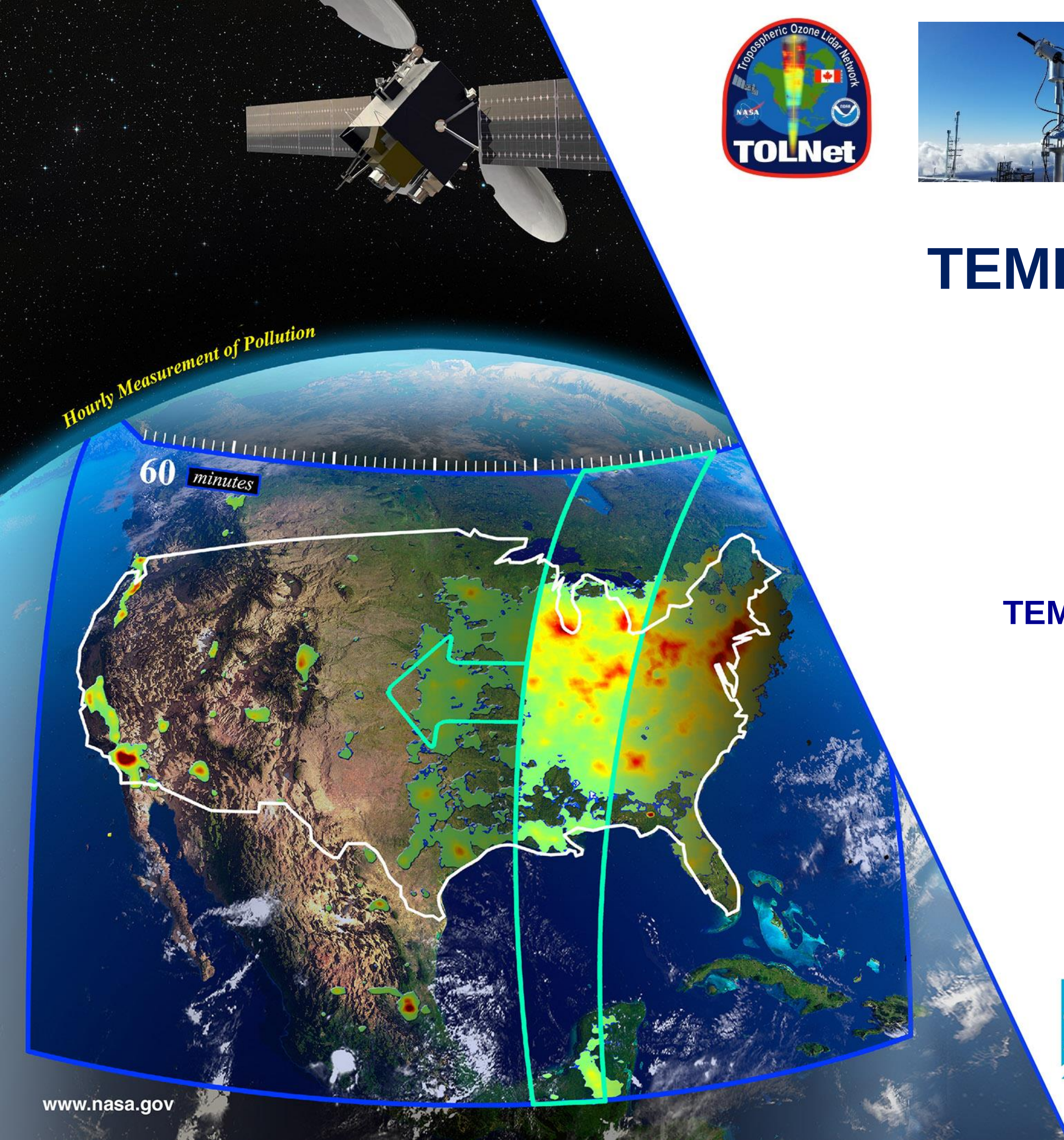

TEMPO STM 2020 Validation

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Ron Cohen
and the
TEMPO, TOLNet , Pandora
Science Teams

13 August 2020

1. Summarize what we know about satellite validation from history and recognize the TEMPO opportunity.

1. Historically coincident, correlative measurements by ozonesondes, aircraft, balloons, satellites, space shuttle, ground-based spectrometers (FTIR, visible), iteration with theory for consistency/understanding. These **mature techniques** resulted in quite good assessment of **precision**, **bias**, **variance**, and some **spatial variance** for (usually, but not ATMOS) a small number of species, especially in the stratosphere.
2. Major historical limitations: **No temporal variance** or gradients on **hourly time scales**; little tropospheric-profile resolution; limited **spectroscopic validation, SZA.**
3. Major new science opportunities: **Spectral radiance validation** with **SZA** effects (Pandora, GeoTASO, GCAS); **Statial resolution; Temporal evolution**; Modeling capabilities at **spatio-temporal scales** from global to urban canyons with many species (gases and aerosols) and **assimilation** of multiple disparate data provide the scientific flame front.

2. Identify what approach are available for TEMPO geostationary spatio-temporal sampling and resolution retrieval assessment.

Fundamental metrics: Precision, Bias, Variance, space/time Gradients, spectroscopic.

	Pandora	Lidar	Ozonesonde	Aircraft, insitu, Geo-TASO, GCAS	Surface	Satellite
Precision	Column	Column, profile	No	Homogeneous airmass	No	No
Bias	Column, profile	Column, profile	Column, profile	Limited profile	No	Column
Variance	Column, profile	Column, profile	Column, profile	Limited profile	No	Column
Gradient (time, space)	Time		no	Space, limited time	Surface time gradient	Space
Spectroscopic validation	Yes	No	No	Yes	No	Yes
Limitation	Fixed location	1 mobile location. Ozone, aerosols, (NO2?)	Few locations. Ozone, NO2	Most a/c infrequent, cost	Bottom 2 m.	Once/day
Advantage	TEMPO-like column obs.	Temporal evolution	Heritage	Multi species, arbitrary locations, a/c simimulator	Extensive network and importance.	Continental coverage

3. (a) Set a plan to first cover the PLRA validation requirements (3 Pandoras, etc.), then,
(b) consider additional validation and science activities and campaigns.

(a) From the TEMPO **PLRA**:
"Compare space-based and ground-based retrievals of products using correlative data collected **from daytime** (solar zenith angles <70° for all products) observations at least **one month each season** from at least **three (3) ground validation sites** in the US to identify and correct regional-scale and diurnal systematic **biases** in the space-based products and to demonstrate required **precisions** in polluted clear-sky scenes to the **levels listed in [Table 2.1].**
We expect to have many more than 3 stations contribute to this baseline effort.

(b) Consider additional Science and Validation activities:
1. Individual and group validation activities are welcome, but no mission budget for these activities; need other support.
2. It's now the time to discuss science/validation aircraft/ground-based campaign (like DISCOVER-AQ et al.)
3. Use the TEMPO **Greenpaper** to design&execute validation & science experiments!

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 113, D16S29, doi:10.1029/2007JD008815, 2008

Validation of Tropospheric Emission Spectrometer ozone profiles with aircraft observations during the Intercontinental Chemical Transport Experiment–B

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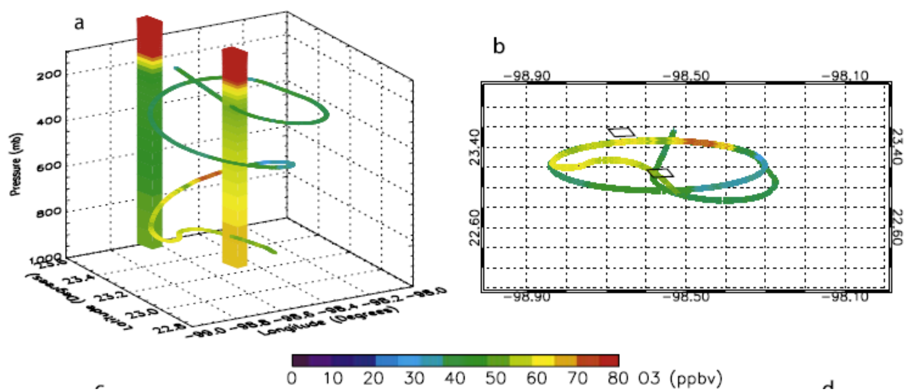
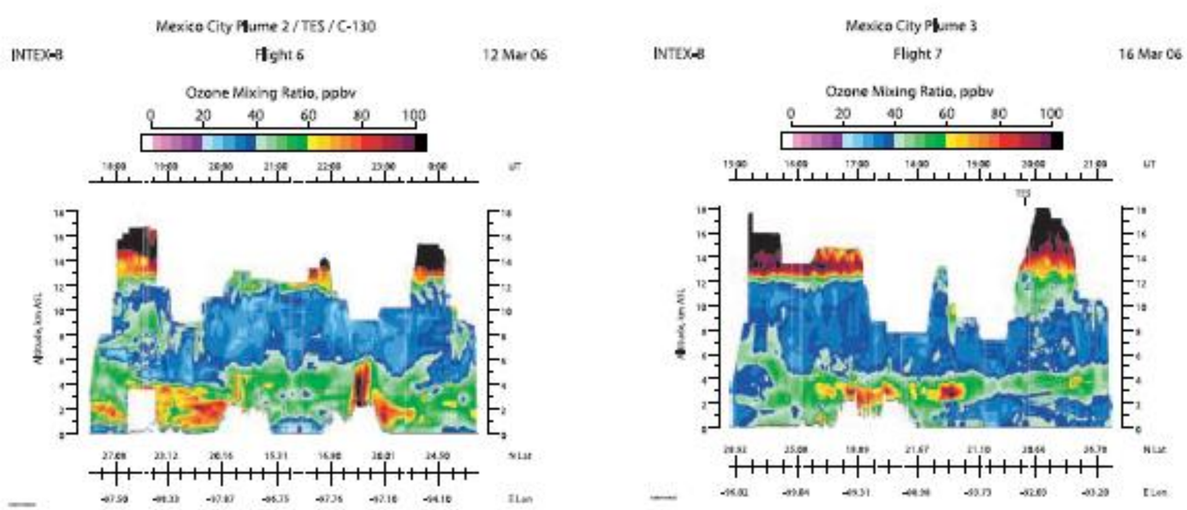
Received 15 April 2007; revised 25 October 2007; accepted 17 December 2007; published 23 May 2008.





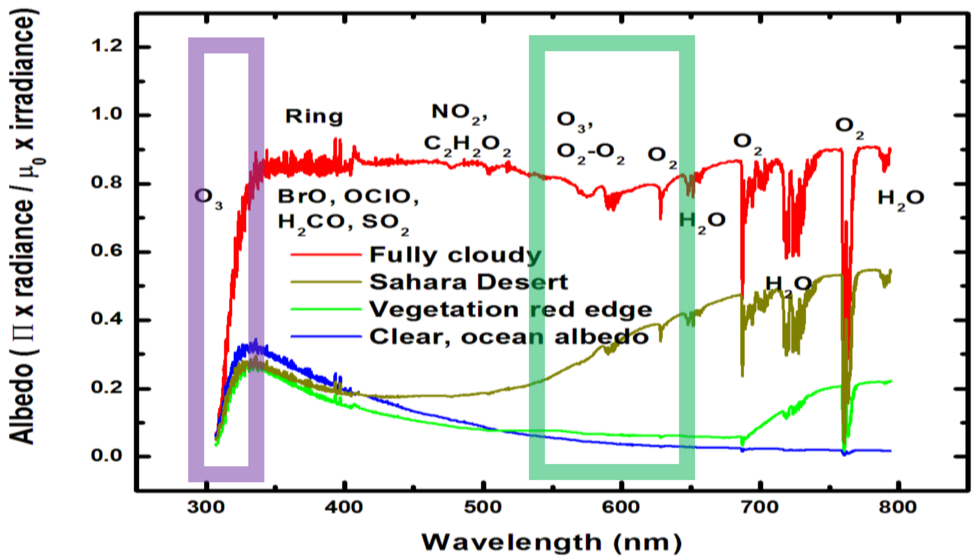
TEMPO Validation-approach Goal:
Quantify the Precision, Accuracy, Bias, Slope, Offset, and Variability Characteristics of TEMPO Retrievals for all Geophysical Conditions

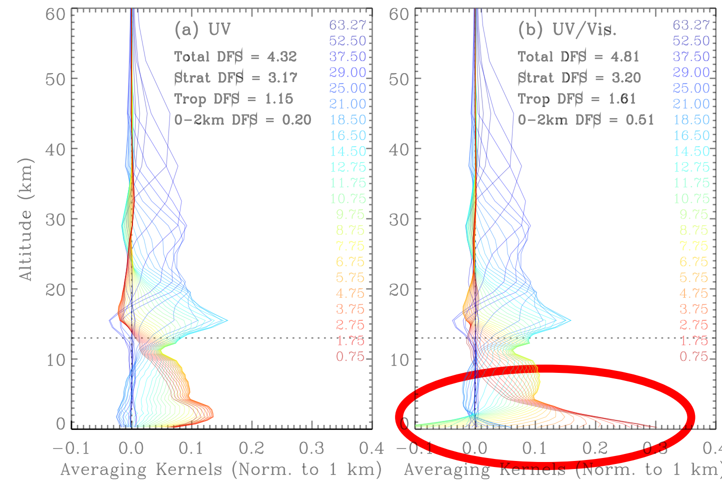
Some important factors to consider

Spectroscopic accuracy
Averaging kernel structure

TEMPO UV/VIS jointed O3P retrievals

■ **UV (290-340 nm) & VIS(540-650 nm), @0.6 nm, 0.2nm/pixel**





❖ ***Benefits of visible fitting (Natraj et al., 2011; Zoogman et al., 2017)***

- UV + visible to help distinguish boundary layer O_3 from free tropospheric O_3.

❖ ***Challenges of visible fitting***

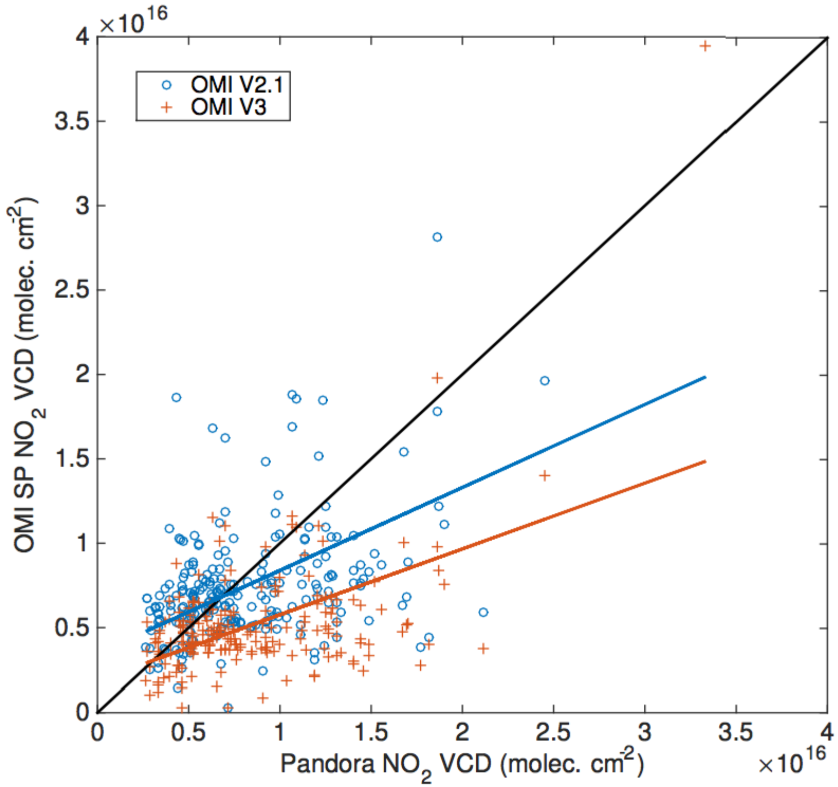
1. weak O_3 absorption, strong interferences from surface reflectance and aerosols/clouds, other gases (O_4, O_2, H_2O)
2. Need accurate radiometric calibration across the spectral range
3. expensive RTM calculations at ∼800 wavelengths

Some important factors to consider

Spectroscopic accuracy
Averaging kernel structure

Spatial resolution
Cloud fraction
SZA
Stratospheric NO_2
Albedo
Local spatial and temporal variability
Spatial heterogeneity
Different sampling geometry
Air mass factor

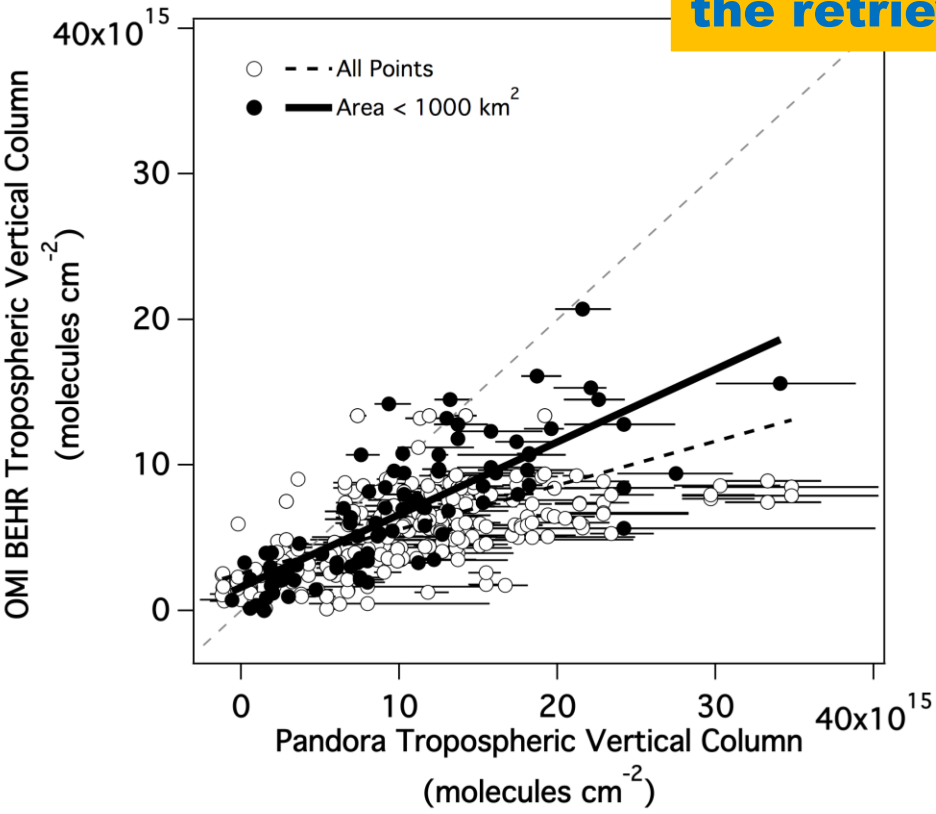
Ialongo et al., AMT 2016



- Fig. 4 from Ialongo et al.
- Compares OMI to Pandora NO_2; both OMI SP 2.1 and 3 used
- Verified that SP 3 corrected high bias in total columns (smaller *y*-intercept)
- Suggests an underestimate of high VCDs from OMI's perspective – resolution or *a priori* issue (compared to Pandora)?
- Other factors: cloud fraction, SZA, Stratospheric NO_2, albedo, spatial resolution, spectral fitting.

Judd, et al., 2019

Comparison of OMI to PANDORA are better using smaller pixels and high resolution a priori inputs to the retrieval (BEHR).



Remaining disagreements related to:

- Local spatial and temporal variability,
- Spatial heterogeneity
- Different sampling geometry
- Air mass factor

Judd, et al., 2019

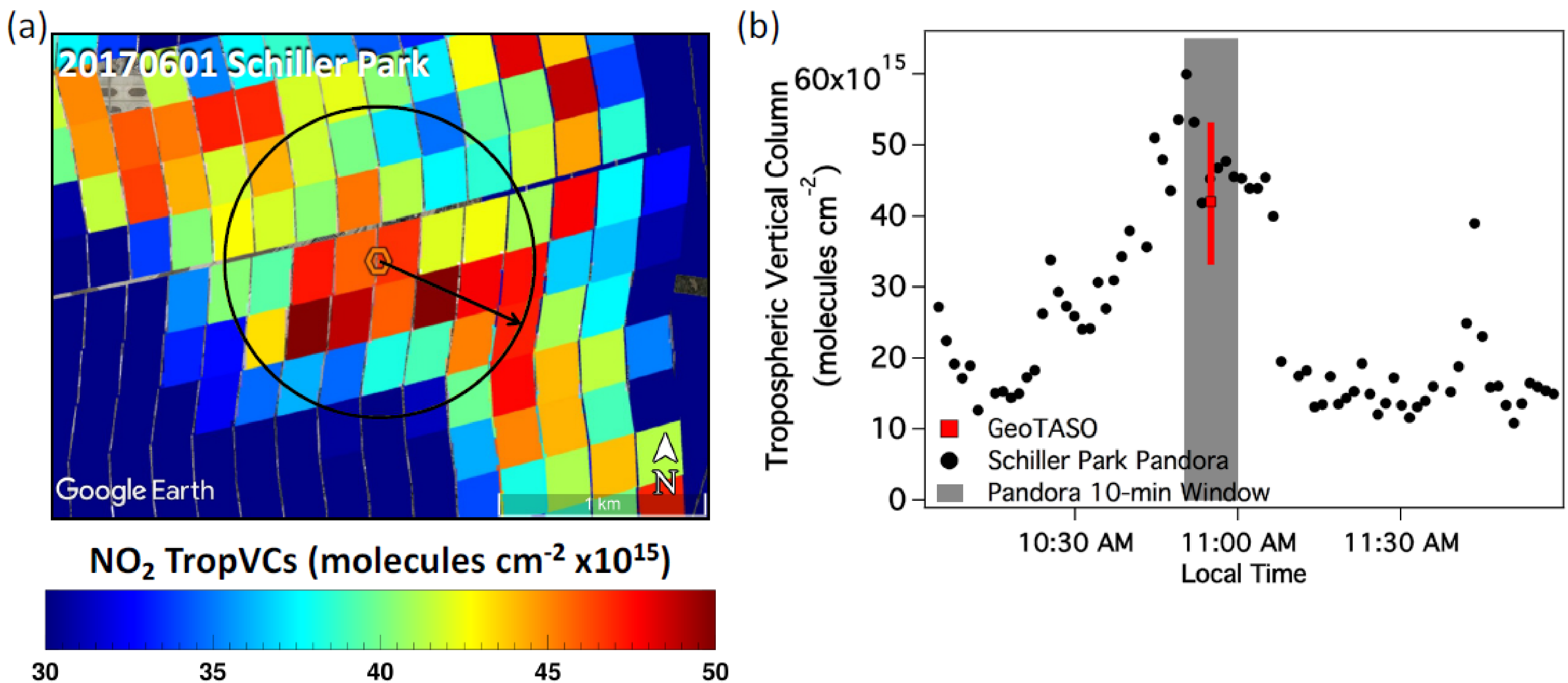


Figure 4: (a) Map of GeoTASO TropVCs on a linear color scale for the Schiller Park overflight on June 1st, 2017 at 15:55 UTC (10:55 LDT) (pink triangle in Figure 3) with the 750 m radius considered in the spatial binning of GeoTASO overlaid and an arrow depicting the Pandora viewing direction (solar azimuth angle) during the overpass time. The Pandora hexagon is colored by the NO_2 TropVC measured by Pandora during the overpass. (b) Time series showing Pandora data (black points) within approximately ± 1 hour of the GeoTASO overpass. The Pandora temporal window for the coincidence is shaded in grey and the GeoTASO TropVC and 10^{th}-90^{th} percentiles from the overpass are shown in red.

Some important factors to consider

Spectroscopic accuracy
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Spatial resolution
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Stratospheric NO_2
Albedo
Local spatial and temporal variability
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Different sampling geometry
Air mass factor

Intercomparison technique

Atmos. Chem. Phys., 10, 4725–4739, 2010
www.atmos-chem-phys.net/10/4725/2010/
doi:10.5194/acp-10-4725-2010

Atmospheric Chemistry and Physics

Intercomparison methods for satellite measurements of atmospheric composition: application to tropospheric ozone from TES and OMI

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The first method (in situ method) uses **in situ** vertical profiles for absolute instrument validation; it is limited by the sparseness of in situ data. The second method (CTM method) uses a chemical transport model **(CTM) as an intercomparison platform**; it provides a globally complete intercomparison with relatively small noise from model error. The third method (averaging kernel smoothing method) involves **smoothing the retrieved profile from one instrument with the averaging kernel matrix of the other**; it also provides a global intercomparison but dampens the actual difference between instruments and adds noise from the a priori.

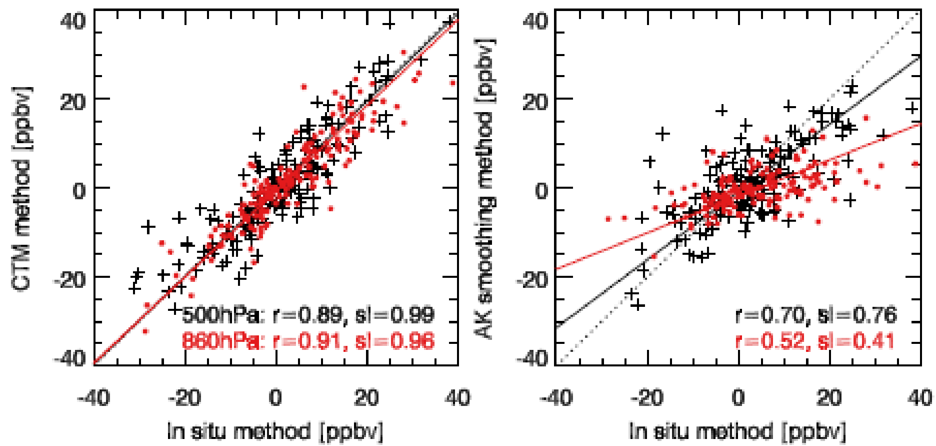

Fig. 6. Differences between TES and OMI estimated by the CTM method (left) and by the averaging kernel (AK) smoothing method (right), relative to the in situ method at 500 hPa (black crosses) and 860 hPa (red dots). The in situ method uses ozonesonde profiles for 2006 as absolute validation. The data are for 180 TES/OMI/sonde coincidences in 2006. Correlation coefficients (r) and slopes of the reduced-major-axis regression lines (sl) are shown inset. Reduced-major-axis regression lines (solid) and the 1:1 line (dashed) are also shown.

List of factors to get right for confident validation

Geophysical factors:

- Albedo
- Local spatial and temporal variability
- 4D heterogeneity
- Spatial resolution
- Cloud fraction
- Stratospheric NO_2

Analysis approach:

- Spectroscopic accuracy
- Averaging kernel structure
- SZA
- Sampling geometry
- Air mass factor
- Intercomparison technique