

Using Airborne spectrometer observations to evaluate space-based NO₂ observations

Presented by Laura Judd, NASA LaRC
TOLNET/Pandora Science Team Meeting
4 June 2020

The overall meeting objective is to mutually emphasize how the TOLNet, Pandora, and other ground-based networks (or aircraft measurements) are prepared to both evaluate and complement geostationary platforms such as TEMPO, GEMS, and Sentinel-4

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Atmospheric
Measurement
Techniques
Discussions

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Evaluating Sentinel-5P TROPOMI tropospheric NO₂ column densities with airborne and Pandora spectrometers near New York City and Long Island Sound

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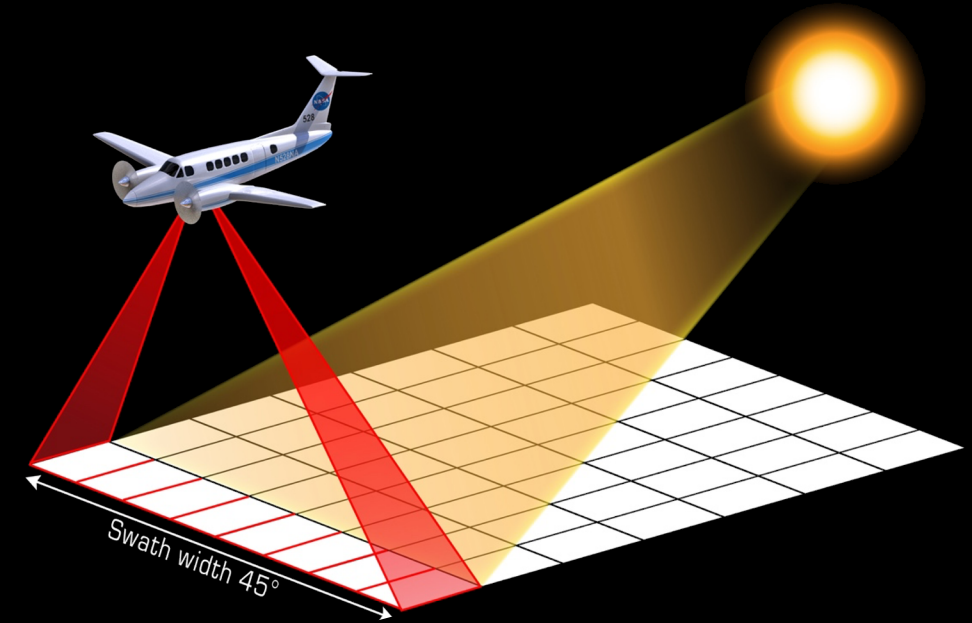
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NASA GCAS/GeoTASO Airborne Spectrometer

Instrument PI:
Scott Janz, GSFC

- Primarily been used for preparatory measurements for geostationary air quality observations as well as emissions mapping
 - Heritage campaigns: DISCOVER-AQ, KORUS-AQ, GOES-R, LMOS, **LISTOS**, OWLETS, FIREX-AQ
- Measures spectra in the UV-VIS-(NIR) at high temporal frequency from which trace gas columns can be remotely retrieved (**NO₂** and HCHO) nominally at 250 m x 250 m
- Observes from the bottom of an airplane with a field of view of ~7 km at a nominal altitude of 28,000 feet executing gapless mapping over areas of interest



Sampling strategy for the airborne spectrometers operating in a push-broom configuration (adapted from Nowlan et al., 2016)

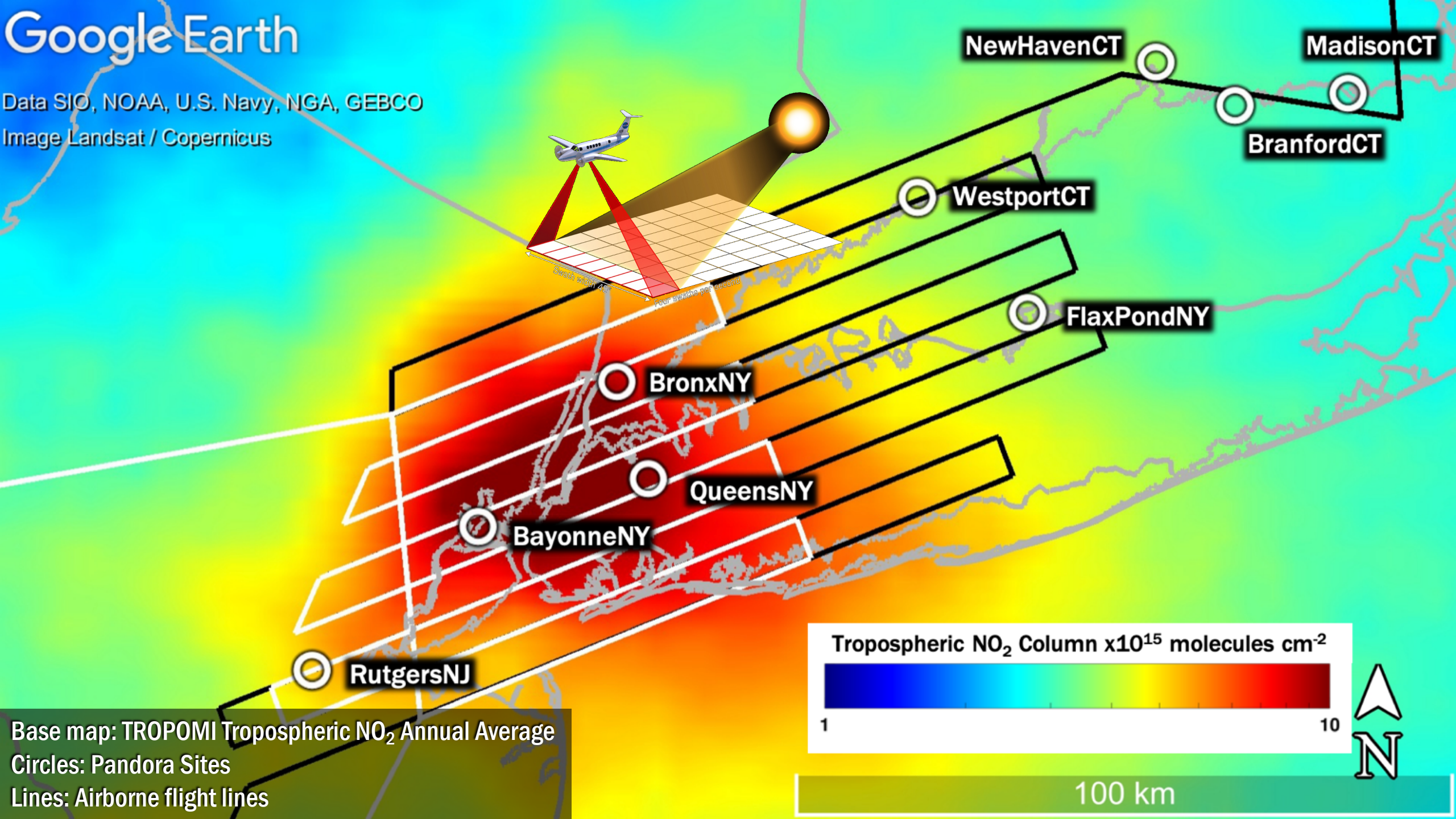
Goal of this presentation:

Demonstrate the capabilities for airborne spectrometers to validate trace gas products from space-based retrievals at moderate to high spatial/temporal resolution using TROPOMI and the LISTOS dataset

Some References:

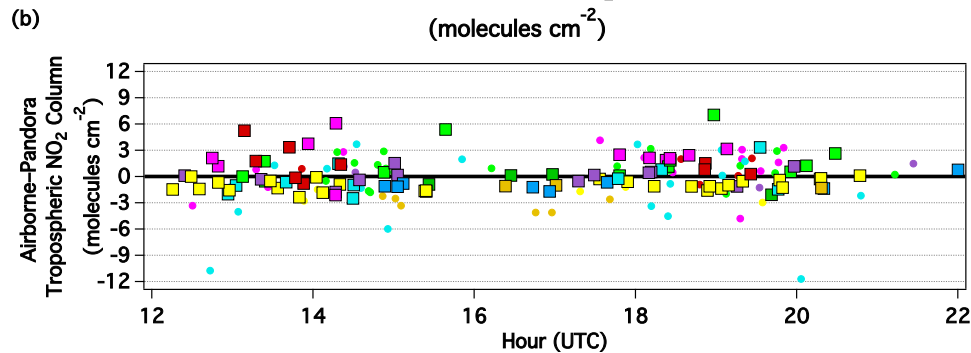
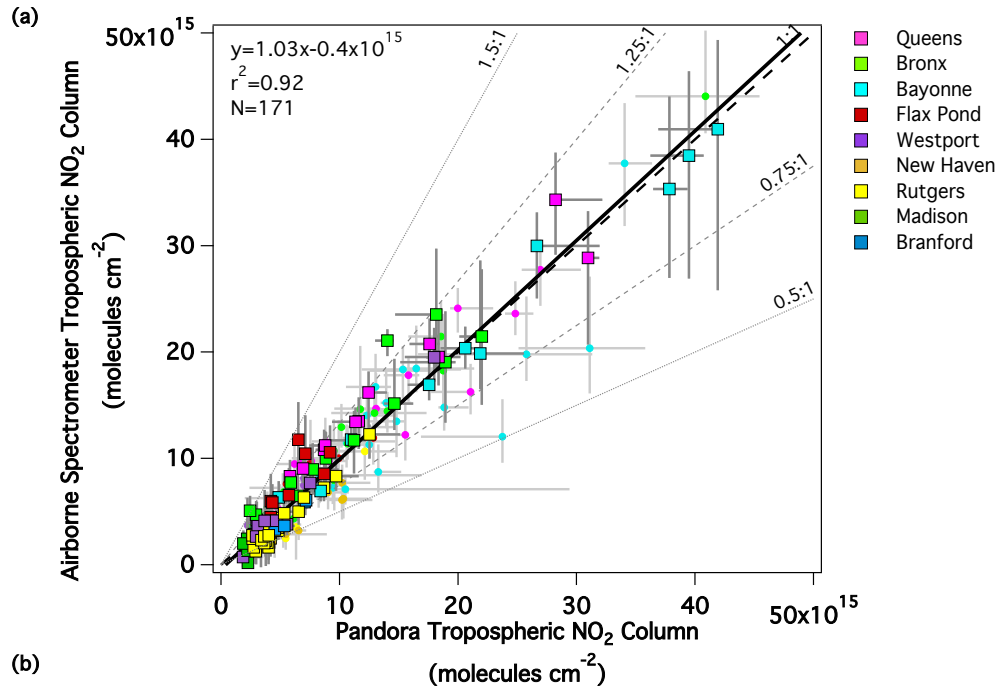
- Kowalewski & Janz, 2014: [doi:10.1117/12.2062058](https://doi.org/10.1117/12.2062058)
Leitch et al., 2014: [doi: 10.1117/12.2063763](https://doi.org/10.1117/12.2063763)
Nowlan et al., 2016: [doi:10.5194/amt-9-2647-2016](https://doi.org/10.5194/amt-9-2647-2016)
Nowlan et al., 2018: [doi:10.5194/amt-2018-156](https://doi.org/10.5194/amt-2018-156)
Judd et al., 2019: [doi: 10.5194/amt-12-6091-2019](https://doi.org/10.5194/amt-12-6091-2019)

Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus



Base map: TROPOMI Tropospheric NO₂ Annual Average
Circles: Pandora Sites
Lines: Airborne flight lines

Airborne Spectrometer vs. Network of Pandoras



Coincidence Criteria

- Median airborne NO_2 Tropospheric Vertical Column (TrVC) within 750 m radius of Pandora location
- Temporally nearest Pandora observations ($\pm$ max/min observation within 5 minutes of overpass)
- Pandora total VC is converted to TrVC by subtracting airborne-retrieval derived stratospheric column

(see paper supplement for sensitivity analysis to this criteria)

Note: Squares in figures are coincidences where Pandora NO_2 columns are not varying more than 30% in a ± 15 -minute window

- There were 171 coincidences over 26 flights/13 days from June-Sept. 2018.
- Airborne and Pandora TrVCs are highly correlated with a slope near 1:1 and no obvious time of day impacts.
- Median percent difference of -1.2% with 95% of temporally stable points (squares) within $\pm 25\%$ or 0.1 DU

(a) Scatter plot showing the temporally closest Pandora TrVC to the aircraft overpass ($\pm$ min/max observation within a ± 5 -minute window from the aircraft overpass) vs. the median airborne TrVC ($\pm 10^{\text{th}}\text{-}90^{\text{th}}$ percentile) within a 750 m radius of the Pandora site. The thick solid black line represents the RMA linear regression. Each point is colored by Pandora location where the outlined squares are points where Pandora TrVCs do not vary more than 30% within a ± 15 -minute window from the aircraft overpass, whereas the circles indicate times where Pandora TrVCs do vary more than 30%. (b) The difference between airborne and Pandora tropospheric NO_2 columns vs. time of day in hours (UTC) colored similarly to (a).

VIIRS True Color

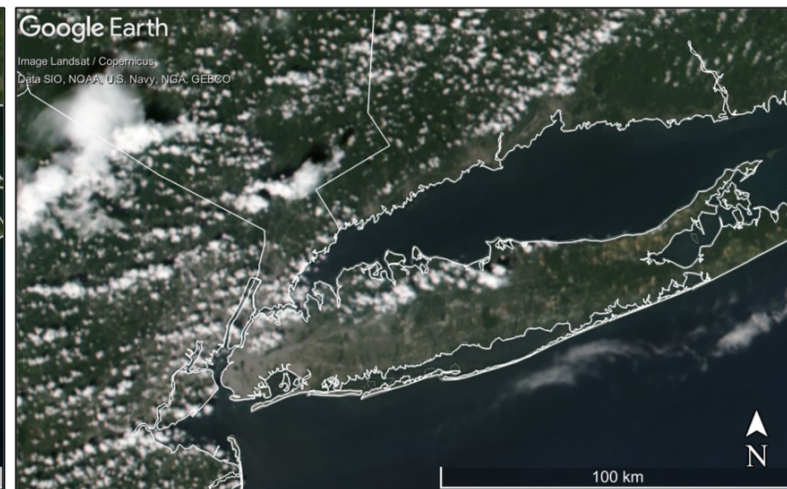
30 June 2018



19 July 2018



06 September 2018



Airborne v. TROPOMI

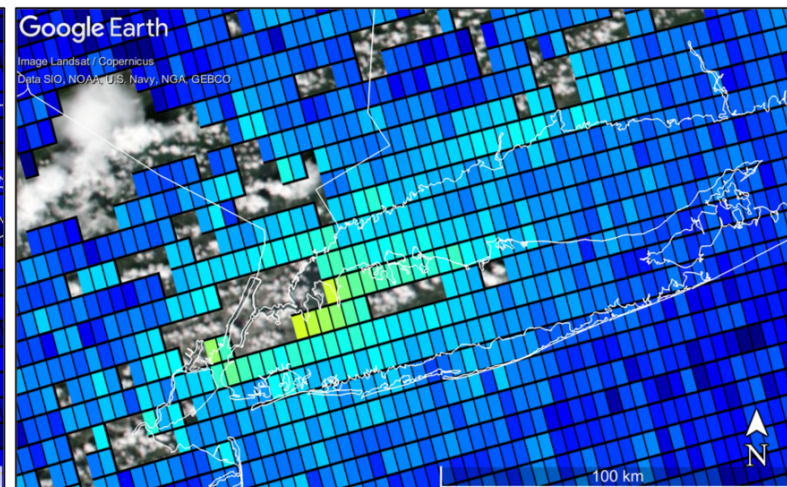
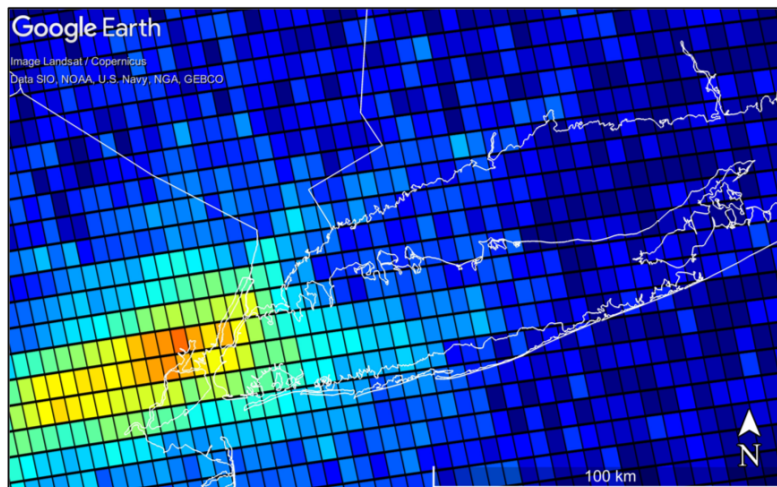
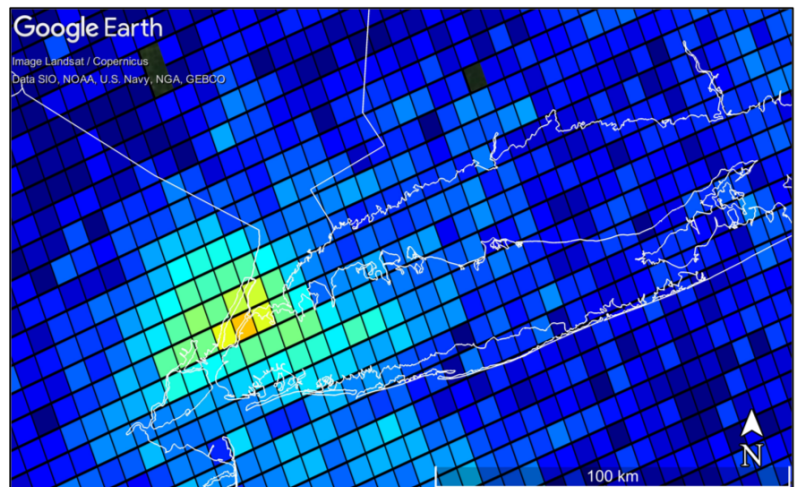
TROPOMI CRF < 50% and airborne data within a ± 30 -minute from overpass and area mapped > 75%

30 June 2018

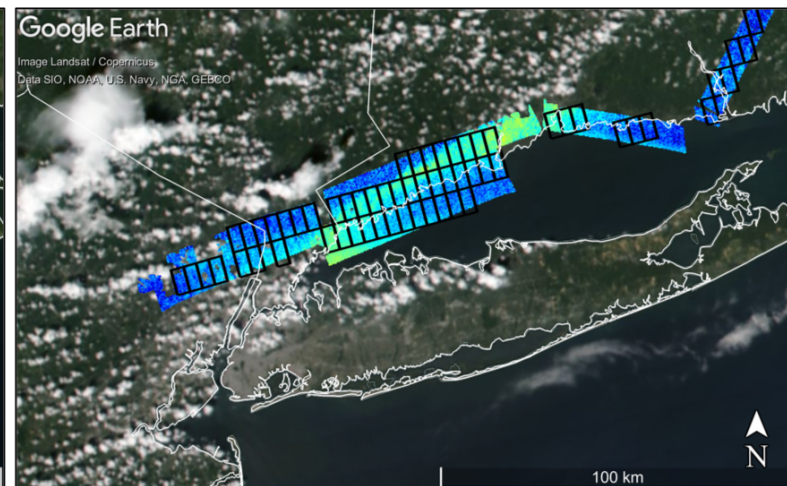
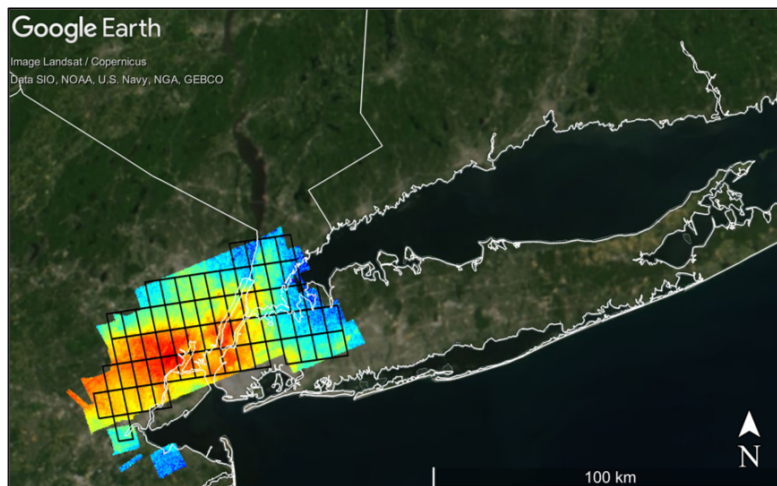
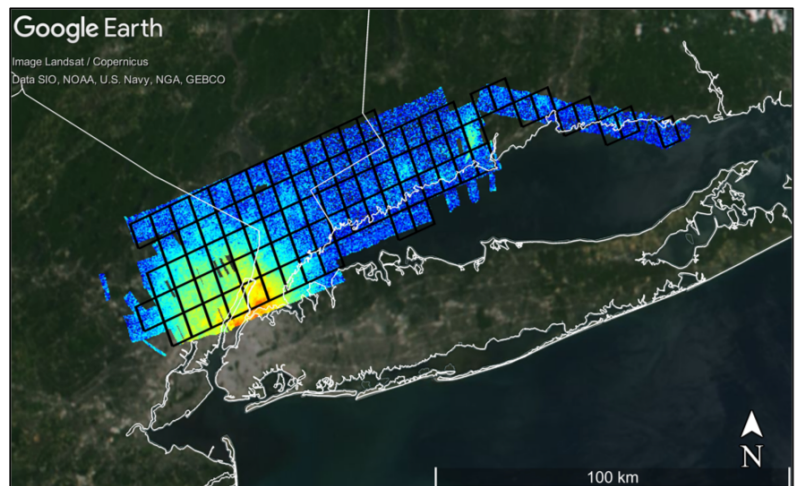
19 July 2018

06 September 2018

TROPOMI
Tropospheric NO₂

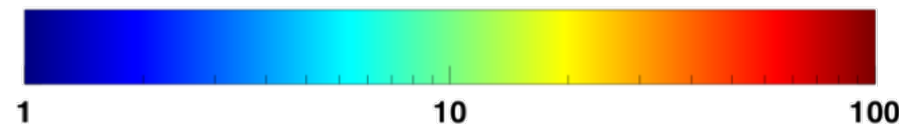


Coincident
Airborne Data



Airborne v. TROPOMI

Tropospheric NO₂ Column $\times 10^{15}$ molecules cm^{-2}



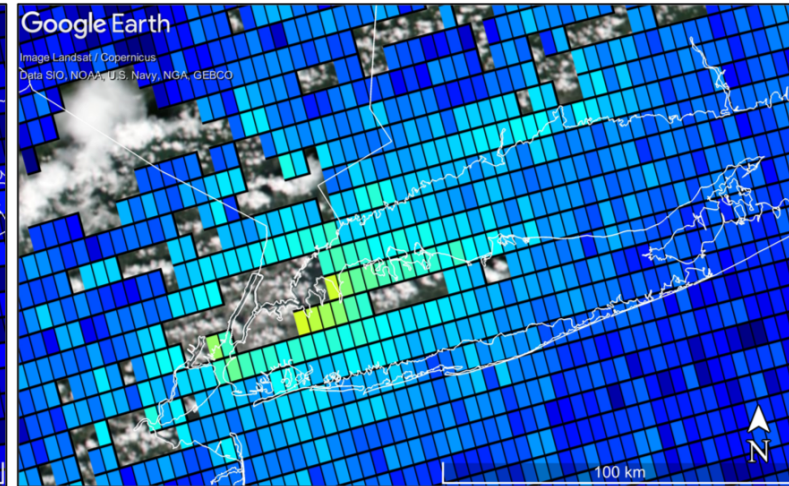
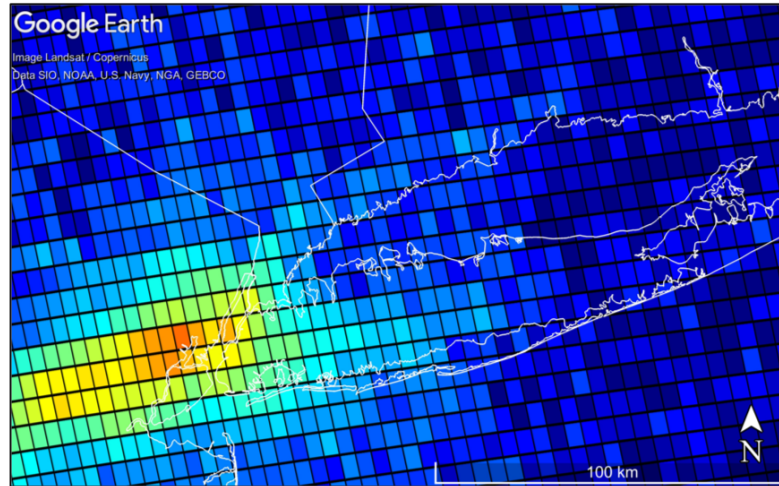
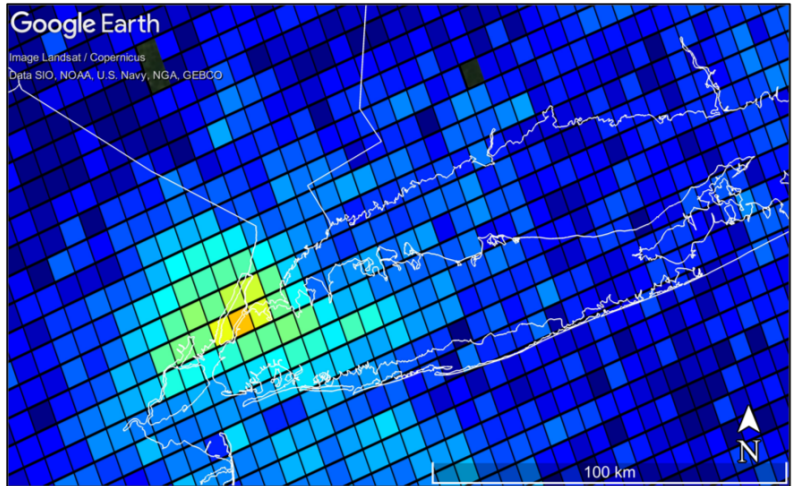
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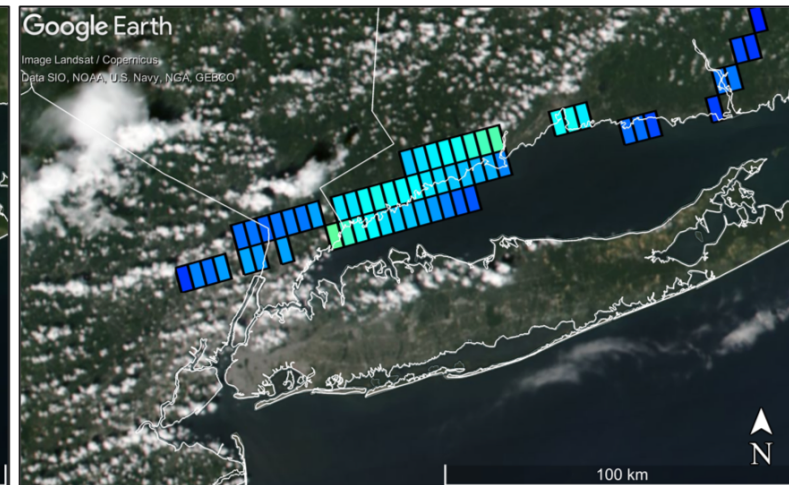
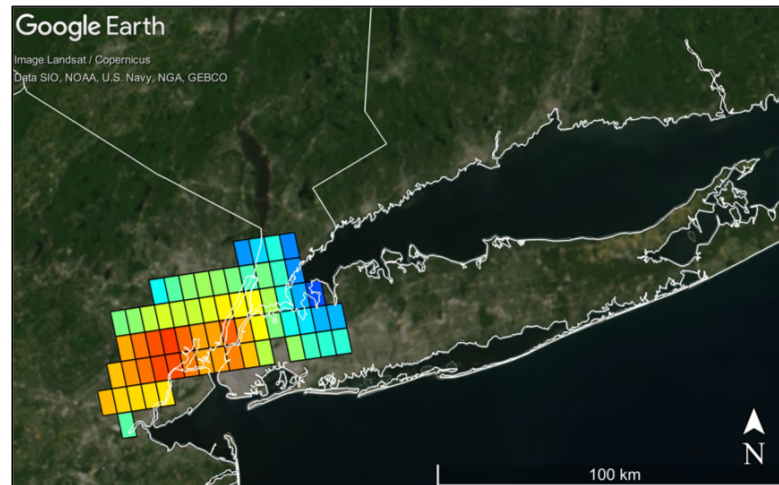
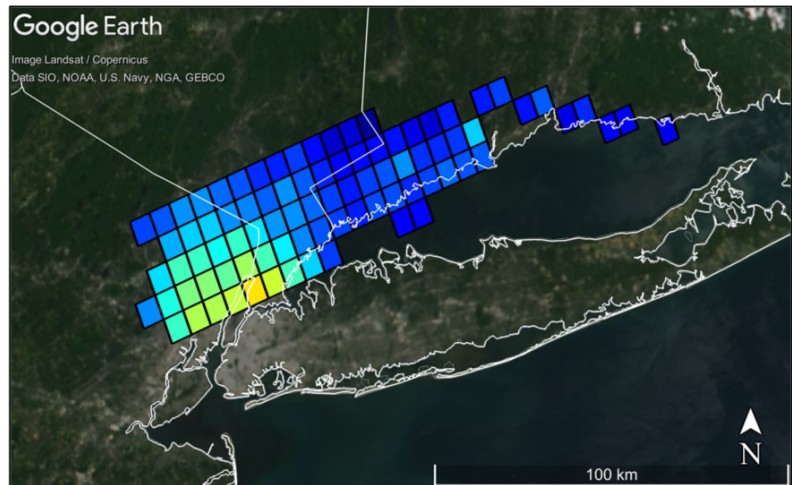
19 July 2018

06 September 2018

TROPOMI
Tropospheric NO₂

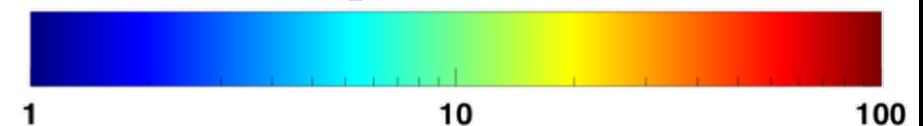


TROPOMI Scale
Airborne Pixels



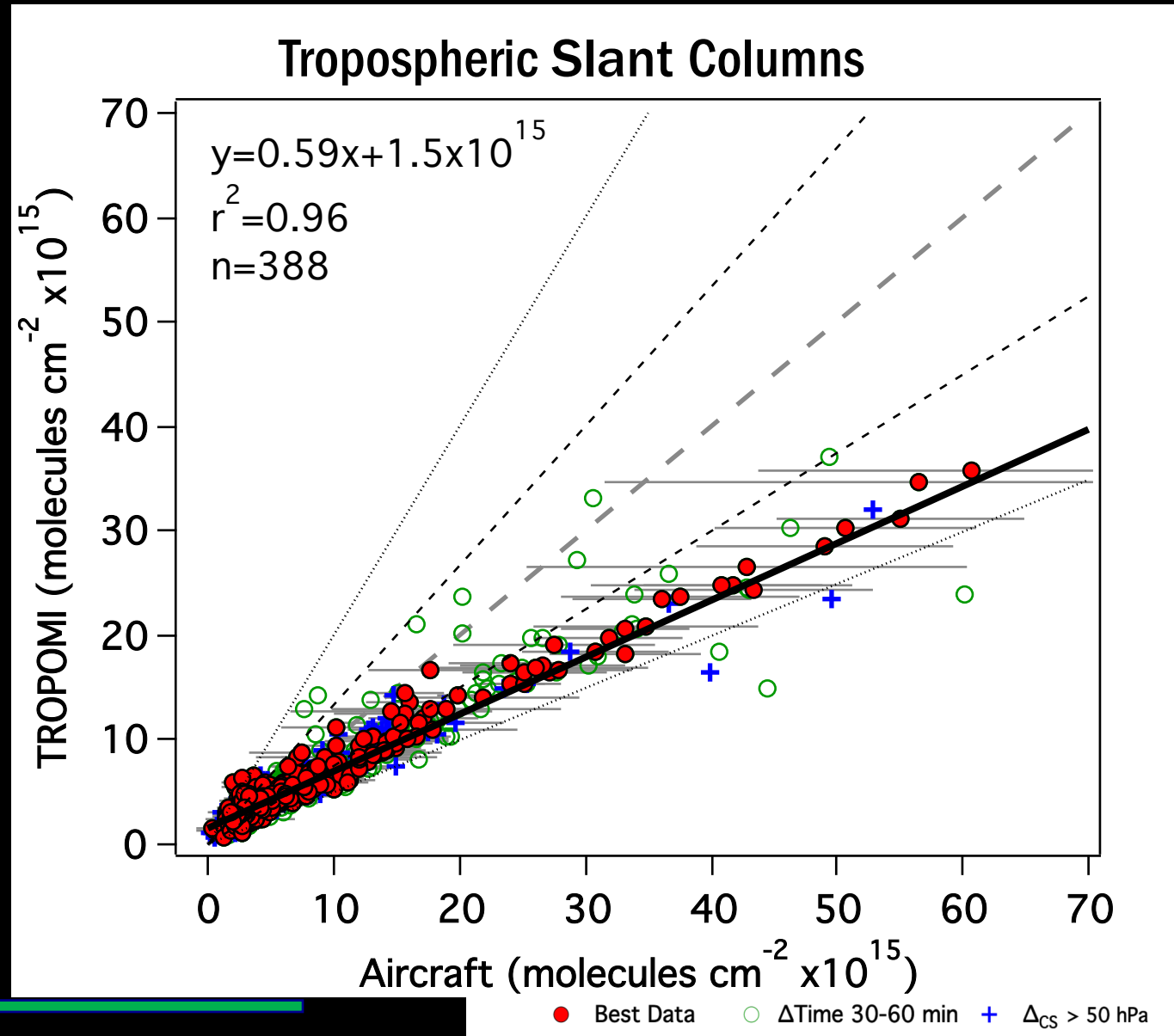
Airborne v. TROPOMI

Tropospheric NO₂ Column x10¹⁵ molecules cm⁻²



Slant-to-slant:

- Very high correlation indicating that satellite and aircraft are sampling largely similar slant columns (at least near the surface where most of the pollution is located)
- Correlation drops when the temporal window is opened from ± 30 to ± 60 minutes ($r^2=0.91$)



Airborne v. TROPOMI

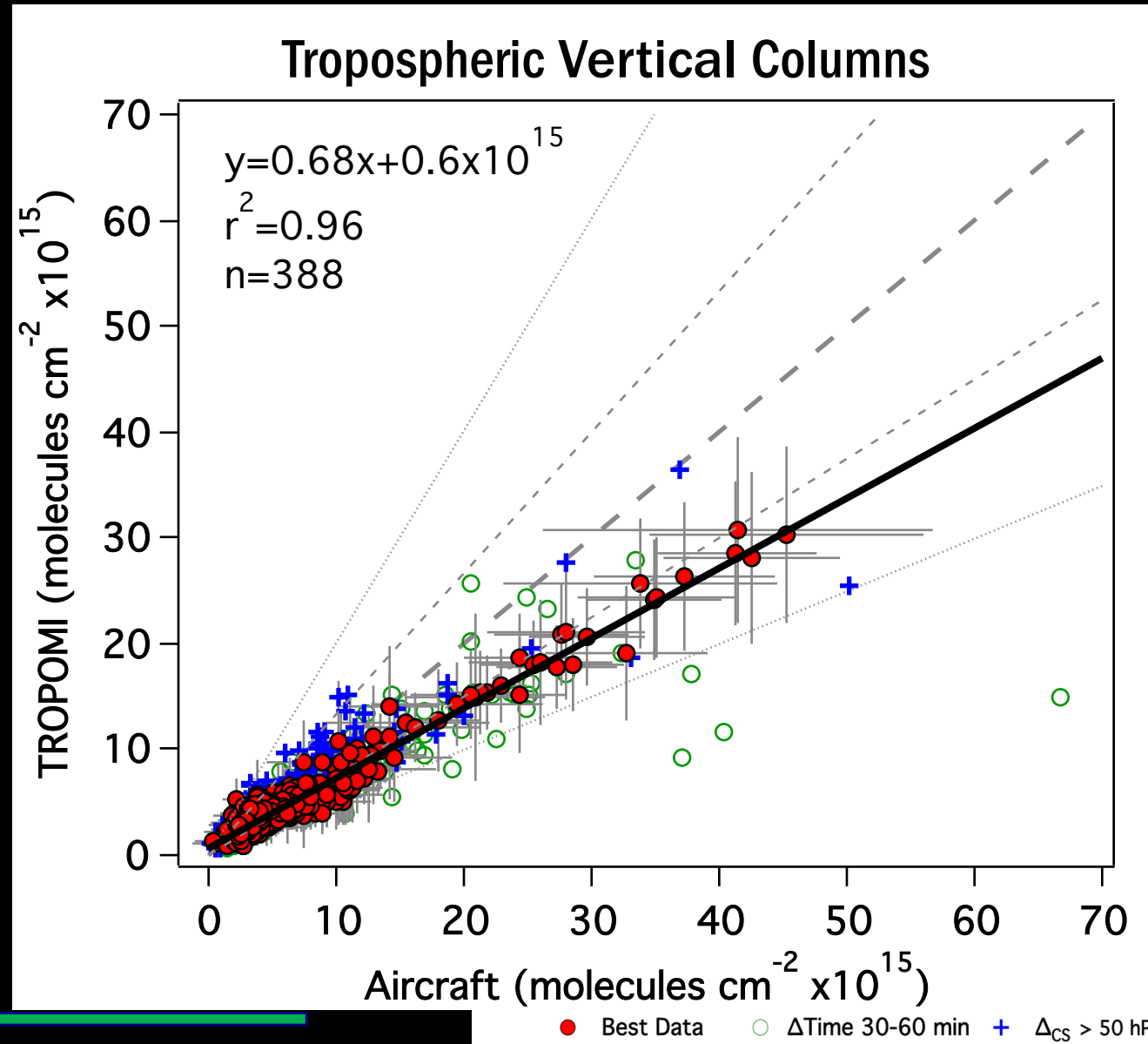
Unless noted: Stats are applied to red points
Ignore blue points for now.

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Vertical-to-vertical:

- Slope improves (expected) it though appears that TROPOMI is biased low in comparison to the airborne TrVC data
(Median percent bias of -19%).
- Bias partially attributed to the a priori profile resolution in the TROPOMI retrieval ($1^\circ \times 1^\circ$)



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Airborne v. TROPOMI

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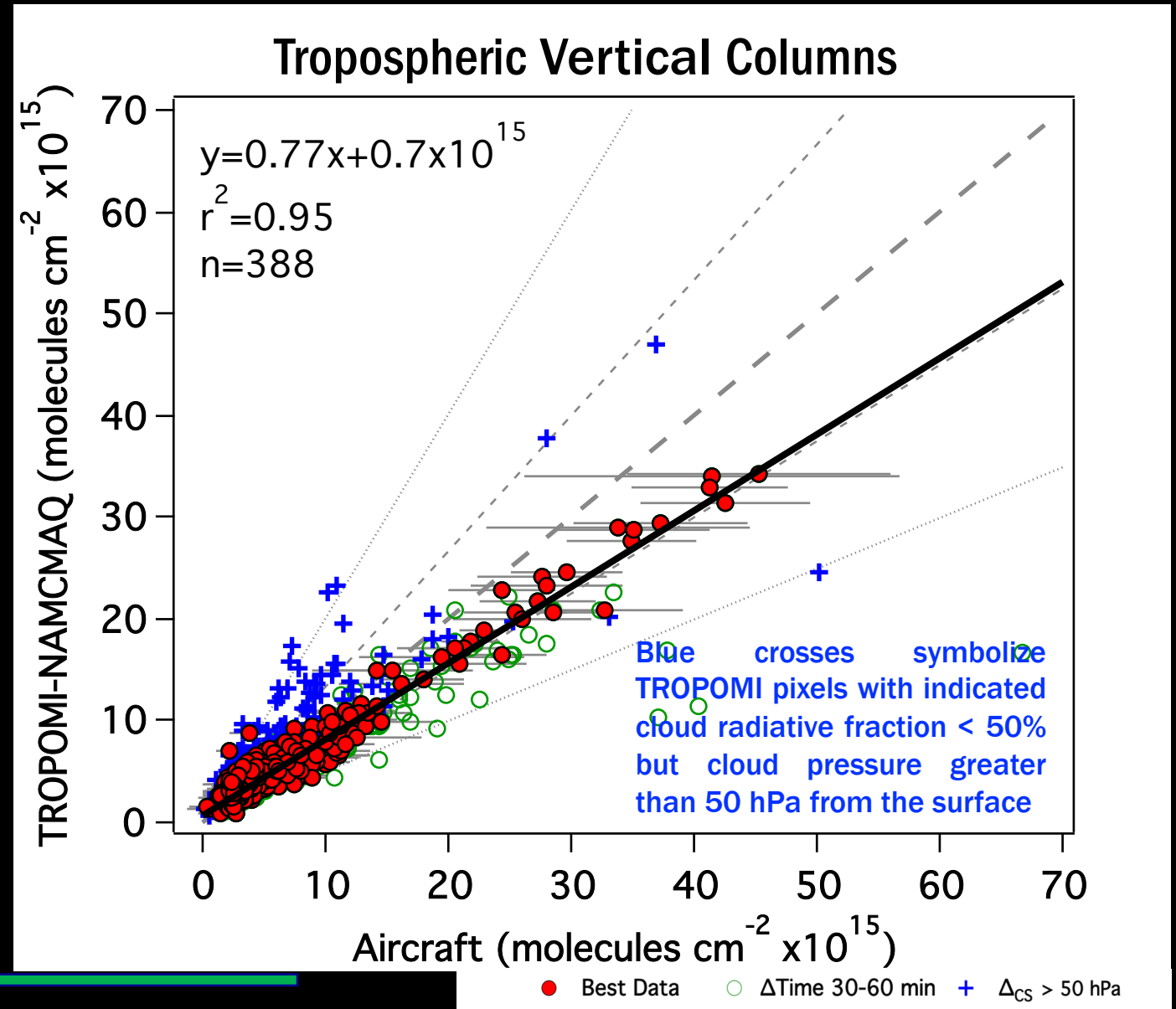
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Vertical-to-vertical with NAMCMAQ 12 km analysis"

- Percent bias improves to -7%
- *Remainder of the bias: ?albedo impacts?*
- Outliers related to cloud pressure height seem to become important when higher resolution data is used (all stats are in manuscript)

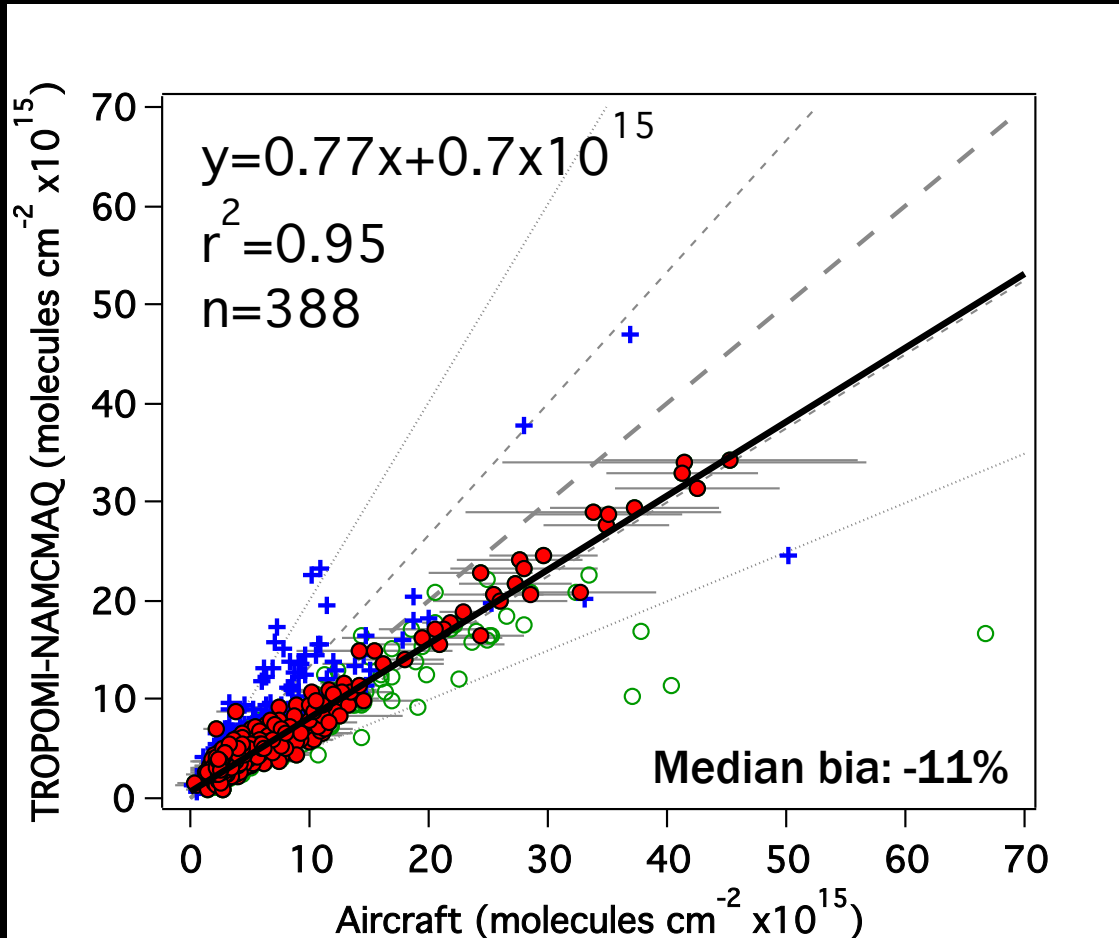


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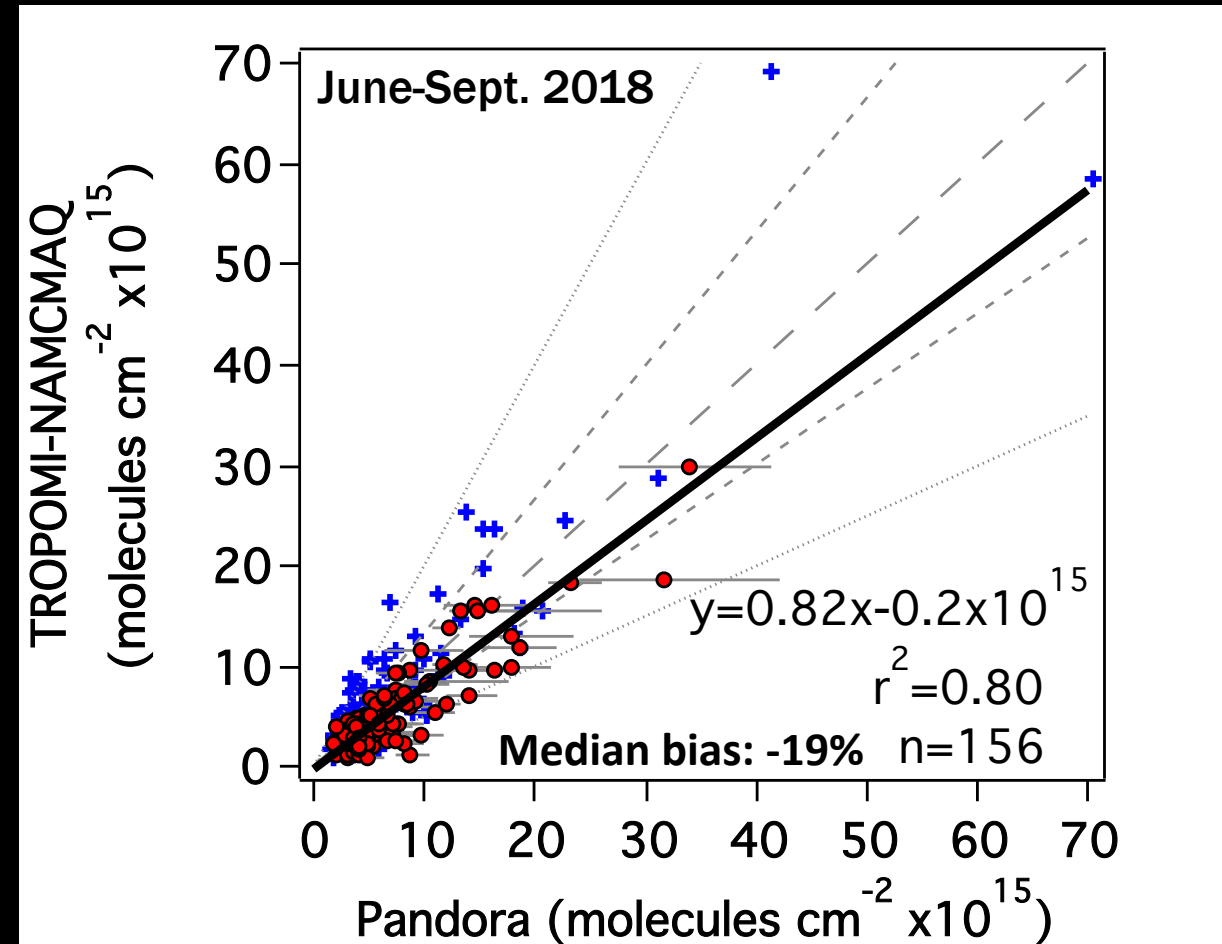
Airborne v. TROPOMI

Airborne v. Pandora v. TROPOMI

Results between Pandora and airborne spectrometer comparison to TROPOMI are similar.



Airborne spectrometers are only deployed for short periods of time, but their observations are more spatially representative of the satellite measurements with the added capability of retrieving at subpixel resolutions.

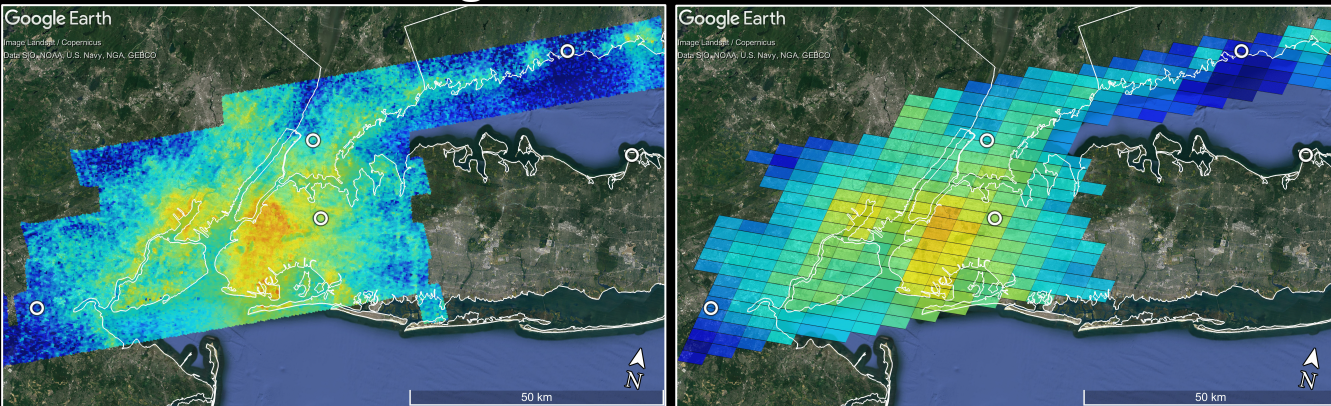


Pandora spectrometer have the benefit of being systematically placed and collect data over a long time period though may be more impacted by spatial heterogeneity in areas subject to variability.

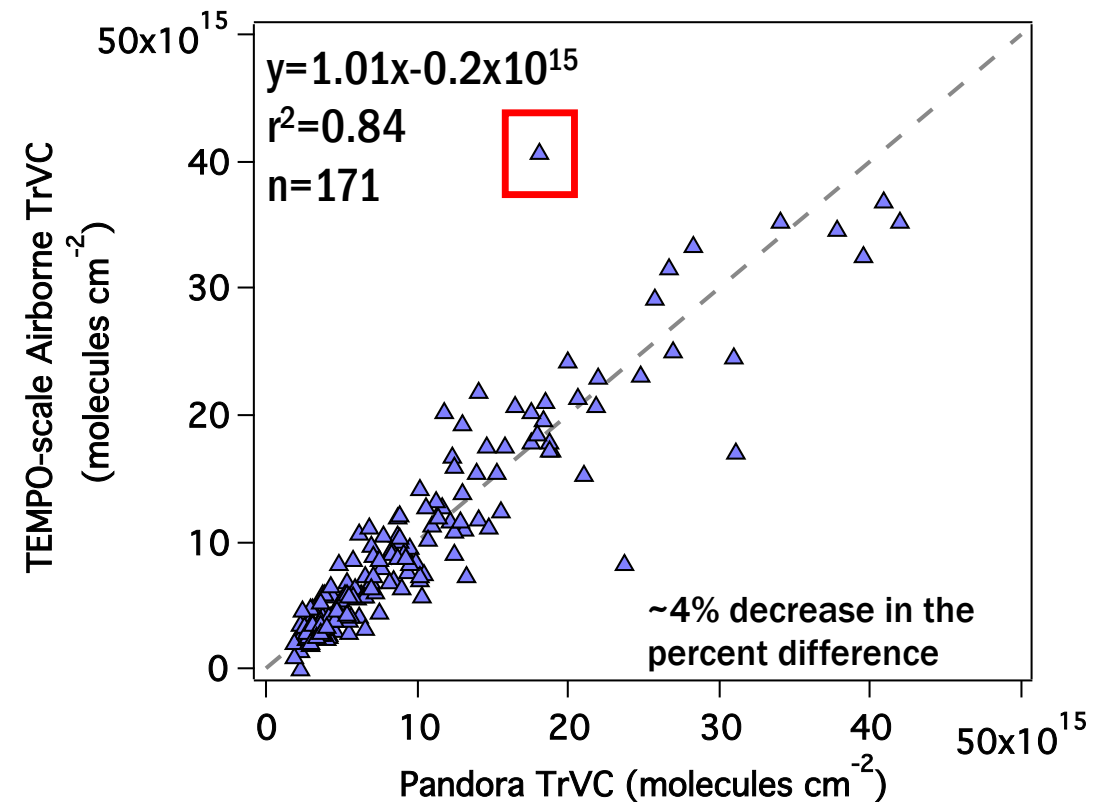
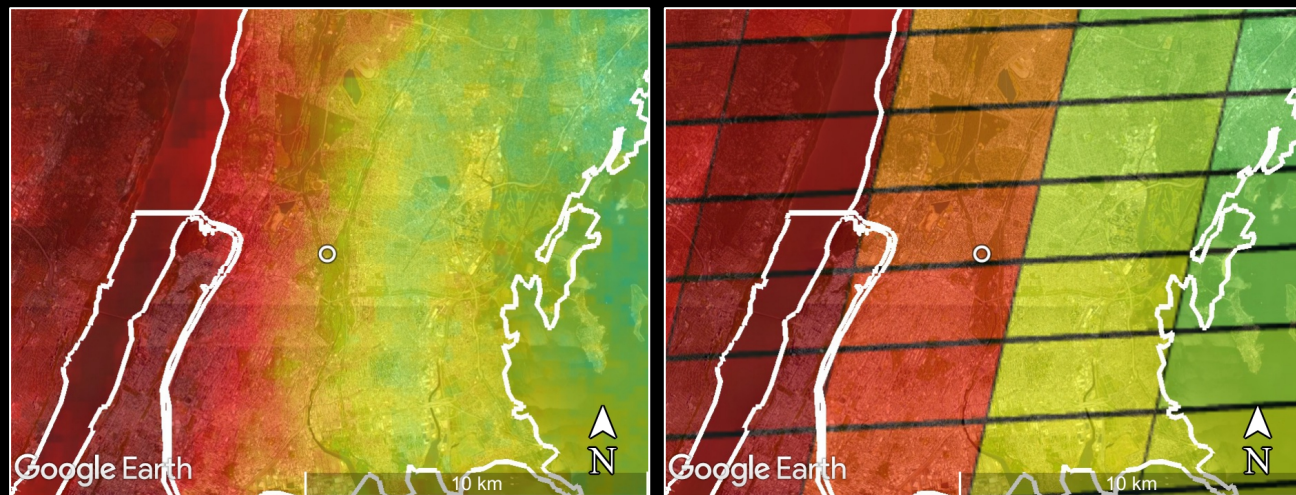
How will an analysis like this look for TEMPO?

How could Pandora comparisons to TEMPO look?

24 August 2018: 4 raster animation



Bronx Pandora: July 2nd AM



Two Challenges

1. Spatial heterogeneity: Less of an issue than before but still can lead to mis-matches in areas with strong gradients
2. Temporal heterogeneity: the high temporal resolution of Pandora and the hourly measurements from TEMPO could help in identifying large changes over the hour time-frame

Take-home thoughts

Airborne spectrometers are another helpful tool in evaluating geostationary trace gas products at high spatial/temporal resolutions.

- Minimizes the unknown of impacts of spatial heterogeneity
- Subject to the same uncertainties associated with satellite products

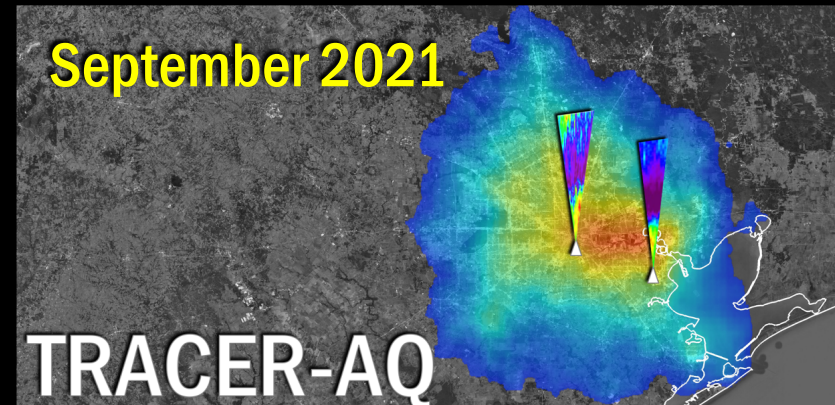
Leveraging future research campaign efforts can help in providing valuable data for validating TEMPO and other space-based UV-VIS instruments.

Other airborne products could also be evaluated in relatively the same manner as NO₂ (e.g., HCHO)

Looking ahead

GCAS will be used to help do similar work for GEMS this fall in South Korea in collaboration with NIER!

- Our first chance to evaluate space-based geostationary trace gas data



Backup Slides

19 July 2018

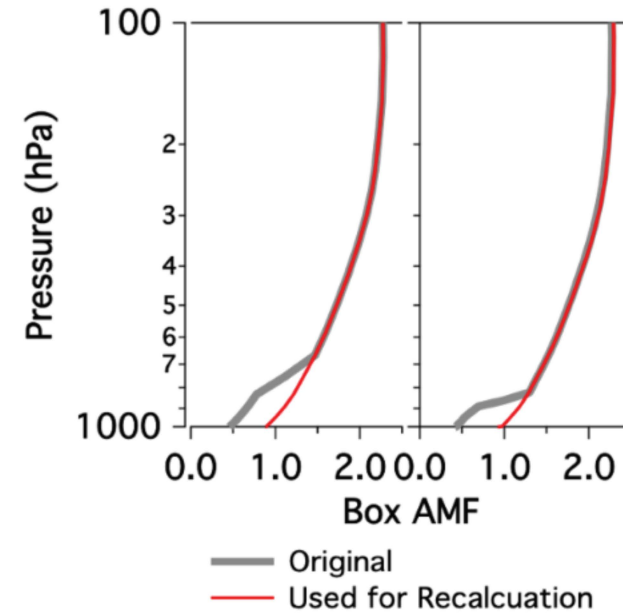
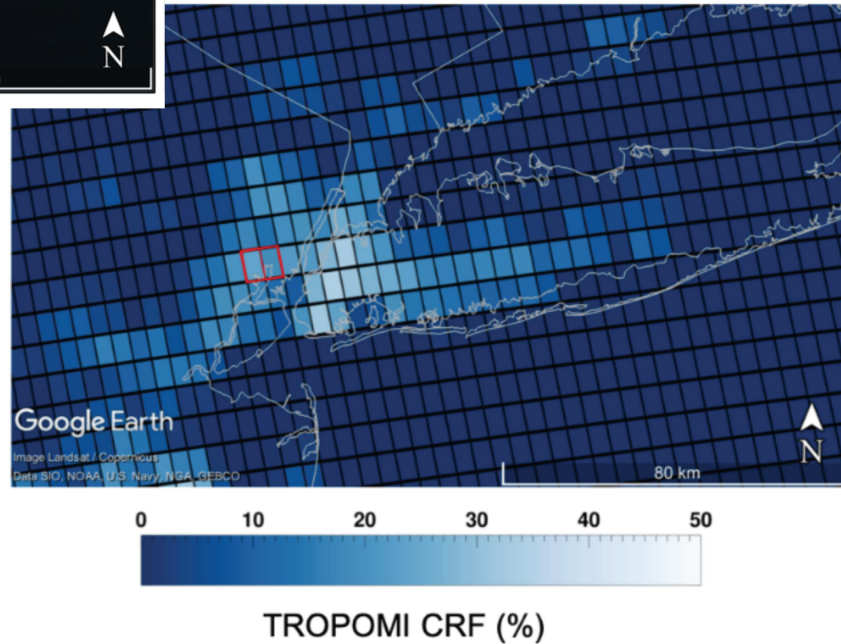


Figure S2: Map showing TROPOMI's CRF retrieved during the 19 July 2018 S5P overpass and original BoxAMFs (grey line) for the pixels outlined in red the map along with a second BoxAMF that is used to recalculate the TROPOMI tropospheric AMF with the removal of the impact of clouds

Table 5: Statistics for TROPOMI and airborne comparisons with the coincidence criteria of CRF < 50% and aircraft sampled within ± 30 minutes of the S5P overpass with different a priori profiles and indication of whether the Δ_{CS} threshold is applied.

TROPOMI Dataset	Δ_{CS} < 50hPa	RMA Fit	r^2	Median Percent Difference	N
Standard	No	$y=0.58x+1.5\times10^{15}$	0.95	--	621
Slant Column	Yes	$y=0.59x+1.5\times10^{15}$	0.96	--	388
Standard	No	$y=0.71x+0.9\times10^{15}$	0.90	-11%	621
<u>TrVC</u>	Yes	$y=0.68x+0.6\times10^{15}$	0.96	-19%	388
NAMCMAQ	No	$y=0.84x+1.0\times10^{15}$	0.83	4%	621
<u>TrVC</u>	Yes	$y=0.77x+0.7\times10^{15}$	0.95	-7%	388

Table 6: Statistics between Pandora and TROPOMI by site for the LISTOS period as well as extended to 19 March 2019

LISTOS Only (June-September 2018)						Valid data from June 2018-March 2019				
Site	RMA Fit	r ²	Median % Difference	Median Column Difference	N	RMA Fit	r ²	Median % Difference	Median Column Difference	N
<u>QueensNY</u>	$Y=0.77x+0.6\times10^{15}$	0.87	-9%	-0.5×10^{15}	22	$Y=0.63x+1.3\times10^{15}$	0.76	-23%	-2.1×10^{15}	68
<u>BronxNY</u>	$Y=0.81x+0.03\times10^{15}$	0.90	-15%	-1.1×10^{15}	20	$Y=0.73x+0.5\times10^{15}$	0.87	-15%	-1.1×10^{15}	33
<u>BayonneNJ</u>	$Y=0.84x-2.1\times10^{15}$	0.87	-38%	-4.1×10^{15}	9	$Y=0.74x-1.8\times10^{15}$	0.88	-41%	-5.3×10^{15}	45
<u>WestportCT</u>	$Y=0.49x+1.1\times10^{15}$	0.50	-19%	-0.6×10^{15}	21	$Y=0.68x+0.4\times10^{15}$	0.95	-21%	-0.9×10^{15}	49
<u>RutgersNJ</u>	$Y=0.63x+0.4\times10^{15}$	0.69	-26%	-0.9×10^{15}	6	$Y=0.76x-0.1\times10^{15}$	0.95	-24%	-1.4×10^{15}	33
<u>FlaxPondNY</u>	$Y=0.53x+0.4\times10^{15}$	0.59	-37%	-1.7×10^{15}	23	$Y=0.53x+0.5\times10^{15}$	0.60	-37%	-1.4×10^{15}	25
<u>NewHavenCT</u>	$Y=0.52x-0.5\times10^{15}$	0.29	-52%	-2.7×10^{15}	25	$Y=0.70x-1.3\times10^{15}$	0.71	-50%	-2.7×10^{15}	47
<u>BranfordCT</u>	$Y=1.22x-2.7\times10^{15}$	0.31	-46%	-1.9×10^{15}	22	$Y=1.2x-2.7\times10^{15}$	0.31	-46%	-1.9×10^{15}	22
<u>MadisonCT</u>	$Y=1.94x-2.7\times10^{15}$	0.12	-24%	-0.6×10^{15}	8	$Y=2.4x-3.9\times10^{15}$	0.02	-24%	-0.7×10^{15}	11

Table 7: Summary statistics for Pandora and TROPOMI over the LISTOS time period and extended to 19 March 2019 with different a priori profiles and indication of whether the Δ_{CS} threshold is applied.

Time Period	Location	TROPMI	Δ_{CS} <	RMA Fit	r^2	Median	N
		Dataset	50hPa			Percent Difference	
LISTOS Only	All Sites	Standard	No	$y=0.82x-0.6\times10^{15}$	0.79	-30%	294
			Yes	$y=0.80x-0.7\times10^{15}$	0.84	-33%	156
		NAMCMAQ	No	$y=1.05x-0.7\times10^{15}$	0.77	-9%	294
			Yes	$y=0.82x-0.2\times10^{15}$	0.80	-19%	156
LISTOS Only	<u>RutgersNJ</u>	Standard	No	$y=0.78x-0.5\times10^{15}$	0.79	-17%	132
	<u>BayonneNJ</u>		Yes	$y=0.76x+0.1\times10^{15}$	0.88	-19%	58
26 June 2018	<u>QueensNY</u>		No	$y=0.74x+0.2\times10^{15}$	0.82	-21%	373
— 19 March 2019	<u>WestportCT</u>		Yes	$y=0.78x-0.3\times10^{15}$	0.87	-27%	195