Towards the CO2Image demonstrator: performance studies using AVIRIS-NG

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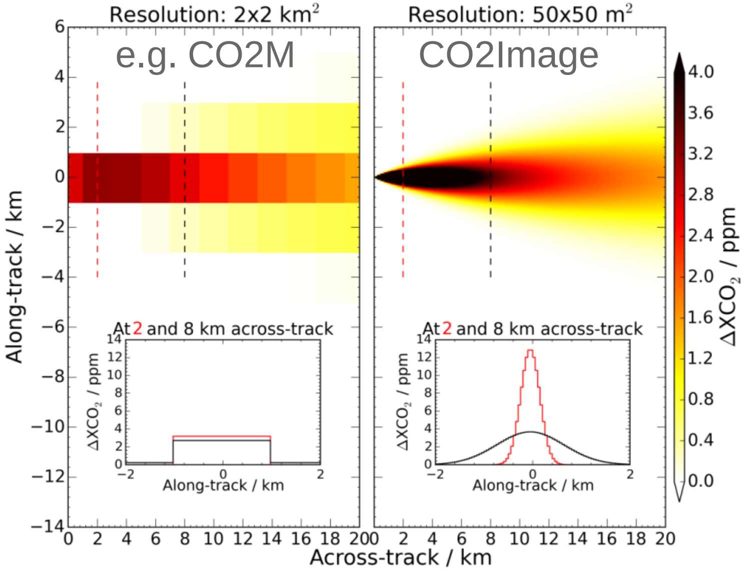
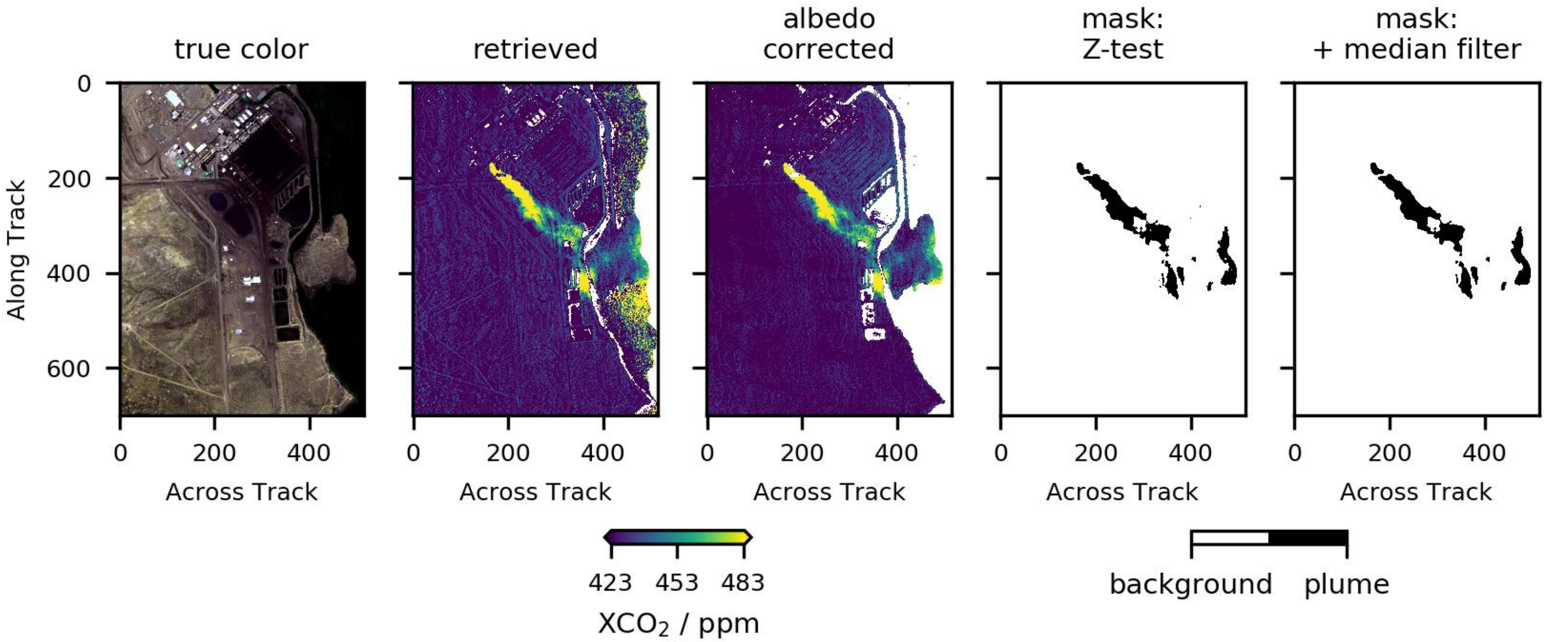


CO2Image

- **Quantification of CO_2 emissions** from large and medium sized power plants (**>1 MtCO_2y^{-1}**)
- **50 m spatial resolution**, 1.3 nm spectral resolution
- **Phase A completed**, launch envisaged for 2025 (DLR CompSat program)

AVIRIS-NG



- Retrieval study with AVIRIS-NG power plant measurements (Δλ ~ 5 nm)
- Identification of favorable retrieval windows and state vector configurations
- Unresolvable correlation of XCO_2 with surface reflectance → Posterior albedo bias correction
- CO_2 emission rate inversion

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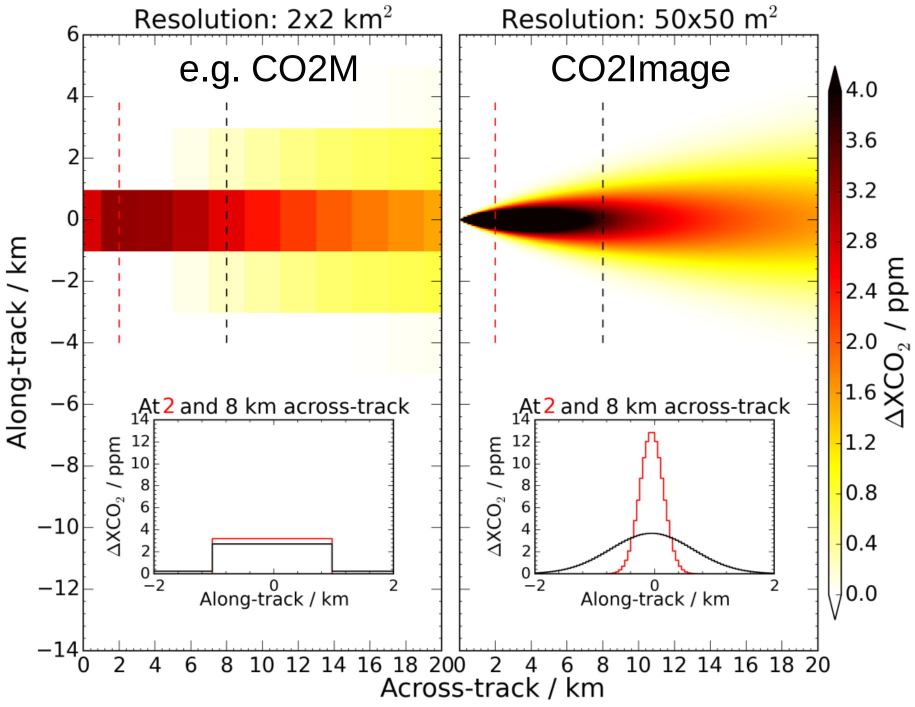
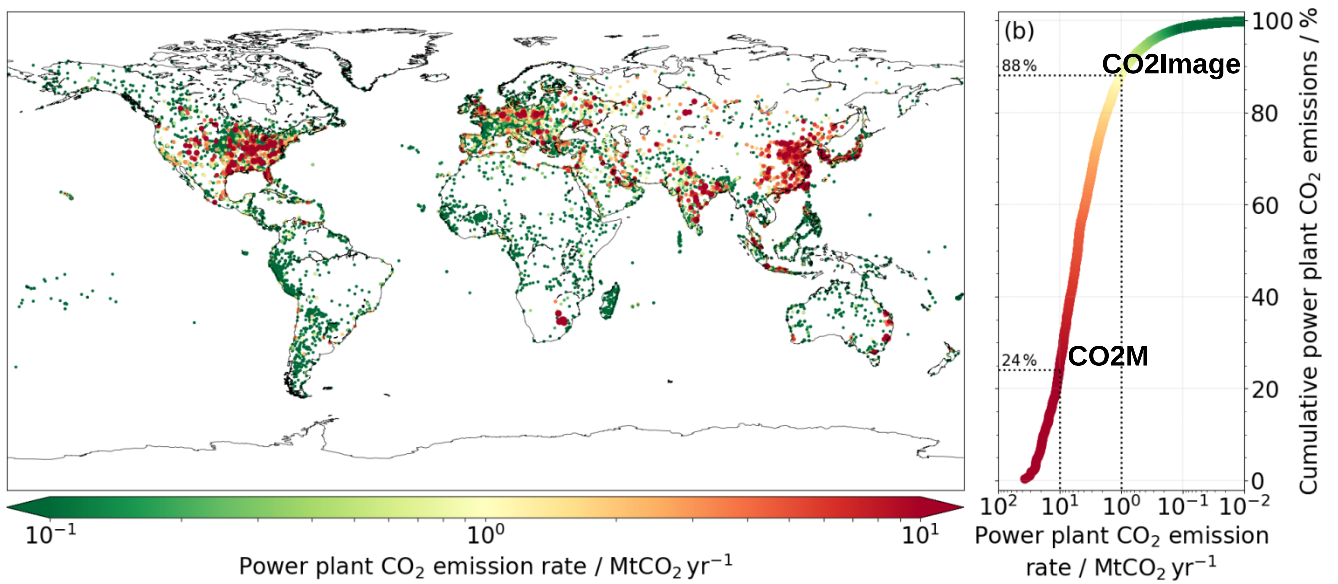
The CO2Image mission: a compact CO_2 monitoring sensor at 50 x 50 m^2 spatial resolution



[Wilzewski et al. (2020)](#)

- Very high spatial resolution entails coarse spectral resolution for sufficient SNR.
- Ideal spectral resolution at Δλ = 1.3 nm in the SWIR-2 spectral range



[Strandgren et al. (2020)](#)

- Simulations show that the planned sensor can be expected to resolve plumes of medium-sized power plants (≥1 $MtCO_2\ y^{-1}$).

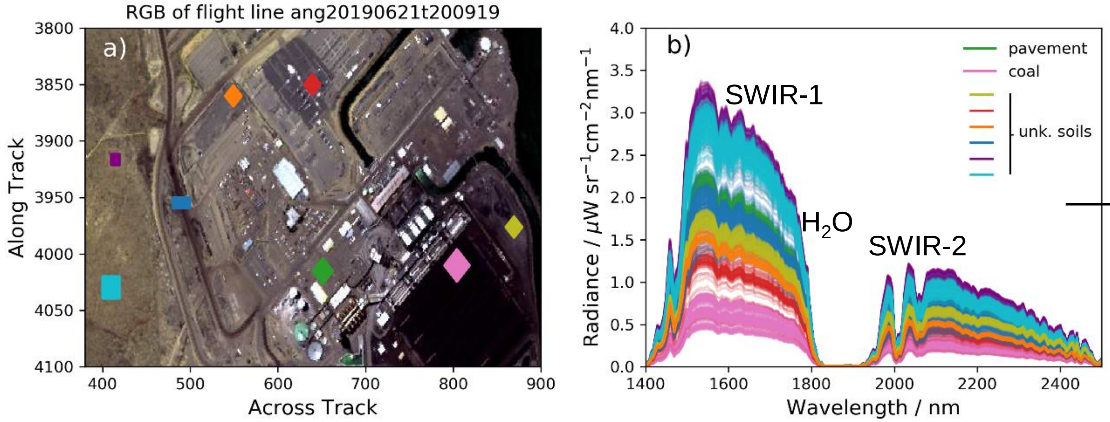
For more information on CO2Image see [presentation by André Butz](#), same session

Retrieval performance studies with AVIRIS-NG

AVIRIS-NG
- Air-borne Sensor
- $\Delta\lambda$ ~ 5 nm
- 380 nm < λ < 2,510 nm
- Observations of power plants

How to retrieve XCO_2 from AVIRIS-NG spectra?
Insights into emission monitoring techniques?

- Identification of an **ensemble of test spectra** composed of background spectra covering various surfaces



a) True color image of AVIRIS-NG measurement in New Mexico, USA
b) Background spectra selected from the colored shapes in a) to test the XCO_2 retrievals (N=1,369)

→ Retrieval tests with various spectral windows and different polynomial baseline fits carried out with the RemoTeC algorithm

Retrieval state vector
- $[CO_2]$
- $[H_2O]$
- Spectral baseline polynomial → albedo
- Spectral shift

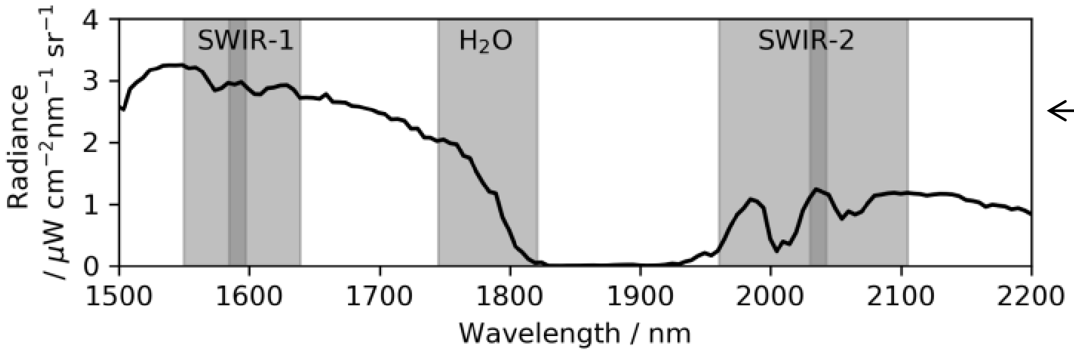
Key results

SWIR-1 spectral range: avg. convergence rate < 70 %

SWIR-2 spectral range: 100 % convergence rate, 2 % scatter in XCO_2, 10 % scatter in XH_2O (on average)

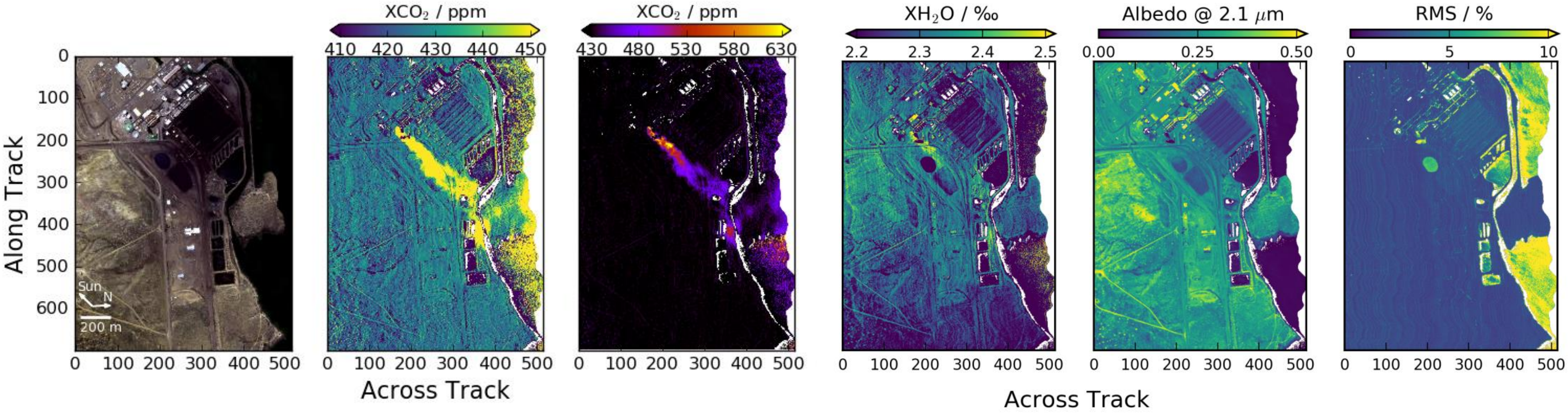
Coupled retrievals (SWIR-1 + SWIR-2 and **extra H_2O window** @ 1.8 µm):

low residuals, 100 % convergence, 2 % and 4 % scatter in XCO_2 and XH_2O, respectively – but trace gas amounts and surface reflectance cannot be detrended (correlation coeff. between albedo and XCO_2: R=0.7)

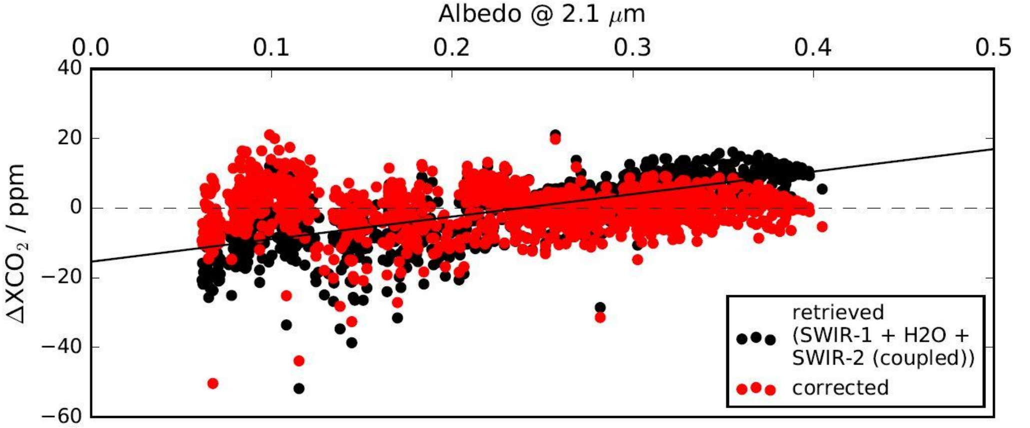


Spectral windows used for power plant XCO_2 plume retrievals (CO_2 bands in individual spectral windows)

Retrieval of XCO_2 plume at Four Corners power plant



- White pixels: non-convergence of retrieval
- Internal plume structure resolved, large enhancements
- XH_2O retrieval shows exhaust plume and albedo correlation
- Spectral RMS error increased over water surfaces and anthropogenic structures
- **Correlation between XCO2 and surface albedo remains**



Linear posterior bias correction, derived from test ensemble retrievals.

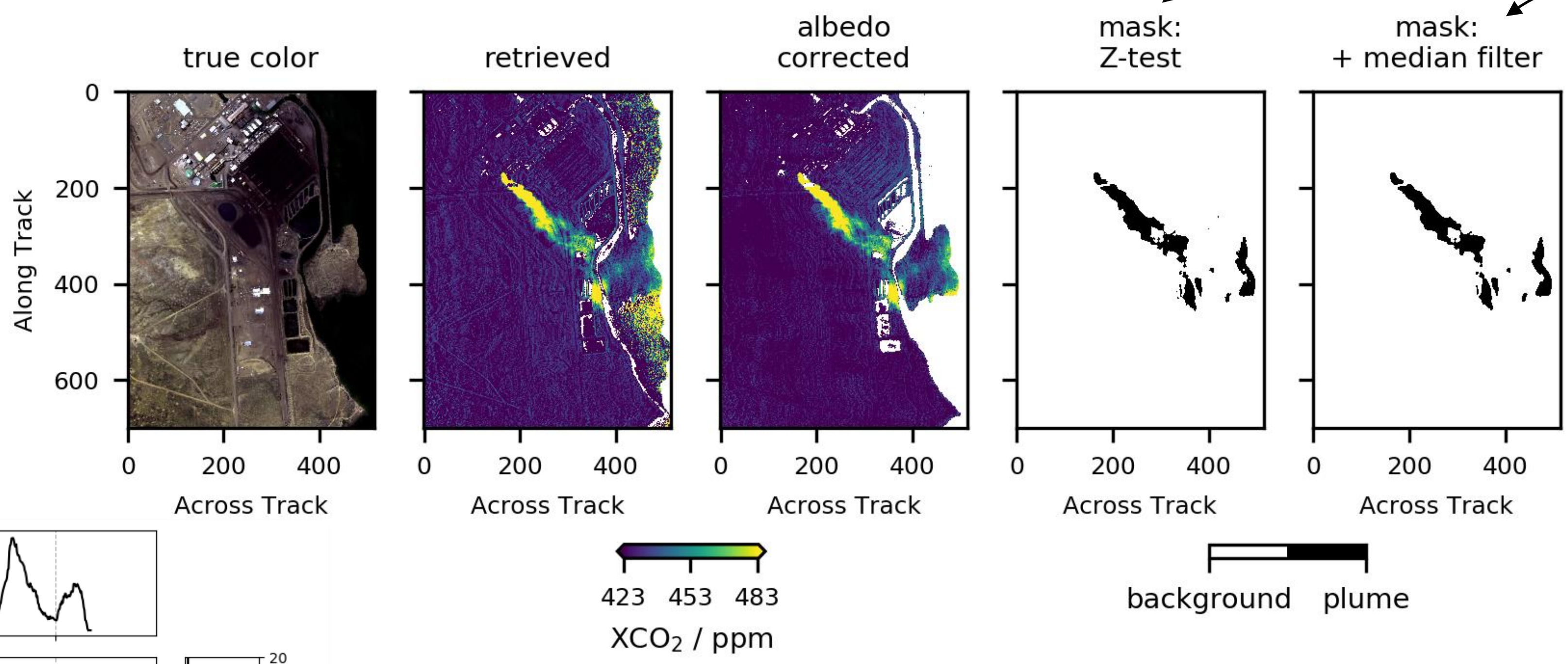
- Dark scenes ($albedo_{@2.1\mu m}$<0.03) removed as XCO_2 retrieval scatter is unrealistically high.
- The correction: reduces the XCO_2-albedo correlation coefficient to below 0.25 in background scenes.
  reduces the XCO_2 background retrieval standard deviation by ~1 ppm.

Plume mask and emission rate inversion

$$Z = \frac{XCO_2 - XCO_2^{bg}}{2\sigma_{bg}} >^! 0.95$$

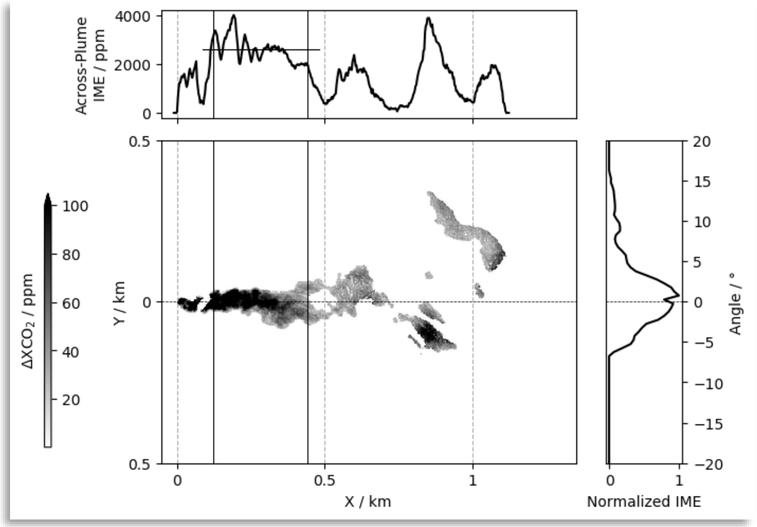
Smooth with median of 5x5 pixel neighborhood

Plume masking procedure inspired by [Varon et al. (2018)](#)



→ Plume is cut off by sensor swath and obstructed by water surfaces

→ mass balance flux inversion



Use plume morphology to calculate cross-plume mass enhancement from an average over a contiguous plume area

Get local wind speed

Wind speed source	Wind speed @ 4Corners [m/s]
ECMWF ERA5 interpolated at stack altitude (116 m); Δt=1h	0.6
Surface measurement @ nearby airport; Δt=2h, Δx≈25km	7.5
NCEP NARR interpolated at 30 m above ground; Δt=3h	6.1

Wind speed uncertainty conservatively estimated at 3 m/s.

Emission rate calculation

	Q (4Corners) / $MtCO_2y^{-1}$
Present study	17.4 ± 8.8
EPA inventory	8.8

Summary and Conclusions

- XCO_2 retrievals from AVIRIS-NG spectra perform best when strong absorption bands of CO_2 and H_2O are included in the spectral fitting windows (i.e. CO_2 bands in SWIR-2, wing of opaque H_2O band at 1.8 µm).

- All retrieval set-ups studied here lead to significant correlation between trace gas columns and surface reflectance: this may be an inherent property of the $\Delta\lambda$ ~ 5 nm resolution of the sensor.

- Fitting individual CO_2 absorption bands in separate spectral windows is beneficial to reduce spectral residuals.

- The retrieval conducted in this work uses all four CO_2 absorption bands in the SWIR and an extra spectral window at 1.8 µm to constrain XH_2O.

- A posterior (linear) albedo bias correction was applied to detrend XCO_2 from ground albedo.

- Emission rates of power plants critically depend on appropriate wind speed information at the height of the stacks; meteorological reanalyses have to be used with caution.

- Future work should derive wind speed information from the shape of the plume.