MethaneSAT XCH_4 retrieval

Sébastien Roche, Christopher Chan Miller, David J. Miller, Bingkun Luo,
Jonathan Franklin, Kang Sun, Xiong Liu, Steven Wofsy, and the MethaneSAT team

IWGGMS-21, Japan, June 10, 2025

Environmental Defense Fund

MethaneSAT™

HARVARD

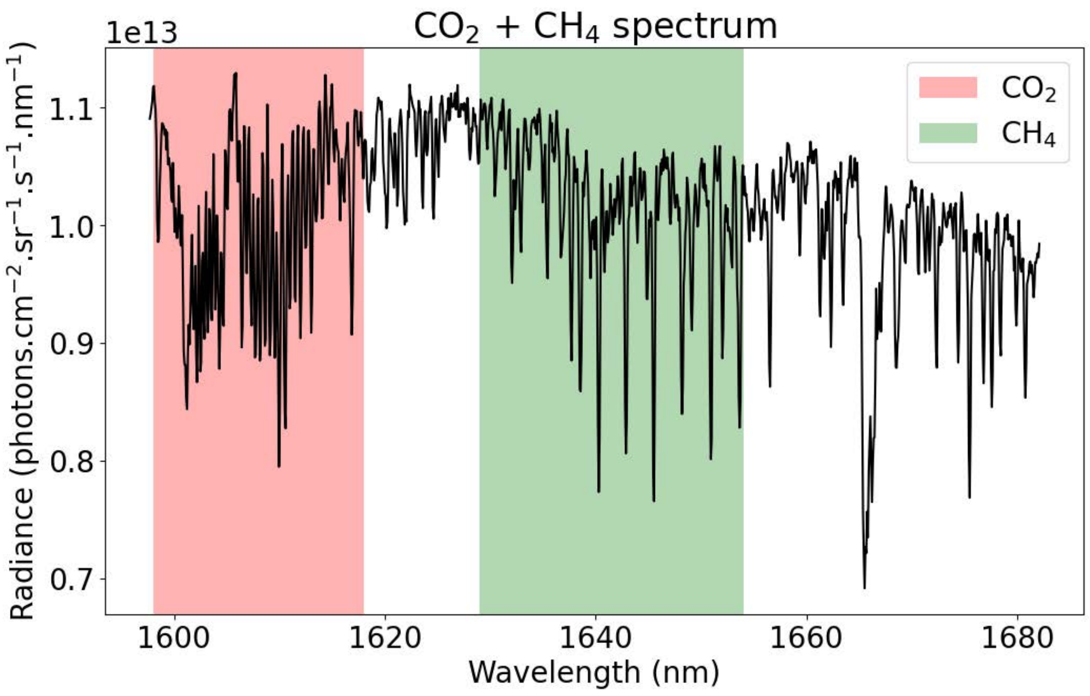
University at Buffalo

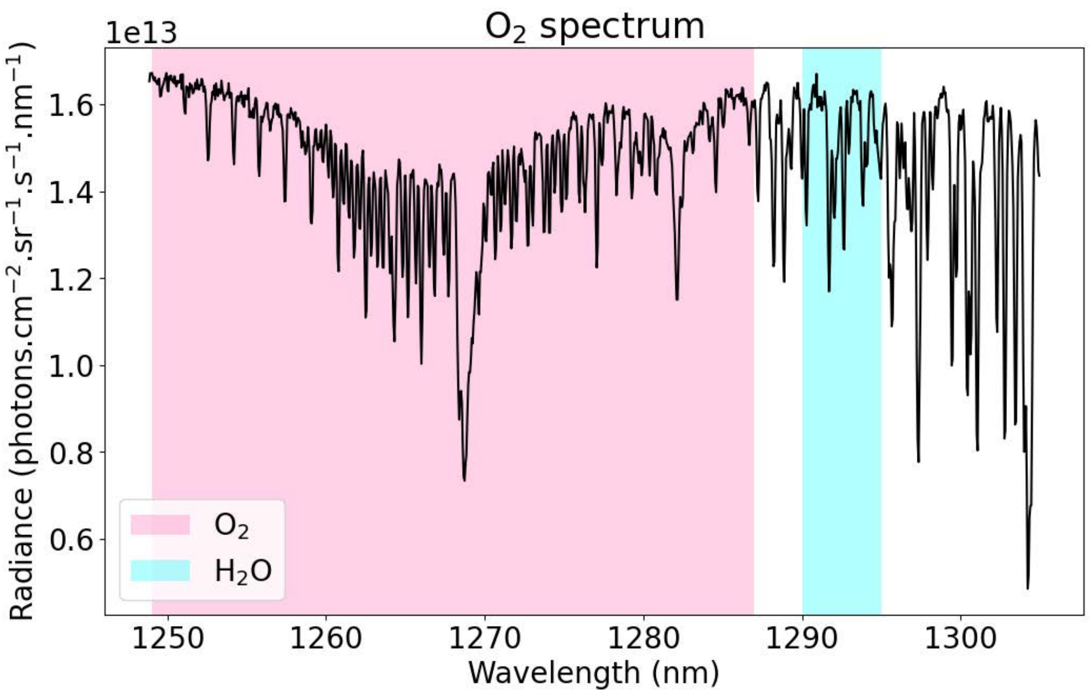
CENTER FOR ASTROPHYSICS HARVARD & SMITHSONIAN

Outline

- MethaneSAT spectra
- Algorithm Overview
- Column averaging kernel and DOFS
- Fit residual vs measurement noise
- Bias correction / destriping
- Post-processing masks
- XCH_4 CO2-proxy precision
- Preliminary comparison with TROPOMI
- Summary
- Data access

MethaneSAT spectra



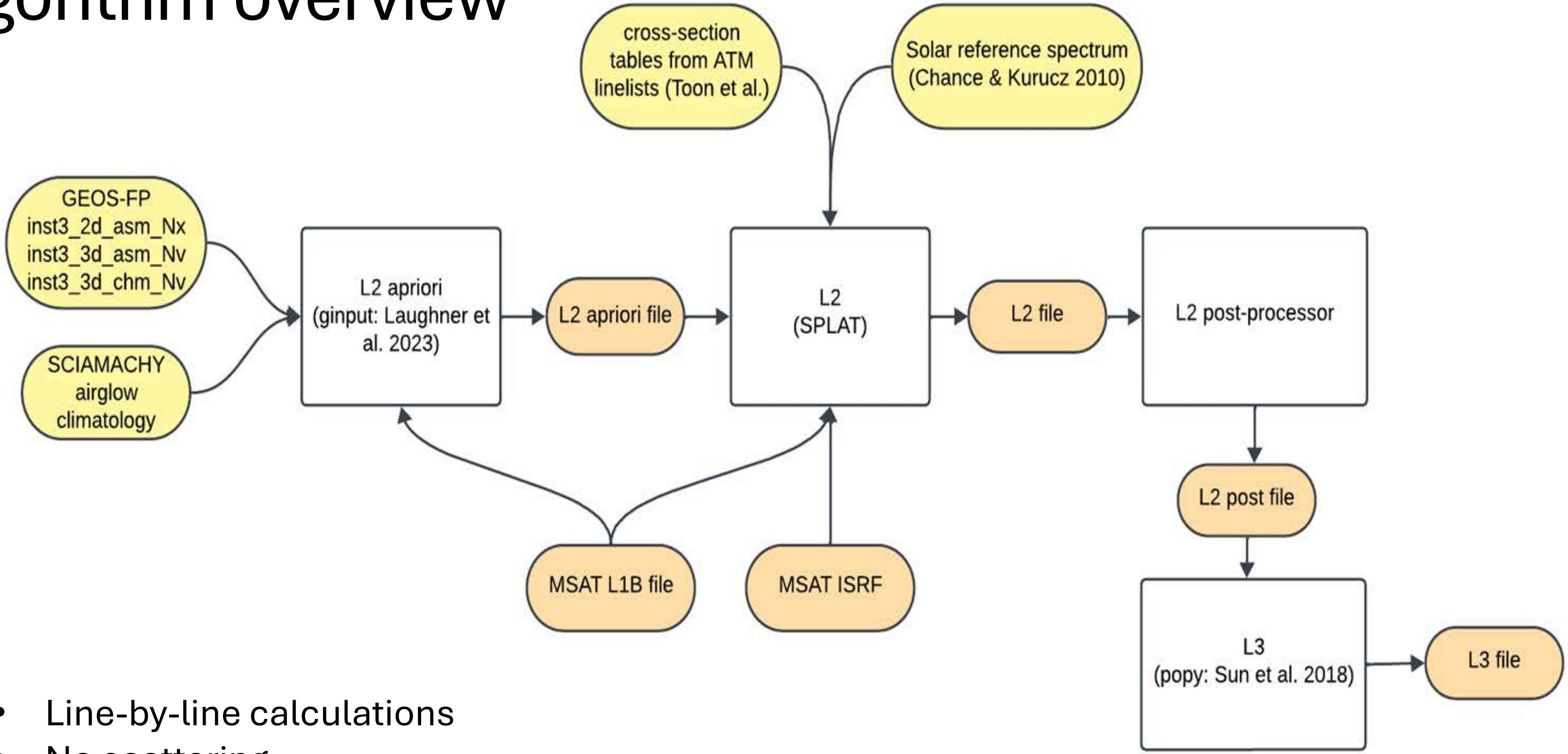


- 2 grating spectrometers:
  - 1249-1305 nm
    - 0.16 nm FWHM
  - 1598-1683 nm
    - 0.24 nm FWHM

- Fitting windows:

CO_2: 1598-1618 nm
CH_4: 1629-1654 nm
O_2: 1249.2-1287.8 nm
H_2O: 1290-1295 nm

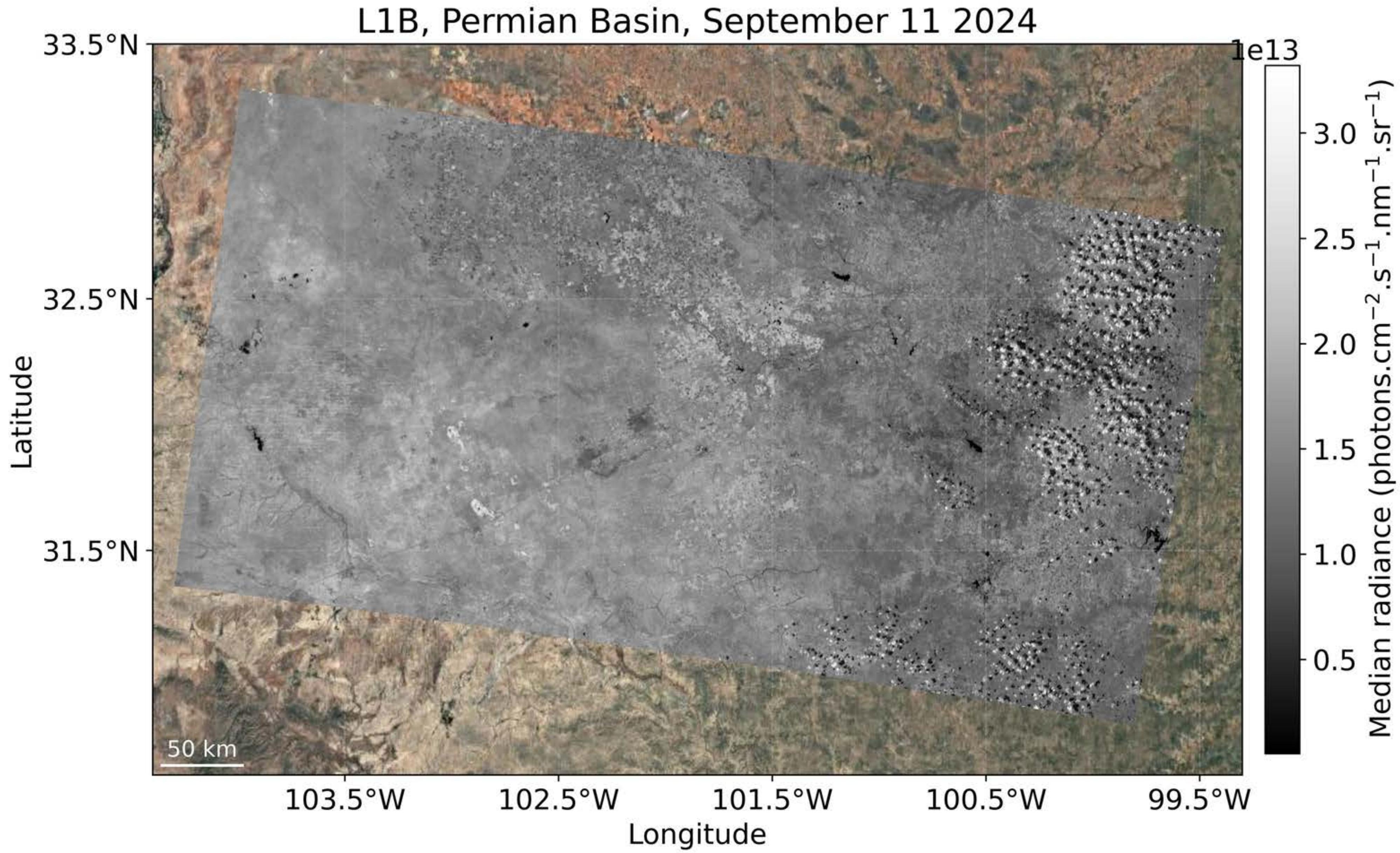
Algorithm overview



- Line-by-line calculations
- No scattering
- CO_2 and CH_4 profile retrievals
- CO_2-proxy method: $XCH_4 = XCO_2^{apriori} \frac{column_{CH_4}}{column_{CO_2}}$

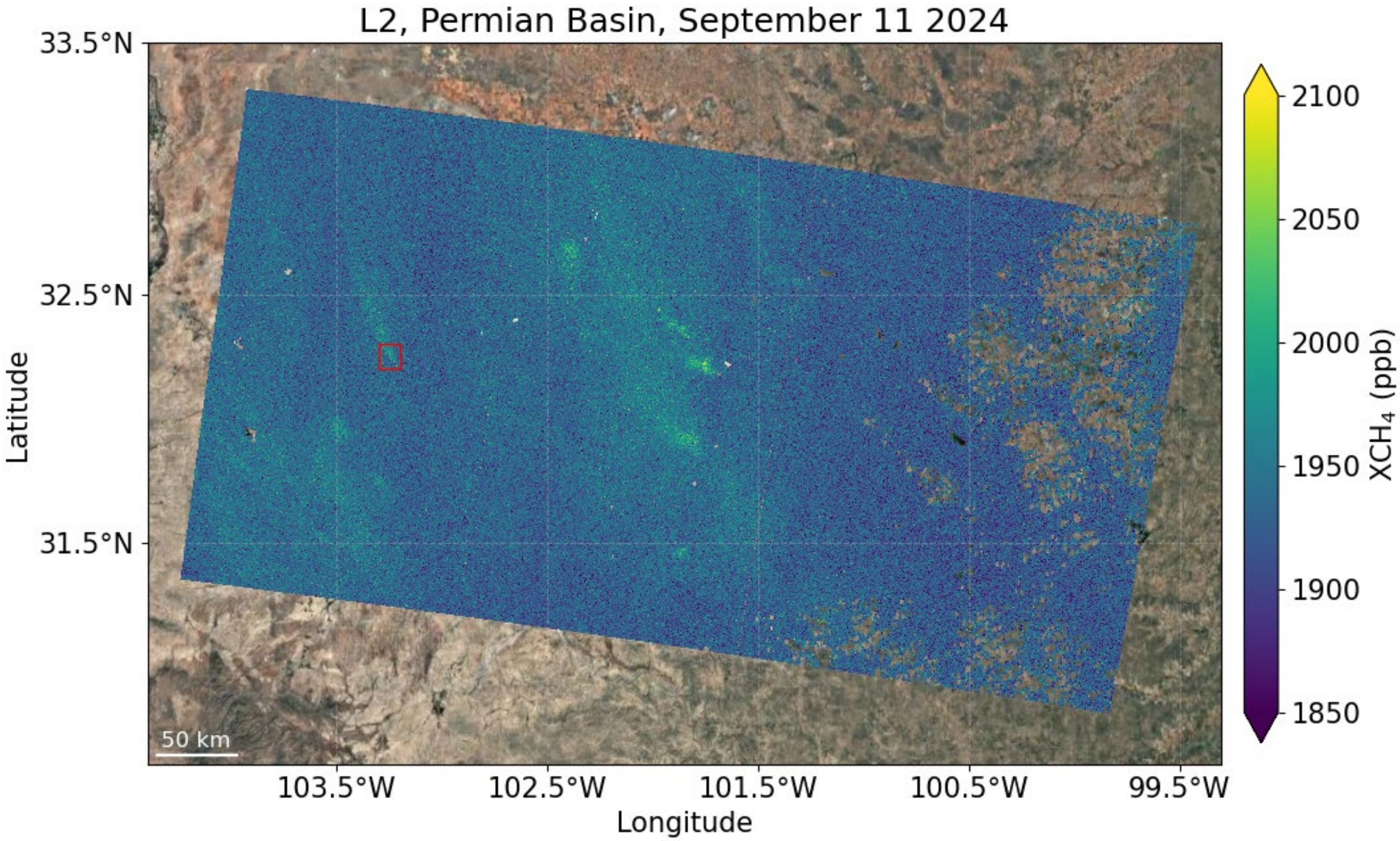
- For L2 forward model details see supplement of Miller et al., 2024: https://doi.org/10.5194/amt-17-5429-2024
- L3 / Physical Oversampling: https://doi.org/10.5194/amt-11-6679-2018
- GINPUT: https://doi.org/10.5194/amt-16-1121-2023

Level1

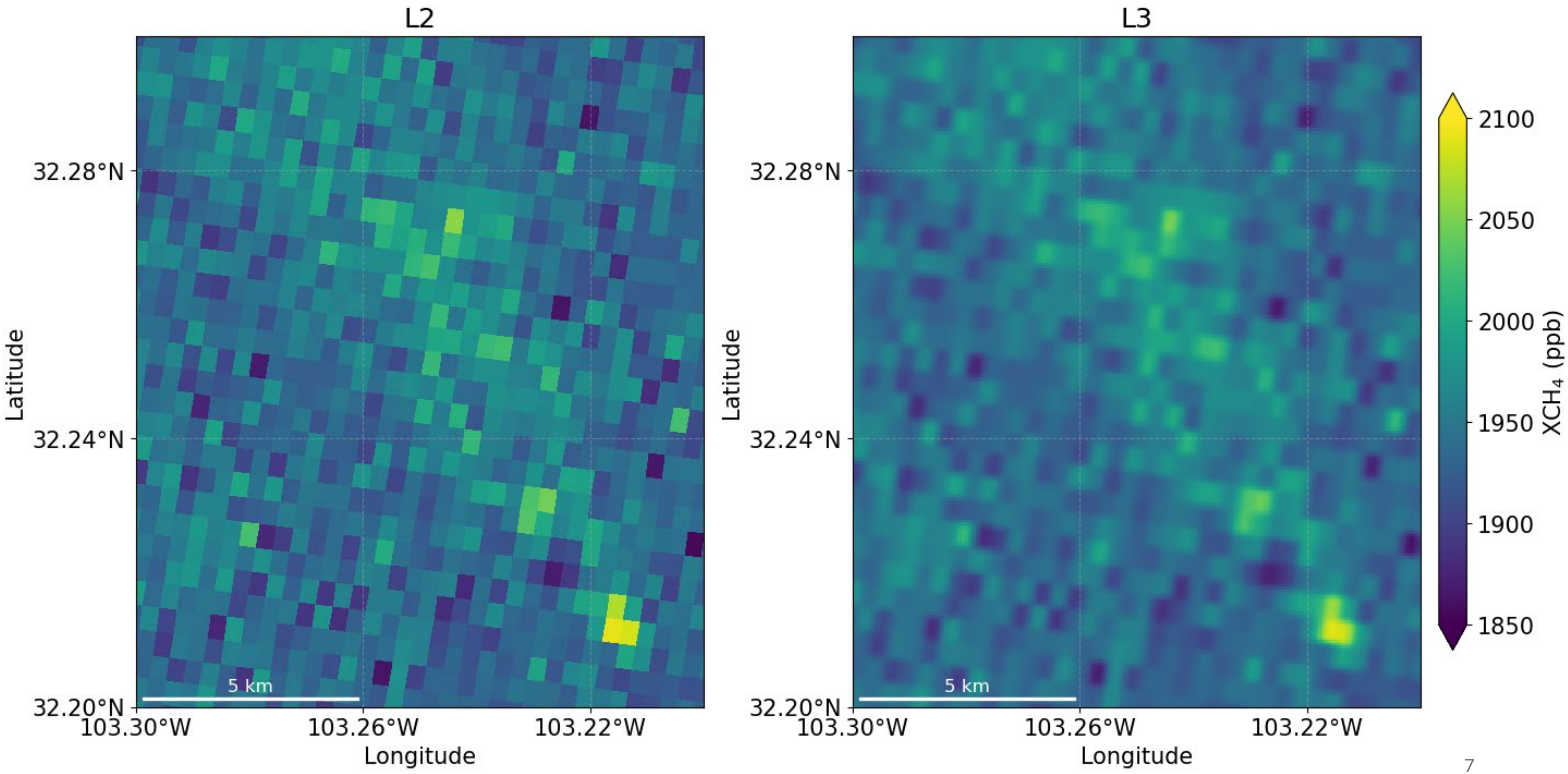


L1B, Permian Basin, September 11 2024
33.5°N
32.5°N
31.5°N
Latitude
103.5°W
102.5°W
101.5°W
100.5°W
99.5°W
Longitude
50 km
1e13
3.0
2.5
2.0
1.5
1.0
0.5
Median radiance (photons.cm−2.s−1.nm−1.sr−1)

Level2

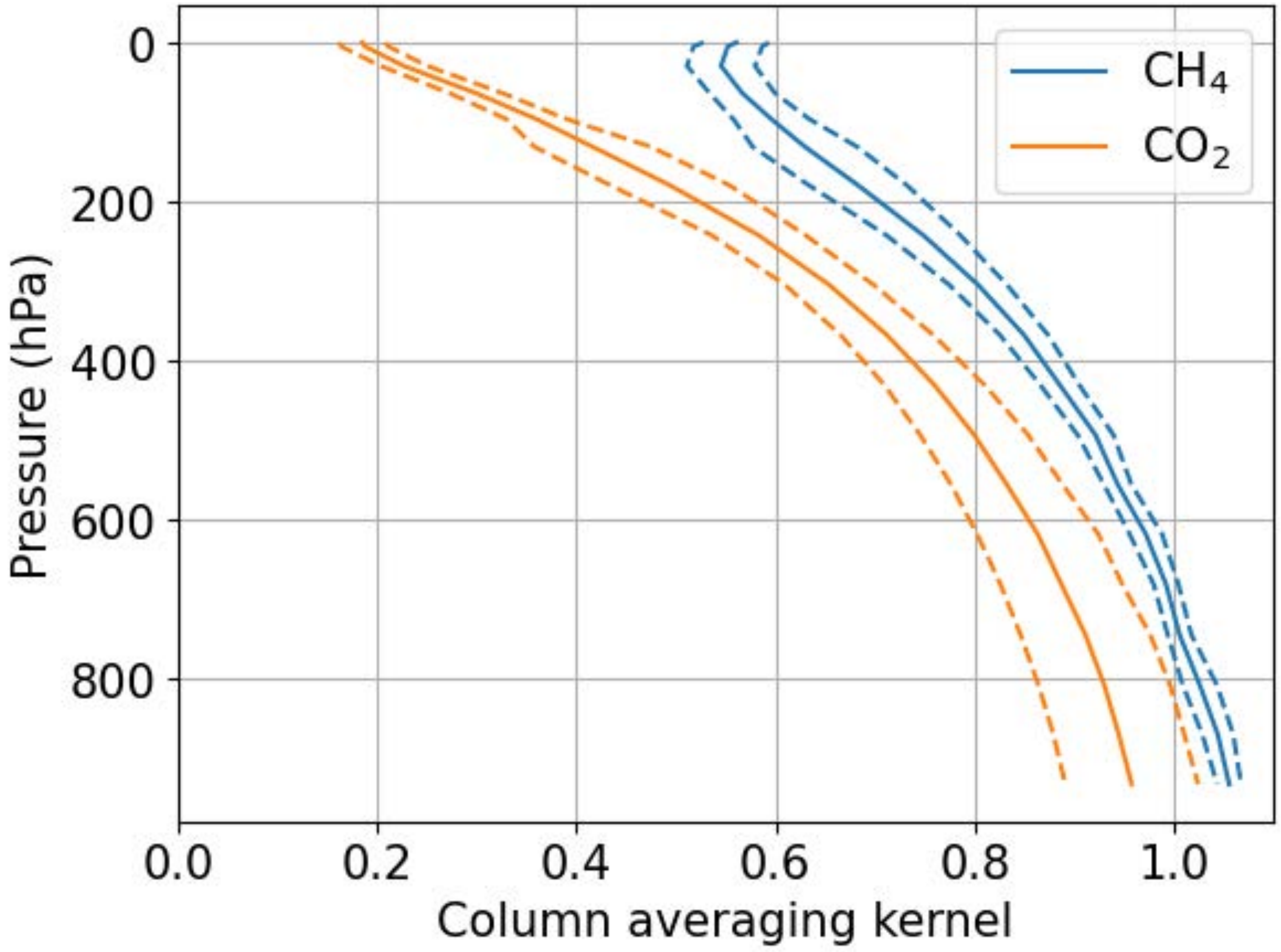

L2, Permian Basin, September 11 2024
33.5°N
32.5°N
31.5°N
Latitude
103.5°W
102.5°W
101.5°W
100.5°W
99.5°W
Longitude
50 km
2100
2050
2000
1950
1900
1850
XCH_4 (ppb)

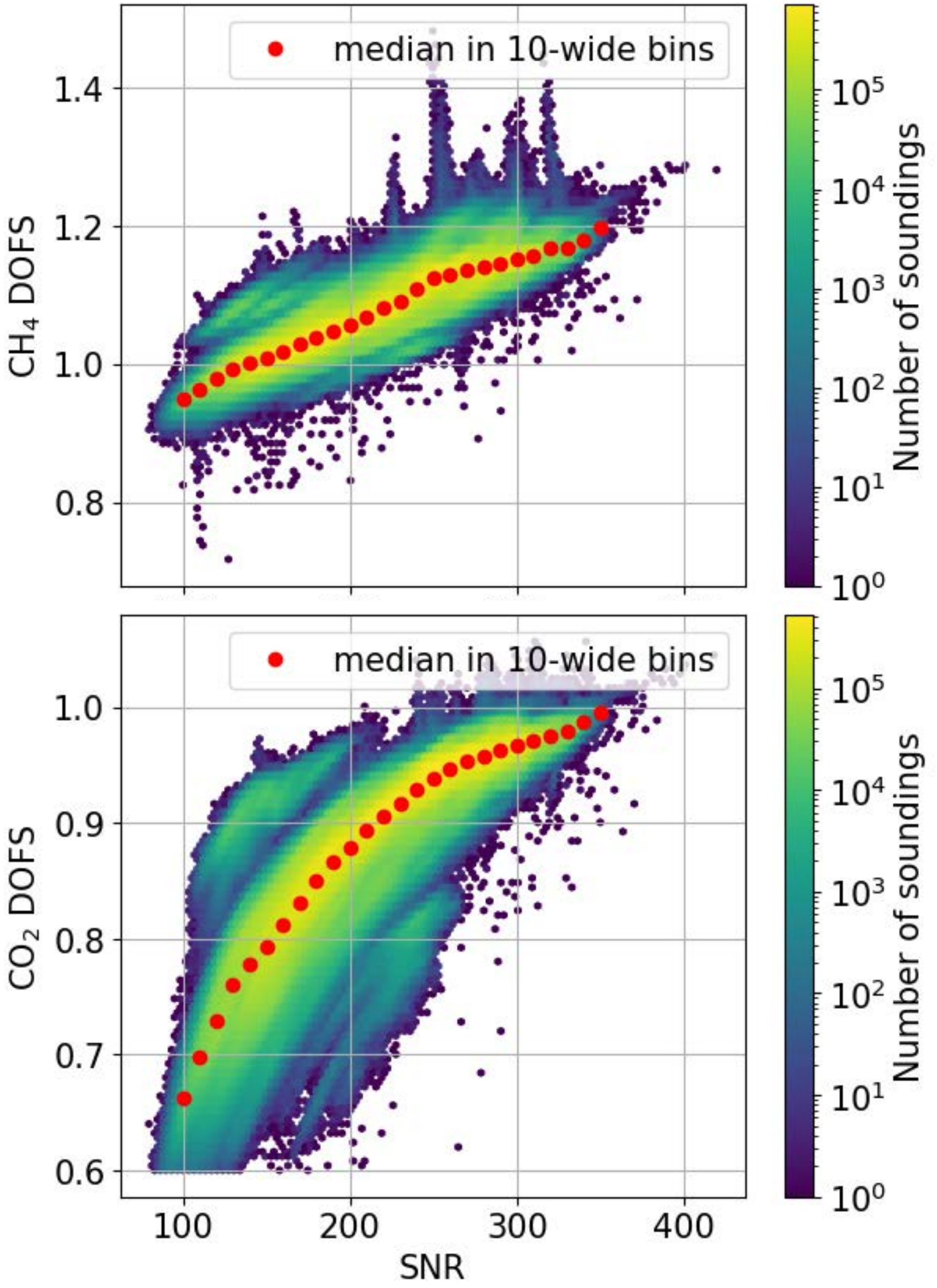
Level3



L2
L3
32.28°N
32.24°N
32.20°N
103.30°W
103.26°W
103.22°W
Longitude
Latitude
5 km
2100
2050
2000
1950
1900
1850
XCH_4 (ppb)

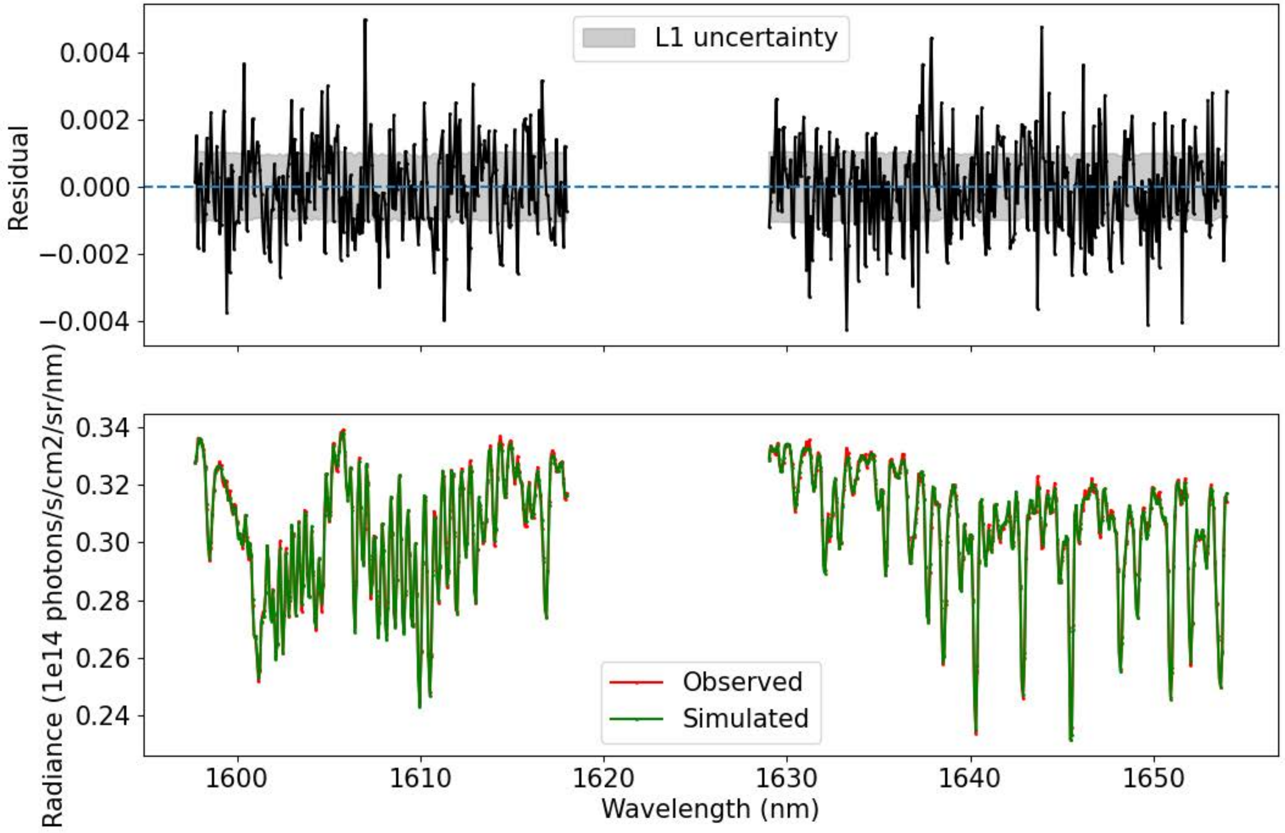
Column averaging kernel and DOFS



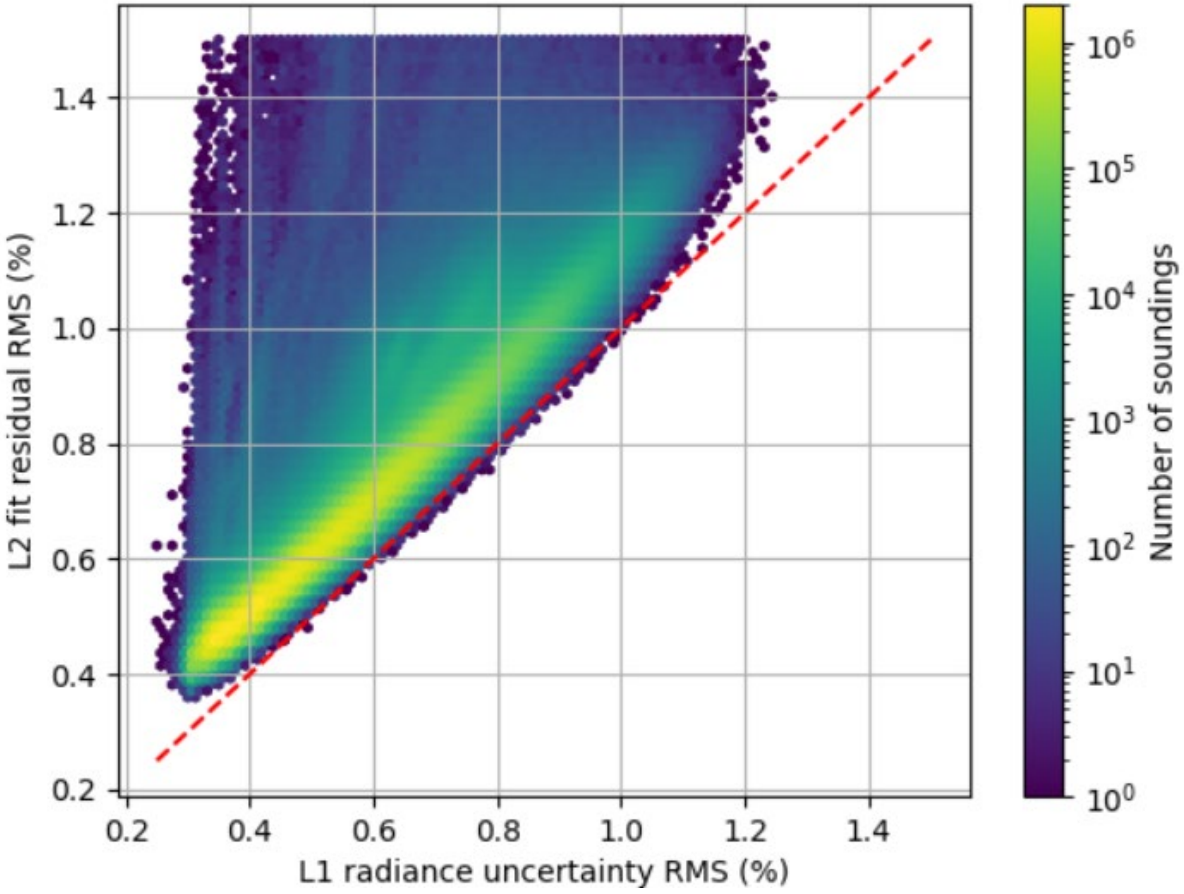


Fit residuals vs measurement noise

Single sounding; SZA=38.5; VZA=10.9; albedo=0.68



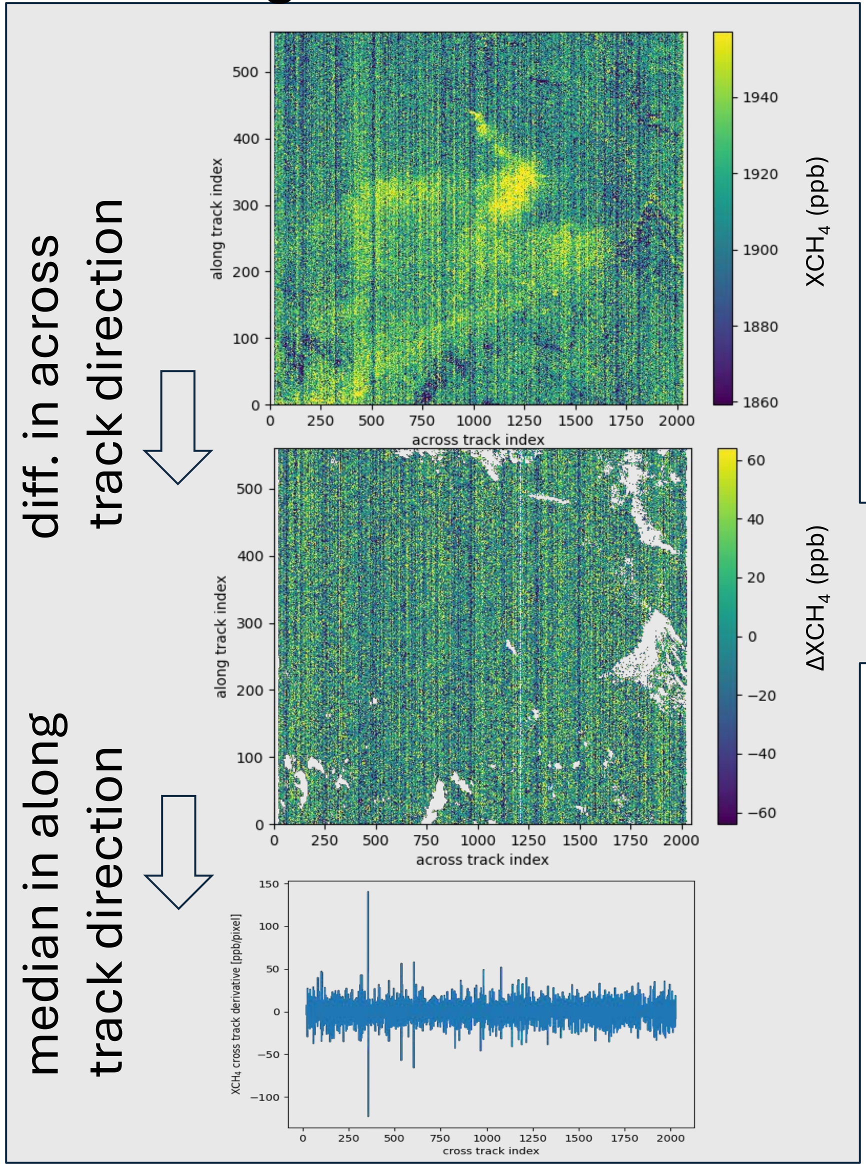
~194M soundings



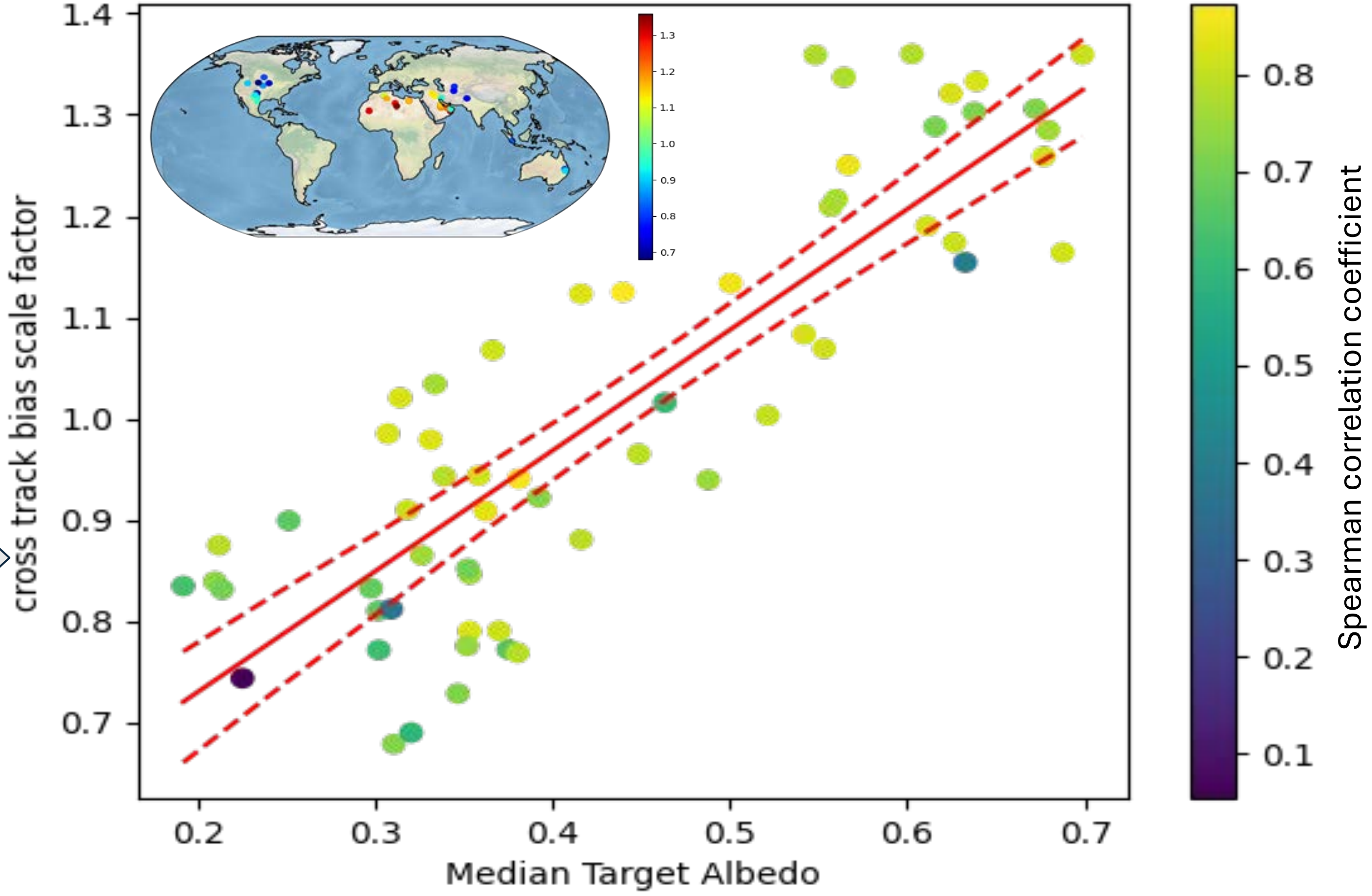
- Retrieval fit residuals close to expected value calculated from L1 radiance uncertainty

XCH_4 across-track striping show strong signal dependence

(1) Compute stripe derivative pattern for clear target



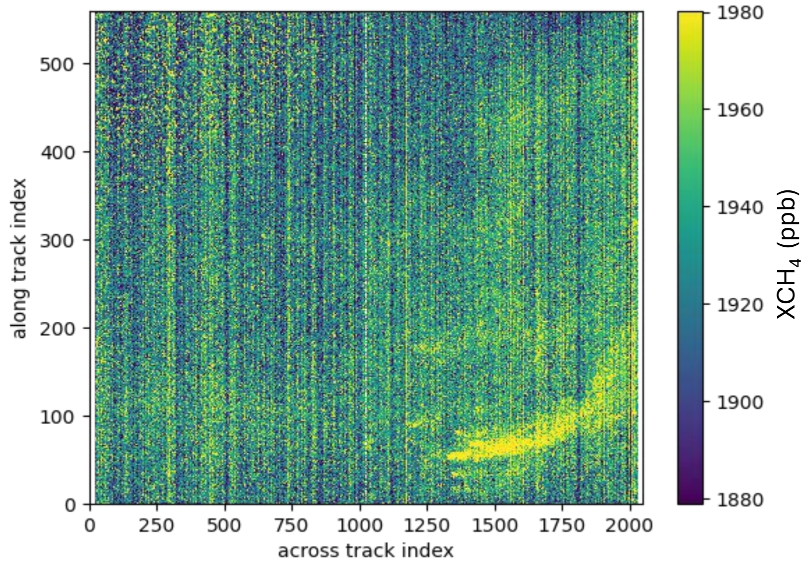
(2) Regress targets against the median of all sufficiently cloud free targets



- Using derivative reduces the impact of real XCH_4 variability within the scene on stripe estimate
- The target-to-target cross-track bias pattern is stable, but differs by a scaling factor
- **The scaling factor is strongly correlated with albedo, possibly indicating a radiometric calibration issue**

XCH_4 across-track destriping algorithm

Raw XCH4



Step 1 - least squares fit scaling median bias pattern + polynomial offset

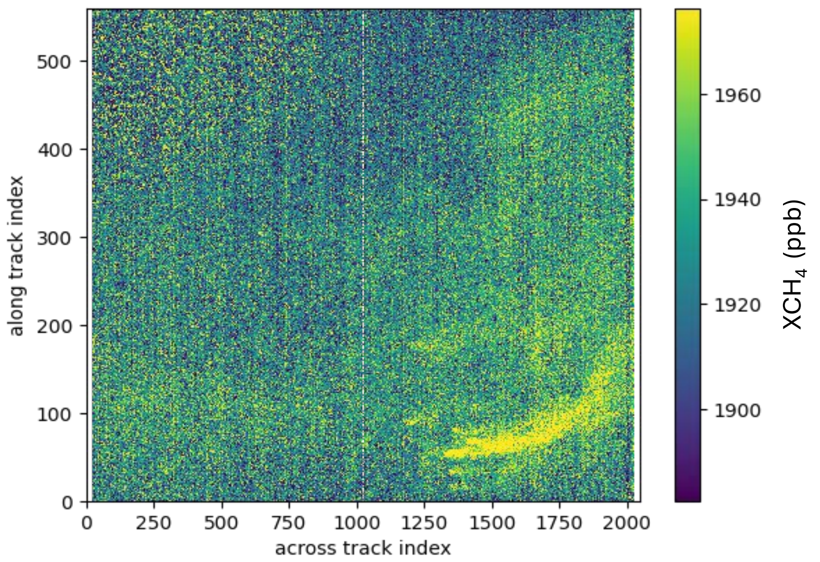
$$\frac{dXCH_4(x;\mathbf{p})}{dx} = p_B \frac{dB(x)}{dx} + \sum_i p_i T_i(x)$$

target along track median

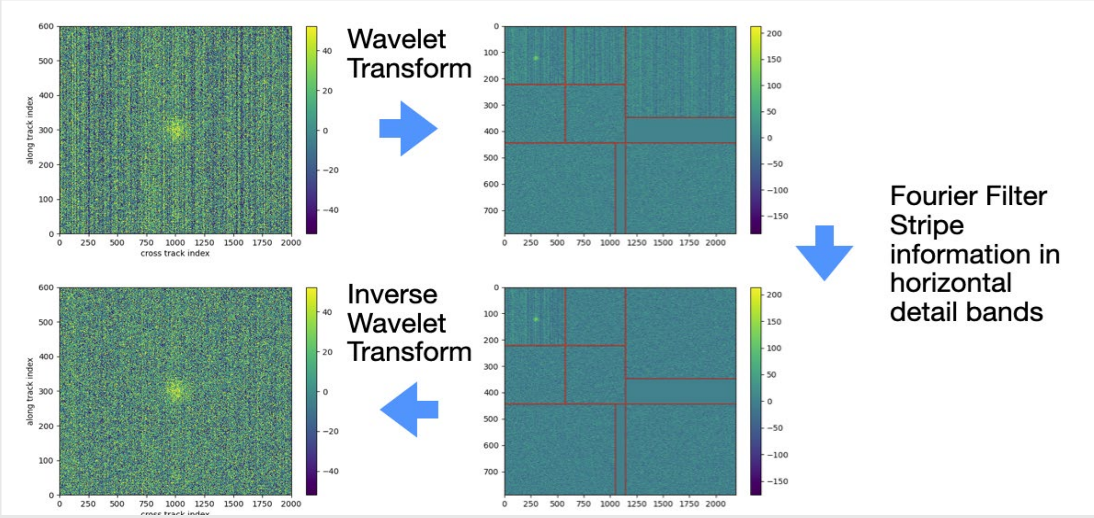
Pattern derived from median of clear target subset

Chebyshev expansion to account for real XCH4 variability

$$bias(x) = p_B B(x)$$

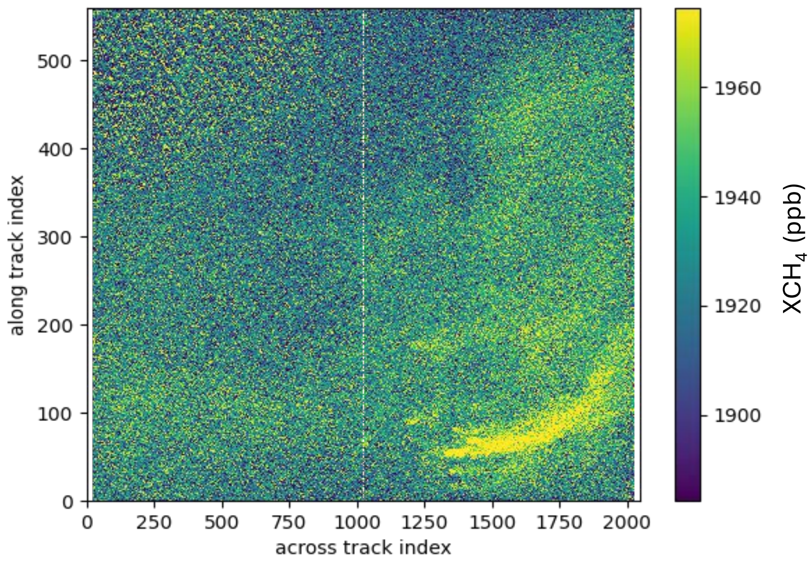


Step 2 - Refinement with wavelet transform method

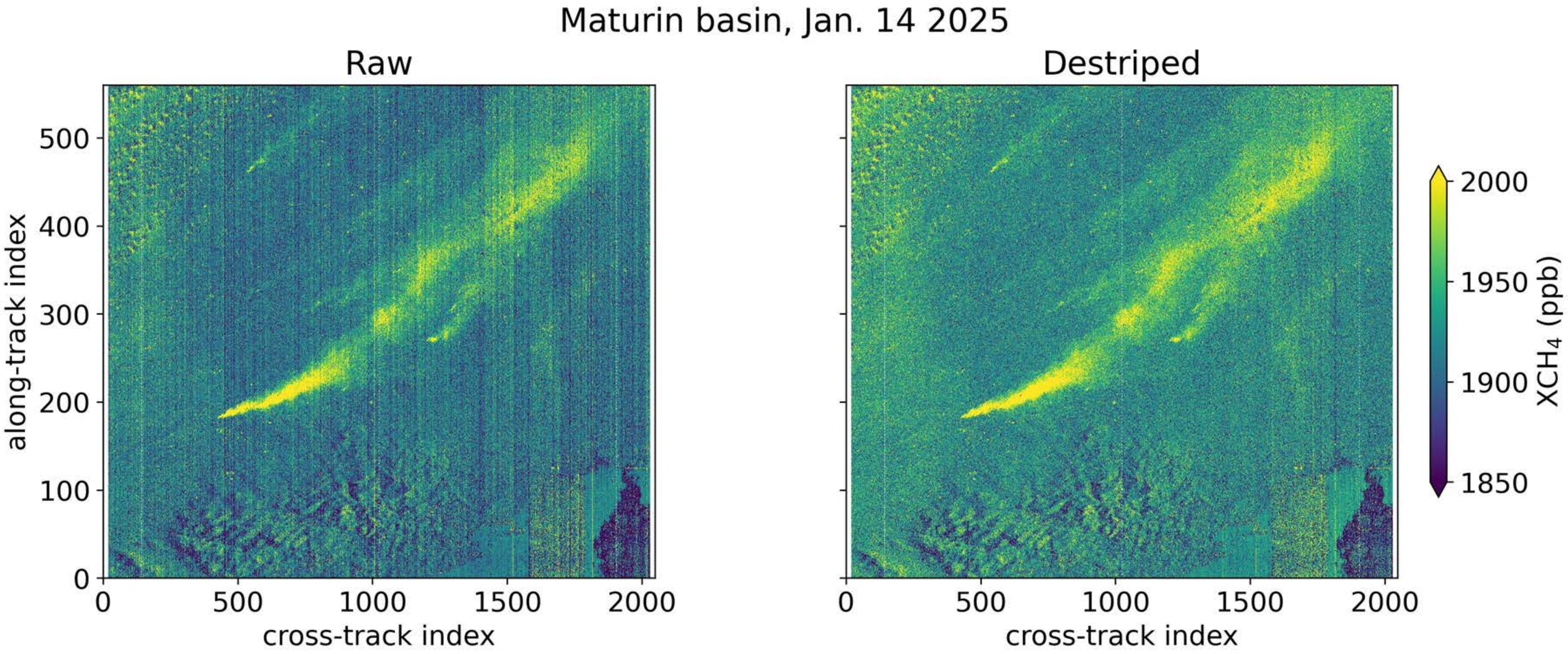


Based on the approach used for TROPOMI CO (Schniesing et al. 2023. Sect. 3.4)

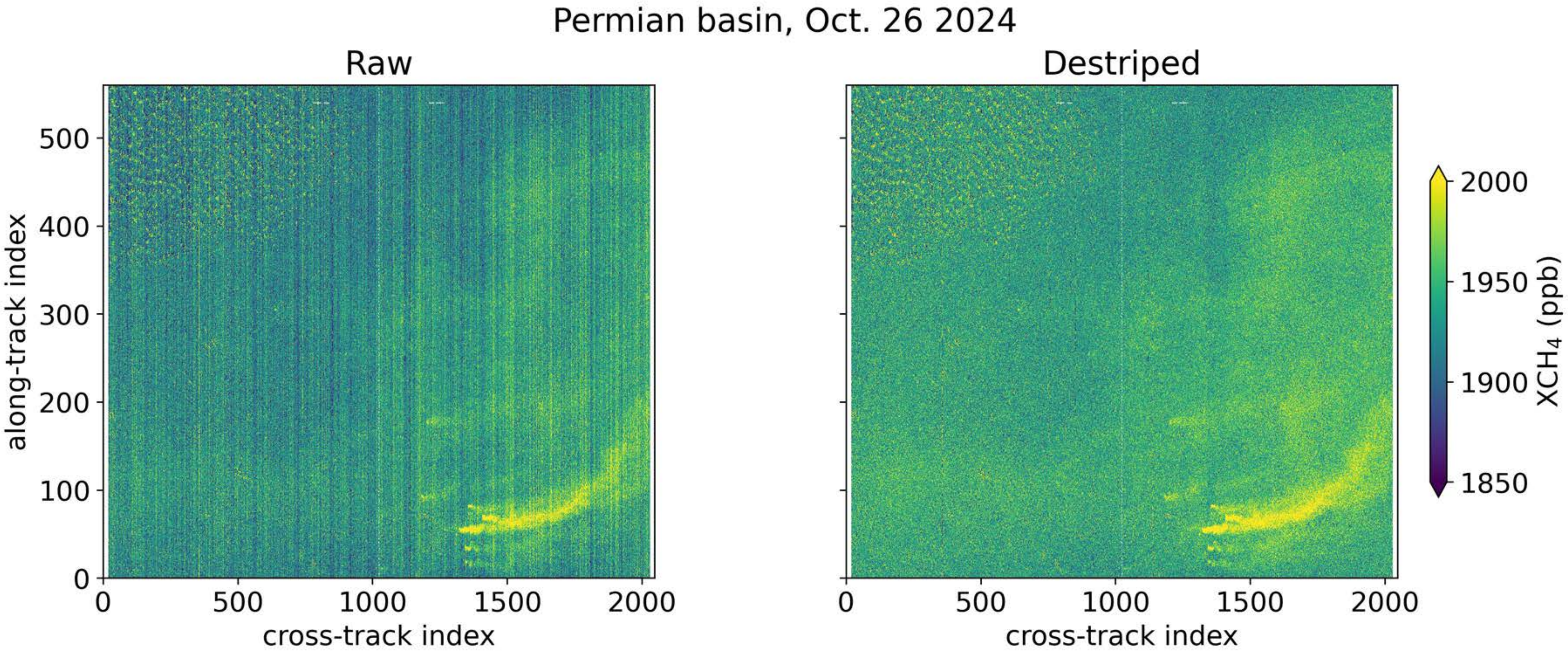
Destriped XCH4



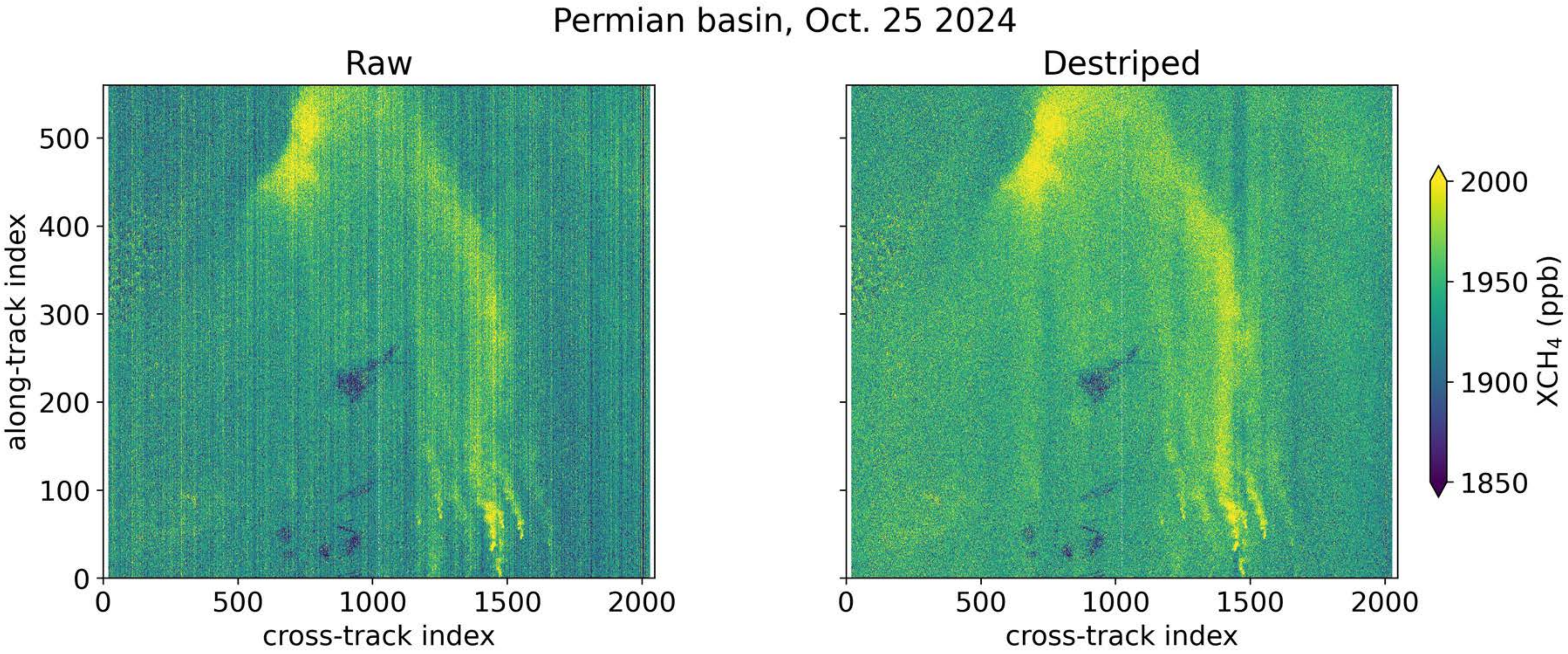
Destriping example 1



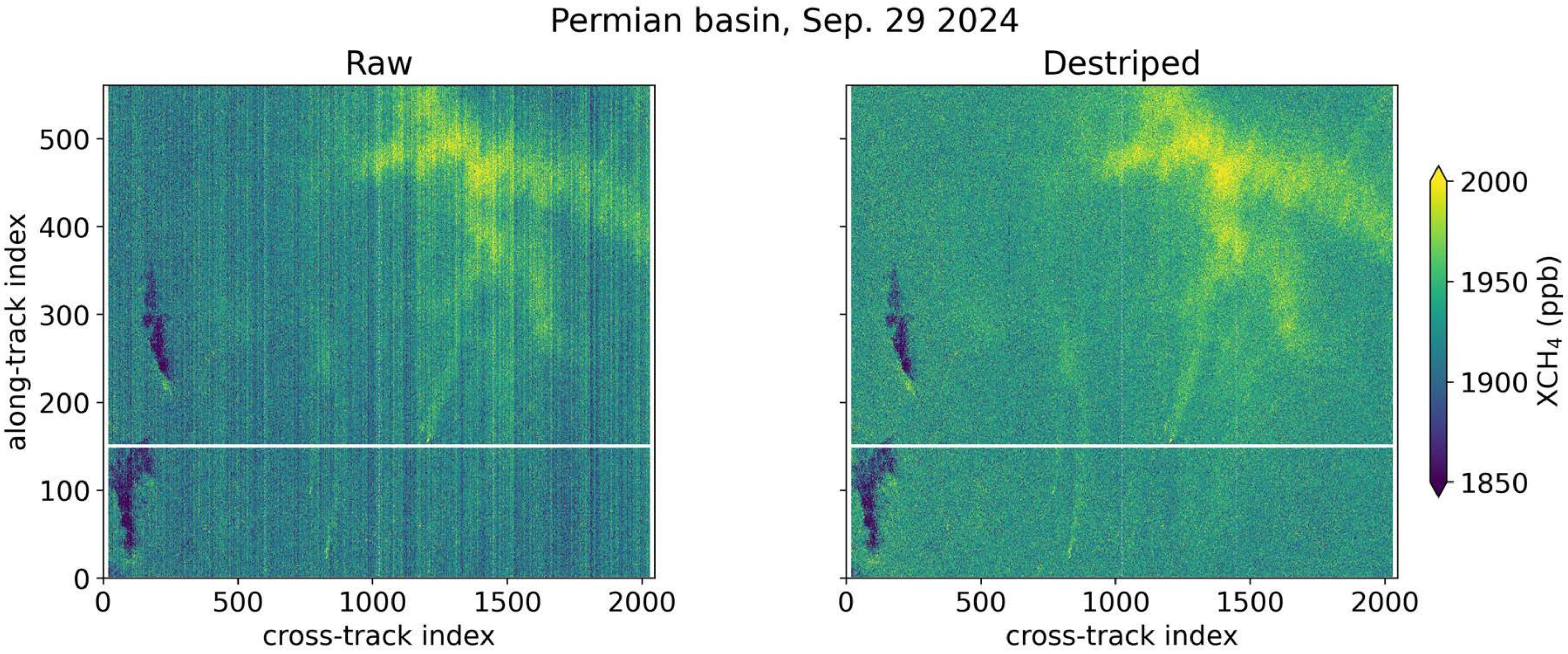
Destriping example 2



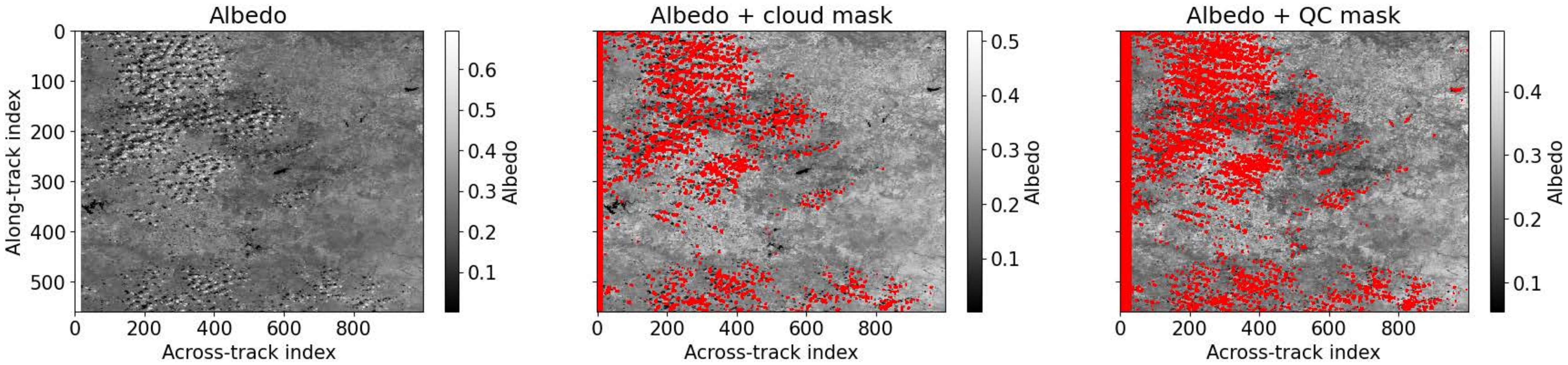
Destriping example 3



Destriping example 4



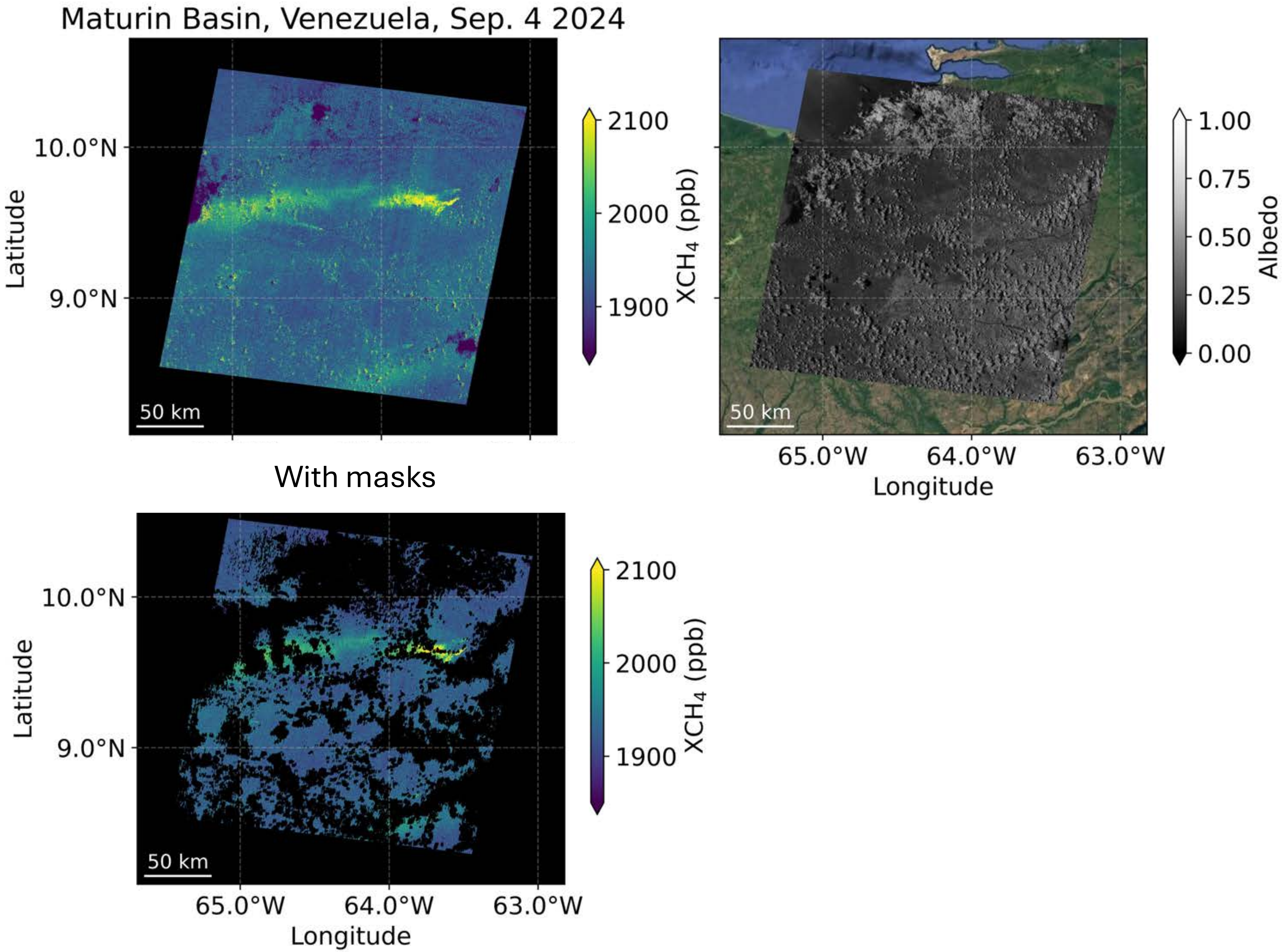
Post-processing masks



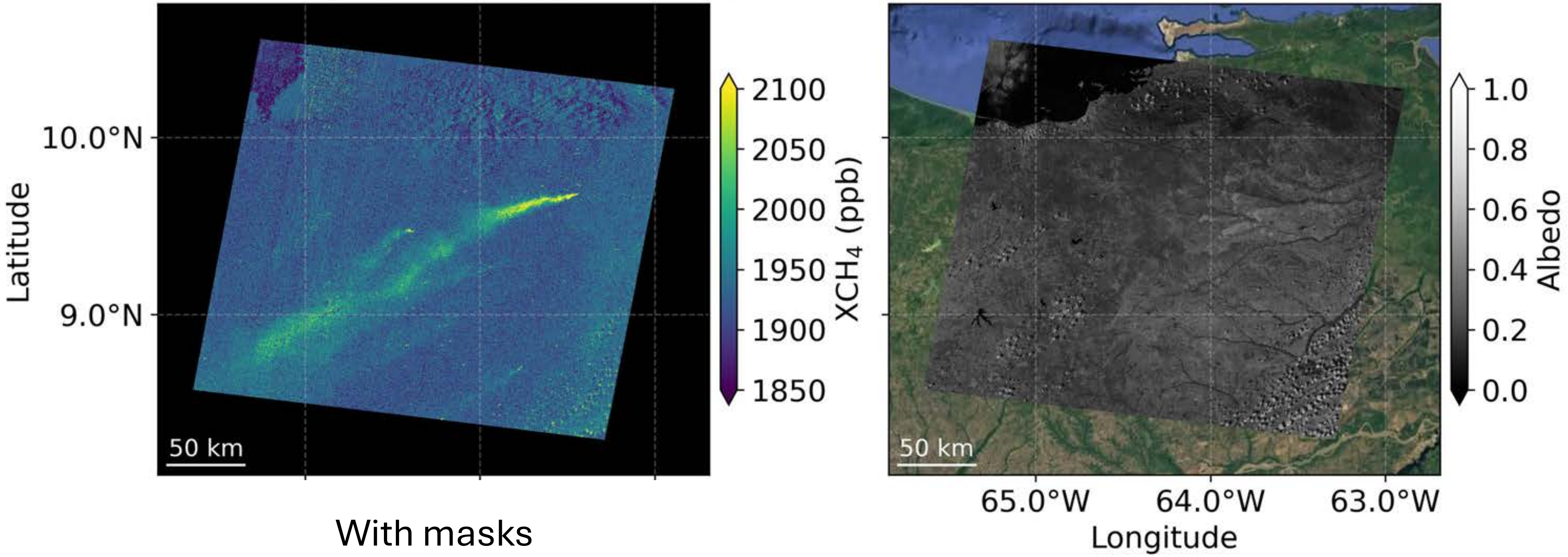
- Cloud mask: thresholds on $|\Delta P|$>20 hPa and $|\delta CO_2|$>2%.
- Effective at masking clouds but do not capture all cloud shadows.
- Shadows are further screened by quality thresholds on signal and fit quality.
- Machine learning algorithms being tested for cloud screening on L1 data from the CH_4 spectrometer (Maya Nasr and Manuel Pérrez-Carrasco: Machine Learning Methods for Enhanced Cloud and Shadow Segmentation in MethaneAIR and MethaneSAT , in prep.).

QC mask = cloud mask + quality control thresholds on:

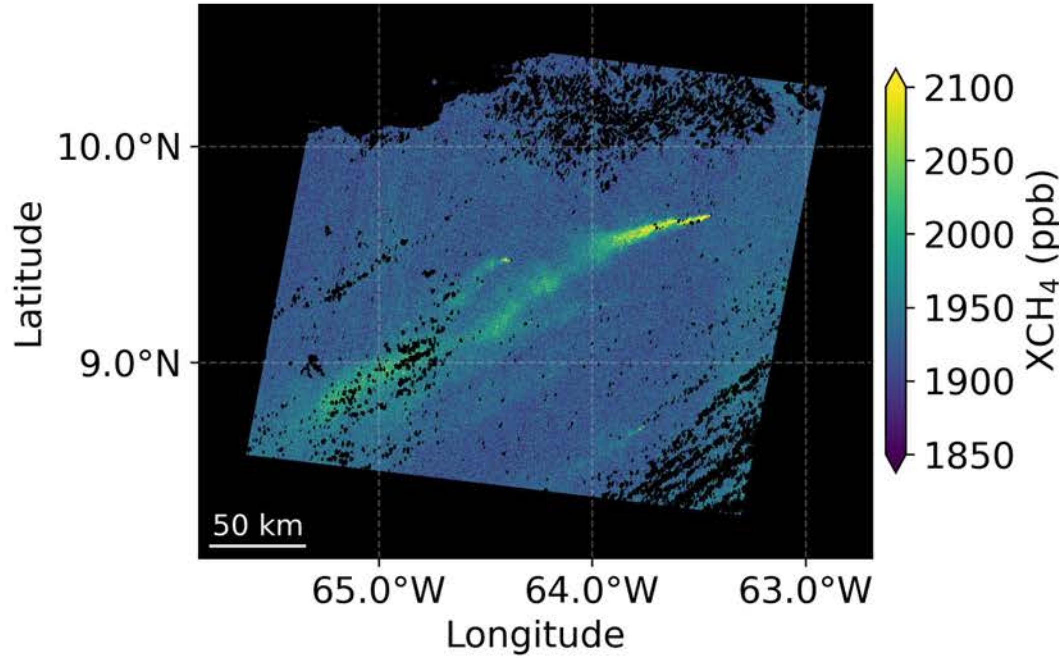
- DOFS<0.6
- Fit residual RMS>5%
- Albedo<0.05
- SZA>70
- VZA>50
- Missing data (e.g. missing frames)


Maturin Basin, Venezuela, Sep. 4 2024
Latitude
10.0°N
9.0°N
50 km
2100
2000
1900
XCH4 (ppb)
1.00
0.75
0.50
0.25
0.00
Albedo
65.0°W
64.0°W
63.0°W
Longitude
With masks

Maturin Basin, Venezuela, Jan. 14 2025

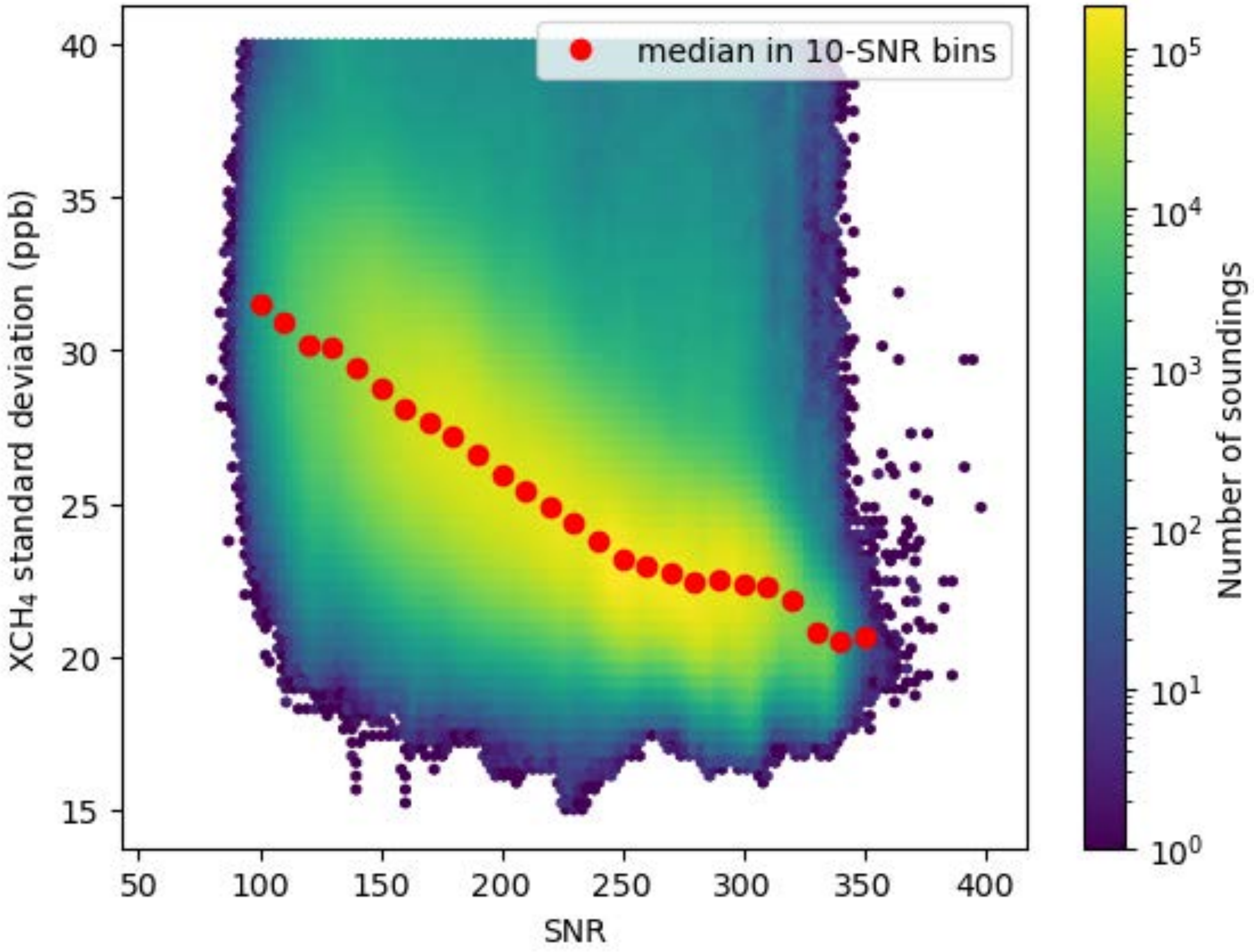


With masks



XCH_4 CO_2-proxy precision

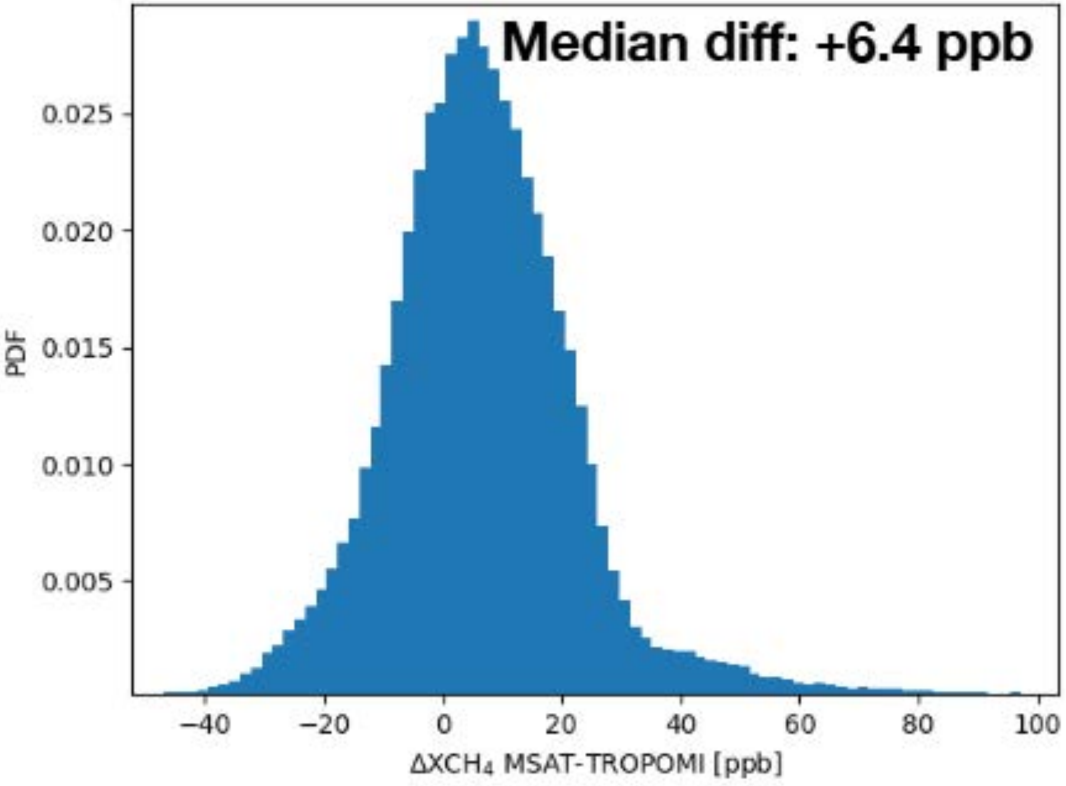
- Native resolution XCH_4 precision is 20-35 ppb, varying with signal.
- **This corresponds to a 2-3.5 ppb precision aggregated at 2x2 km^2 (well within the mission requirement of 3ppb @ 5x5 km^2)**



Point-in-polygon comparison with TROPOMI

- Compare each TROPOMI sounding to the average of MethaneSAT soundings it covers.
- Nearest TROPOMI swath usually within ~2 hours of MethaneSAT collection
- TROPOMI observations adjusted to use MethaneSAT prior:

$$x' = \hat{x} + (A - I)(x_{a,TROPOMI} - x_{a,MethaneSAT})$$



- Tail of high MethaneSAT XCH4 - possibly from TROPOMI underestimating scenes with high sub grid XCH4 variability
- MethaneSAT median bias ~6.4 ppb higher than TROPOMI.
- TCCON is ~5.3 ppb higher than TROPOMI (Lorente et al., 2023)

Summary

- L2 XCH_4 single sounding precision: 20-35 ppb (2-3.5 ppb at 2x2 km)
- +6.4 ppb median diff. with TROPOMI (TCCON has +5.3 ppb median diff. with TROPOMI)
- Root cause of striping unresolved and under investigation, corrected in post-processing.

Data access

- https://www.methanesat.org/data
- https://data.methanesat.org/en/emissions-map
- https://developers.google.com/earth-engine/datasets/publisher/edf-methanesat-ee (L3 and L4 targets + MethaneAIR)
- Public preview request form (L3 images from ~180 collections, L2/L3 data over limited targets):

https://forms.gle/jqw4Mvr63dsV1fUF8