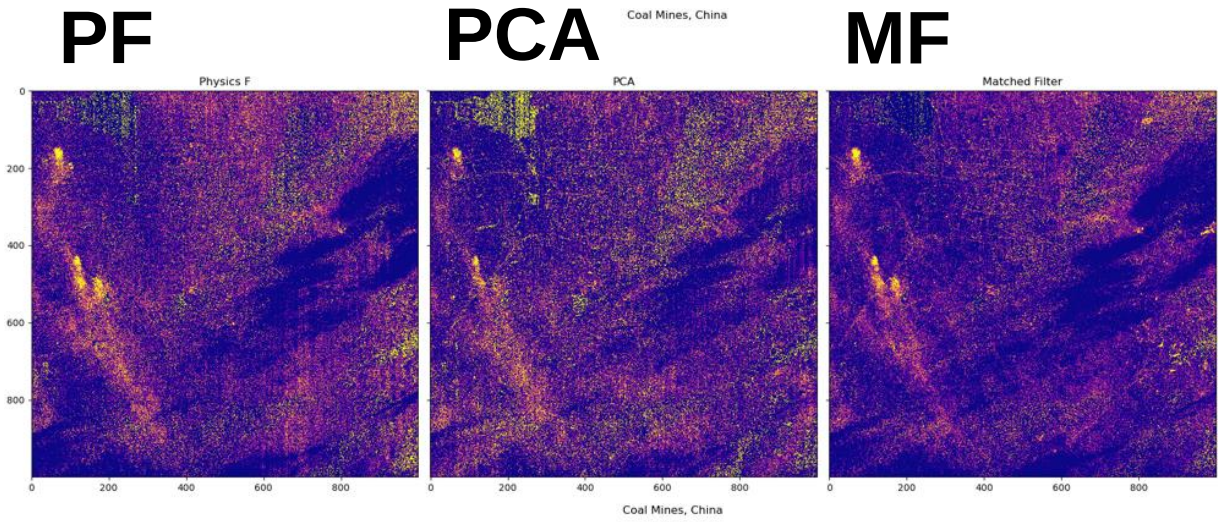
Work in progress

EnMAP: XCH4: China, coal mining area

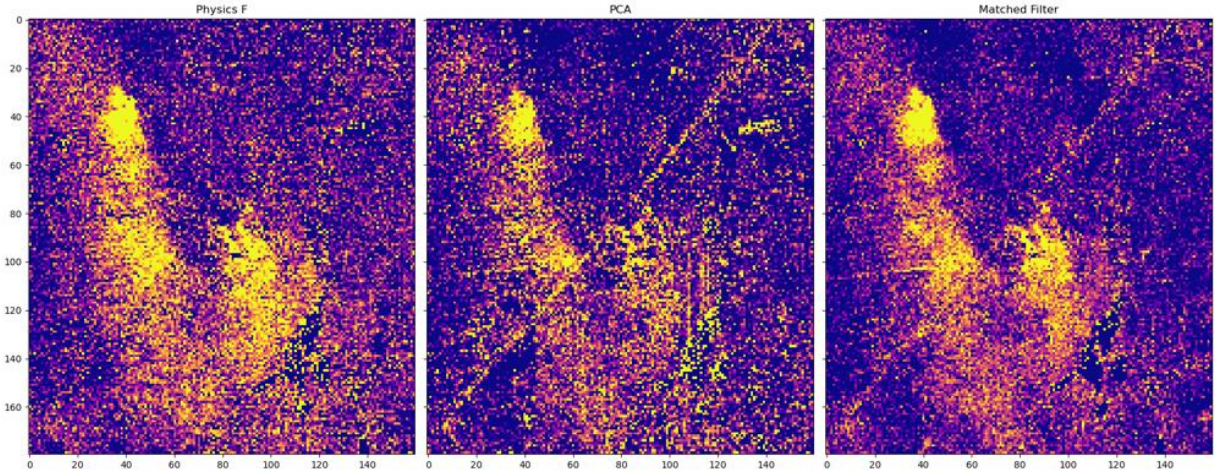
PF **PCA** **MF**

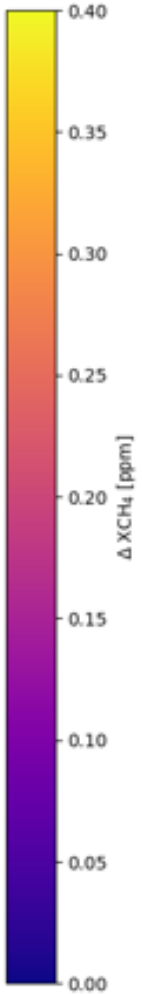
Entire image

30 x 30 km²



Zoom





Work in progress

Methane emission plume signals but also surface features, striping, noise, … (to be investigated & optimized)

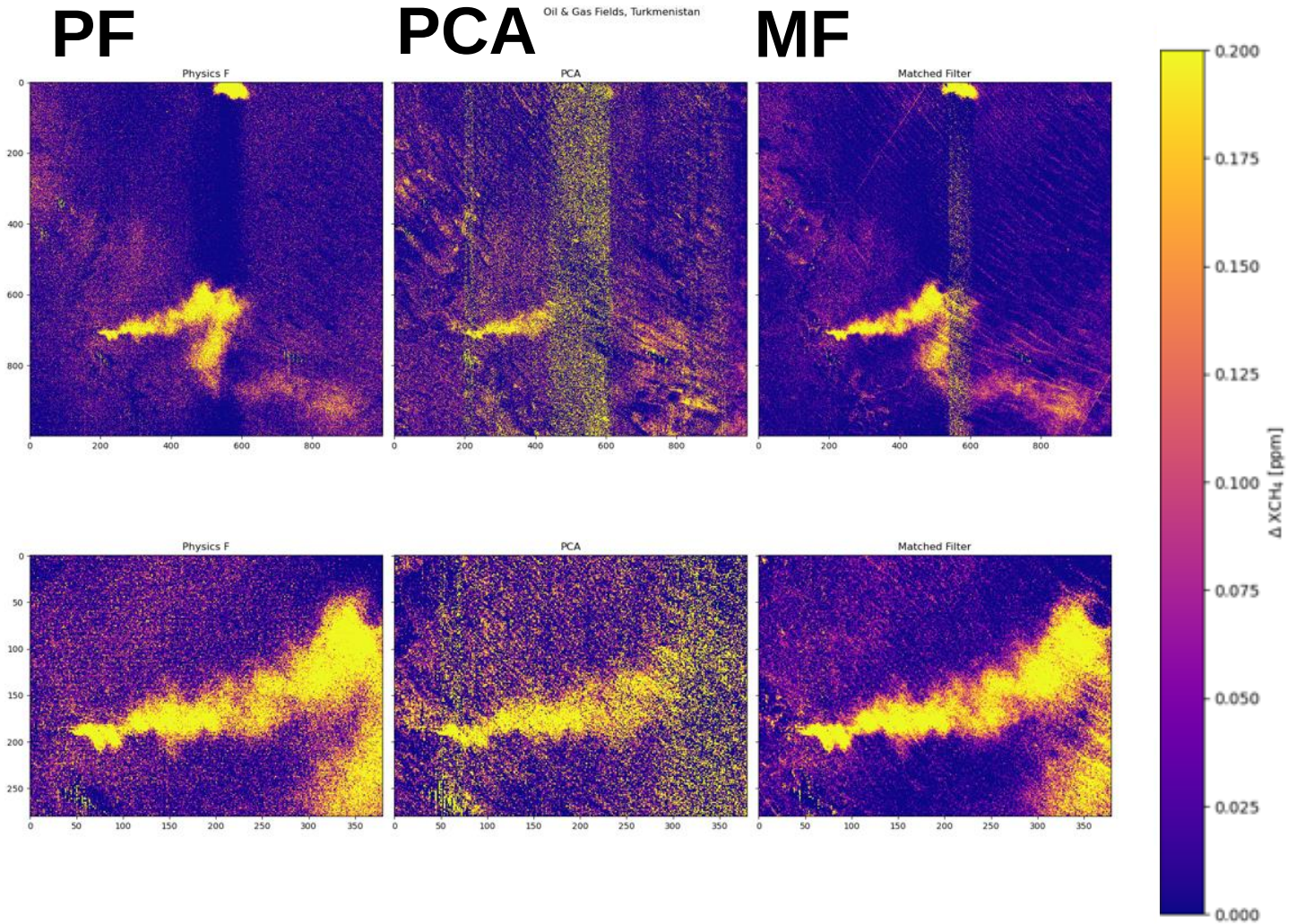
EnMAP: XCH4: Turkmenistan, O&G field

PF **PCA** **MF**

Entire image

30 x 30 km²

Zoom



Work in progress

Methane emission plume signals but also surface features, striping, noise, … (to be investigated & optimized)

Summary & conclusions

- Improved TROPOMI/S5P WFMD retrieval algorithm and related XCH_4 data product (thanks to funding from ESA via GHG-CCI+ & other projects)
  - Details see Schneising et al., AMT, 2023 (https://amt.copernicus.org/articles/16/669/2023/)
- New WFMD v1.8 XCH_4 data product available & continuously temporally extended
  - See information and links on IUP Carbon/GHG website: https://www.iup.uni-bremen.de/carbon_ghg/
- Detailed comparisons with OPERational product (v02.04.00)
  - Overall reasonable to good agreement
  - Reprocessed OPER product significantly improved compared to initial version
  - WFMD typically better coverage and much reduced striping (next OPER will have reduced striping)
- Multi-algorithm merged TROPOMI/S5P XCH_4 product (under development within GHG-CCI+)
  - Level 2 product including averaging kernels etc. (lite, i.e., containing only most relevant parameters)
  - Initially WFMD and OPER (currently available SRON scientific product is similar as OPER)
  - Main purpose: “Ensemble applications”: Users can easily use (switch between) both products
- Methane retrieval and emission estimation from hyperspectral imagers PRISMA & EnMAP
  - Under development, detailed comparisons planned, e.g., in ESA MEDUSA