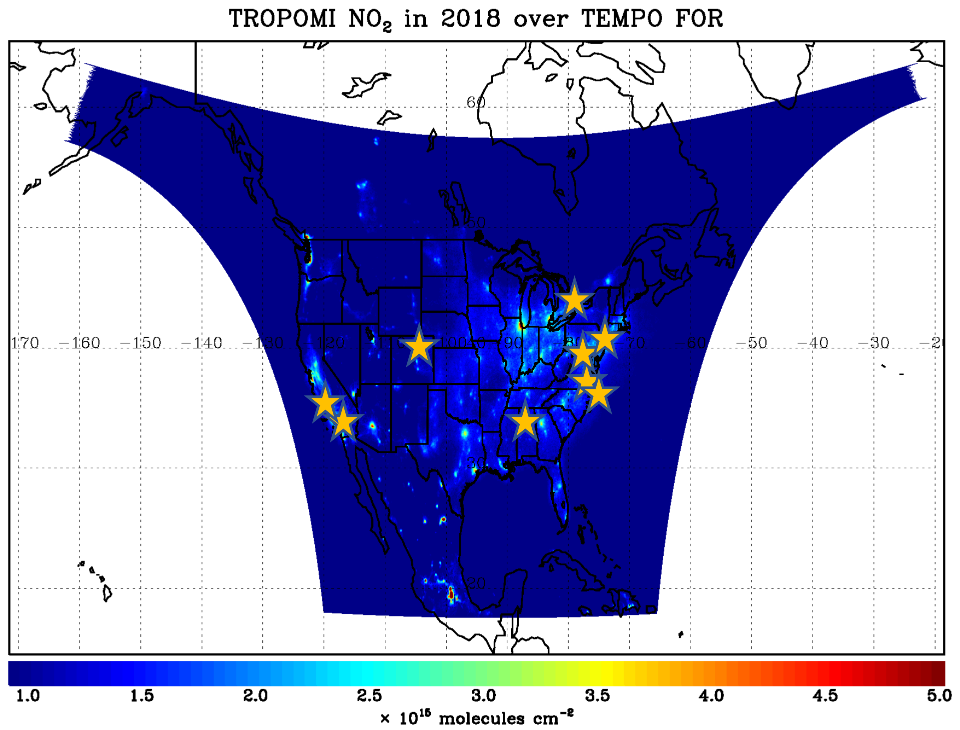
# Intricacies of TEMPO retrievals that affect the validation strategy (a few examples)

- Surface treatment: BRDF effects may produce spatially correlated biases (related to view angle) that may complicate ground-based validation at a limited number of sites; (see Fasnacht poster on BRDF effects)
- Clouds and aerosol: Aerosol may be a significant factor in retrievals, particularly in urban regions (see Vasilkov posters on cloud and aerosol).
  - Non-absorbing aerosol may be implicitly treated as a cloud by the cloud algorithm or aerosols may be treated explicitly using e.g., aerosol information from a data assimilation system.
  - Cloud algorithms also impacted by surface effects.
  - Ground-based systems will be differently affected (e.g., Pandora direct sun less affected)
- Radiative transfer: GEO necessitates calculations at higher view angles than is needed for LEO (see Korkin et al., JQSRT, 2020 for comparison of Monte Carlo and VLIDORT with sphericity correction)
- A priori information (examples of how to deal with this, e.g., Choi et al., 2020)

# Intricacies of TEMPO retrievals that affect the validation strategy (continued)

- Use of LEO satellites for cross validation:
  - For a given point, the LEOs will observe at a range of view angles and for each view angle a slightly different local solar time.
  - OMI may be drifting through an afternoon orbit at the time of TEMPO.
- LEOs can help tie together data from 3 GEOs, all with different algorithms.

# What can TOLNet Contribute to the TEMPO Mission?




| Species/Products | Required Precision | Temporal Revisit |
|---|---|---|
| 0-2 km $O_3$ (Selected Scenes) Baseline only | 10 ppbv | 2 hour |
| Tropospheric $O_3$ | 10 ppbv | 1 hour |

## Goal: 8 TOLNet Instruments by Time of Launch

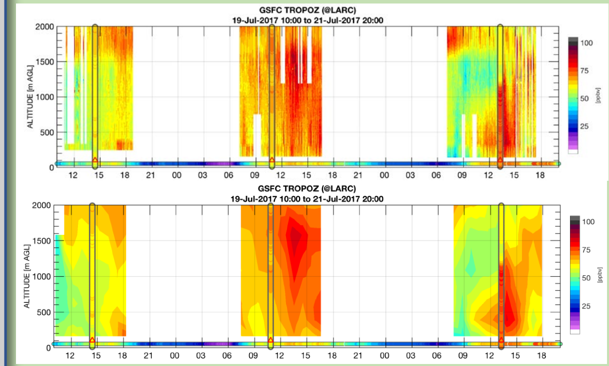
| Institution | Point(s) of Contact |
|---|---|
| NASA GSFC | John Sullivan, Thomas McGee |
| NASA JPL | Thierry Leblanc, Fernando Chouza |
| NOAA CSL | Andy Langford, Chris Senff, Raul Alvarez, Sunil Baidar |
| UAH | Michael Newchurch, Shi Kuang |
| Hampton U. | Pat McCormack, Jai Su, John Anderson |
| NASA LaRC | Tim Berkoff, Guillaume Gronoff |
| CCNY | Fred Moshary |
| ECCC | Kevin Strawbridge |
| NASA Ames | Matthew Johnson (Modeling Effort) |
| NASA LaRC | Gao Chen, Michael Shook, Ali Aknan, Crystal |

**Contact: john.t.sullivan@nasa.gov**
**Website:** https://www-

# What can TOLNet Contribute to the TEMPO Mission?

## Model Evaluation

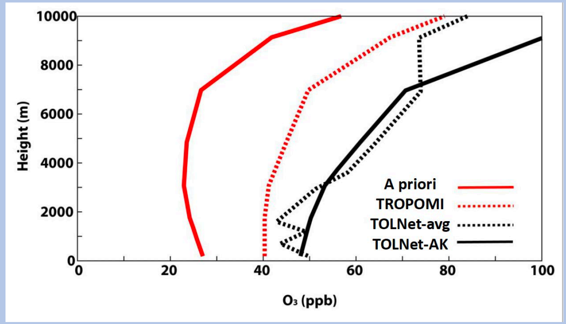
Evaluate and improve existing chemical transport models that will feed into TEMPO priors using time-resolved observations of vertical gradients.




Example: NASA GEOS-CF (Composition Forecast) model evaluation using TOLNet Ozone profile data during NASA OWLETS field campaign (Courtesy J. Sullivan, E. Knowland, N. Dacic)

## Product Validation

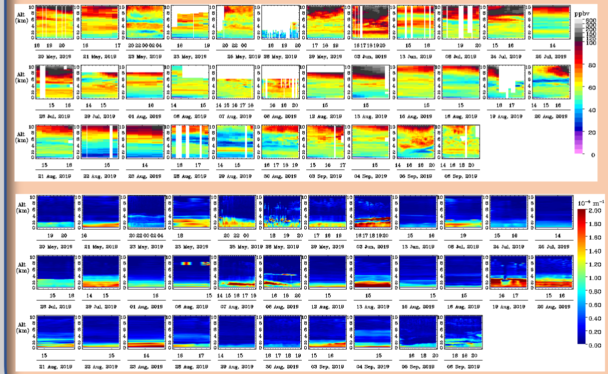
Downscale TOLNet observations and use averaging kernels to better understand what TEMPO will see from space and how effective it will be at characterizing tropospheric ozone variability.




Example: Differences between TOLNet high resolution observations and the same observations when applied to the TROPOMI S5P averaging kernel (Courtesy M. Johnson)

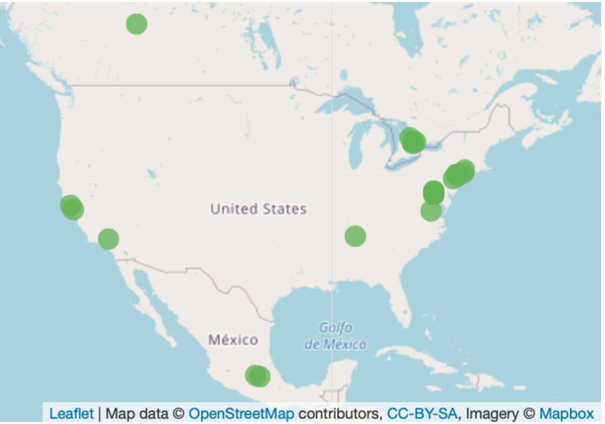
## Improve Science

Calendar of ozone lidar and UV aerosol observations taken during FIREX-AQ. TOLNet observations are critical at understanding process studies to improve the overall science goals of the TEMPO mission



Example: TOLNet high resolution observations during FIREX-AQ (Courtesy S. Kuang, M. Newchurch)

# Pandonia Global Network (PGN) in the TEMPO field of regard




**Stations**

Busan - 17
LabGSFC - 29
CharlesCityVA - 31
GreenbeltMD - 32
MountainViewCA - 34
OldFieldNY - 51
RichmondCA - 52
LabGSFC - 53
QueensNY - 55
ElkridgeMD - 57
LabSciGlob - 59
NewHavenCT - 64
Altzomoni - 65
HuntsvilleAL - 66
WrightwoodCA - 68
NewBrunswickNJ - 69
Izana - 101
Downsview - 103
Downsview - 104
Helsinki - 105
LabIBK - 106
Egbert - 108
StGeorge - 109
Innsbruck - 110
Innsbruck-FKS - 111
BuenosAires - 114
Rome-ISAC - 115
Rome-SAP - 117
Athens-NOA - 119
FortMcKay - 122
StonyPlain - 123
ComodoroRivadavia - 124
Cordoba - 125
ManhattanNY-CCNY - 135
Rome-SAP - 138
MexicoCity-UNAM - 142
Toronto-Scarborough - 145
Yokosuka - 146
BronxNY - 147
Ulsan - 150
NyAlesund - 152
Brussels-Uccle - 162

https://www.pandonia-global-network.org/
Thomas.Hanisco@nasa.gov, Alexander.Cede@LuftBlick.at

We currently have 20+ PGN instruments in the TEMPO field of regard (10+ to add by 2022).

New in 2020-2021 (using DOAS capability for operational data products):

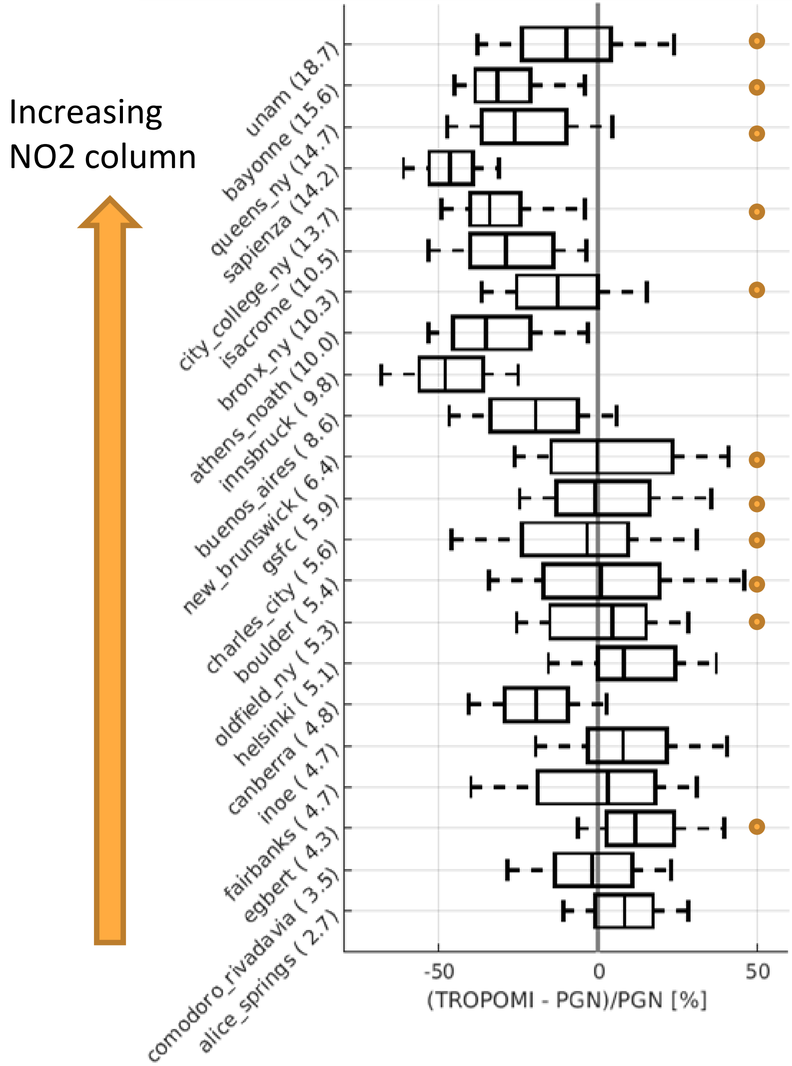
- Temperature corrected $O_3$ columns
- $SO_2$ Columns
- $NO_2$ Columns, profiles, surface concentration
- HCHO Columns, profiles, surface concentration

# Example Application: PGN comparisons to TROPOMI

The PGN provides years-long data sets from around the world to compare with TROPOMI

Urban, rural, oceanic, and mountain regions are represented (TEMPO FOR ● )

These types of comparisons can be used to refine TEMPO retrievals



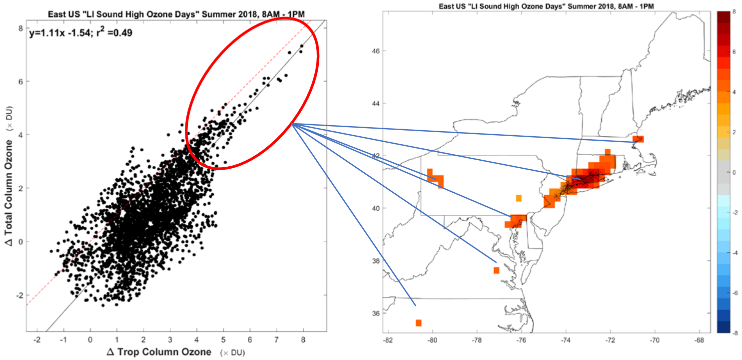

**Verhoelst et al**, : Ground-based validation of the Copernicus Sentinel-5p TROPOMI $NO_2$ measurements with the NDACC ZSL-DOAS, MAX-DOAS and Pandonia global networks,

*Atmos. Meas. Tech. Discuss.*, https://doi.org/10.5194/amt-2020-119, in review, 2020.

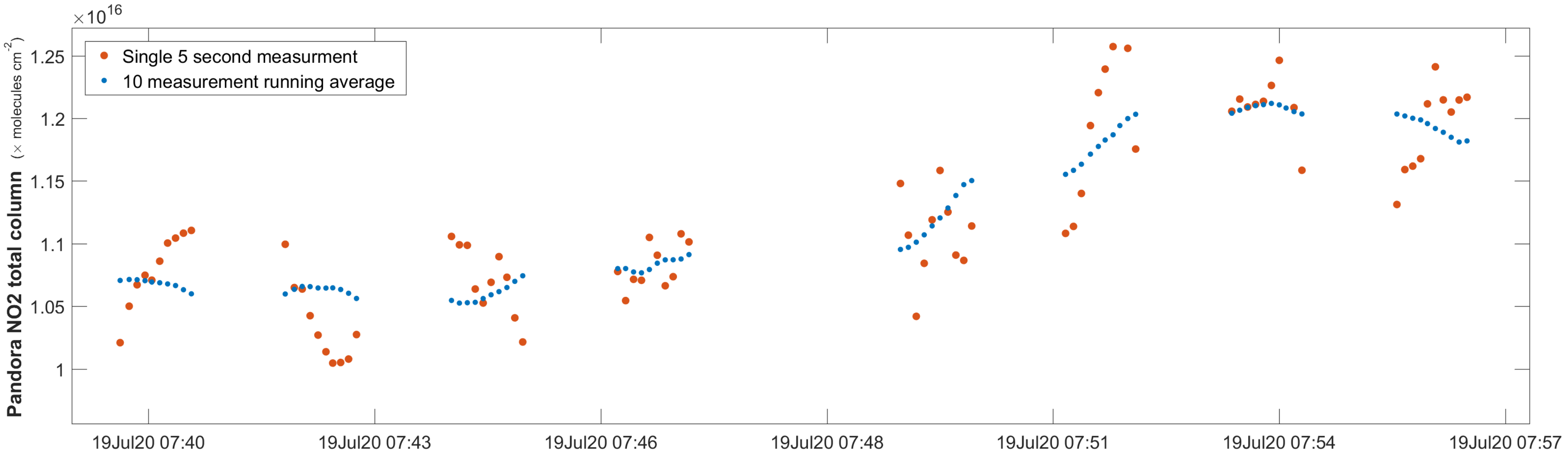
## EPA is seeking to expand Pandora validation sites beyond urban polluted regions

Rural expansion …

- provides context to dense urban networks
- can be optimized to investigate the large (by total mass and uncertainty) NO2 background tropospheric column
- will hopefully serve as a useful, spatially dense, characterization asset for TEMPO 0-2KM ozone product (below right) and regional tropospheric ozone budgets more generally (bottom right corner)
- is supported by rural NCORE, CASTNET along EPA/State legacy of infrastructure support + value added validation/science measurements


- For average of 10 ozone-polluted days in northeast US in 2018, GEOS-CF simulates ozone column growth through mid-day is virtually all due to tropospheric growth, and spatially aligned over large urban sources
- Intra-Pandora precision is better than intra-Pandora accuracy, suggesting Pandora diurnal patterns should be useful validation metric




## High-frequency direct sun measurements

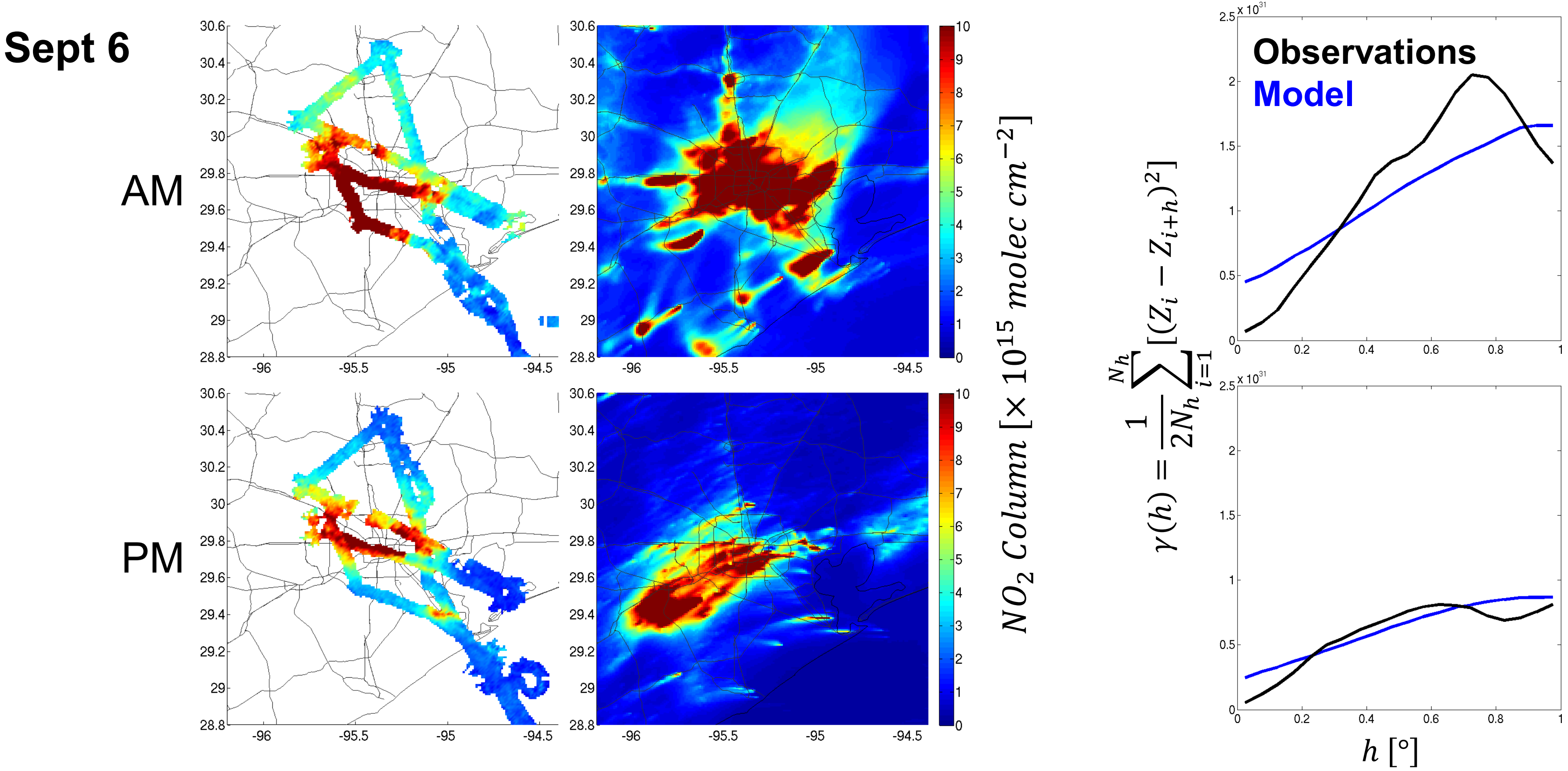
- Performing thoughtful ~5-second direct-sun Pandora experiments may provide useful details on air overhead and how it might relate to TEMPO during your routine sampling schedule.

- ~1-minute variability is due to vertical eddies and coupled advection, and nearby or large sources .
- Cross-correlation of compounds (e.g., $H_2O$, $NO_2$, HCHO) at short time-scales can help with cross-validation of TEMPO products and understanding local emission/chemistry fields

- **Given that UV/Vis lacks sensitivity all the way down to the surface, the combination of high-frequency column and gas in situ measurements at a site should be useful for understanding whether TEMPO is capturing gradients at the surface in the near-field to your site, an important quantity for extrapolating surface exposures from column data.**

# *Accounting for Horizontal Variability in Pandora Validations of TEMPO*

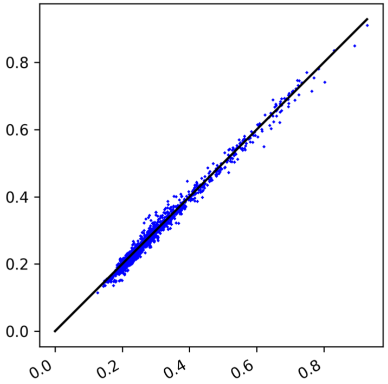
Measured and modeled $NO_2$ structure functions over Houston from DISCOVER-AQ



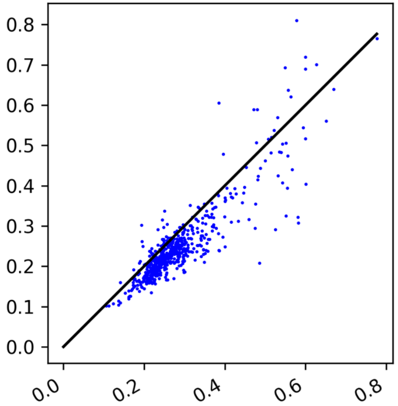
## *Accounting for Horizontal Variability in Pandora Validations of TEMPO*

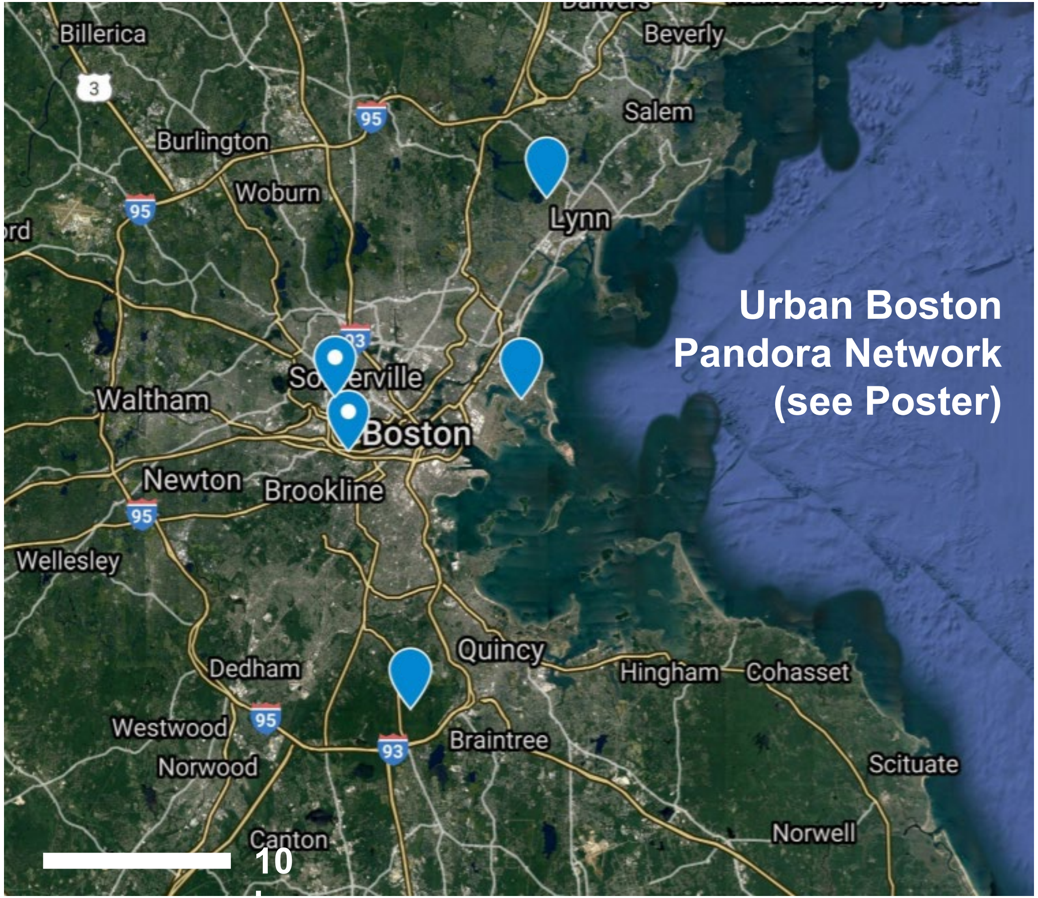
Observed Small-Scale Variability in Boston

Pandora 155
vs. Pandora 107
***Collocated at BU***

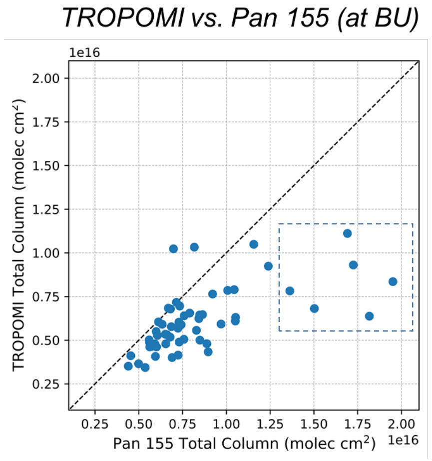


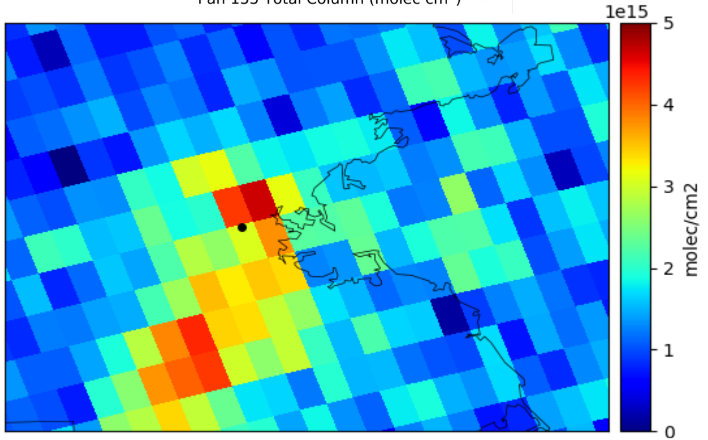

Pandora 155 (BU) vs. Pandora 107 (Harvard)
***~3.0 km distance apart***

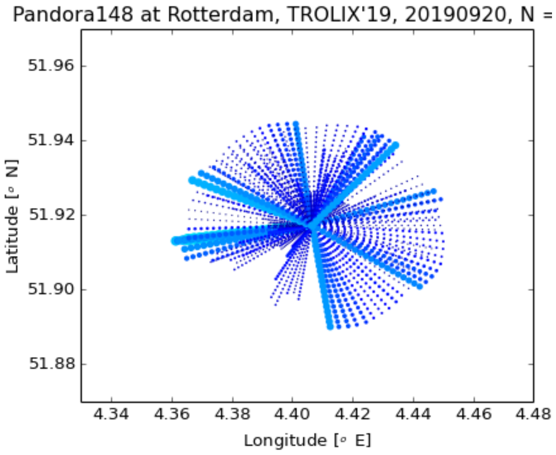


# *Accounting for Horizontal Variability in Pandora Validations of TEMPO*

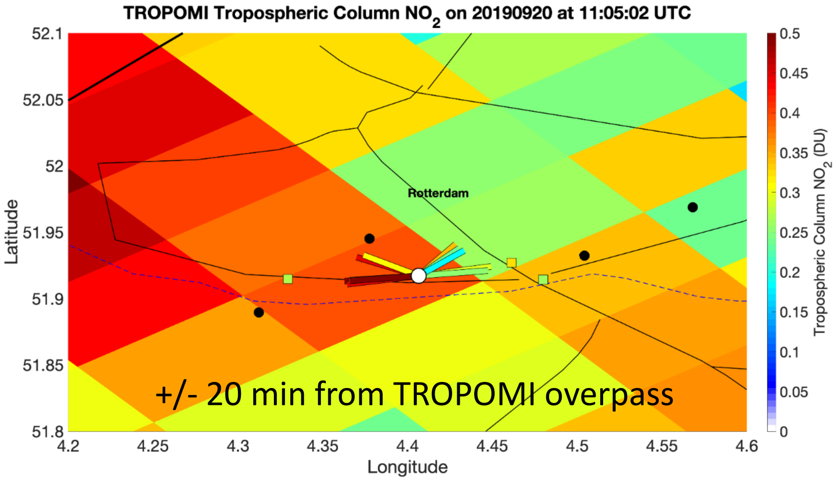


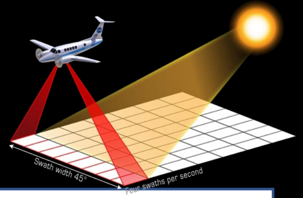

TROLIX'19

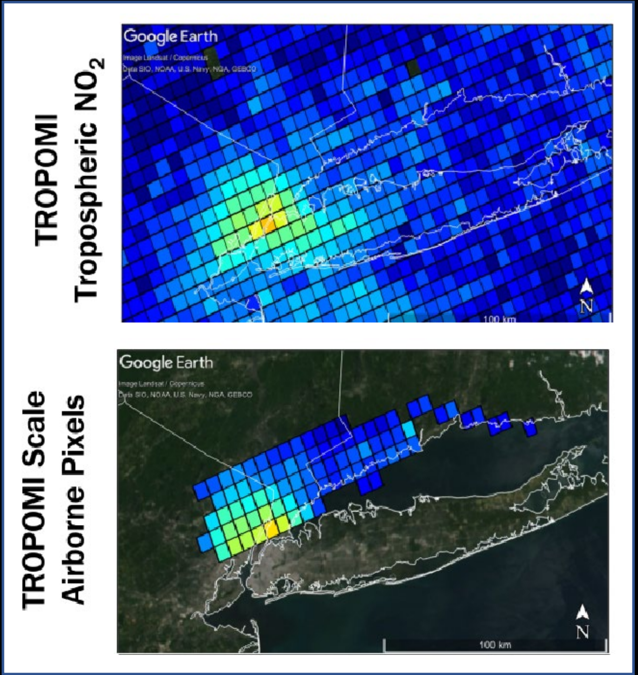
(from Elena Spinei Lind)

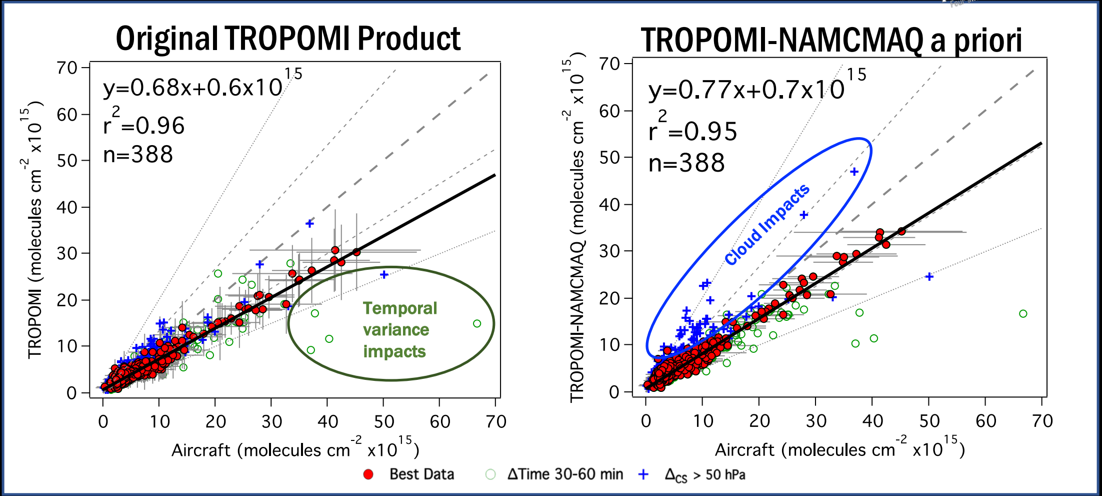


# Validation with Airborne Spectrometers

## Lessons learned from TROPOMI $NO_2$ Evaluation




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

https://amt.copernicus.org/preprints/amt-2020-151/

1. Minimizes large uncertainty based on subpixel variance (if temporally coincident)
2. A resource to test out impacts to assumptions made in retrieval (e.g., a priori, clouds, etc.)
3. Repeated aircraft/TEMPO obs. + other reference measurements can help flag temporal mismatches
4. GCAS can fly with other helpful instruments like aerosol lidars or other hi-res imagers to add context to validation efforts