Illustrating the spatiotemporal complexity of NO_2 columns using a multi-perspective observing system: moving toward geostationary product validation and applications

Laura Judd[1], Scott Janz[2], Jayne Boehmler[2], Sanxiong Xiong[2], Tom Hanisco[2], Alexander Cede[3], Luke Valin[4], Eric Baumann[4], Jim Crawford[1], Katherine Travis[1], Prajjwal Rawat[1], Angelique Demetillo[1], Dan Goldberg[5], Omar Nawaz[5], Benjamin de Foy[6], Jeremiah Johnson[7], Barry Lefer[8]

[1] NASA Langley Research Center, [2] NASA Goddard Space Flight Center, [3] Luftblick, [4] US EPA, [5] George Washington University, [6] Saint Louis University, [7] Ramboll, [8] NASA Headquarters

Here, we highlight NO_2 data collected as part of the Synergistic TEMPO Air Quality Science (STAQS) field campaign in summer 2023 with a focus on ideas for interpreting of spatiotemporal complexity of NO_2 columns from under TEMPO.

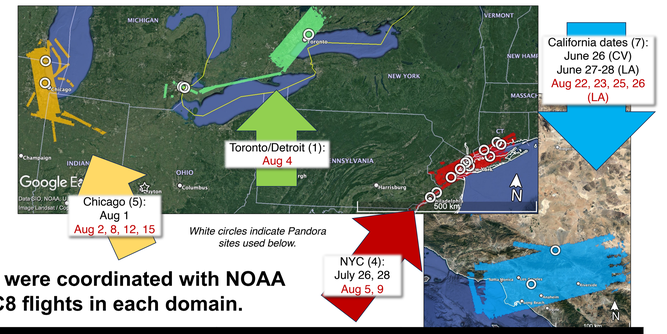
This poster includes:

- ⇢ Summary of STAQS NO_2 data collected
- ⇢ Morning/Midday/Afternoon observations to mimic geostationary observations
- ⇢ GCAS vs Pandora & TROPOMI
- ⇢ Applications of field data for emissions and model evaluation

STAQS NO_2 Observing System

In four major urban areas, we mapped NO_2, HCHO, ozone, and aerosols multiple times of day over emission sources and ground-sites from NASA aircraft.

The map to the right shows the areas mapped with labeled dates of each flight. Red labels indicate days that coincide with TEMPO observations.

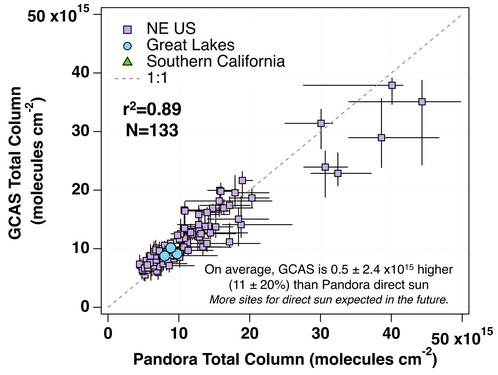


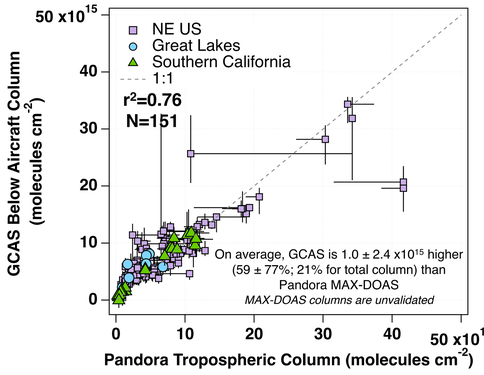
STAQS flights were coordinated with NOAA AEROMMA DC8 flights in each domain.

Instrument	Data Products	Sampling Strategy	Data Availability	Reference Examples
GCAS	Aircraft-based NO_2 Column (250 x 560 m)	Systematic sampling of a ~ 50 x 140 km area 3x per day (morning-midday-afternoon)		Nowlan et al. (2018); Judd et al. (2020)
Pandora	Surface-based NO_2 and HCHO direct-sun total columns and MAX-DOAS tropospheric columns	Routine sampling from over 15 instruments (heavily weighted in the NYC domain) with 80+ in the TEMPO FOR	http://pandonia-global-network.org/	Herman et al. (2009); Cede (2021)
TROPOMI	LEO satellite-based NO_2 Column (3.5 x 5.5 km at nadir)	Routine overpasses in the early afternoon LT from low earth orbit	https://search.earthdata.nasa.gov	van Geffen et al. (2022)
TEMPO	GEO satellite based NO_2 Column (~hourly)	TEMPO operated for 10 flight days during STAQS	Public release of data in April 2024	

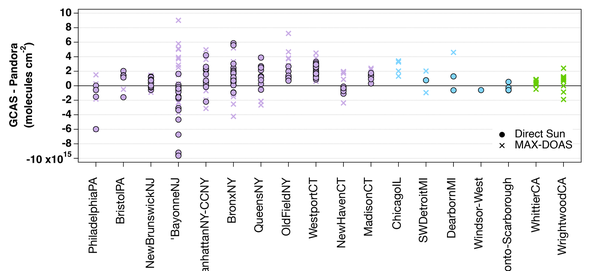
- ⇢ GCAS NO_2 retrieval a priori include GEOS-CF for the trace gas and meteorological files and MODIS BRDF Kernels from MCD43A1 for surface reflectance properties.
- ⇢ Future GCAS processing will include 3 more days in June in southern California and August 8th in Chicago as well as HCHO products.
- ⇢ **GCAS NO_2 below aircraft columns include from surface to ~ 9 km altitude on average.**
- ⇢ *Future work will also include NO_2 profile observations from the NOAA AEROMMA DC8 flights co-located with STAQS*

STAQS GCAS vs. Pandora Spectrometers





Plots show the median GCAS value within 750m of the Pandora site during the overpass. Vertical bars are the 25th-75th percentile within that 750m radius. The Pandora value is the nearest in time where the horizontal bars represent the max/min within 15 minutes of the GCAS overpass.

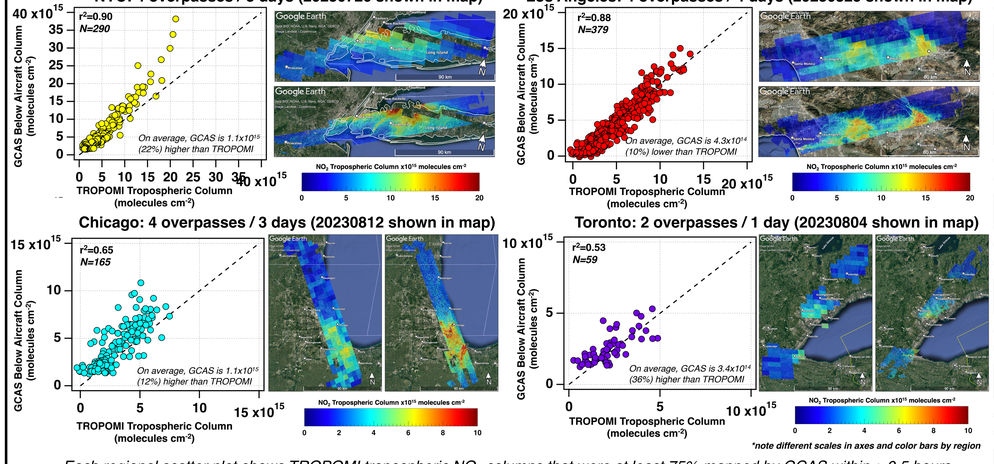


Overall, the direct-sun Pandora observations correlate with GCAS measurements as well as previous campaigns with a median of 10% (interquartile range between -4—24%).

There are no obvious diurnal based biases between GCAS and Pandora with the exception of a few outliers in the morning hours.

The largest outliers occur at BayonneNJ, which is on the highly heterogeneous shoreline near the Port of Newark. Three MAX-DOAS coincidences above are off scale with the furthest being -22x10¹⁵ molecules cm⁻². Additionally, there is a suspected high bias in the BayonneNJ direct-sun product that is to be investigated further.

STAQS GCAS vs. TROPOMI v2.5 by region



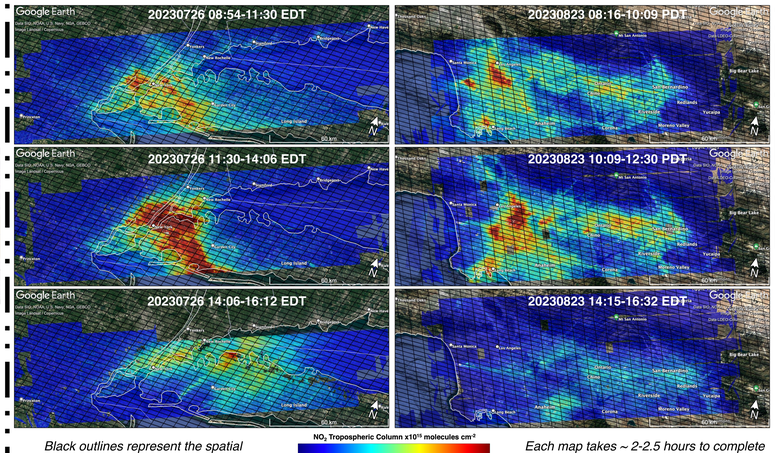
Each regional scatter plot shows TROPOMI tropospheric NO_2 columns that were at least 75% mapped by GCAS within ± 0.5 hours from the TROPOMI overpass. The GCAS value represents a spatially averaged column over the TROPOMI pixel area.

Overall, GCAS and TROPOMI compare quite well (r^2=0.83) with close 1:1 agreement in columns up to at least 10x10¹⁵ molecules cm⁻².
Tropospheric slant columns are even more correlated (r^2=0.93; not shown).
Biases appear to be largest in Chicago and NYC where TROPOMI is consistently lower than GCAS on the days sampled.

Morning/Midday/Afternoon observations to mimic to GEO: *NYC & LA examples*

GCAS NO_2 examples from LA and NYC below show days with large dynamic ranges of pollution varying throughout the day.

In conjunction with Pandora observations, GCAS data can help address questions on the impact of spatial heterogeneity on TEMPO validation efforts.



Black outlines represent the spatial resolution of TEMPO over each city.

Each map takes ~ 2-2.5 hours to complete with east-west lines flown from south to north.

Recent GCAS Data Applications

Evaluating Sectorized Emissions and Models with GCAS in Houston

Goal: To better understand uncertainties in sectorized NO_x emission inventories with high-resolution airborne data in combination with source-apportioned CAMx in Houston.

This work is to be expanded to NYC and Chicago during STAQS.

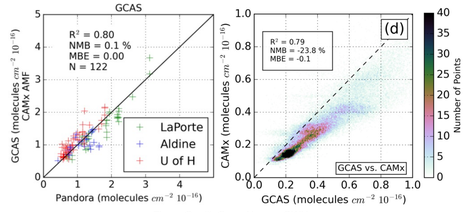


Figure Credit: Omar Nawaz, GWU

GCAS agrees with Pandora 1:1. GCAS comparisons to CAMx showed an underestimation of sources particularly in the more urbanized area of Houston (rather than industrial).

See Nawaz et al. (2023) to see more details on this analysis!

Ongoing analysis is using the flux divergence method and a multi-linear regression model to quantify sectorized emission biases.

Preliminary results show on-road emissions in the TCEQ inventory may need to be increased by a factor of 1.7.

To see more details on these results, please see presentation by Ben de Foy on Monday at 10:50 PST MC 3004 West: A12D-04.

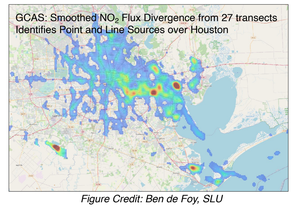


Figure Credit: Ben de Foy, SLU

Other Recent Work with GCAS

Tzortziou et al. (2023)	*Tao et al. (2022)*	*Johnson et al. (2023)*	*Baker et al. (2023)*	*Dressel et al. (2022)*
Intimately tracking NO_2 pollution over the New York City-Long Island Sound land-water continuum	Investigating changes in ozone formation chemistry during summertime pollution events over the Northeastern United States	Satellite remote-sensing capability to assess tropospheric-column ratios of formaldehyde and nitrogen dioxide	Photochemical model assessment of single source NO_2 and O_3 plumes using field study data	Daily satellite observations of nitrogen dioxide air pollution inequality in New York City, New York and Newark, New Jersey

Looking ahead:

- → These datasets will be used to validate TEMPO NO_2 products in the months leading up to data release this spring.
- → GCAS will be deployed Feb-March 2024 to Asia under-flying GEMS in the Philippines, South Korea, Malaysia, and Thailand.
- → Research and analysis using these high-resolution capabilities to evaluate emissions and other air quality related objectives will continue.

This work would not be possible without NASA R&A for STAQS funding support as well as the STAQS, PGN, TEMPO, and S5P TROPOMI teams and PIs for the dedicated hard work in data collection and processing.

Email contact: laura.m.judd@nasa.gov