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Impact of a priori contribution on CO retrievals from infrared hyperspectral measurements

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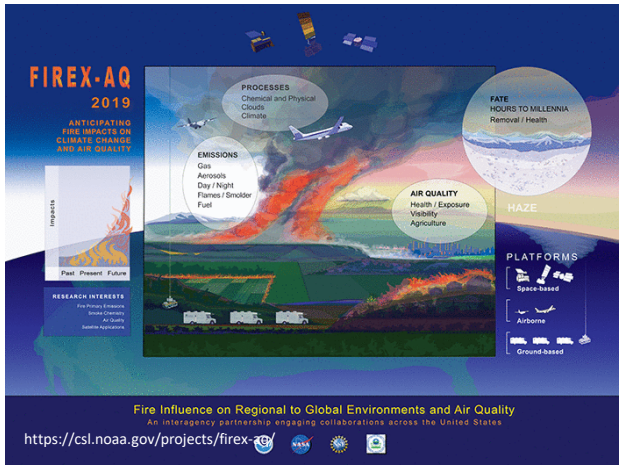
Background | NAST-I measurements for wildfire observation

Wildfire

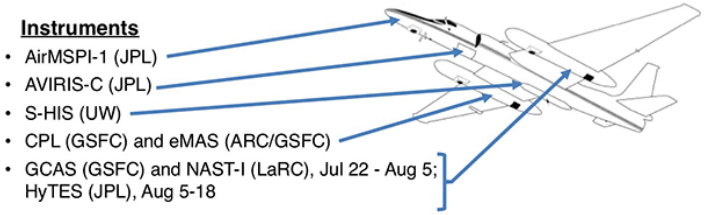
FIREX-AQ

(Fire Influence on Regional to Global Environments and Air Quality)

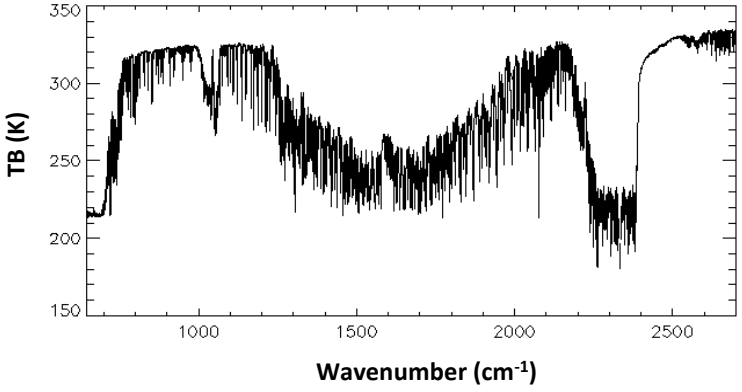


NAST-I

(National Airborne Sounder Testbed – Interferometer)

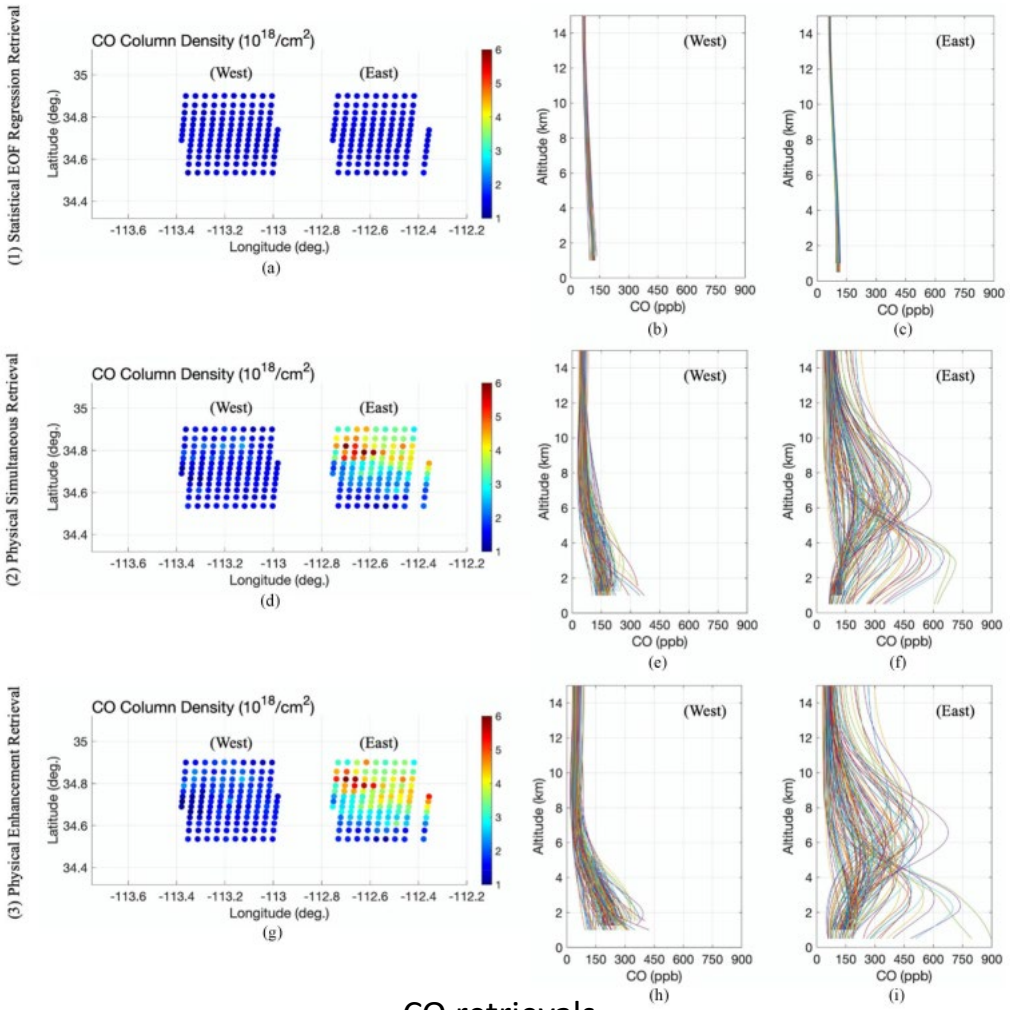


Instrument layout for FIREX-AQ NASA ER-2 aircraft



Background | NAST-I standard retrievals and PCRTM-RA

NAST-I standard retrieval algorithm



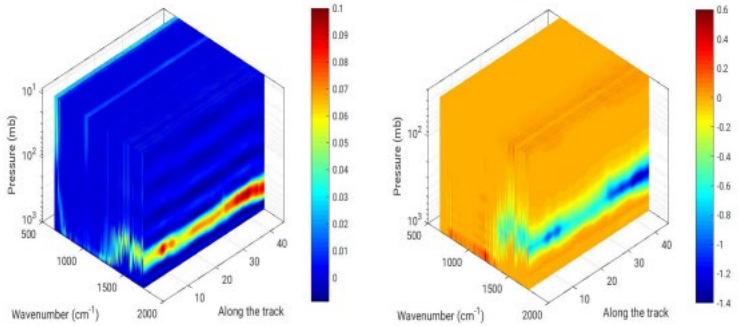
CO retrievals

Zhou et al. 2021 (IEEE STARTS)

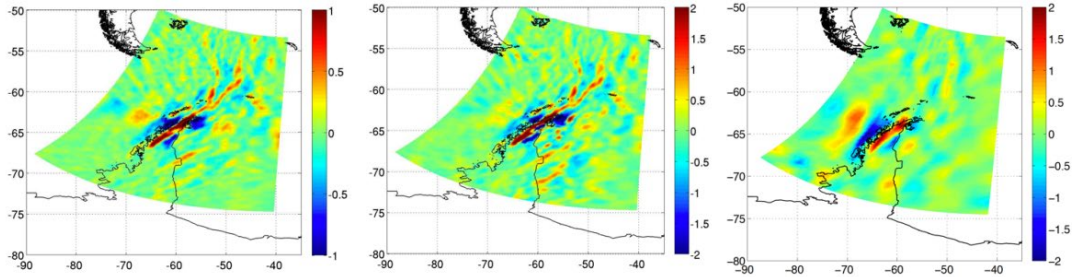
you can find more information on 13p.06 (Daniel Zhou)

PCRTM-RA

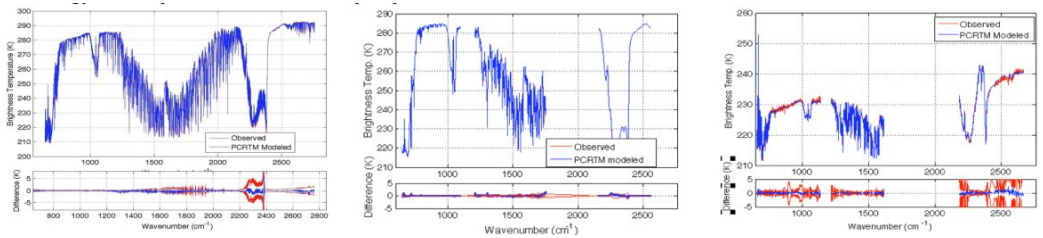
(Principal Component-based Radiative Transfer Mode-Retrieval Algorithm)



Temperature and water vapor Jacobian



Gravity wave detection

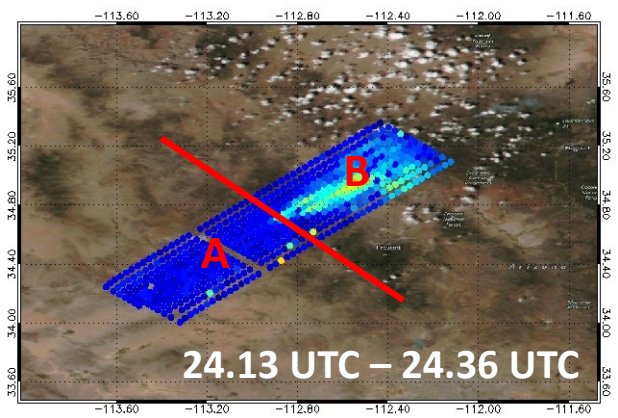


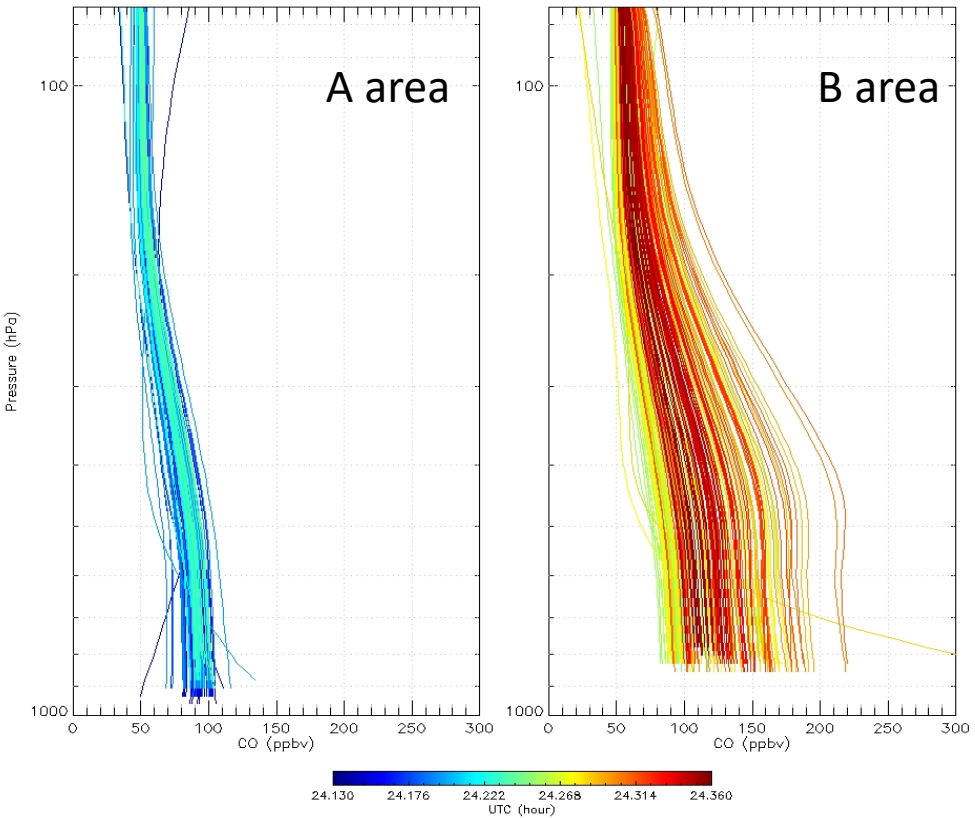
Retrieval residuals for major hyperspectral sounders

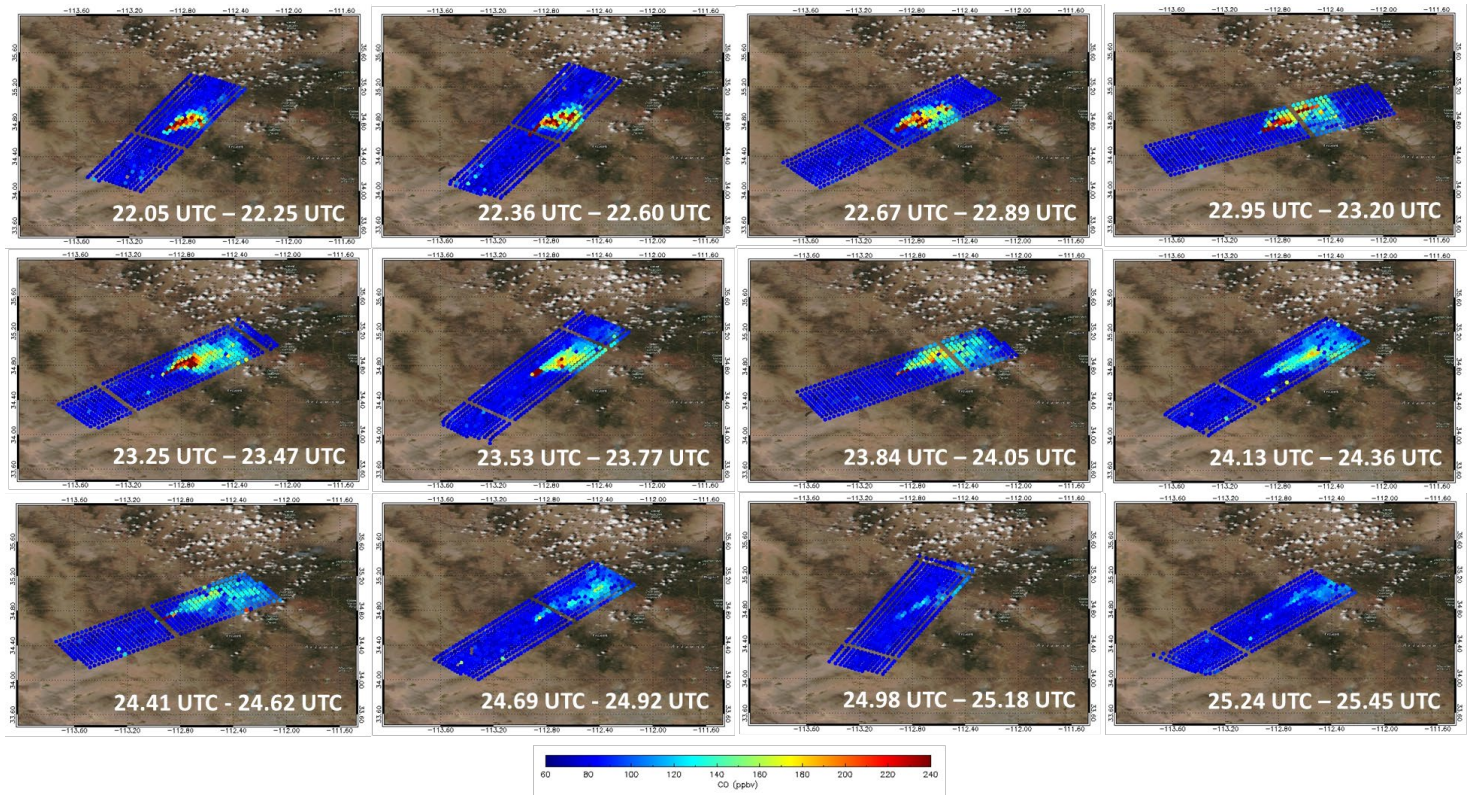
Wu et al. 2019 (IEEE IGARSS)

you can find more information on 1.07 (Xu Liu) and 13p.04 (Xu Liu)

Motivation | Representation issue of PCRTM-RA CO retrievals







- PCRTM-RA can still successfully capture the plume feature even when the level of trustiness of $\mathbf{X_a}$ is defined by the variability of global CO.

- One can think that default $\mathbf{S_X}$ may not be optimum (maybe too tight) since most of the default $\mathbf{S_X}$'s variability would be variability of background CO. It can cause a less-dynamic structure of CO retrieval. To describe fire-affected CO features better, relaxed $\mathbf{S_X}$ may be needed.

Introduction | What you will see from this talk

From this talk, I will share the results of

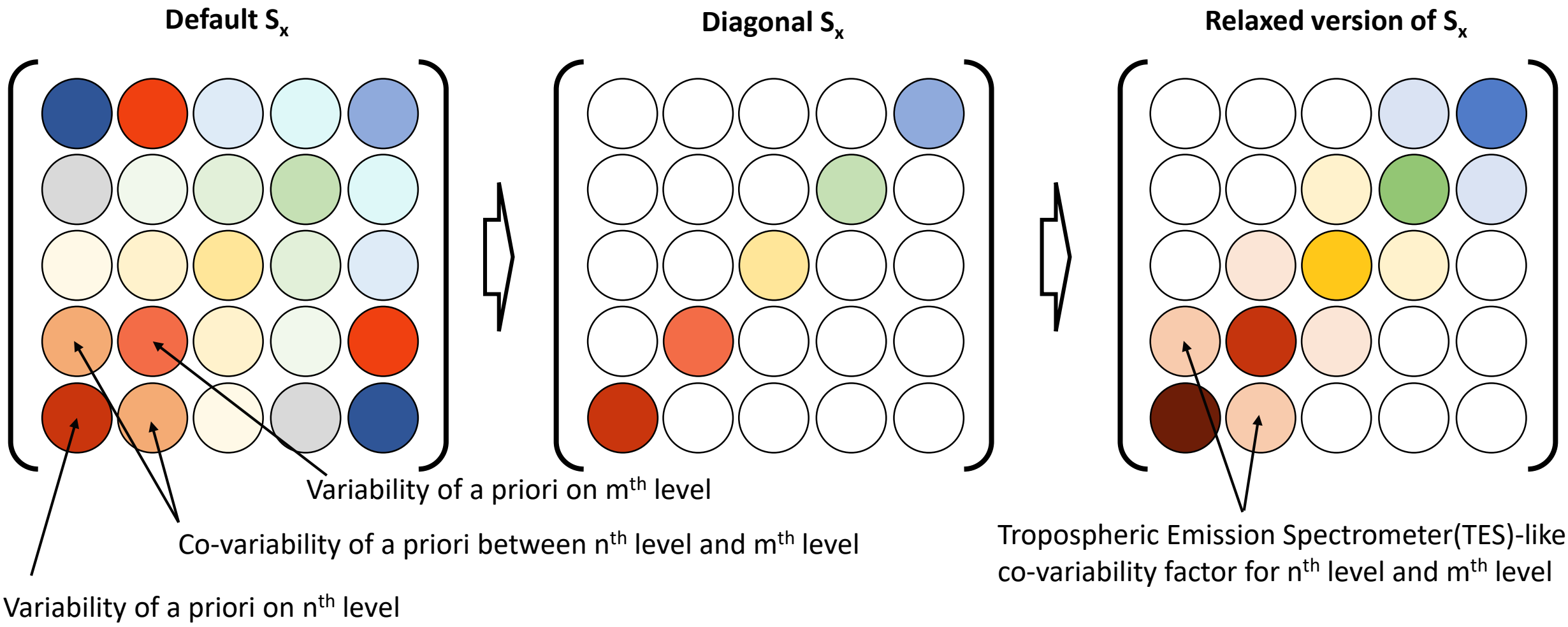
1) the impact of the a priori contribution matrix on CO retrieval from PCRTM-RA by **decreasing the contribution of determining CO vertical structure**.

- **relaxed S_x** for NAST-I
- **averaging kernel**
- **assessment** of improved CO retrievals from synthetic NAST-I measurements

2) the capacity of enhanced PCRTM-RA for **capturing CO distribution**.

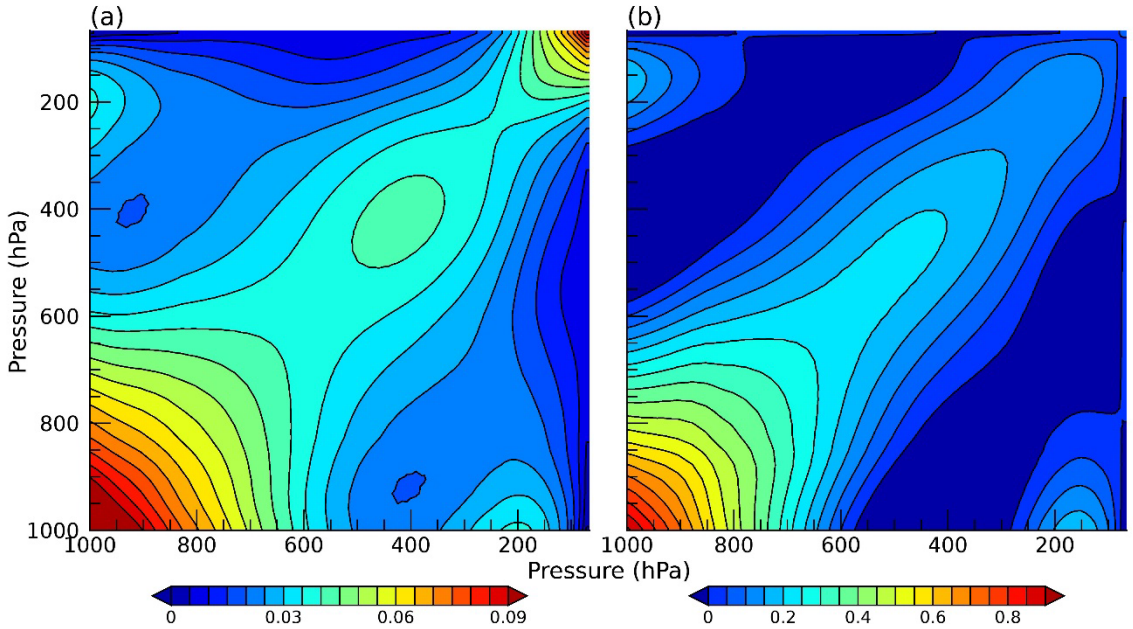
- **demonstration** of CO retrievals
- **comparison** with in-situ observations

Methodology | How to make new S_x for NAST-I measurements

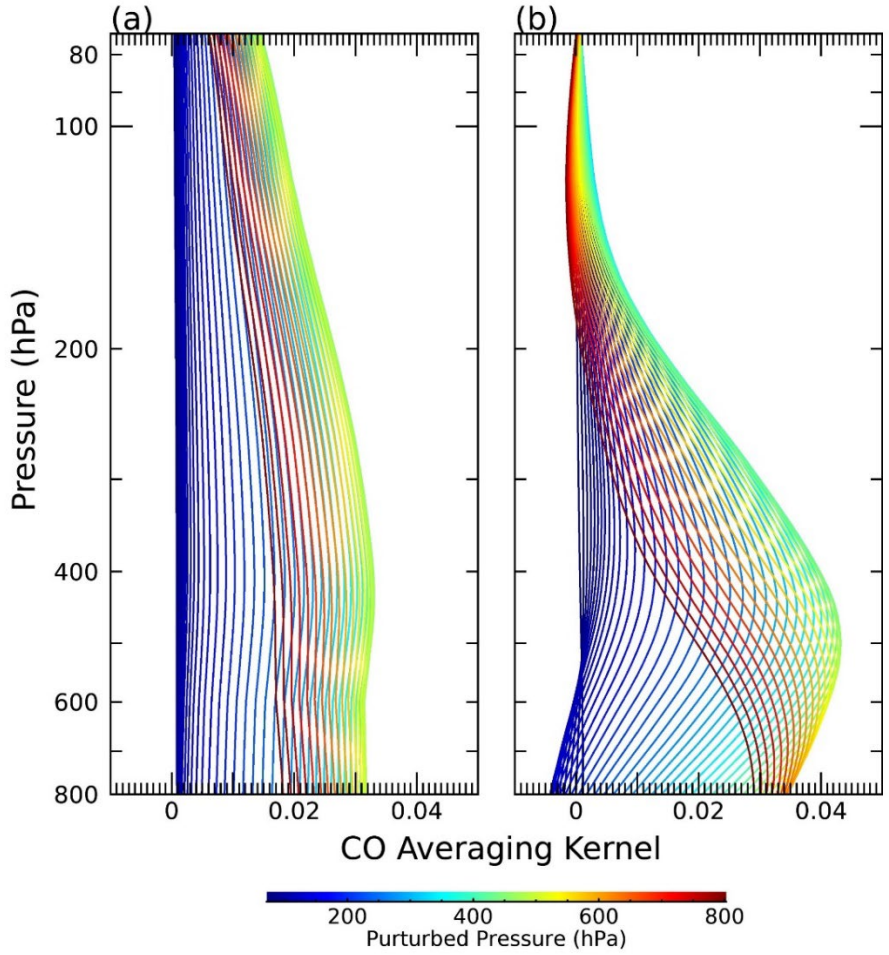


Results | Covariance matrix and Averaging kernel

(a) Default S_x and (b) Relaxed S_x



An example of averaging kernels from (a) Default S_x and (b) Relaxed S_x

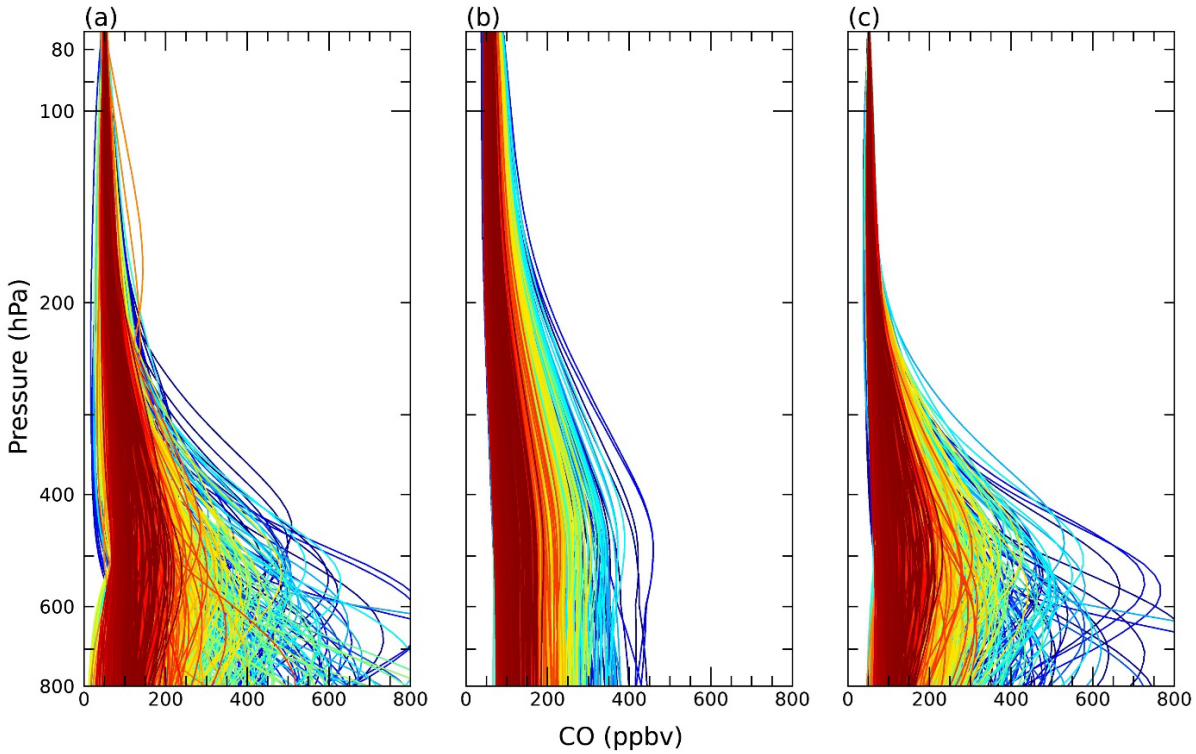


- Relaxed a priori allows a retrieved CO profile to have a smaller vertical correlation than the original one.

- PCRTM-RA better captures a perturbation level when we use the relaxed one.

Results | Assessment of improvement from a synthetic dataset

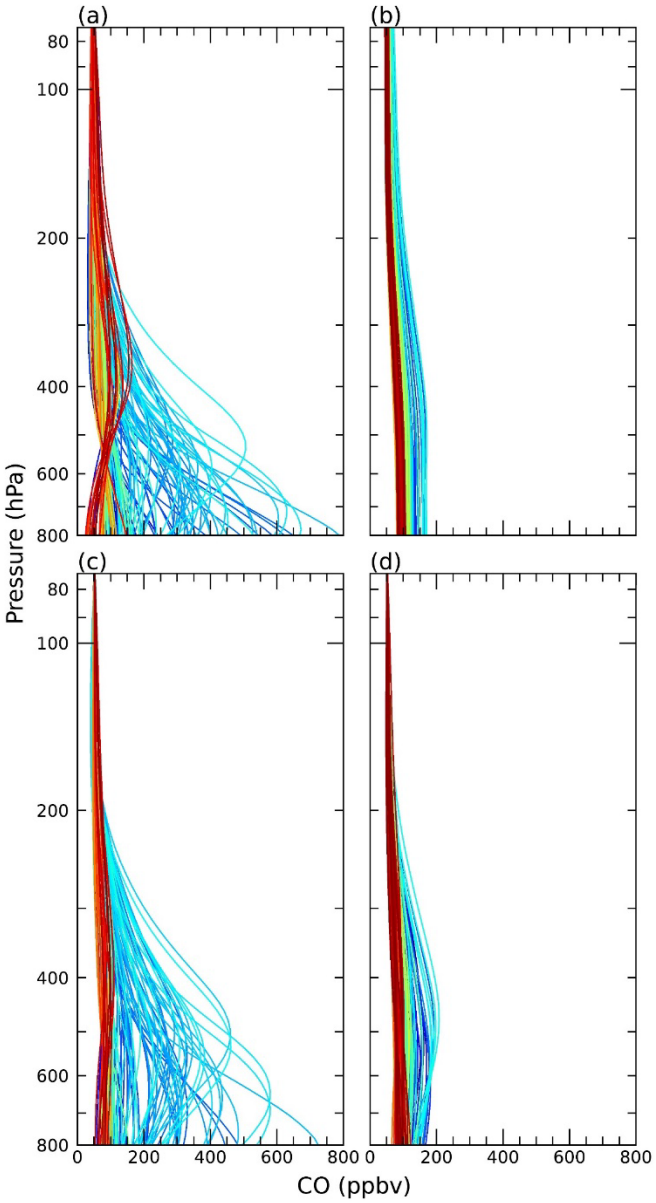
(a) Truth (b) Retrievals with default S_x, and (c) Retrievals with relaxed S_x



- CO profiles retrieved with a relaxed constraint better represent the vertical variation of the true profiles.

- Using a relaxed contribution matrix for better-representing enhanced CO emission also works well for CO retrieval in a clean environment.

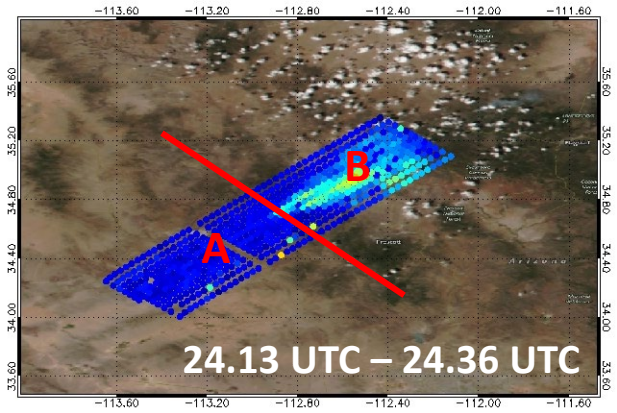
High CO (a, c) **Low CO (b, d)**

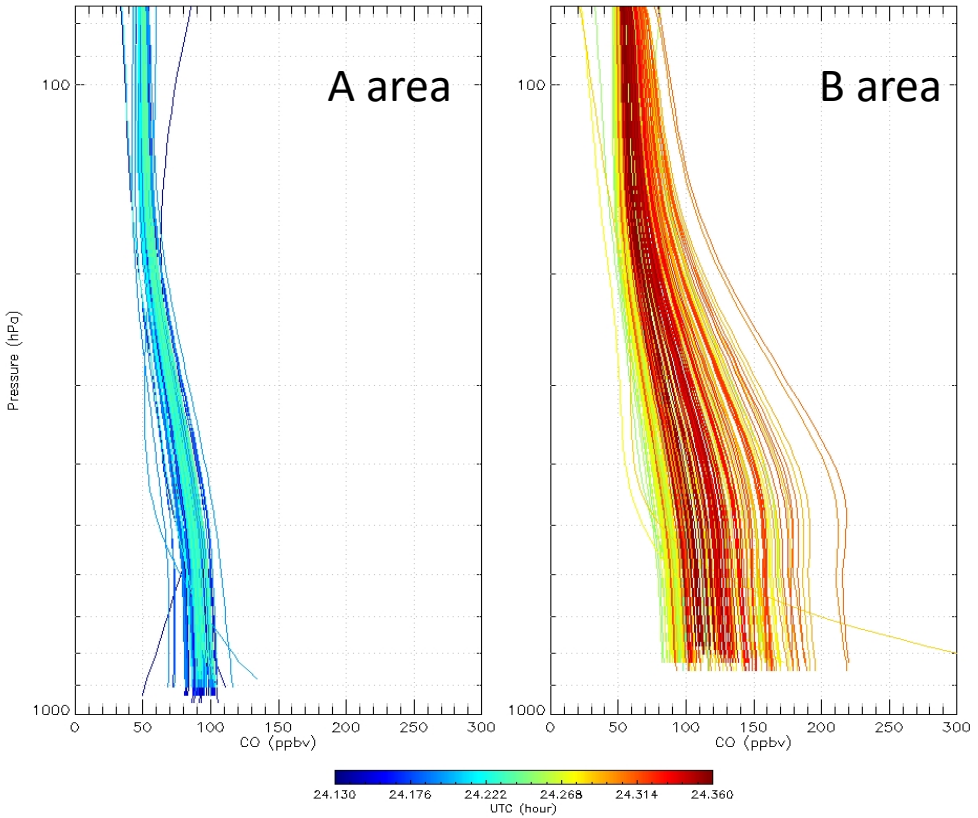


Truth (a, b)

Retrieval with relaxed S_x (c, d)

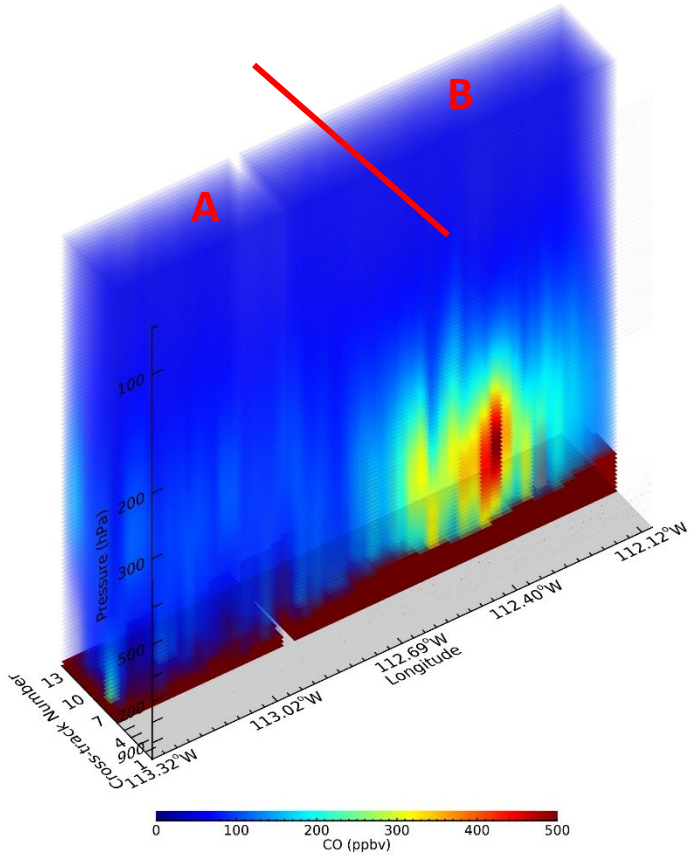
Results | CO retrievals before/after S_x relaxation





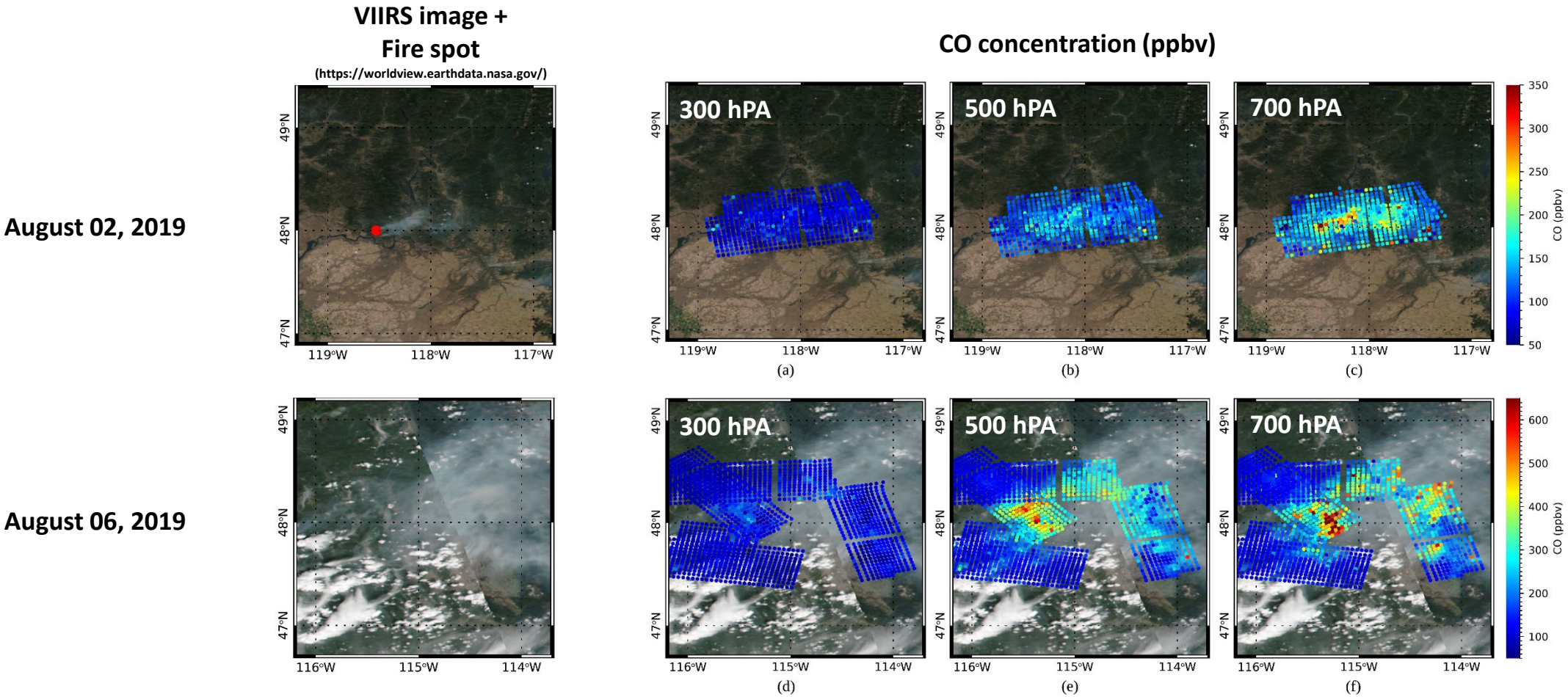
Before & After

Partial three-dimensional structure of CO



A similar retrieval change (i.e., less-dynamic structure -> more-dynamic structure) happens in actual NAST-I measurements.

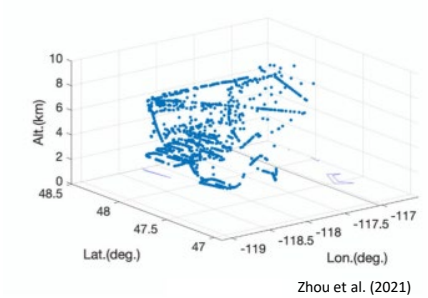
Results | Demonstration of CO retrievals (vertical structure)



- PCRTM-RA retrieved CO can be used to clearly separate the clean air from the polluted air with heavy plume area identified.
- For August 6, 2019 case, the highest concentration area at 700 hPa is slightly shifted toward the South-East direction than that on 500 hPa.

Results | Comparison with in-situ observations

NASA DC-8

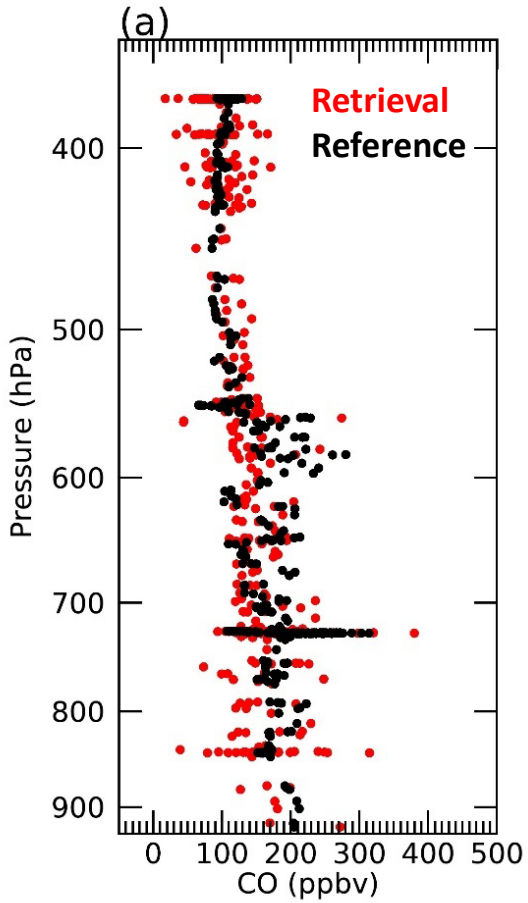


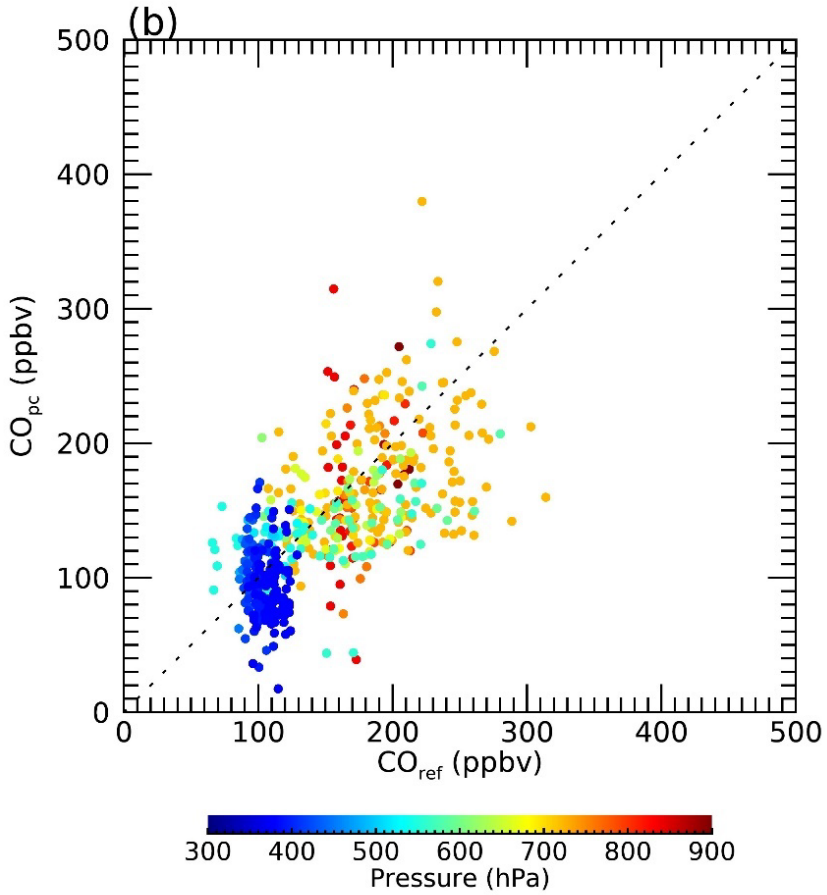
Zhou et al. (2021)

Sampling locations

Differential Absorption Carbon monOxide Measurements (DACOM)

(a) Comparison of ret.(red) and ref.(blk) along with pressure level &
(b) its scatter plot for August 6, 2019





Summary & Lessons

- The a priori used in the standard PCRTM-RA for global CO retrieval limits the variation of retrieved CO profiles.
(vertical distribution characteristics of the global scale CO profiles, the lack of information provided by observations for CO retrieval, …)

- Adaptive modification on the standard PCRTM-RA has been made by localizing the vertical correlation imposed by the a priori and therefore providing a de facto relaxed constraint.

- Using the updated a priori constraint results in a notable improvement in the vertical structure of retrieved CO profiles, i.e., increased variability over mid-lower altitude and suppressed variability over high altitude CO that better matches the truth.

- Despite the challenges of reconcilliating results from different types of measurements, we can still confirm a reasonable agreement between retrieval and in-situ observation.

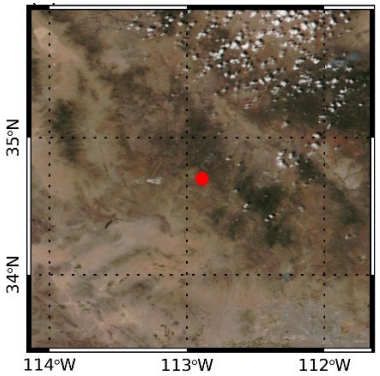
Lessons I have learned from this work:

- More careful use of the constraint is required if measurements cannot provide enough information. At the same time, it may be hard for the current community to have enough information to define 'off-diagonal' factors of constraint matrix for wildfire-related atmosphere.

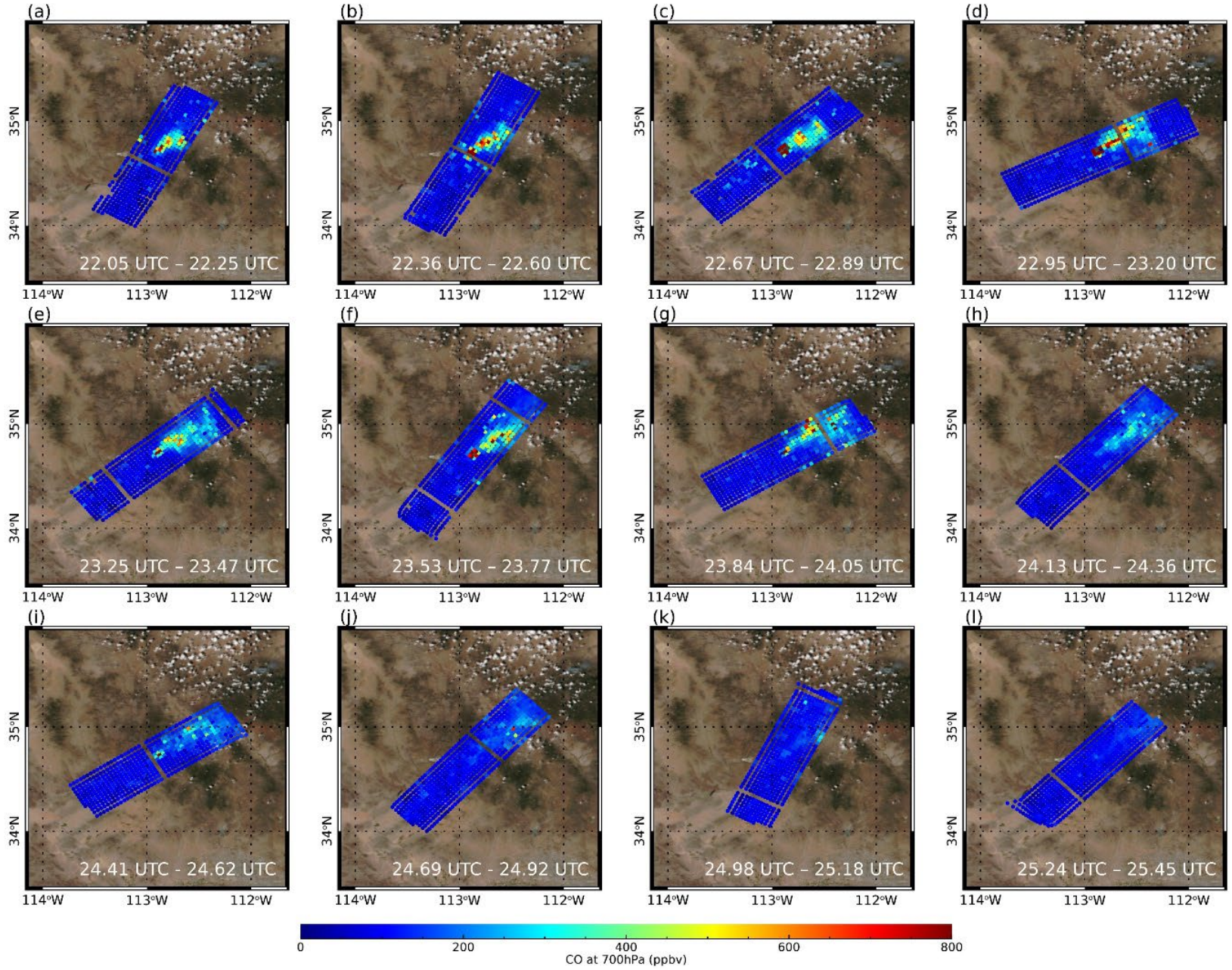
- Just using a diagonal-like constraint contribution matrix and relying more on measurements to define the vertical structure (*it should increase an ill-posed issue though*) could be an alternative if we do not know well about vertical correlation.

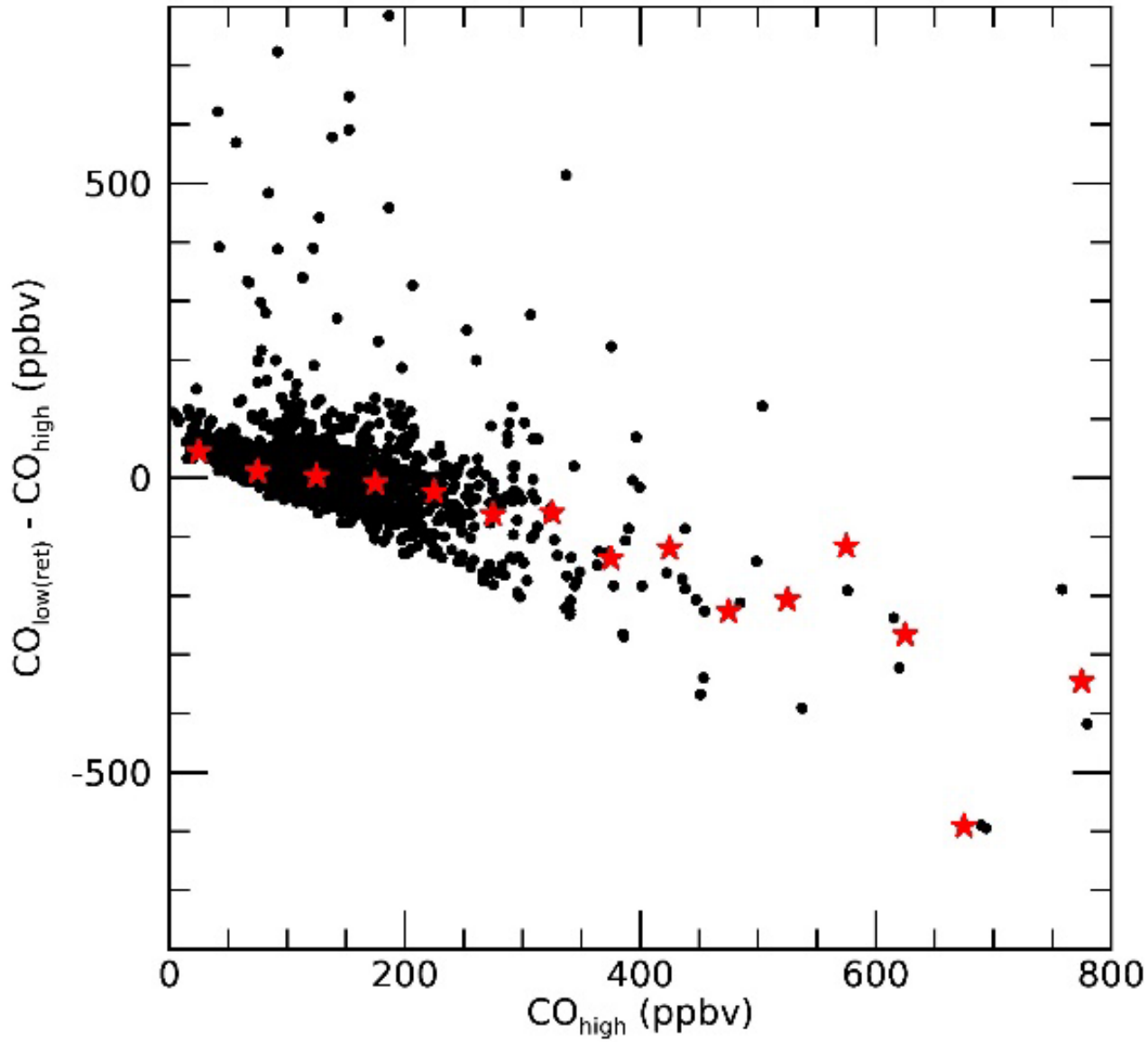
Results | Demonstration of CO retrievals (plume development)

VIIRS image + Fire spot
(https://worldview.earthdata.nasa.gov/)



CO concentration (ppbv) at 700 hPa, August 16, 2019




500
0
-500
0
200
400
600
800
$CO_{low(ret)}$ - CO_{high} (ppbv)
CO_{high} (ppbv)