Characterizing TEMPO NO_2 column-surface relationships using mobile, aircraft, and ground-based observations over Baltimore, MD

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1. Spatial distributions from TEMPO and TROPOMI over Baltimore city generally agree

Vertical column densities over the Baltimore area generally agree, while there are spatial differences.

TROPOMI observes ~30% lower NO_2 than TEMPO, TEMPO observes greater spatial variability.

Slant column densities show higher spatial agreement than vertical columns.

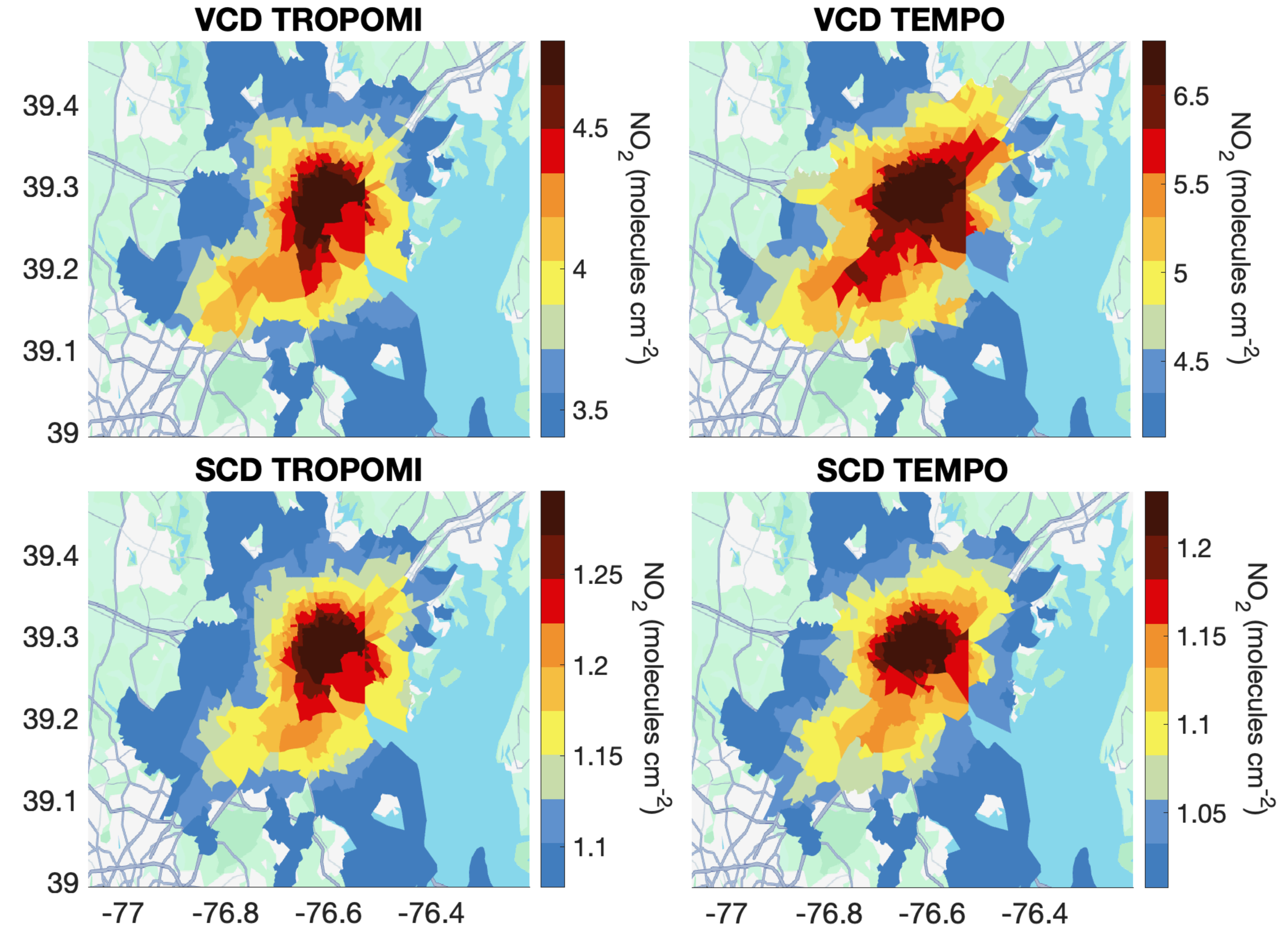


Figure 1. Averaged tropospheric column densities (top) and slant column densities (bottom) (1 x 10^{16} molecules cm^{-2}) averaged to census tracts over Baltimore MD, from TROPOMI (left) and TEMPO (right). Limited to high quality cloud free pixels from coincident overpasses from 2024.

2. Satellite products agree with stationary ground-based Pandora columns, with a smaller bias for TEMPO

On average, TROPOMI has higher correlation with Pandora observations, while TEMPO has a lower normalized mean bias.

Improved correlation between TEMPO during TROPOMI overpass times only (~13:30 LT); but is still lower than TROPOMI-Pandora.

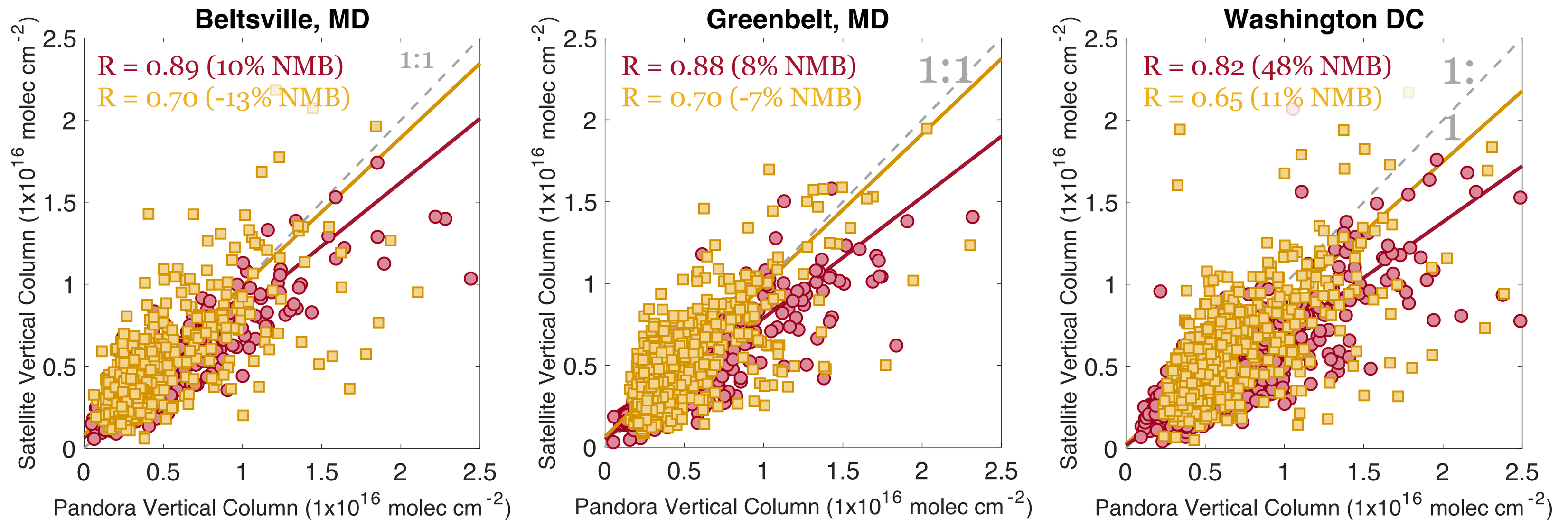


Figure 2. Pandora tropospheric columns with coincident TROPOMI (red) and TEMPO (yellow) observations for Pandora's in Beltsville, MD (left), Greenbelt, MD (middle), and Washington DC (right). TEMPO observations have been limited to TROPOMI overpass times. Pearson correlation coefficients and median normalized mean biases are shown on plots. 1:1 line is shown in grey.

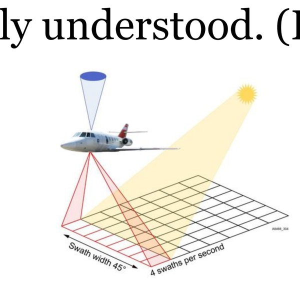
Are satellite observations accurately capturing the NO_2 distribution and variability at the surface?

We evaluate the performance of TROPOMI and TEMPO in capturing NO_2 spatial distributions over urban areas and explore TEMPO's ability to capture surface level diurnal variations. We integrate high-resolution in-situ surface NO_2 observations from a mobile laboratory with high resolution coincident aircraft column observations from GCAS and CHAPS-D instruments to assess their ability to accurately reflect surface-level pollution in Baltimore, MD.

Summary

- TROPOMI and TEMPO capture similar spatial distributions over the Baltimore area; while there are spatial differences. (Box 1).
- Both satellite products have a high correlation with ground-based Pandora observations, while TEMPO has a lower median normalized mean bias. TEMPO-Pandora correlation increases when limited to TROPOMI overpass times (~13:30 LT) but is still slightly lower than TROPOMI-Pandora (Box 2).
- TEMPO observes diurnal changes occurring later than observed by stationary monitors, by ~3 hours on average. Individual days show this delay in the observed diurnal pattern, while some days TEMPO accurately captures surface level changes. Pandora observations, by comparison, show a weak diurnal variation. (Box 3).
- GCAS provides high resolution NO_2 distribution over Baltimore for a single day where we have concurrent observations. Both satellite products agree well with GCAS, while TROPOMI has a higher correlation. (Box 4).
- Mobile observations map out a similar NO_2 distribution at the surface compared to the satellite and aircraft— but there are differences in the spatial distribution that are not yet fully understood. (Box 5).

CHAPS-D COMPACT HYPERSPECTRAL AIR POLLUTION SENSOR



5. Spatial NO_2 distributions mapped from mobile, airborne, and satellite observations

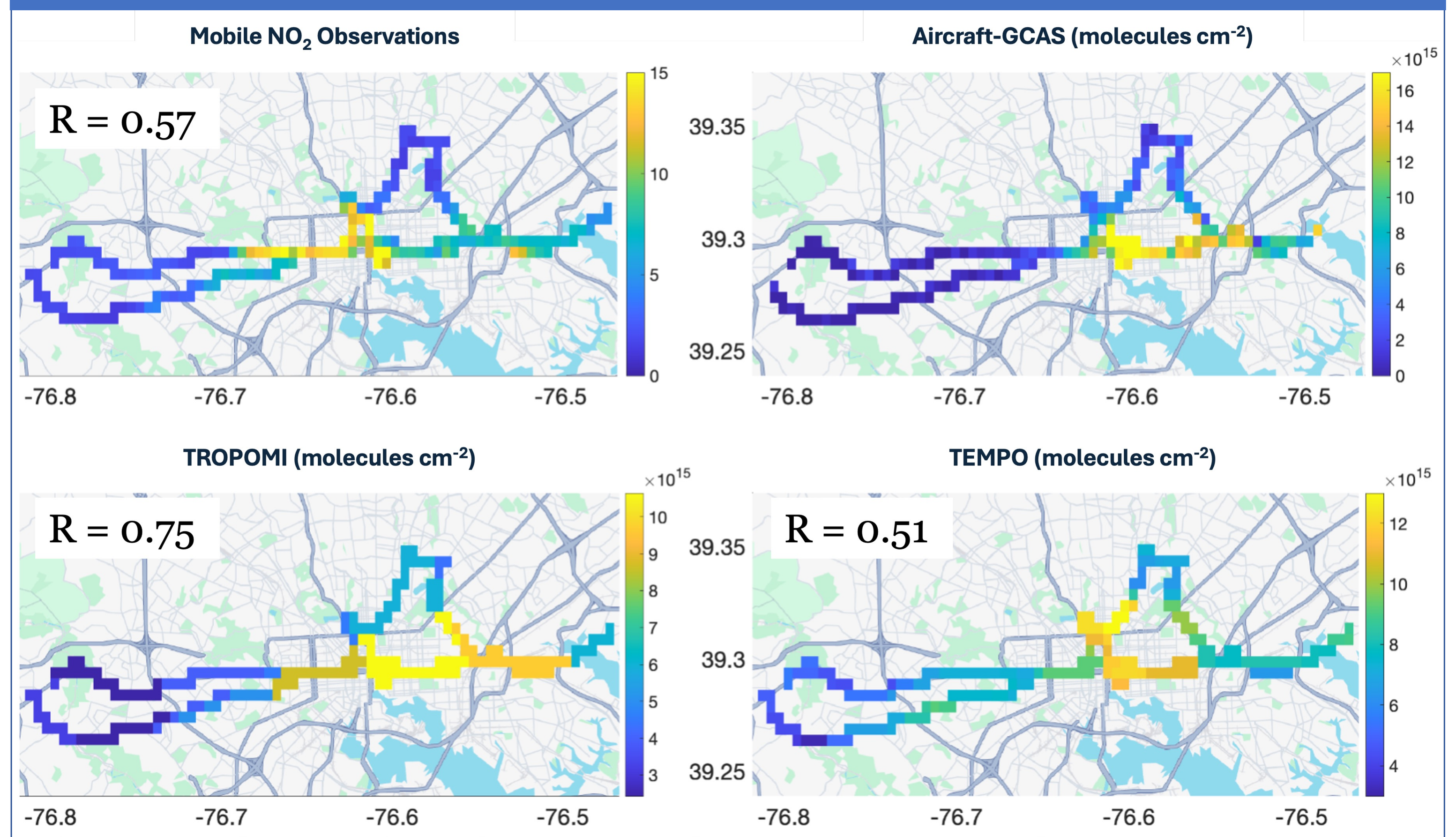


Figure 5. Observations from 3 October 2024 averaged to 0.05° x 0.05 ° grid. Mobile NO_2 observations smoothed to the 35th percentile over 5-minute averaging period (top left). GCAS slant column densities (top right). TROPOMI overpass at 1:30 LT (bottom left). Average of TEMPO overpasses from 12-15 LT (bottom right).

3. Diurnal changes observed from TEMPO occur ~1-3 hours after changes observed from surface monitors on average

On average, diurnal variations observed from TEMPO observe later than observed by surface monitors. Individual days demonstrate this feature on ~50 % of days.

There are individual days where TEMPO captures the diurnal variation at the surface.

Pandora observations do not capture diurnal variation as observed at the surface.

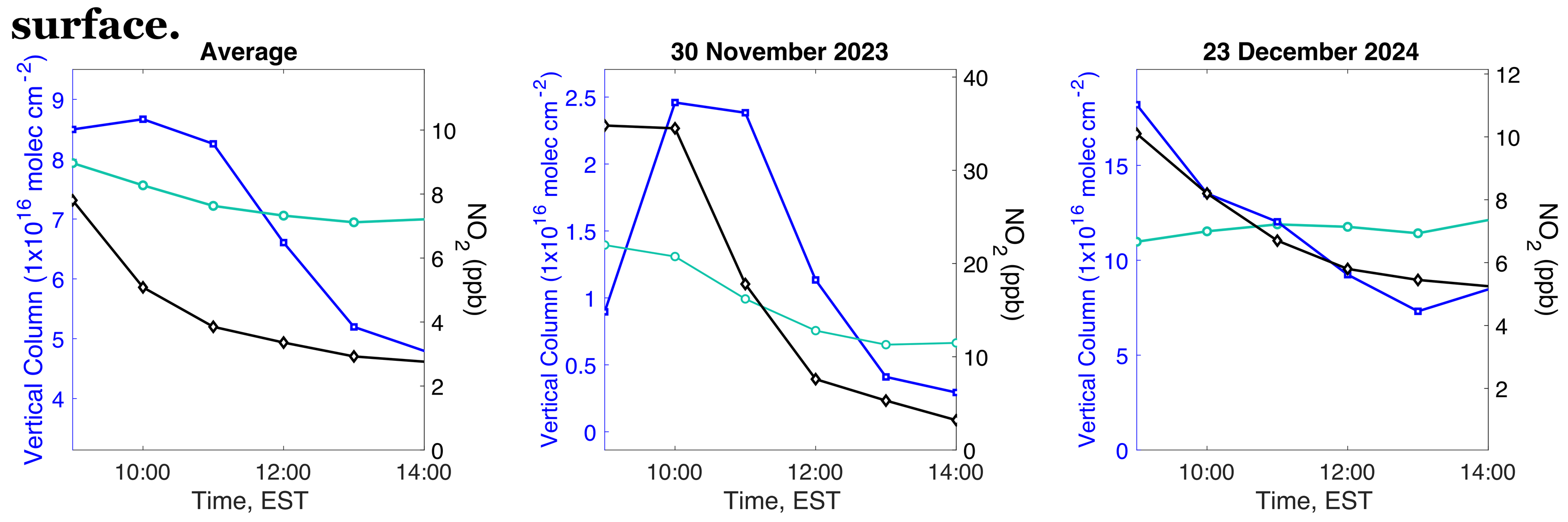


Figure 3. Diurnal variations from TEMPO (blue), Pandora (teal) and EPA surface monitor (black) in Beltsville, MD. Average diurnal variations from September 2023-June 2025 (left). Example day (30 Nov 2023) demonstrating TEMPO's delay in diurnal pattern divergence (middle). Example day (23 Dec 2024) demonstrating TEMPO capturing the diurnal variation at the surface (right).

4. Averaging TEMPO overpasses improves correlation to GCAS columns, while still weaker than correlation with TROPOMI

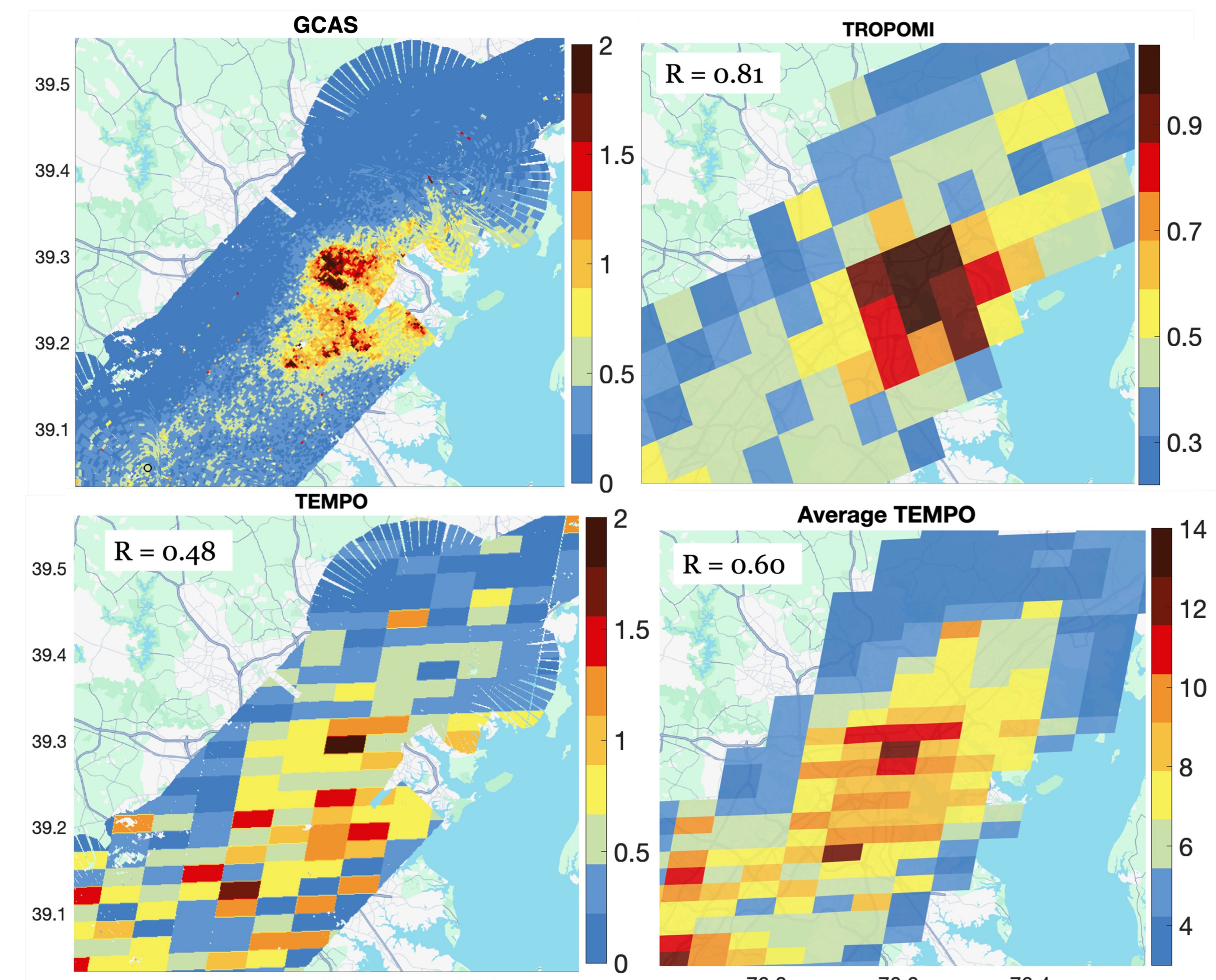


Figure 4. 3 October 2024 NO_2 observations (1 x 10^{16} molecules cm^{-2}). GCAS slant column densities over Baltimore (top left). TROPOMI 13:30 LT overpass (top right). TEMPO 13:30 LT overpass (bottom left). Average of TEMPO 12:00-15:00 LT overpasses (bottom right). Pearson correlation coefficients are in comparison to GCAS data averaged to the satellite spatial grid.