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Advanced Methane Plume Detection and Inversion Using GF-5B AHSI: A Statistical-Physical Coupling Approach

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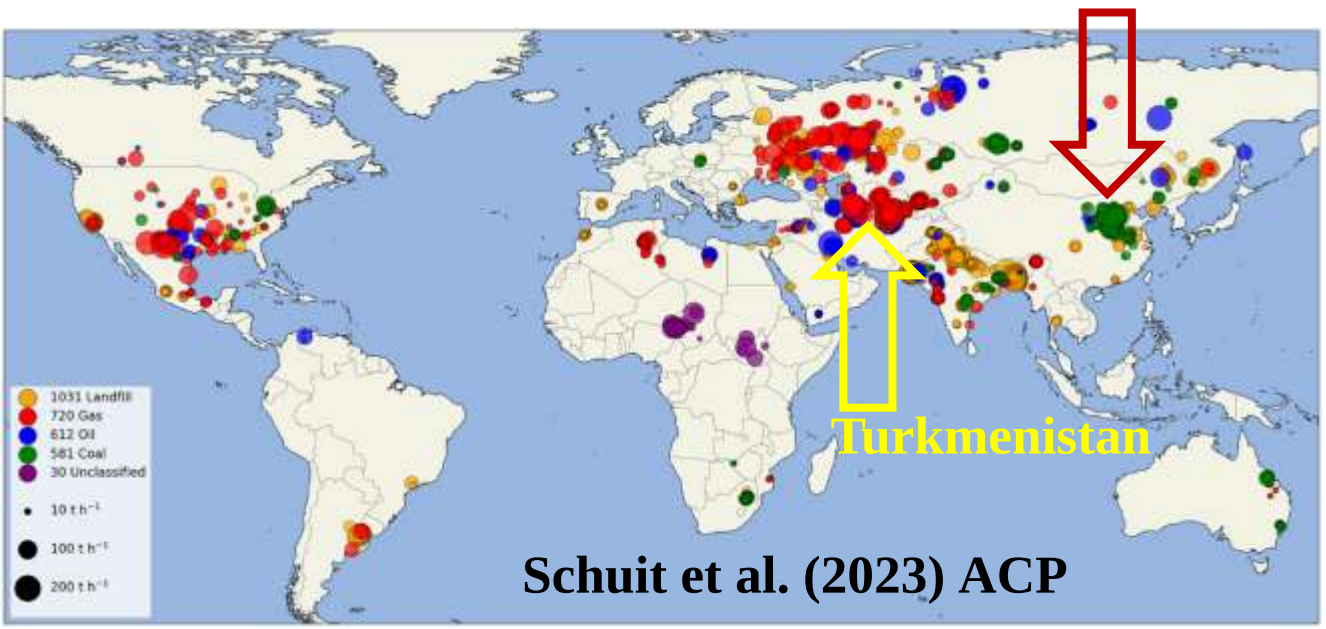
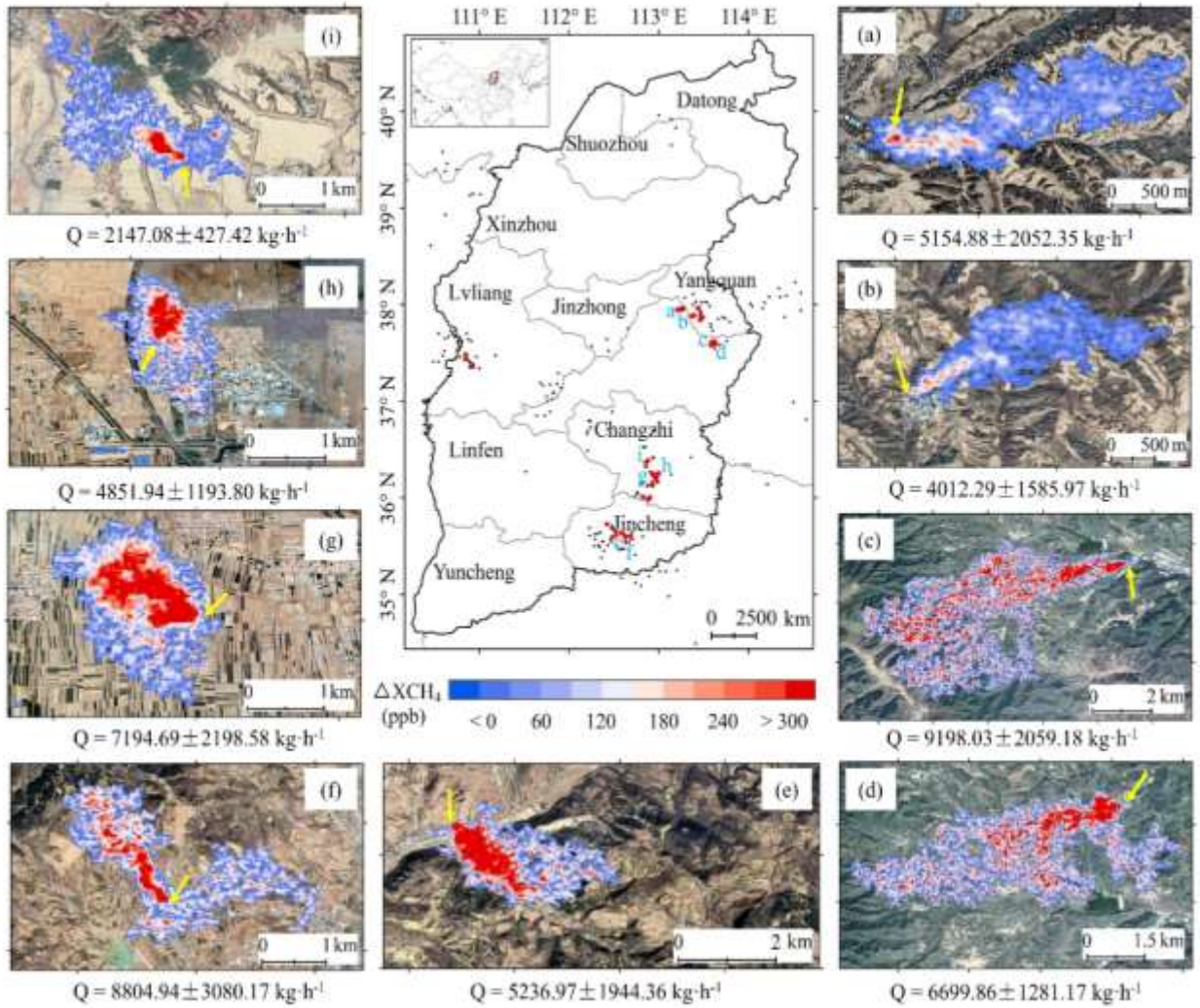
Background: Methane point source emissions in Shanxi

(a) TROPOMI: 134 points in Shanxi

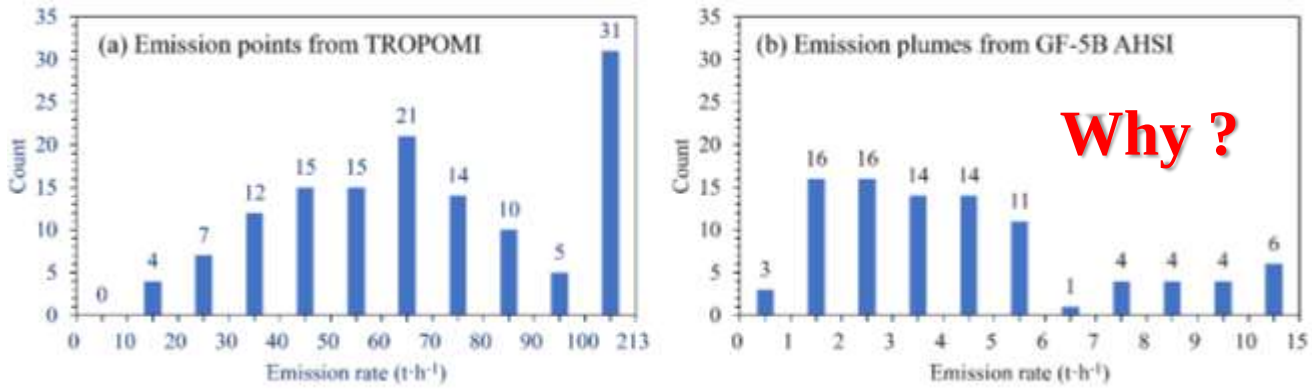


(b) GF-5B/AHSI: 32 points, 93 plumes



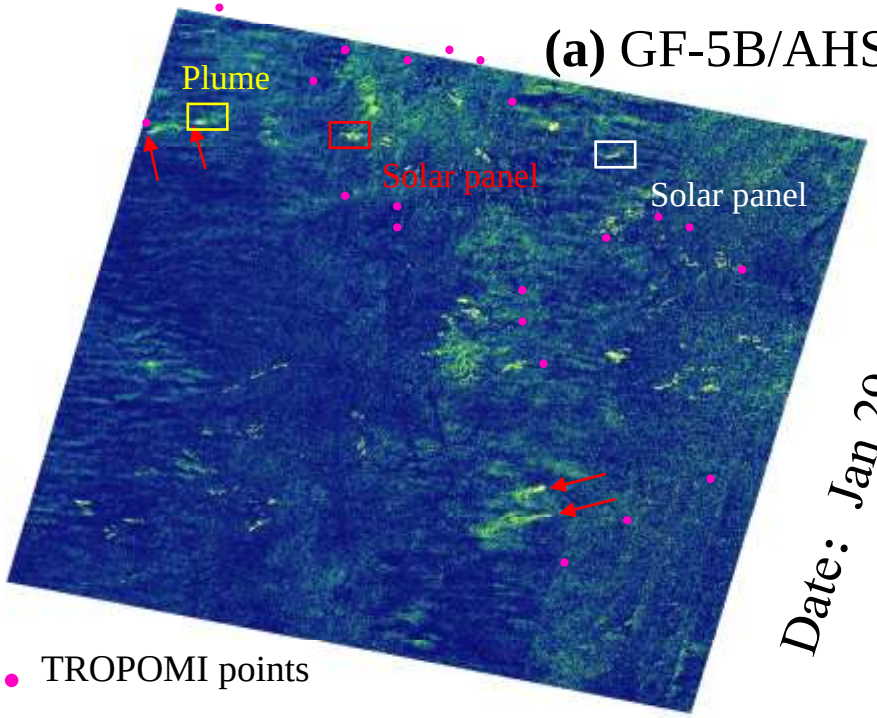
(c) Difference

TROPOMI >> AHSI

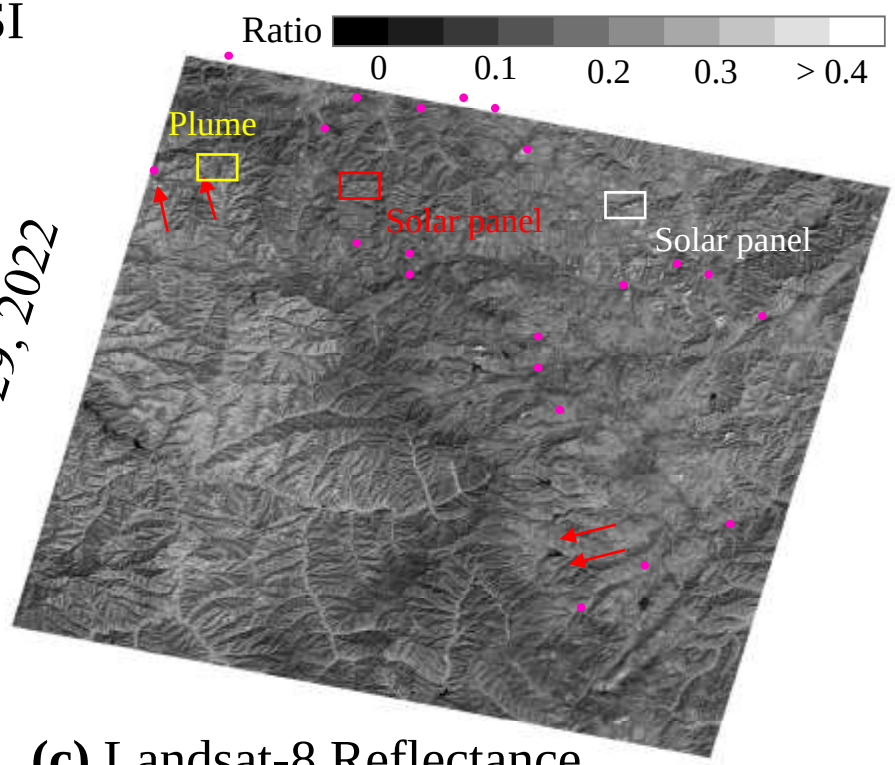


He et al., 2024 AMT (Shanxi/ China):
https://amt.copernicus.org/articles/17/2937/2024/

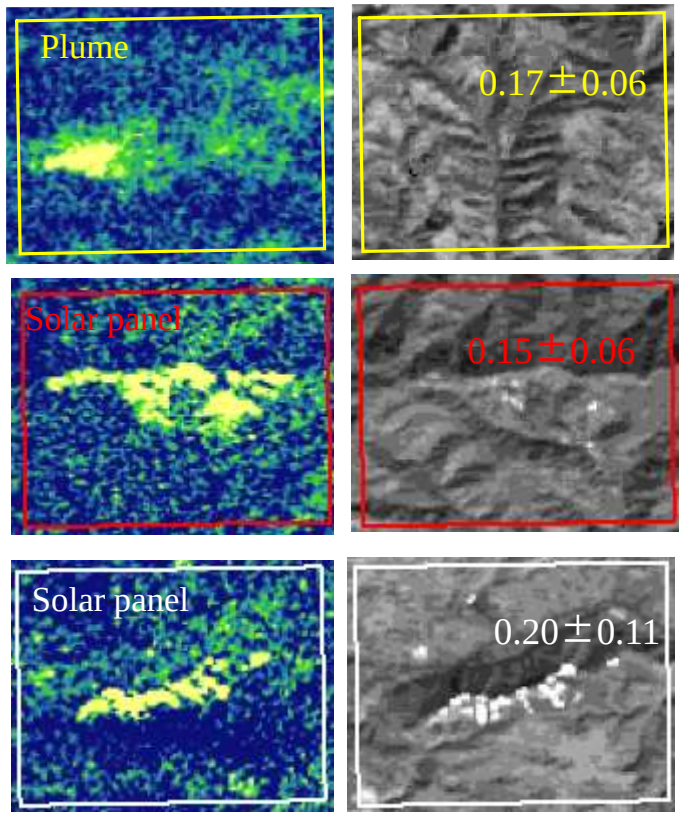
Background: Highly heterogeneous surface effect



Date: Jan 29, 2022



(c) Landsat-8 Reflectance

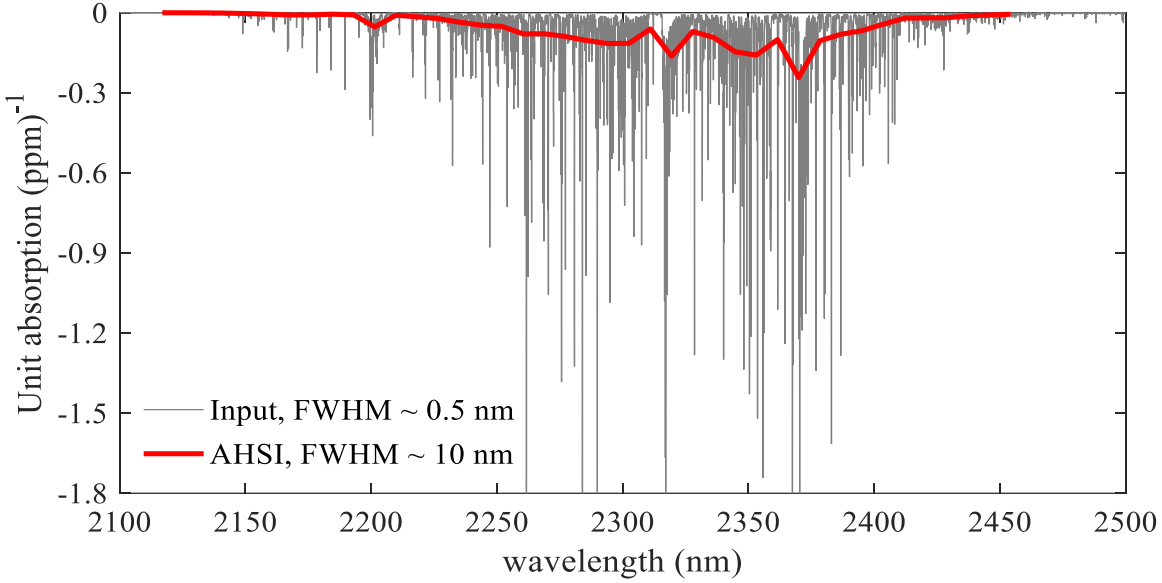


(d) Highly heterogeneous surface

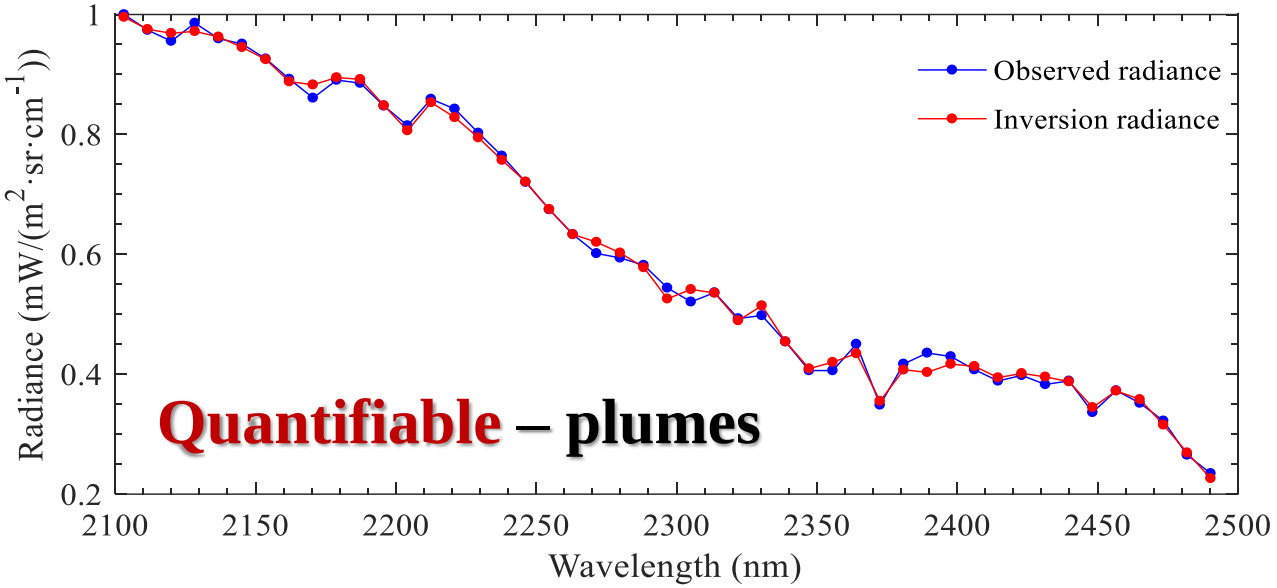
Evaluation and quantification ?

Methods: Statistical and physical

(a) Statistic – Matched-Filter



(b) Physical – Iterative maximum a posteriori



Quantifiable – plumes

Background mean

Observation

Disturbance of absorption

$$\Delta XCH_4 = \left((\boldsymbol{x} - \boldsymbol{\mu})^T \sum^{-1} \boldsymbol{t} \right) \Big/ \left(\boldsymbol{t}^T \sum^{-1} \boldsymbol{t} \right)$$

Background covariance

Efficient – unknow sources detection

Observation

Forward Model

Observation error covariance

$$\chi^2 = [\boldsymbol{y} - \mathbf{F}(\boldsymbol{x}, \boldsymbol{b})]^T \mathbf{S}_\varepsilon^{-1} [\boldsymbol{y} - \mathbf{F}(\boldsymbol{x}, \boldsymbol{b})] + (\boldsymbol{x} - \boldsymbol{x}_a)^T \mathbf{S}_a^{-1} (\boldsymbol{x} - \boldsymbol{x}_a),$$

State Vector

A Priori

A Priori Error Covariance

Methods: Physical inversion processes

Beer-Lambert

(a) Forward model

Incident solar

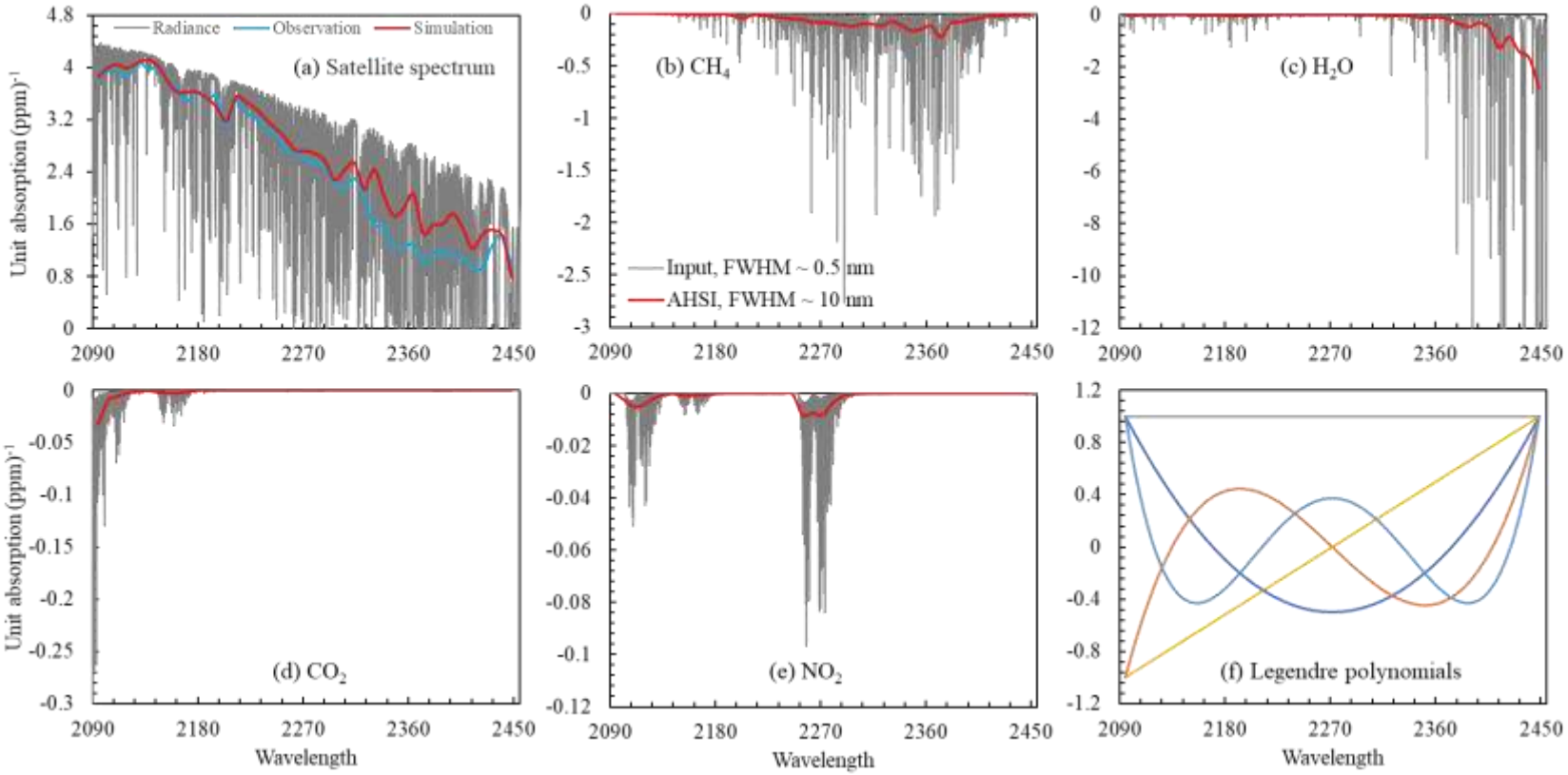
Optical depth

$$\boldsymbol{F^h(x, b)} = I_0(\lambda) \exp\left(-\sum_{n=1}^{6} s_n \sum_{l=1}^{72} A_l \tau_{n,l}\right) \sum_{k=0}^{K} a_k \lambda^k$$

Backscattered radiance

Airmass factor

Polynomial coefficient

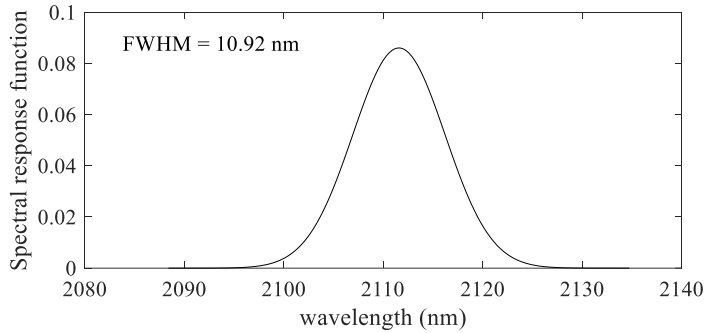


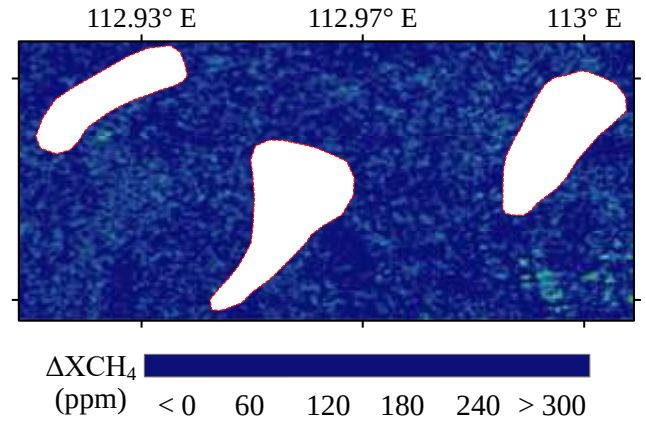
(a) XCH_4 inversion

State Vector

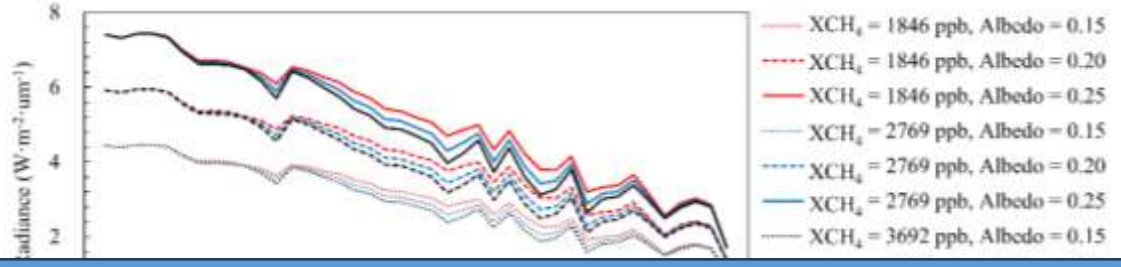
$\boldsymbol{x}_a$

- **Gases**: CH_4, H_2O, CO_2, NO_2
- **Legendre**: Polynomial coefficients
- **Spectral calibration**: Spectral shift
- **Surface reflectance**: Albedo

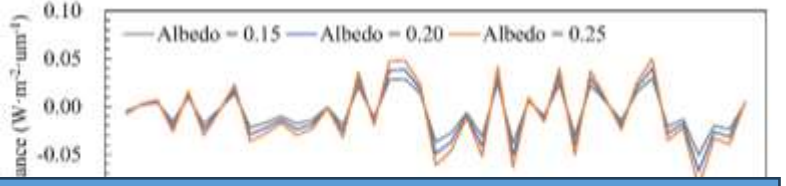




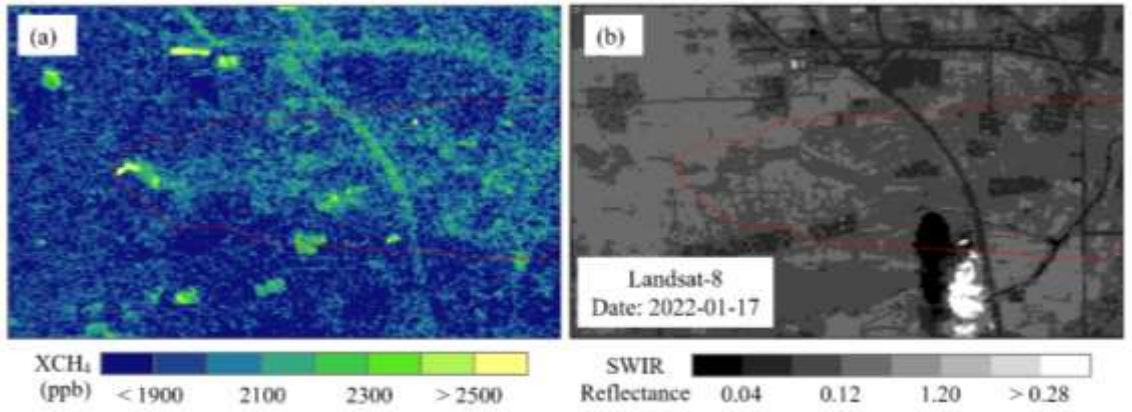
Results: Single-simulation and WRF-LES simulation

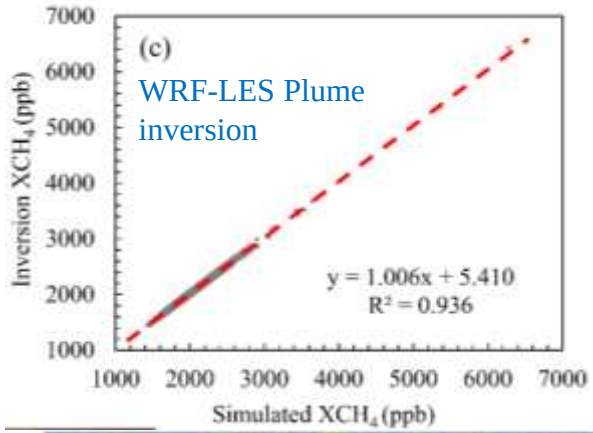


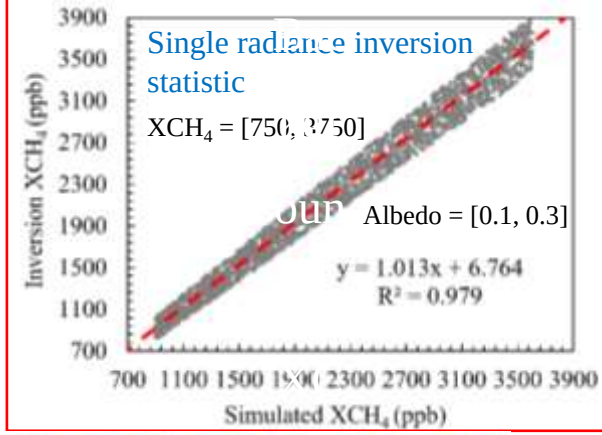
Noise = Max(radiance) / SNR

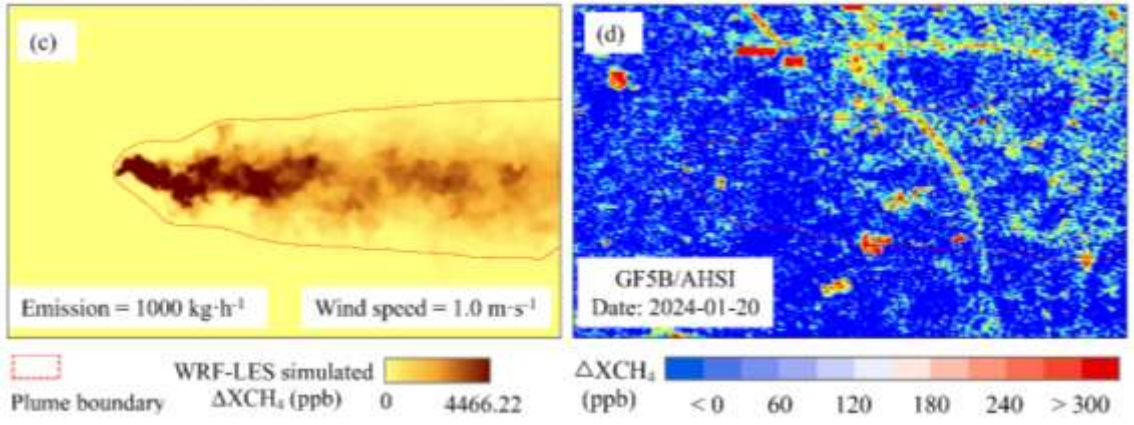


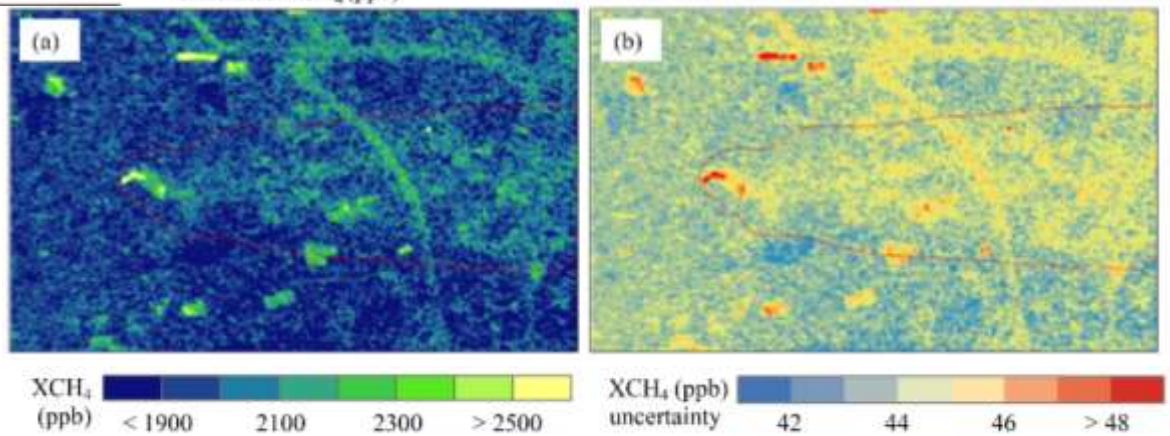
Ask for help: Is there any other way to add the XCH_4 absorption spectrum to the satellite observed spectrum?







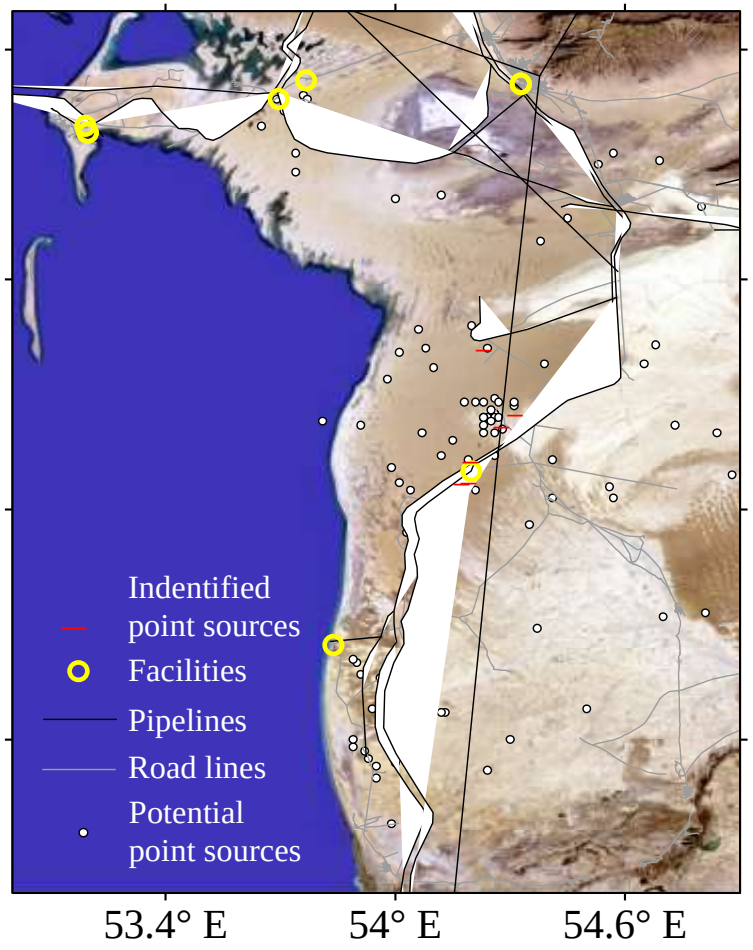




Results: ΔXCH_4 plumes in west coast of Turkmenistan

(b) XCH_4 enhancement from statistical method (Match-Filter)

- *Repeated observations*
- *Smooth surface*
- *Different widths of GF-5B/AHSI and PRISMA*



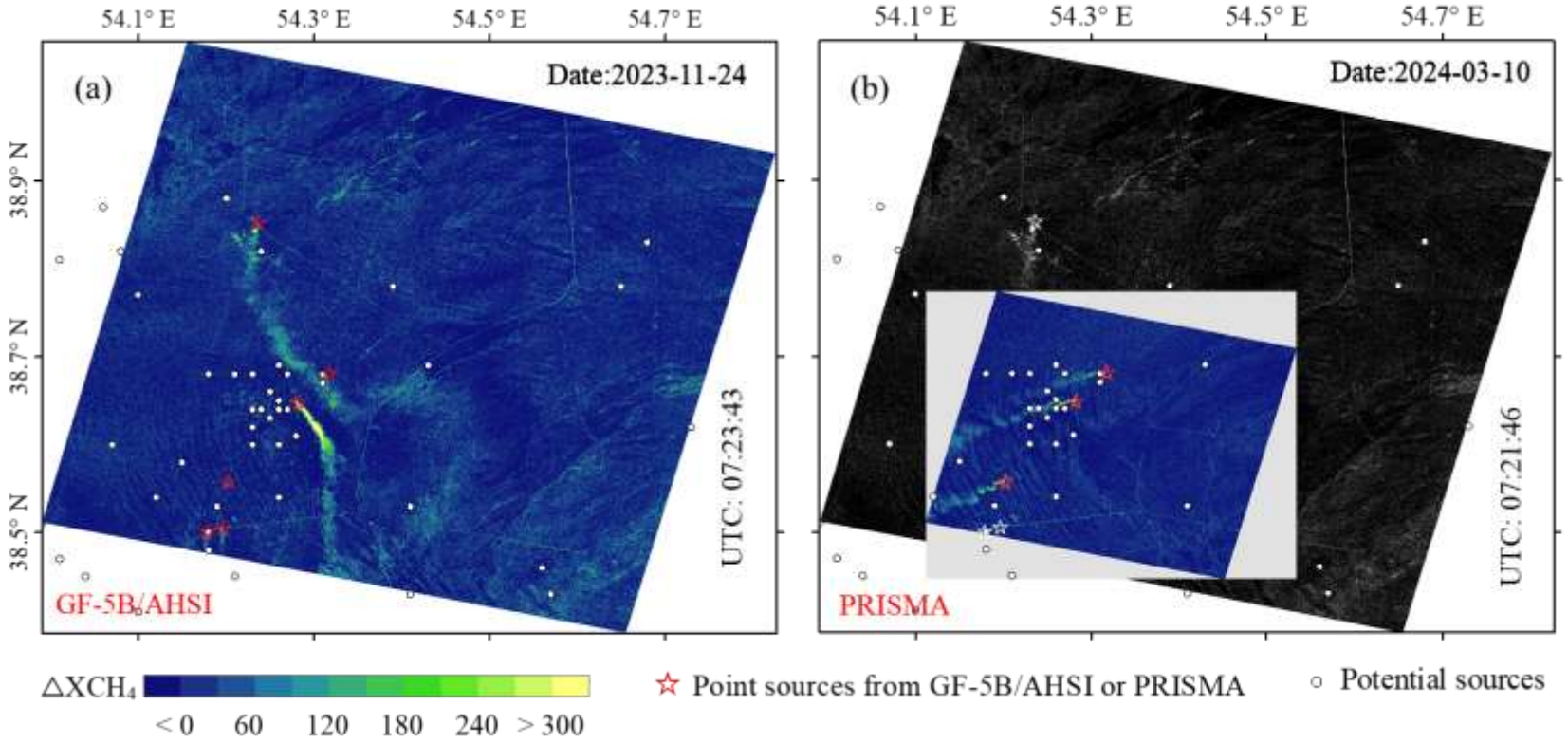
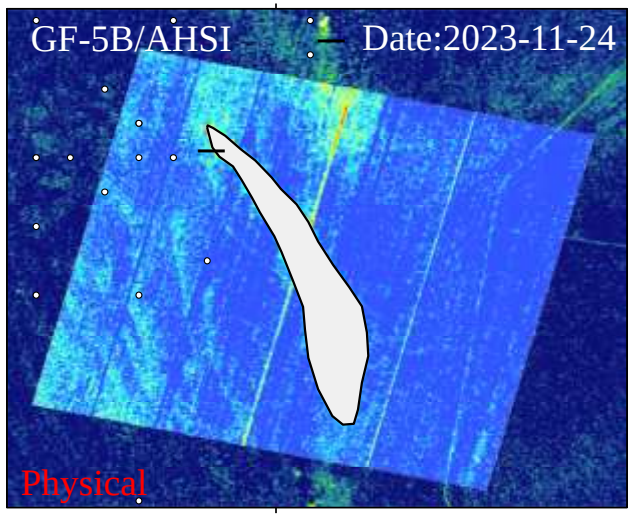


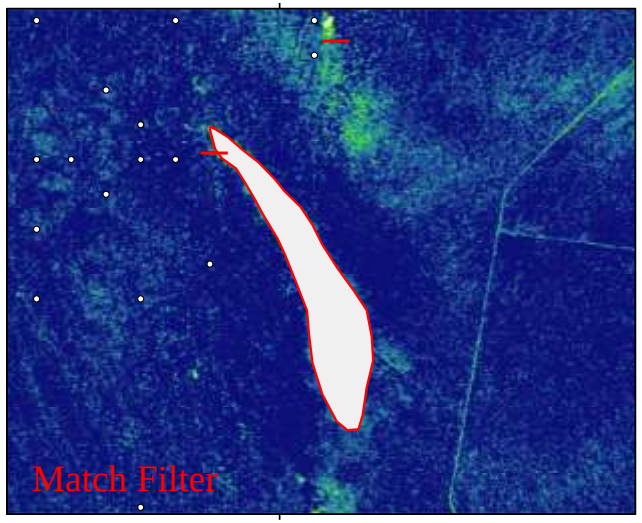
Figure R1. Repeated observations of the same point sources with GF-5B/AHSI (a) and PRISMA (b). There are 6 and 3 ΔXCH_4 plumes were observed by one scene of image from GF-5B/AHSI and PRISMA, respectively.

Results: XCH_4 plumes in west coast of Turkmenistan

(c) Match Filter vs physical method (Iterative maximum a posteriori)

- *Similar plumes with Match-Filter*
- *Some strips for GF-5B/AHSI*



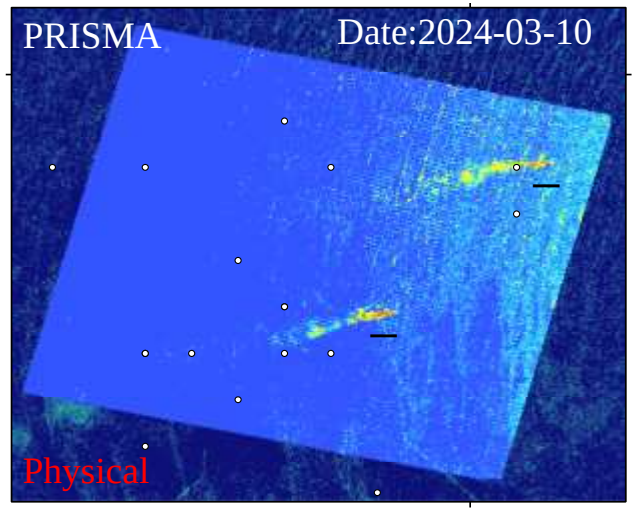


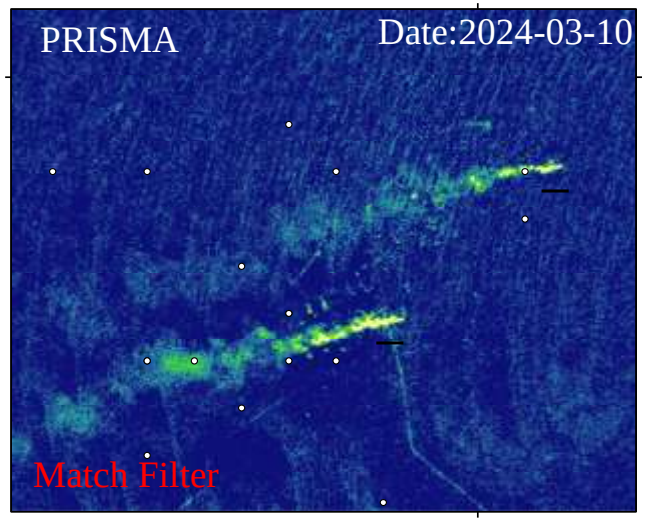
XCH_4 (ppb)

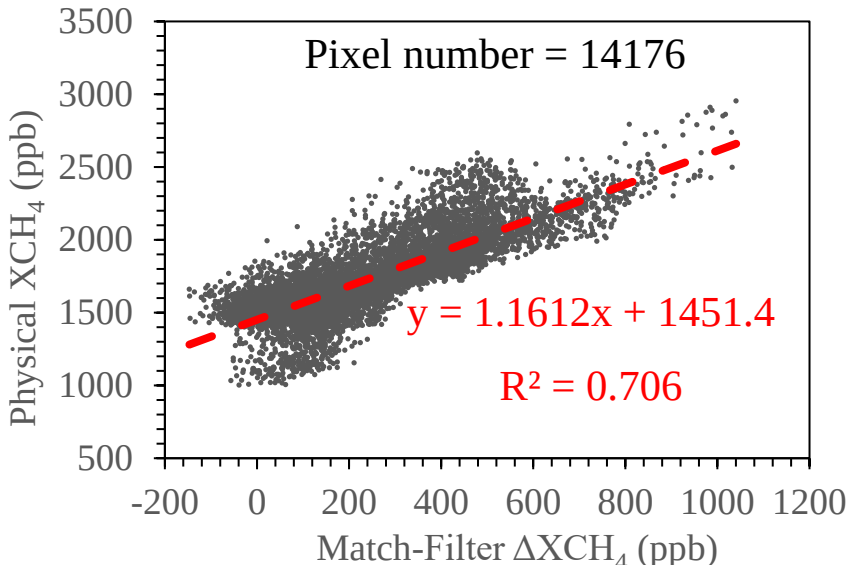
< 1500 1600 1700 1800 >1900

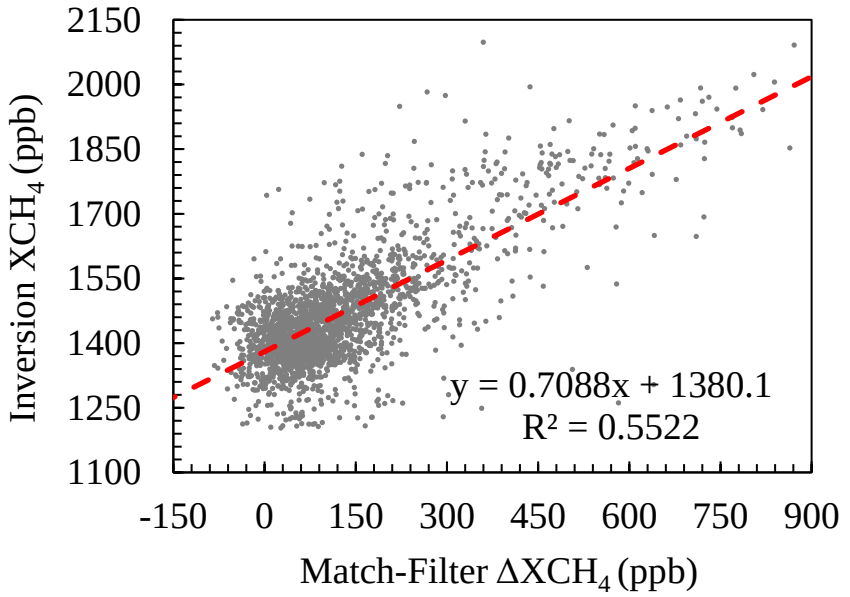
$\triangle XCH_4$ (ppb)

< 0 60 120 180 240 > 300





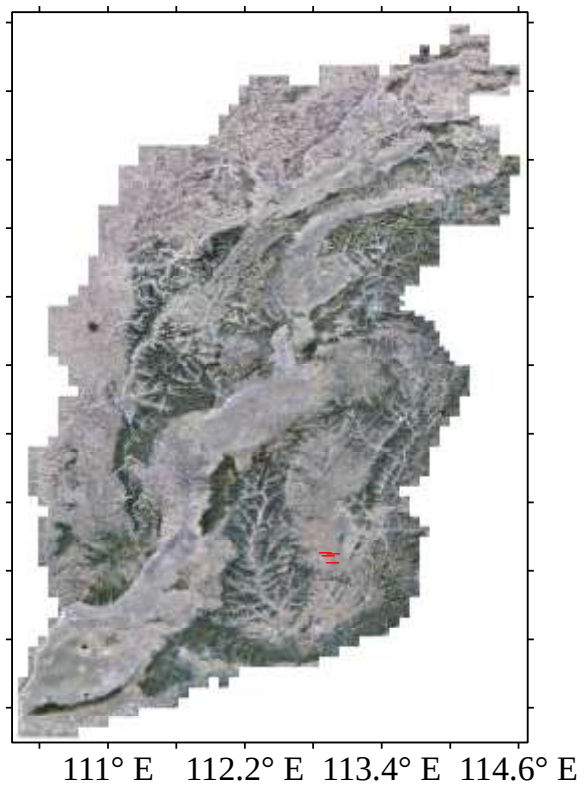




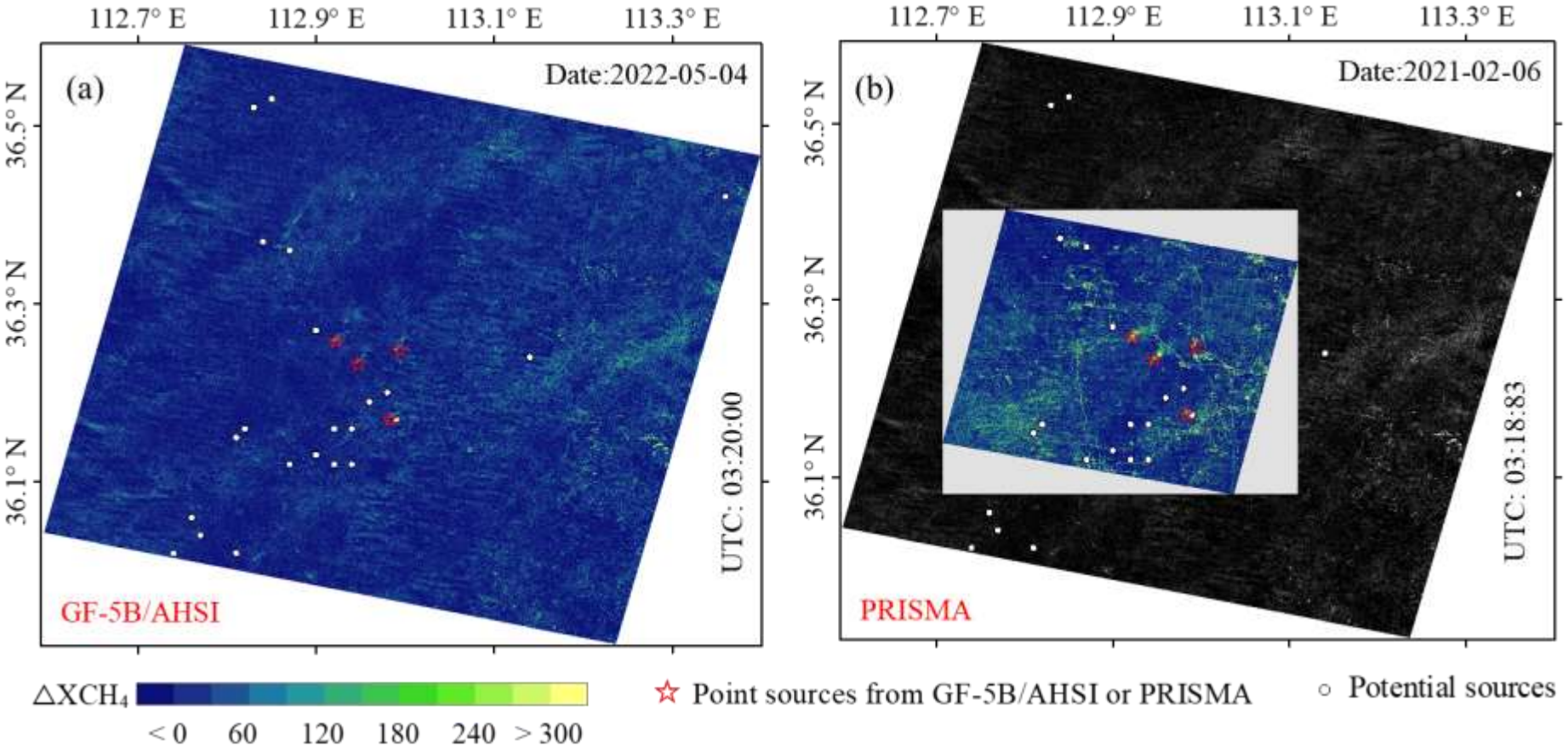
Results: ΔXCH_4 plumes in Shanxi/China

(d) XCH_4 enhancement from statistical method (Match-Filter)

- *Repeated observations*
- ***Highly heterogeneous surface***
- *Different widths of GF-5B/AHSI and PRISMA*

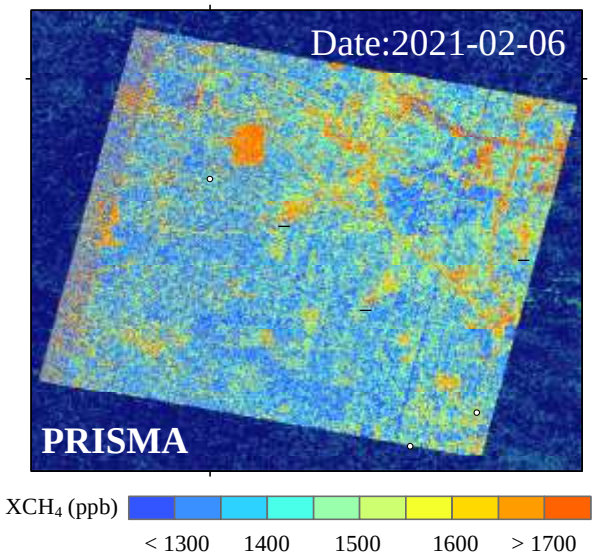


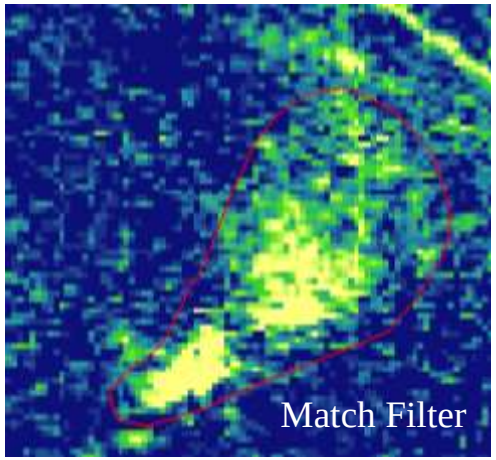
Changzhi/Shanxi, China

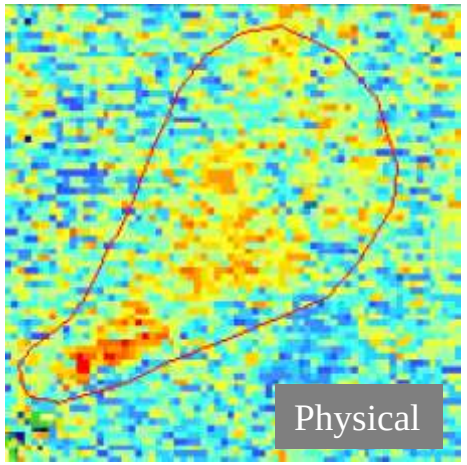


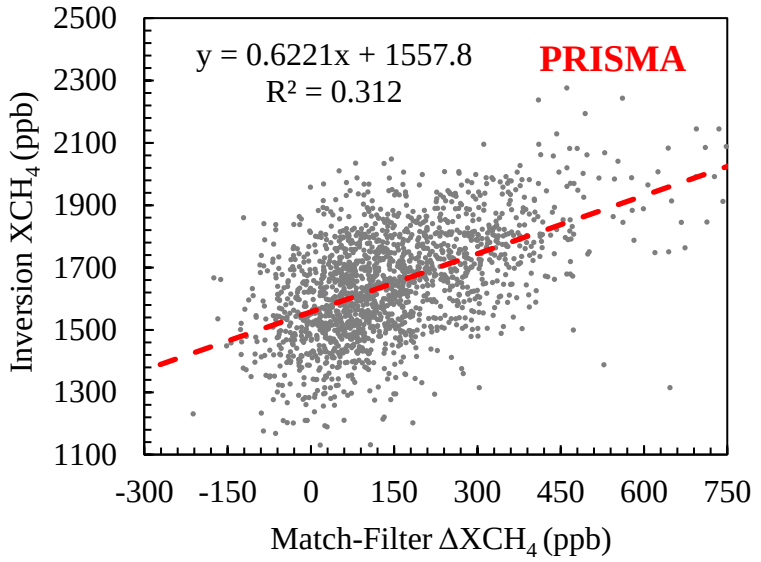
Results: XCH_4 plumes in Shanxi/China

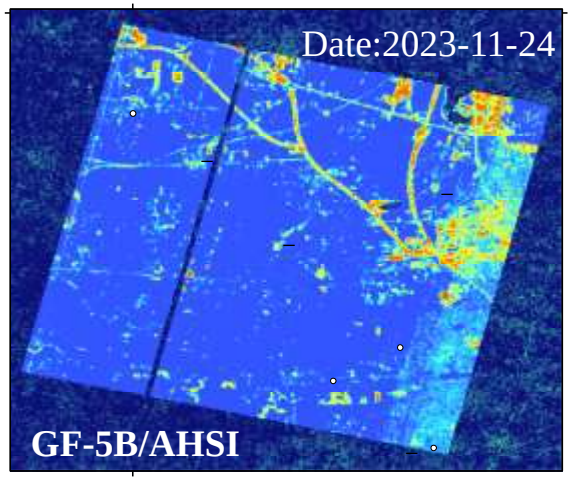
(e) Match Filter vs physical method (Iterative maximum a posteriori)

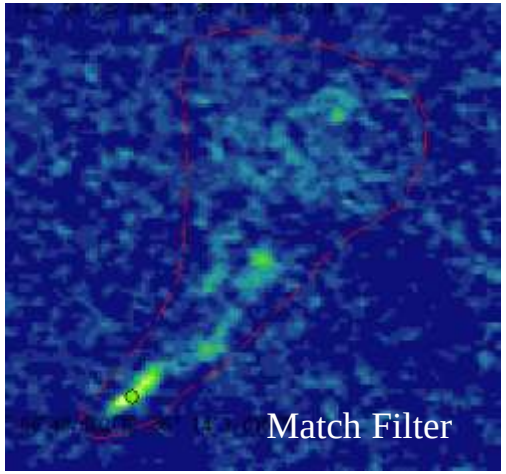


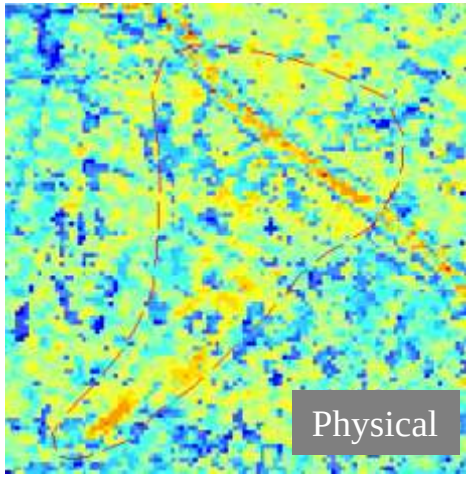


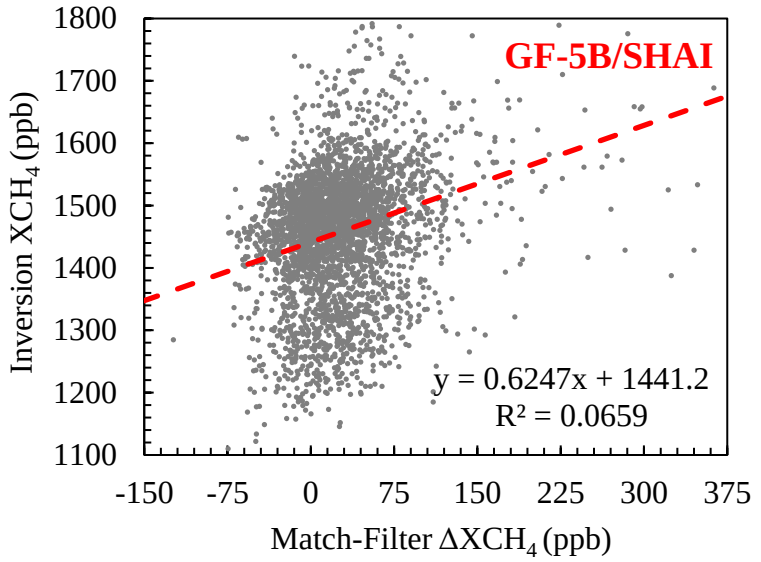












Results: Optimization of state vectors initialization

(f) Match Filter vs physical method (Iterative maximum a posteriori)

(1) More unstable for Shanxi/China

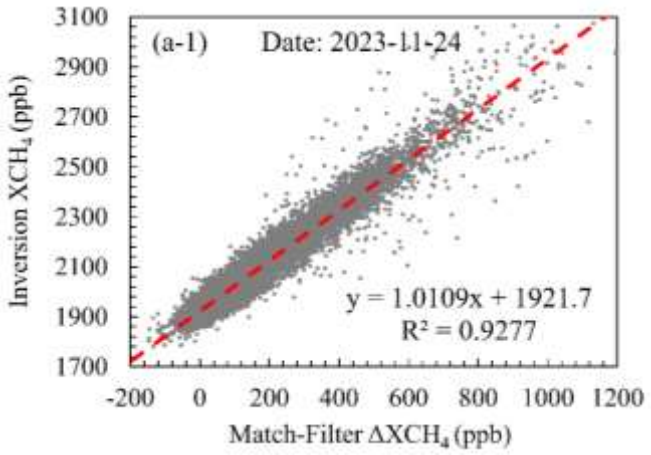
(2) Sensitive to stronger XCH_4 enhancement

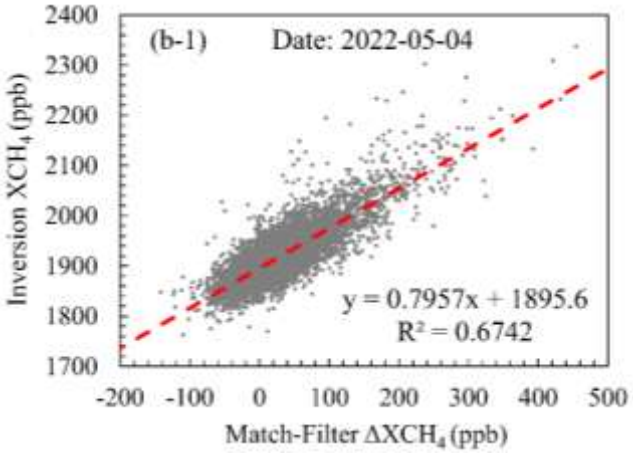
Control experiment

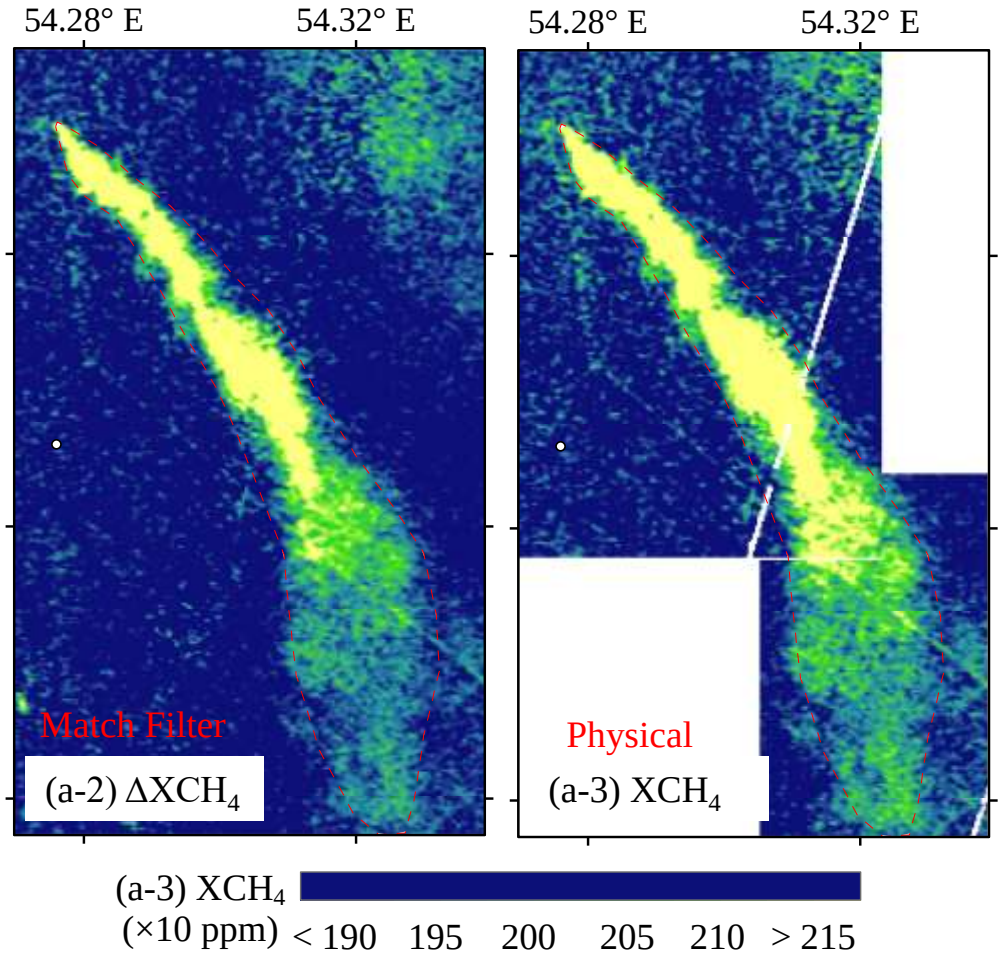
(1) initial XCH_4 with TROPOMI and Match Filter results;

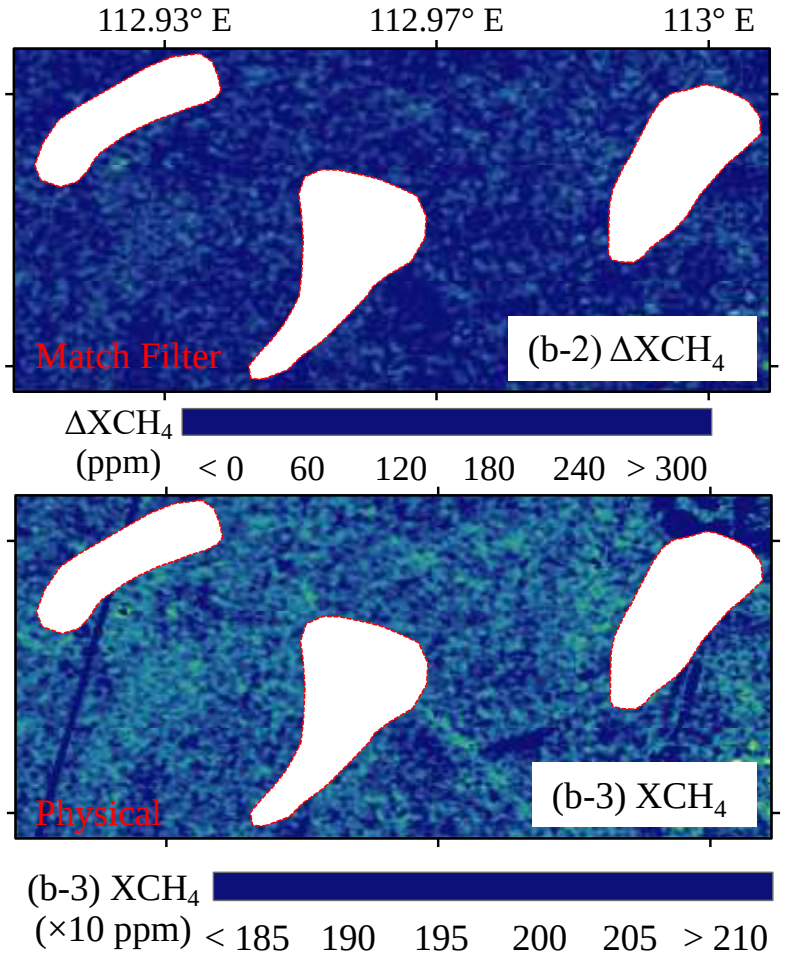
(2) Albedo from MODIS and Landsat;

(3) Reduce the state vector error.



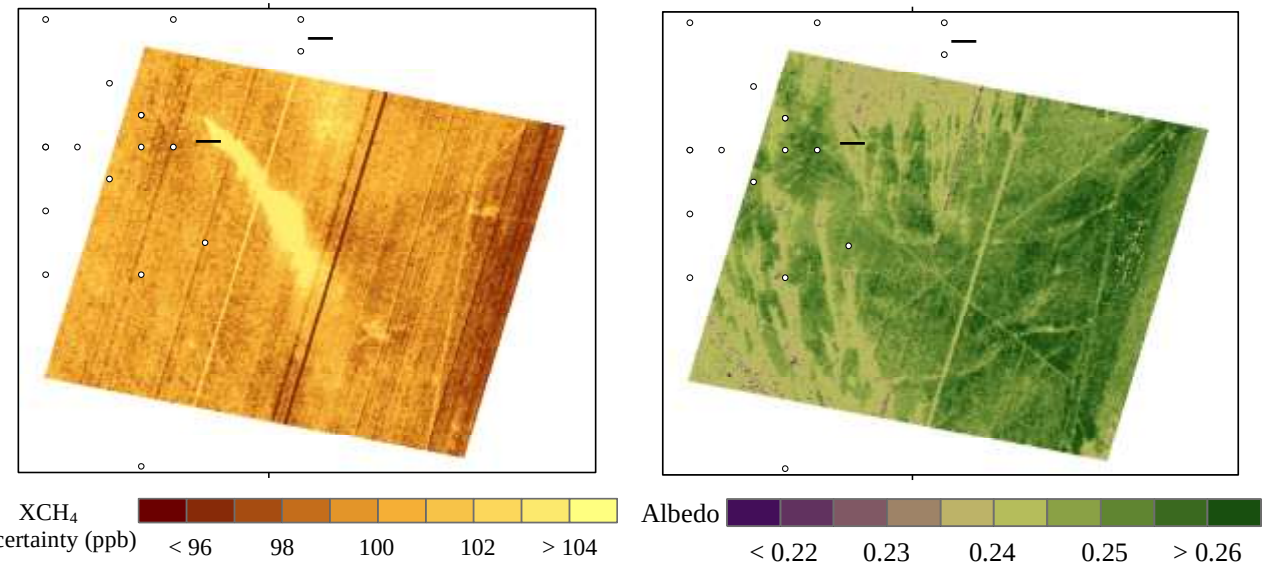


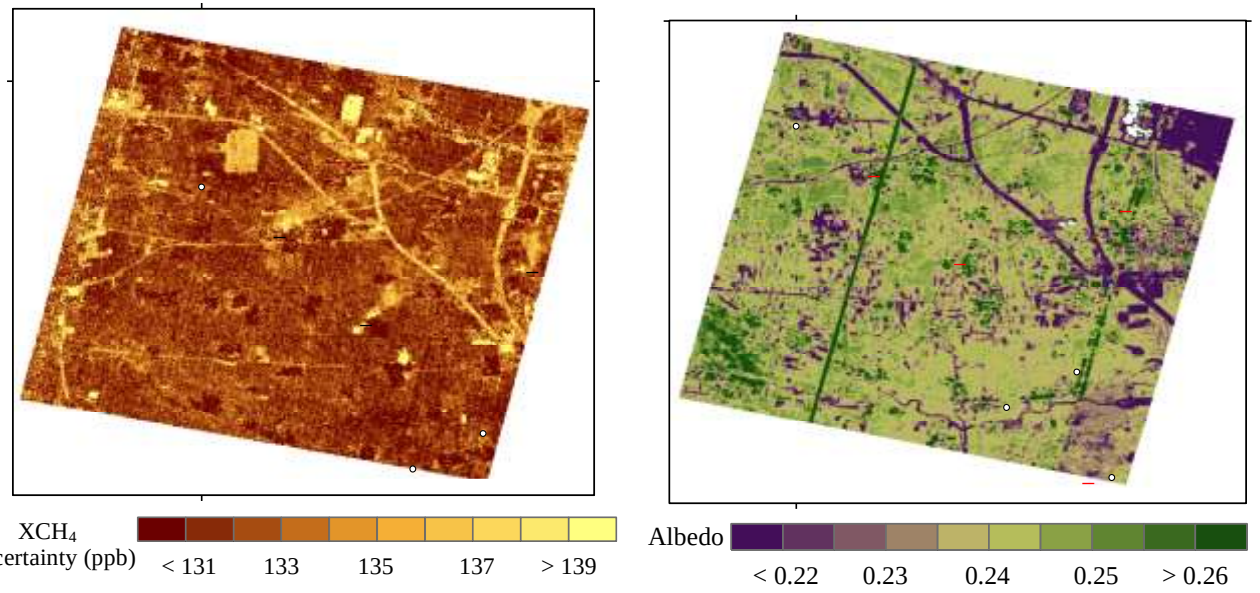




Discussions: Come back to our previous questions

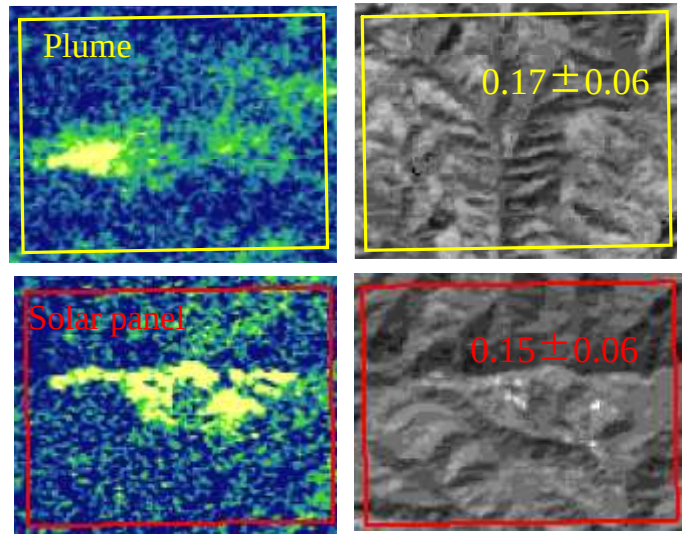
(g) XCH_4 uncertainty and surface albedo from physical method





Heterogeneous surface effect ?

TROPOMI >> AHSI



MODIS land properties : 2105-2155 nm