# The Information Content of Dense Carbon Dioxide Measurements from Space: A Case Study with OCO-3

July 13th , 10:00-12:00 JST
July 12th, 1:00-3:00 UTC
July 12th, 19:00-21:00 MDT

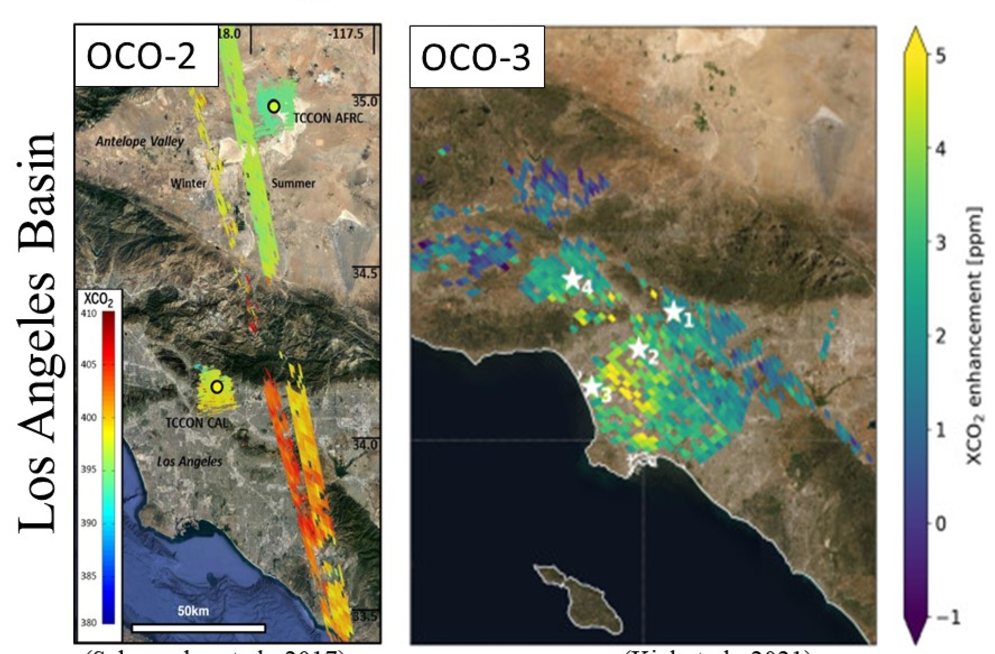
dustin.roten@utah.edu

Dustin Roten[1], John C. Lin[1], Lewis Kunik[1], Derek Mallia[1], Dien Wu[2], Tomohiro Oda[3,4,5], and Eric A. Kort[6]

[1]University of Utah, Salt Lake City, [2]California Institute of Technology, [3]Universities Space Research Association, [4]University of Maryland, [5]Osaka University, [6]University of Michigan

## Introduction

- Informing science and policy surrounding anthropogenic emissions of carbon dioxide ($CO_2$) requires the use of: (1) accurate, statistically driven emission estimates, (2) timely in-situ and remotely sensed $CO_2$ observations, and (3) computational/statistical tools capable of linking (1) and (2).
- For the purposes of monitoring, reporting, and verifying emissions from anthropogenic sources around the world, in-situ measurements provide localized, high temporal resolution observations in selected urban areas around the world. The use of space-based instrumentation has increased the coverage of $CO_2$ observations to a near-global-scale.
- This work implements an observing system simulation experiment (OSSE) to characterize the flux information contained in *synthetic* "Snapshot Area Map" (SAM) observations from NASA's OCO-3 instrument. This instrument provides more spatial coverage over targeted urban areas than its predecessors. Additionally, this instrument is housed on the International Space Station, providing a varying revisit time to target cities.




(Schwander et al., 2017) (Kiel et al., 2021)

## Methodology

- Bayesian inversion methods were used to minimize the cost function:

$$L_S = \frac{1}{2}(\vec{z} - \mathbf{H}\vec{s})^{\mathrm{T}}\mathbf{R}^{-1}(\vec{z} - \mathbf{H}\vec{s}) + \frac{1}{2}(\vec{s} - \vec{s}_p)^{\mathrm{T}}\mathbf{Q}^{-1}(\vec{s} - \vec{s}_p)$$

- In the above cost function, $\vec{s}$ is approximated such that:

$$\hat{s} = \vec{s}_p + (\mathbf{HQ})^{\mathrm{T}}(\mathbf{HQH}^{\mathrm{T}} + \mathbf{R})^{-1}(\mathbf{HQ})$$

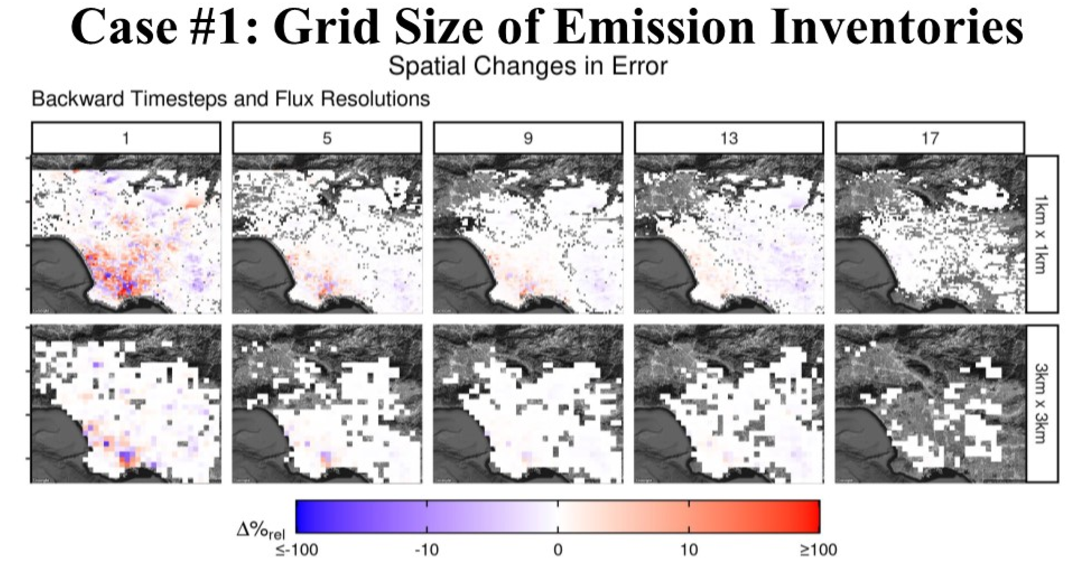
- Multiple SAMs can be aggregated and used to calculate posterior scaling factors, $\hat{\lambda}$. **K**, **S** represent disaggregated sectoral emissions.

$$\hat{\lambda} = \vec{\lambda}_p + (\mathbf{KS})^{\mathrm{T}}(\mathbf{KSK}^{\mathrm{T}} + \mathbf{R})^{-1}(\vec{z} - \mathbf{K}\vec{\lambda}_p)$$

- The amount of flux information contained in each SAM is quantified based on how much the posterior emissions were optimized by the inversion scheme above. Three scenarios were investigated.
- The amount of optimization from the use of multiple SAMs was also investigated using an iterative process. Two scenarios were investigated.

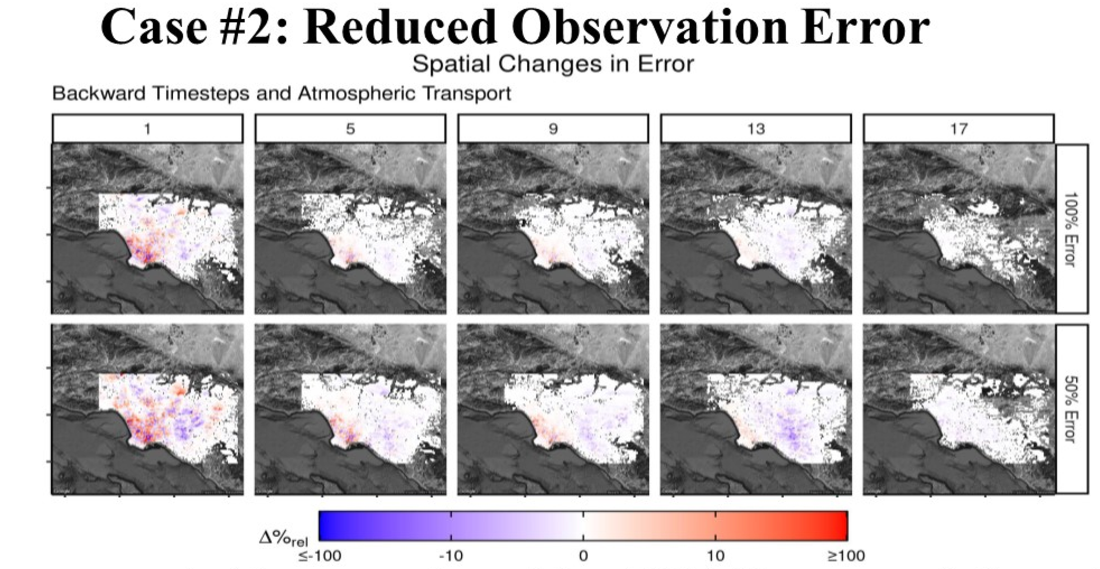
## Results

### Case #1: Grid Size of Emission Inventories



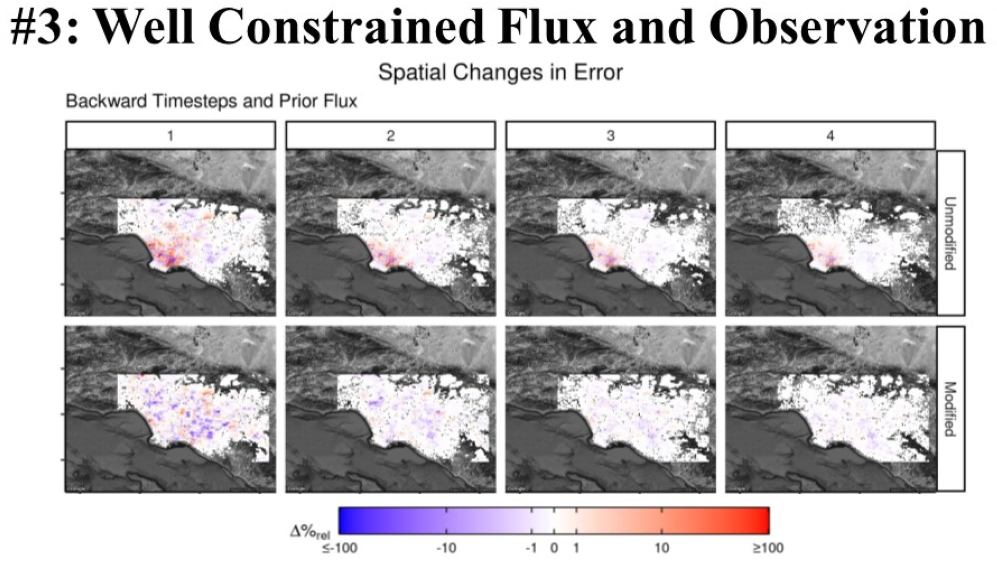

- **R** incorporated errors from the atmospheric model (X-STILT, **H**), OCO-3 instrument, **Q** was constructed by the differences between the ODIAC (prior) and Vulcan 3.0 ("true") emission inventory. These input grids were coarsened, with results from 1x1km, 3x3km, 5x5km, and 7x7km cases.
- Although errors were reduced in $XCO_2$-space, total flux was overestimated due to spatial correlations over-correcting flux values adjacent to large point sources (LPSs) with high uncertainty.

### Case #2: Reduced Observation Error



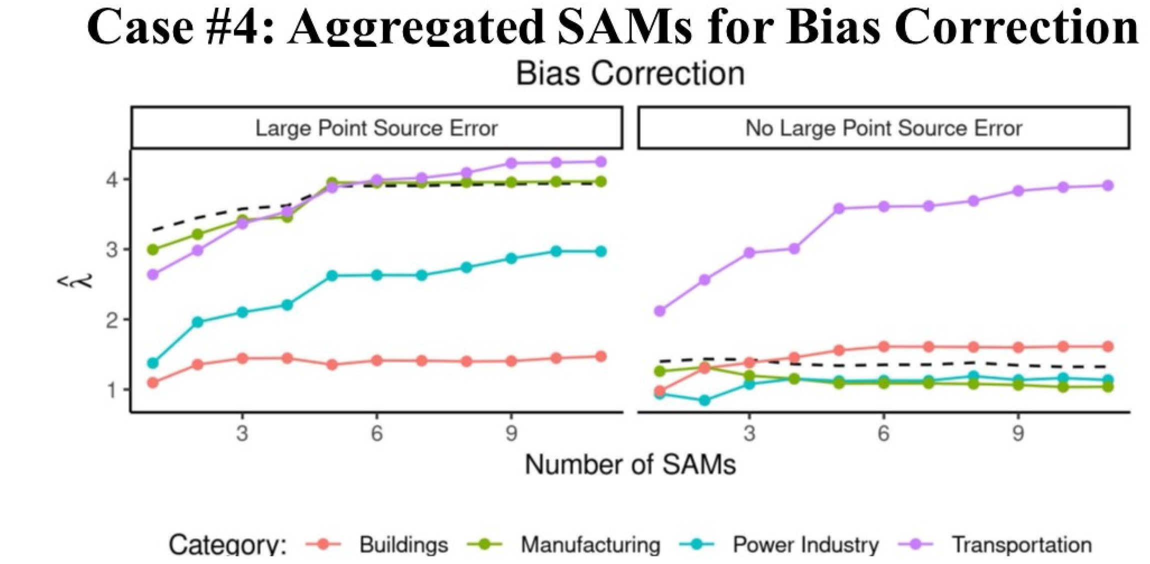

- The transport error in **R** was reduced by 50% (1ppm to 0.5ppm). All other parameters remained unchanged.
- Compared to the previous case, errors in $XCO_2$-space were further reduced. However, the overestimation of the flux around cells with LPSs was exacerbated. Over-corrections were propagated across more hourly timesteps than in the previous case.

### Case #3: Well Constrained Flux and Observation Error




- High uncertainty around cells containing LPSs is driven by mismatched LPS locations between the two emission inventories. This third test case used a custom inventory in which LPS cells were properly aligned.
- The differences between the Vulcan 3.0 and custom inventories were used to construct **Q**.
- Although no error reduction in $XCO_2$-space was detectable, there were areas of error reduction in flux estimates for 1-3hrs before the SAM.

### Case #4: Aggregated SAMs for Bias Correction




- Two scenarios were considered: (1) a large systematic bias (25% of true emissions) in all sectors and (2) a large systematic bias in area emissions with well-known LPS values.
- Under both conditions, prior flux estimates are well-corrected after five SAMs are included in the inversion scheme. The Manufacturing and Power sectors (both containing LPSs) benefitted from the inversion as well. The Building sector was poorly optimized in both cases.

## Conclusions

Current and future space-based $XCO_2$ observing platforms are increasing our capabilities of monitoring emissions at a near-global scale. However, the low signal-to-noise ratio associated with this type of measurement presents challenges at the urban/city-level scale. The OSSE and inversion approach in this work characterized the urban information available in 11 *synthetic* SAMs from the OCO-3 instrument.

Results demonstrated that individual SAMs have the capability to provide modest corrections to flux estimates during the 1-3hrs leading up to the time of the observation. However, the effectiveness of these corrections depend on LPS values being properly located within the emission domain.

SAMs are most effective when aggregated together in a Bayesian inversion scheme. Results demonstrated that the use of multiple SAMs can correct systematic biases in sector-specific emission estimates. This highlights the need for high-resolution $XCO_2$ observations over the world's megacities.

In the future, a dynamic approach to error/uncertainty quantification may adjust spatial sensitivities more appropriately, and corrective factors may be calculated at the cell-wise level rather than the sectoral level. As more observing platforms come online, these methods will become crucial in understanding $CO_2$ contributions from megacities around the world.