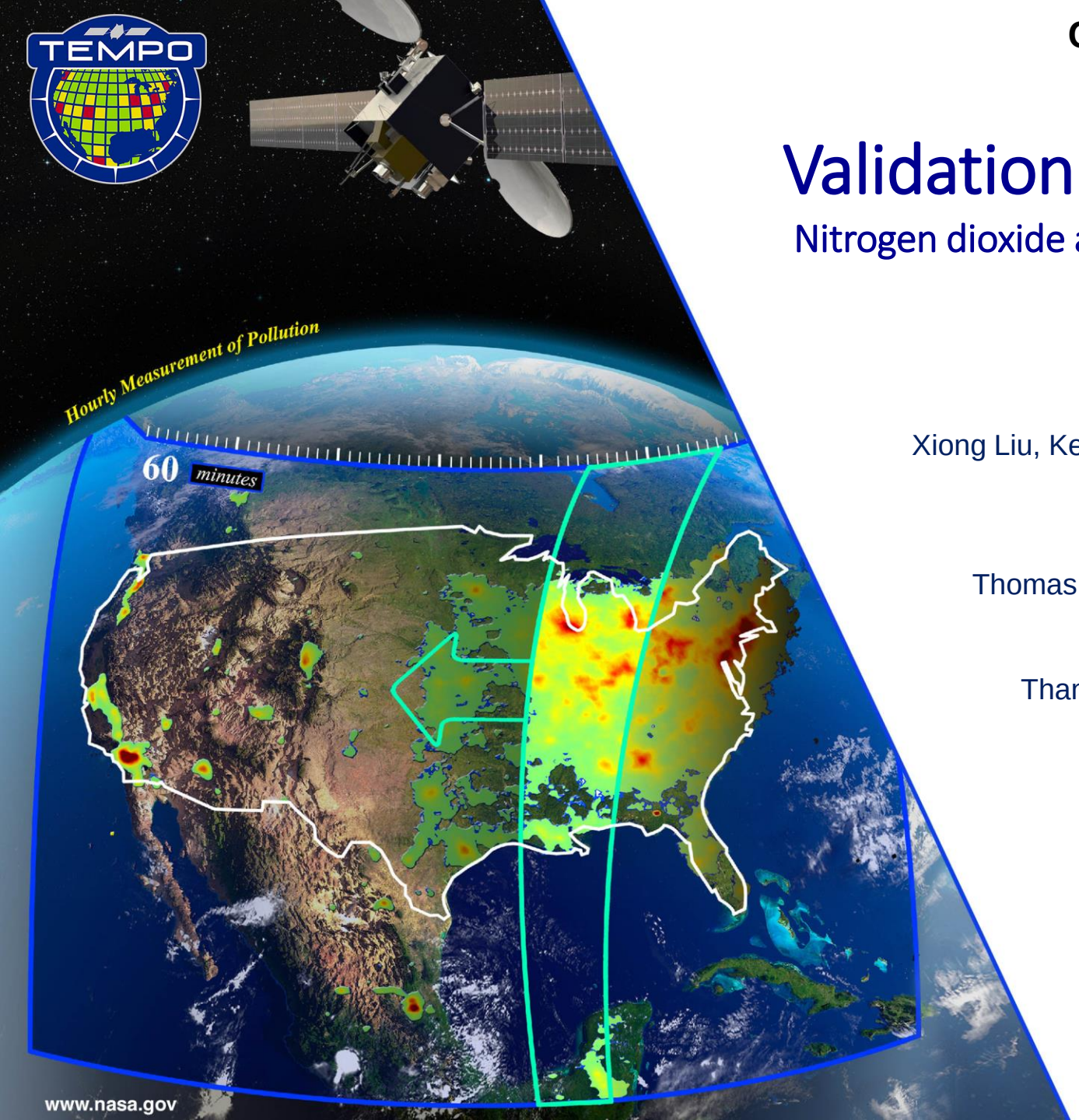


CEOS AC-VC Meeting #20
15-18 October 2024

Validation of TEMPO NO2 and HCHO

Nitrogen dioxide and Formaldehdye using Pandora and TropOMI

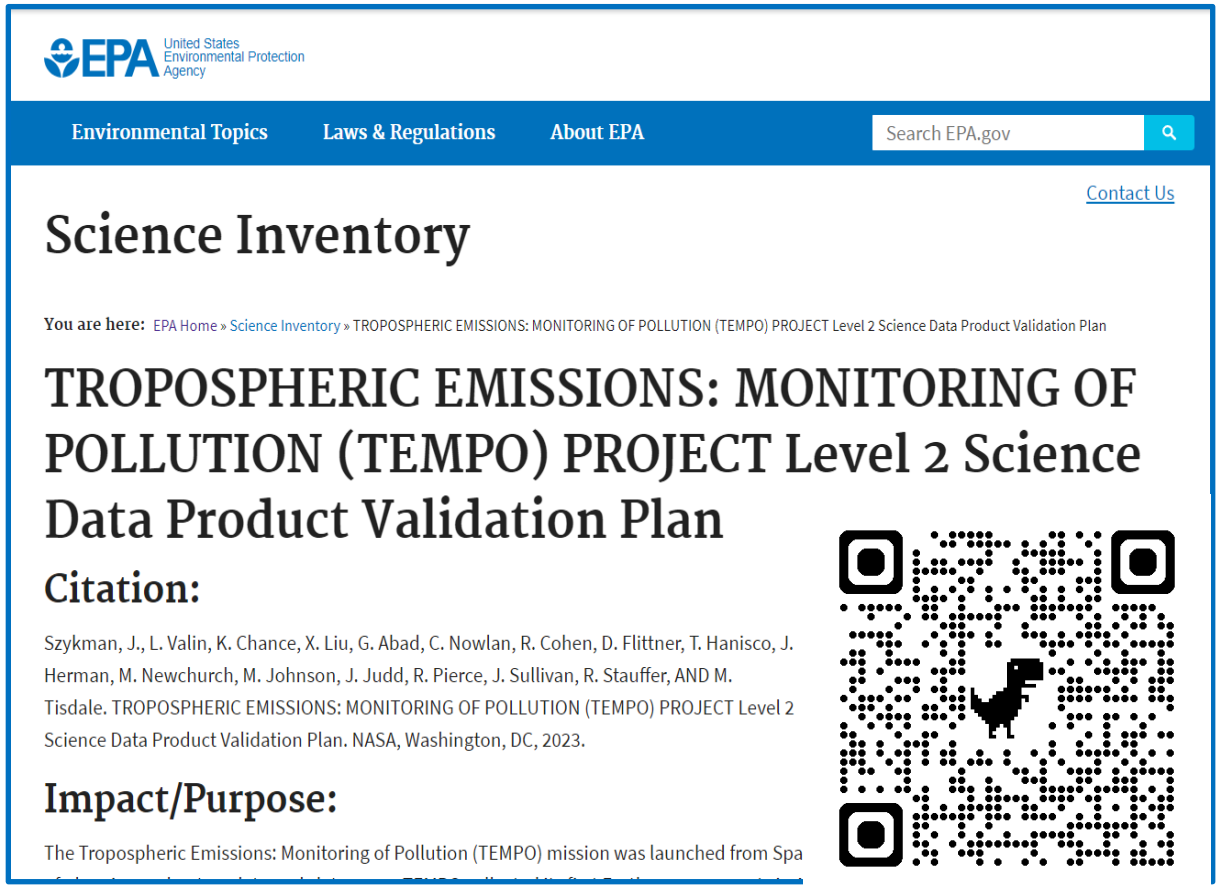
Barron Henderson, US EPA
James Szykman and Luke Valin
US EPA
Xiong Liu, Kelly Chance, Gonzalo Gonzalez Abad, Caroline Nowlan
SAO TEAM
Katherine Travis, Prajjwal Rawat
NASA LaRC
Thomas Hanisco, Nader Abuhassan, and Alexander Cede
NASA GSFC / SciGlob / Luftblick

Thanks to the rest of the TEMPO Validation Team!

***Disclaimer**: The views expressed in this presentation are those of the authors and do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency.*

NASA Smithsonian Ball UNITED STATES ENVIRONMENTAL PROTECTION AGENCY SSEC

Validation Efforts Help Advance TEMPO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Science Inventory

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TROPOSPHERIC EMISSIONS: MONITORING OF POLLUTION (TEMPO) PROJECT Level 2 Science Data Product Validation Plan

Citation:

Szykman, J., L. Valin, K. Chance, X. Liu, G. Abad, C. Nowlan, R. Cohen, D. Flittner, T. Hanisco, J. Herman, M. Newchurch, M. Johnson, J. Judd, R. Pierce, J. Sullivan, R. Stauffer, AND M. Tisdale. TROPOSPHERIC EMISSIONS: MONITORING OF POLLUTION (TEMPO) PROJECT Level 2 Science Data Product Validation Plan. NASA, Washington, DC, 2023.

Impact/Purpose:

The Tropospheric Emissions: Monitoring of Pollution (TEMPO) mission was launched from Spa

EPA Science Inventory: 362165
or
https://tempo.si.edu under documents

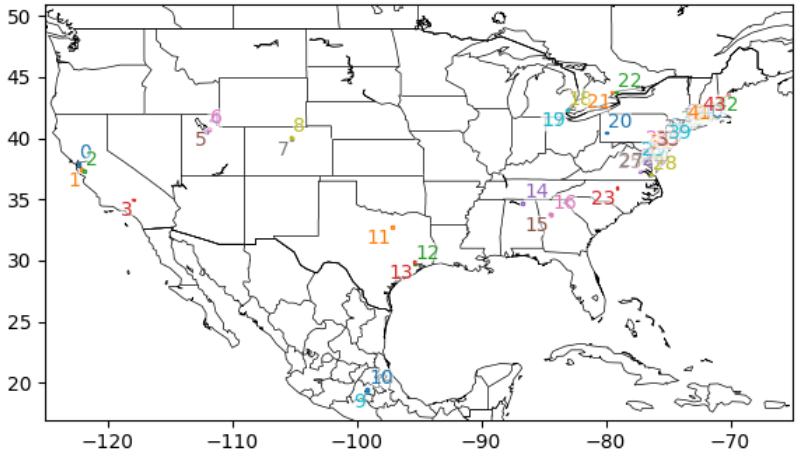
- Facilitated and led by EPA in collaboration with TEMPO Validation and Science Team, NASA, and NOAA.
  - Developed the validation plan
  - Expanded the Pandonia Global Network of Pandoras
  - Validated baseline L2 data products: ozone, nitrogen dioxide, and formaldehyde.
- Providing real-time feedback to TEMPO algorithm developers and science team.
  - Early results identified a priori profile issues.
  - Early results identified unrealistic AMF spatial variation.
  - Development team updated algorithm to V2 and V3
- ***EPA's Automated Analysis System now V3***
  - V3 Nitrogen dioxide correlating well with Pandora and TropOMI.
  - V3 Formaldehyde correlating well with Pandora
  - Comparison to surface monitors useful for air quality managers
- Validation report anticipated soon…

TEMPO Validation Methodologies

➢ Correlative measurements : TropOMI and Pandora

- Pandora stations: best ground-based validation dataset available for total vertical columns.
- TropOMI: state-of-the-art satellite retrievals at similar spatial resolution.

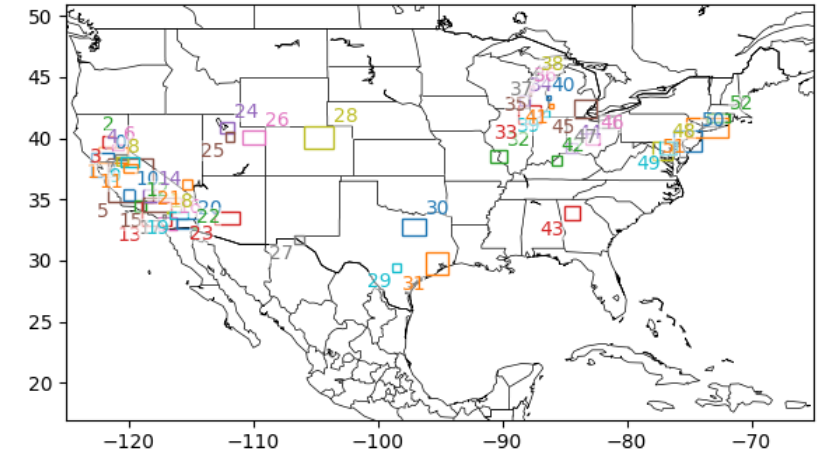
➢ Analysis Regions: Pandonia Global Network and Ozone Nonattainment Areas.



0: RichmondCA
1: MountainViewCA
2: SanJoseCA
3: EdwardsCA
4: SouthJordanUT
5: SLC-Hawthorne
6: SLC-UT
7: BoulderCO
8: BoulderCO-NCAR
9: MexicoCity-UNAM
10: MexicoCity-Vallejo
11: ArlingtonTX
12: HoustonTX
13: AldineTX
14: HuntsvilleAL
15: AtlantaGA
16: Atl-S.DeKalb
17: DearbornMI
18: SWDetroitMI
19: Windsor-West
20: PittsburghPA
21: Downsview
22: Toronto-Scarborough
23: ChapelHillNC
24: CharlesCityVA
25: WashingtonDC
26: BeltsvilleMD
27: GreenbeltMD
28: HamptonVA-HU
29: PhiladelphiaPA
30: BristolPA
31: NewBrunswickNJ
32: BayonneNJ
33: ManhattanNY-CCNY
34: BronxNY
35: QueensNY
36: WestportCT
37: CornwallCT
38: OldFieldNY
39: NewHavenCT
40: MadisonCT
41: LondonderryNH
42: EastProvidenceRI
43: CapeElizabethME

- 44 **Pandora** stations
- Most stations in the east

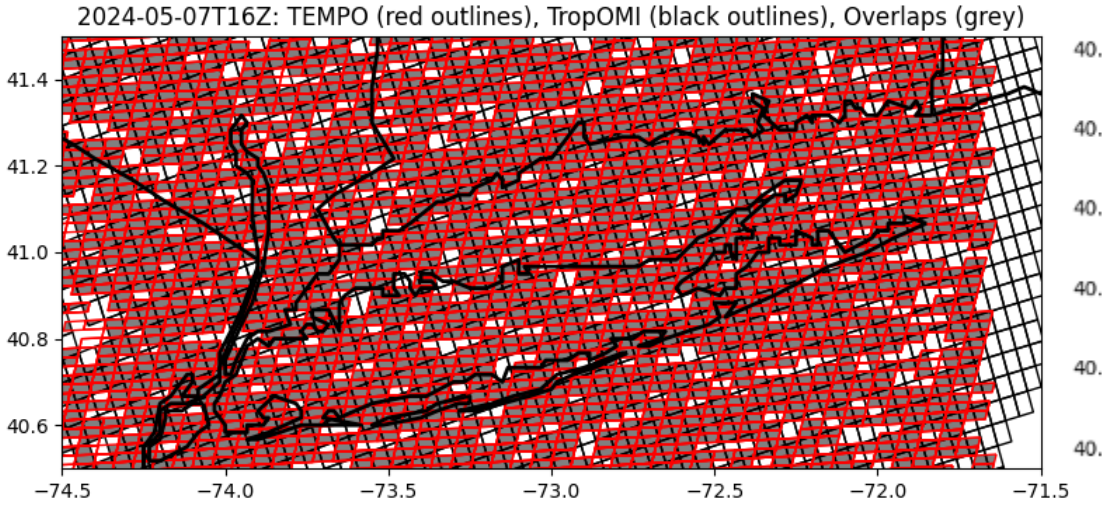
- 52 **Nonattainment Areas**
- Better spatial coverage
- Of special interest for emissions control

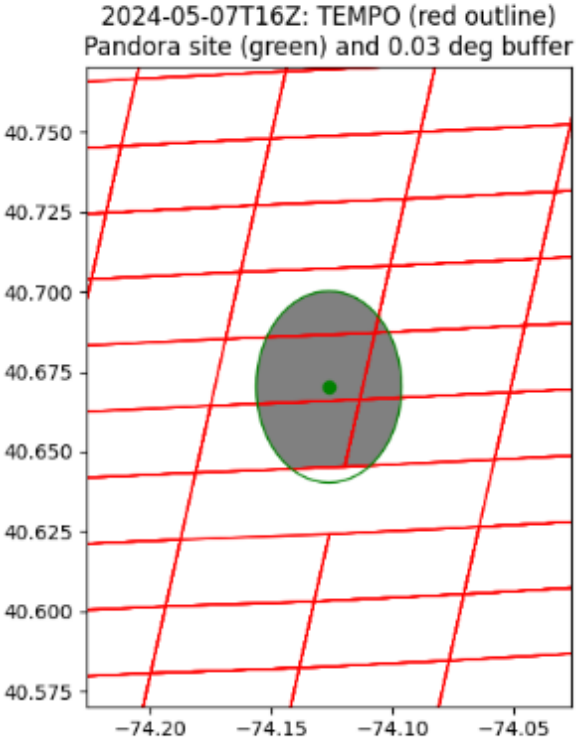


0: S.Francisco
1: Sacramento
2: Tuscan_Buttes
3: Chico
4: Sutter_Buttes
5: S.Joaquin
6: Nevada_Co
7: Amador_Co
8: Calaveras_Co
9: Tuolumne_Co
10: S.Luis_Obispo
11: Mariposa_Co
12: Ventura_Co
13: LA-S_Coast
14: East_Kern
15: LA-Desert
16: S.Diego
17: Pechanga
18: Morongo
19: Coachella_Val
20: Imperial_Co
21: Las_Vegas
22: Yuma
23: Phoenix
24: Salt_Lake
25: Provo
26: Uinta_Basin
27: El_Paso
28: Denver
29: S.Antonio
30: Dallas
31: Houston
32: St_Louis
33: Chicago
34: Milwaukee
35: Sheboygan
36: Manitowoc_Co
37: Door_Co_Rev
38: Door_Co
39: Benton_Harbor
40: Muskegon
41: Allegan_Co
42: Louisville
43: Atlanta
44: Cincinnati
45: Detroit
46: Columbus
47: Cleveland
48: Washington
49: Baltimore
50: Philadelphia
51: New_York
52: Connecticut

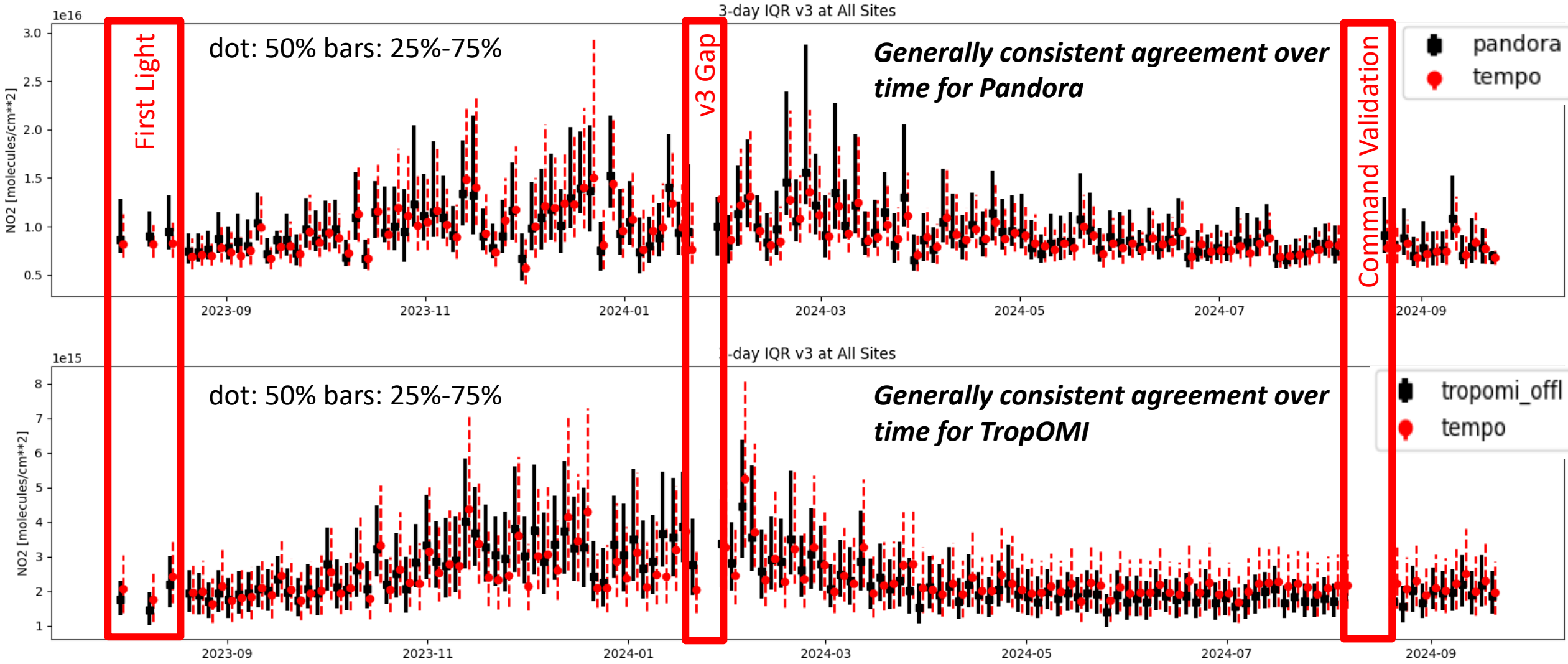
TEMPO Validation Methodologies

- **Get level 2 data for TEMPO, TropOMI, and Pandora**
  - Python bindings for EPA's Remote Sensing Information Gateway (pyrsig)
  - Trainings available – see QR code
- **Find time intersections**
  - TropOMI: same hour (e.g., 19:00:00Z to 19:59:59Z)
  - Pandora: overpass within 15min of observation
- **Find spatial intersections**
  - TropOMI: pixels overlap
  - Pandora: overlap a buffer
- **Pool intersections for statistical analyses**





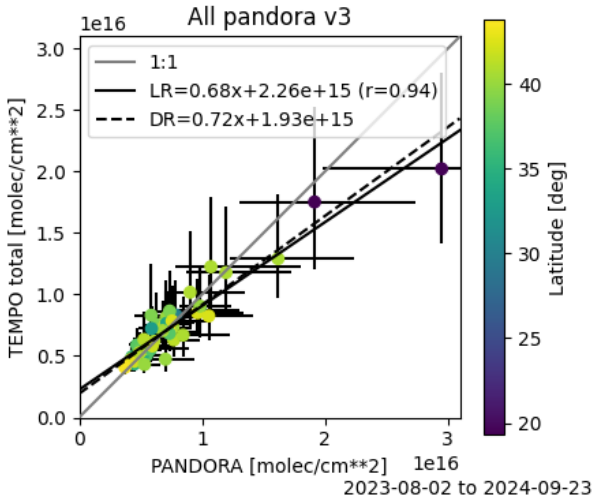
NO2 Data Record Overview
August 2023 to Sept 2024

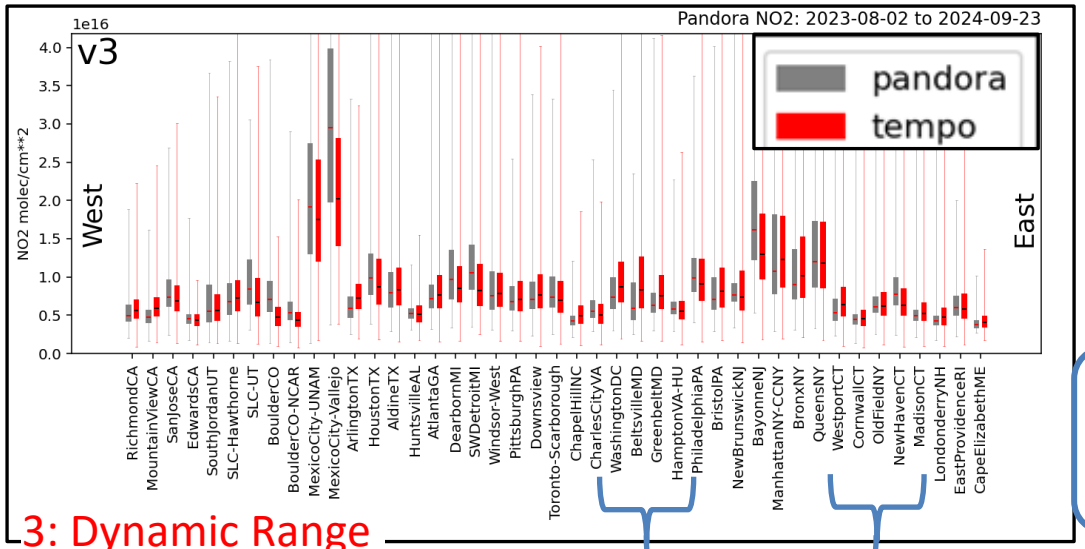


TEMPO NO2 Agrees well with Pandora

TEMPO L2 vs Pandora Total NO_2

1: Spatial Variability

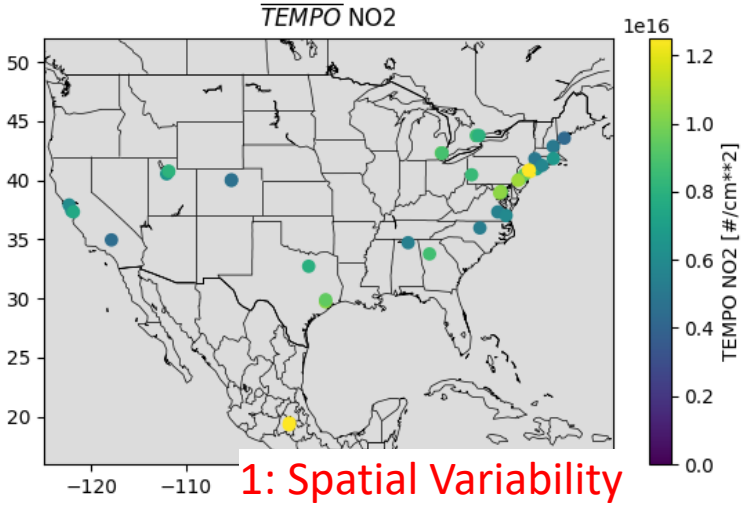




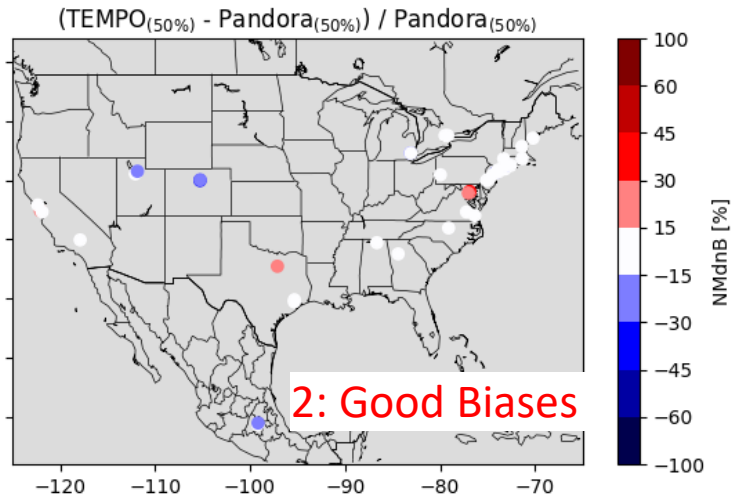
3: Dynamic Range

Compared to Pandora direct sun measurements, TEMPO:

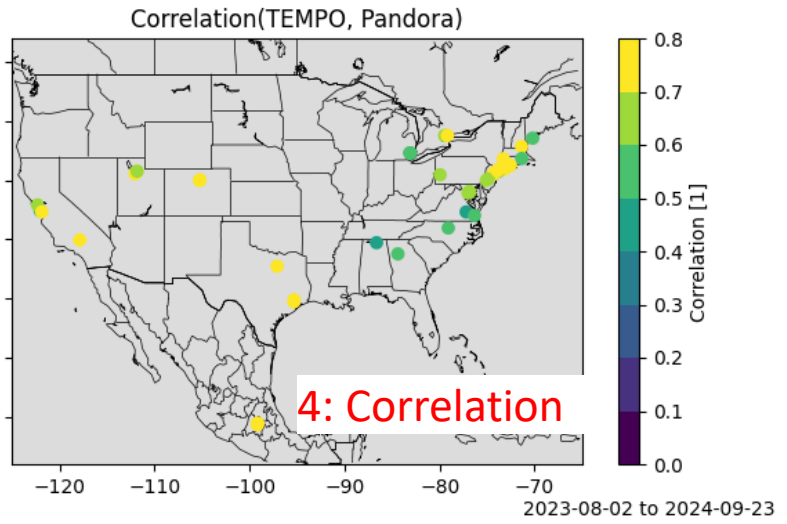
1. Reproduces spatial variability
2. Low fractional biases by locations.
3. Reproduces dynamic range by site
4. Correlates well at most sites.
5. Even reproduces relatively small intra-regional urban/rural gradients quite well.



1: Spatial Variability



2: Good Biases

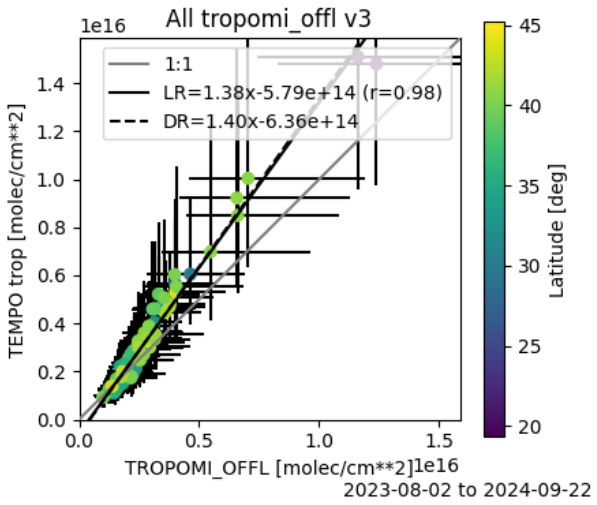


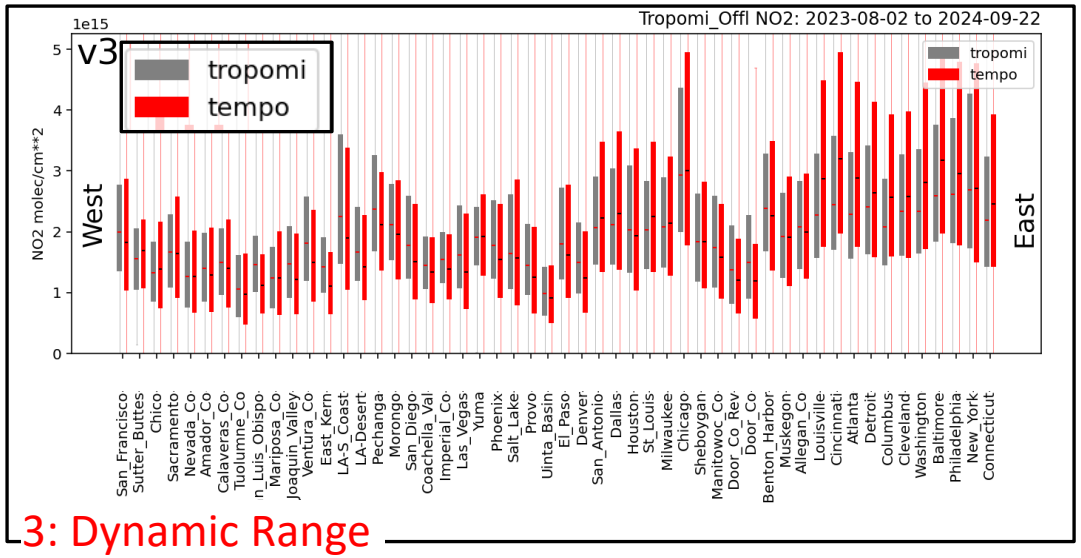
4: Correlation

TEMPO Agrees well with TropOMI

TEMPO L2 vs TropOMI Tropospheric NO_2

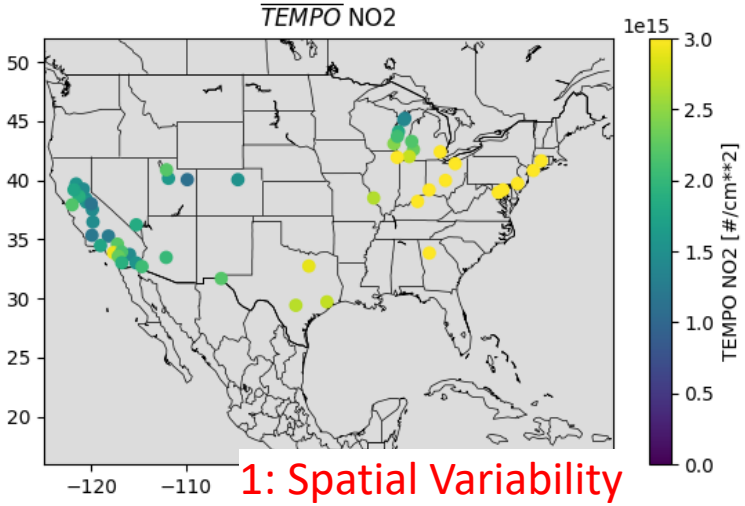
1: Spatial Variability



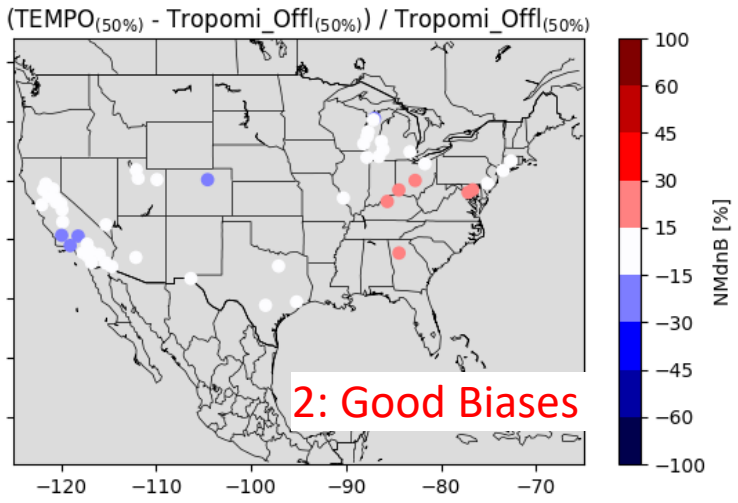


3: Dynamic Range

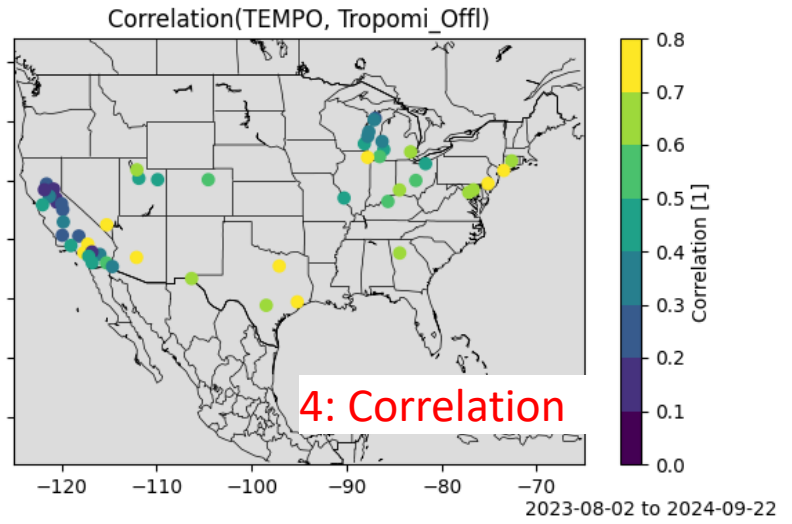
- TropOMI correlation is useful because we don't have Pandora everywhere.
- Here we explore comparisons at Ozone Nonattainment Areas
- Similar story to Pandora/TEMPO, captures spatial variability, dynamic range with a mix of site-specific correlations.
- Higher slope than Pandora, but this is tropospheric column.



1: Spatial Variability



2: Good Biases



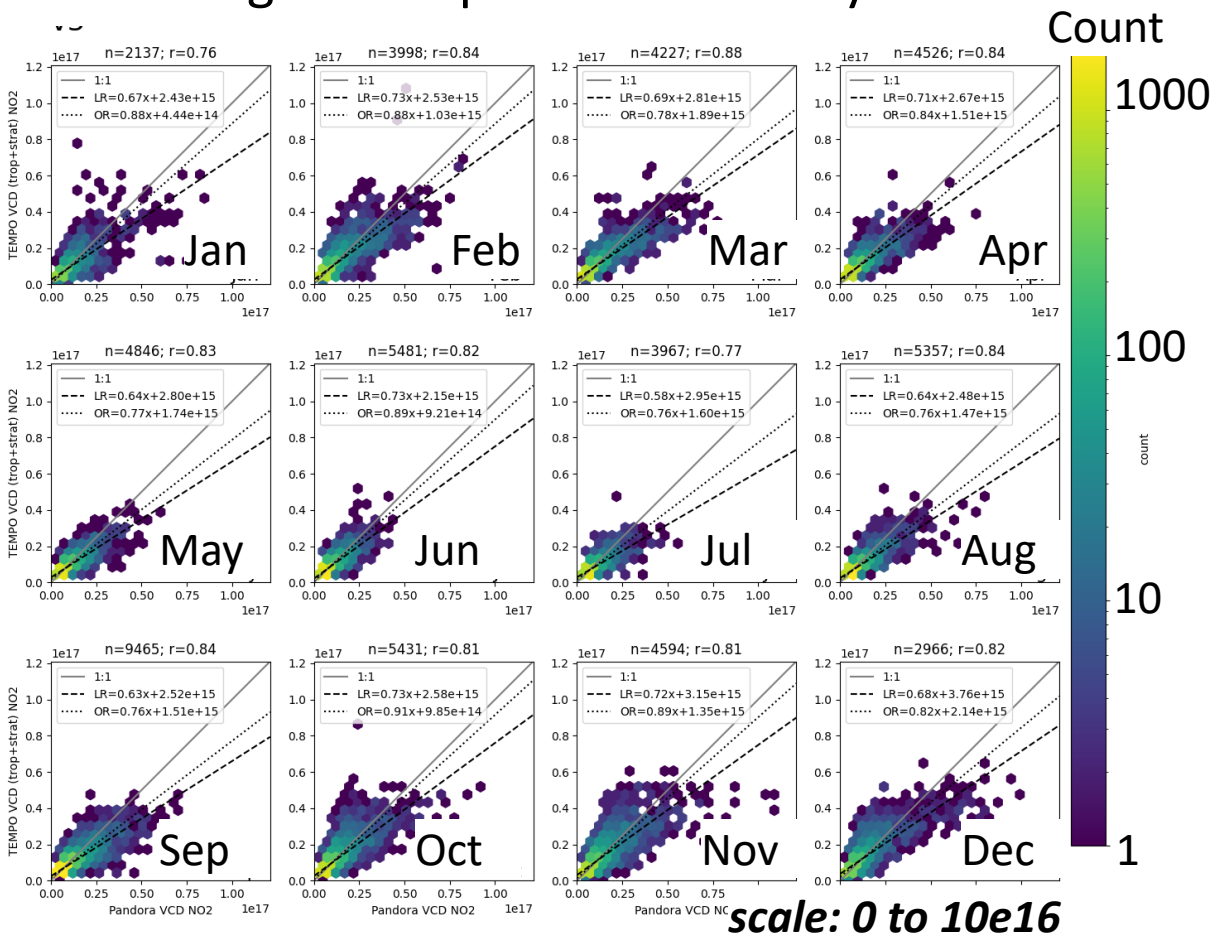
4: Correlation

Seasonal and Diurnal Performance is Consistent

TEMPO L2 vs Pandora Total NO2

Consistent monthly performance

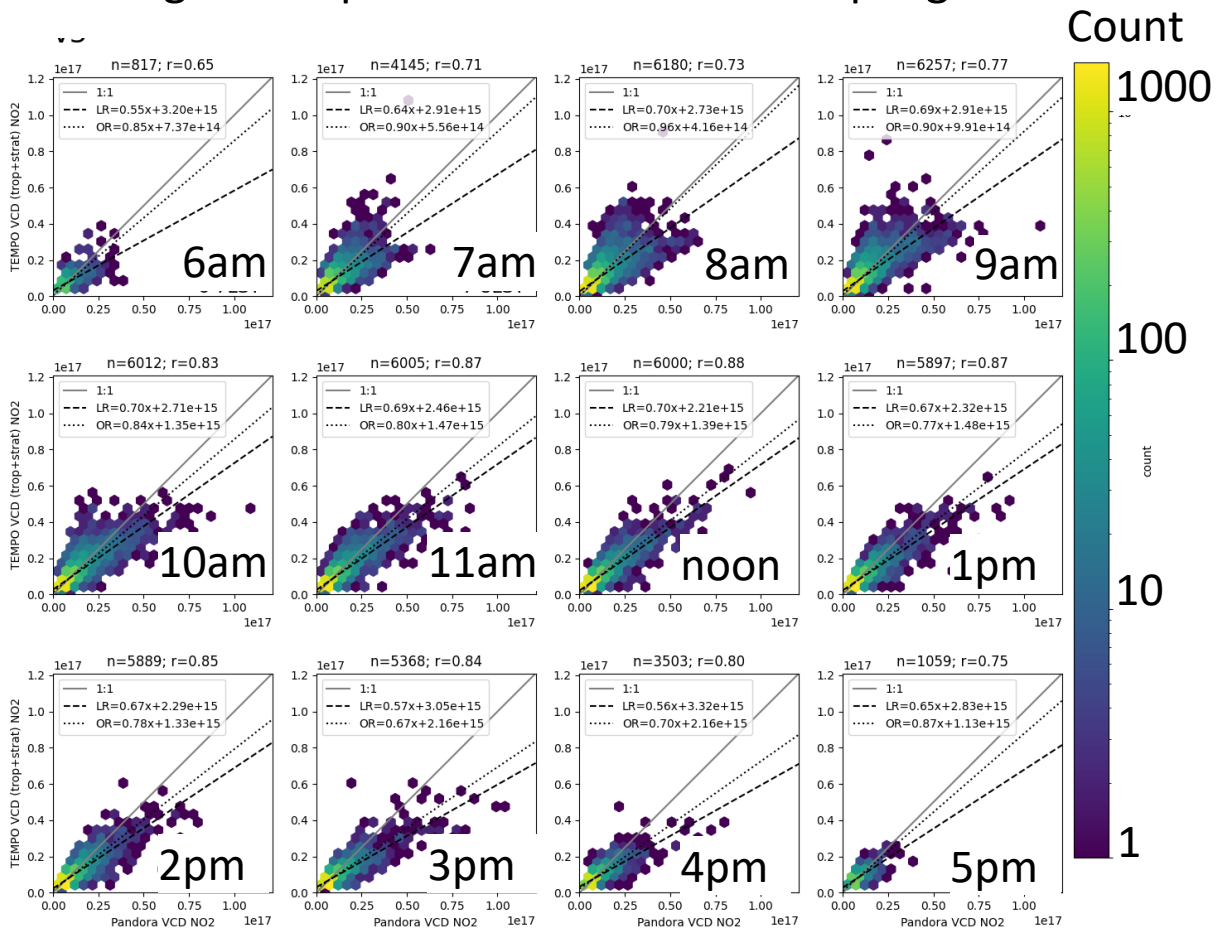
- Dynamic range varies by month as expected
- Orthogonal slopes consistent by month



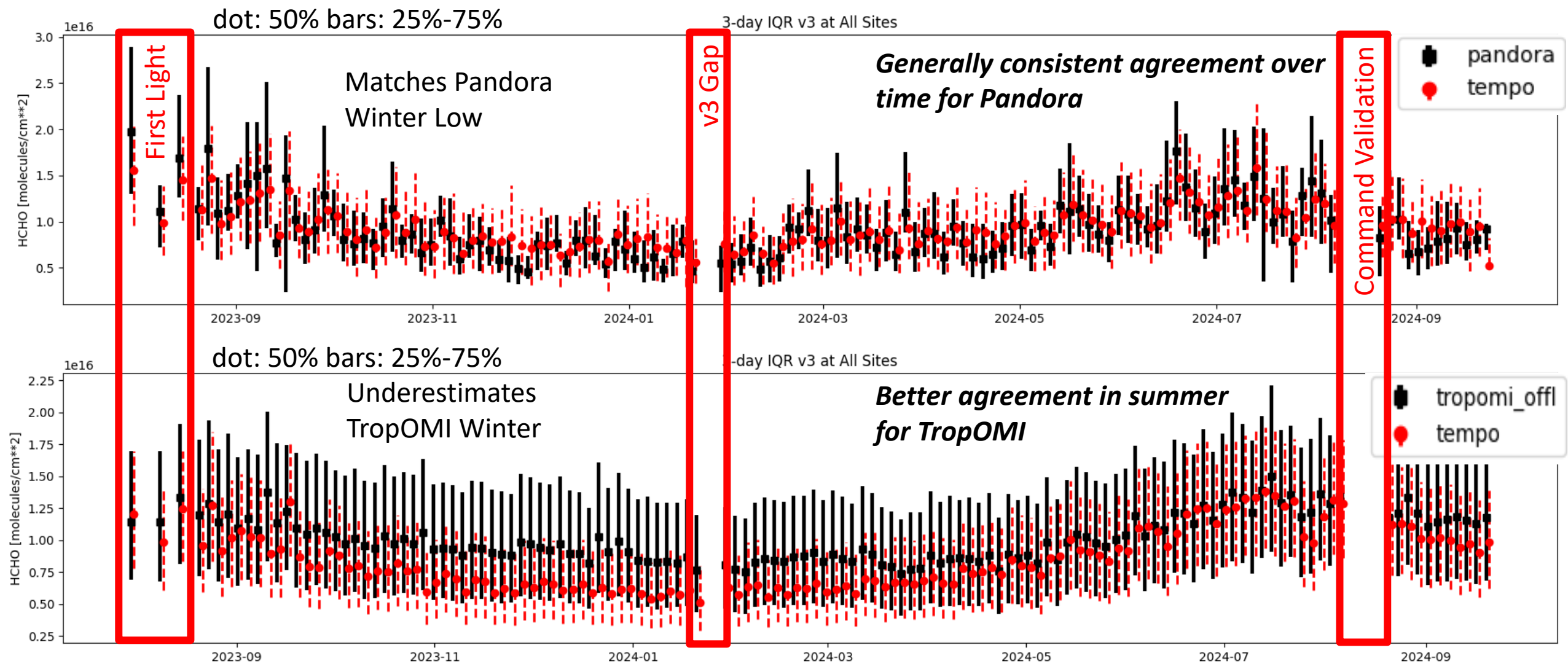
scale: 0 to 10e16

Consistent diurnal performance

- Dynamic range varies by time of day as expected
- Orthogonal important due airmass sampling.



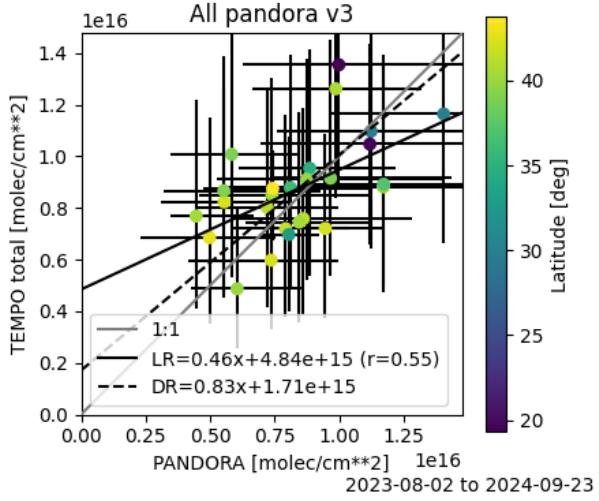
HCHO Data Record Overview
August 2023 to Sept 2024

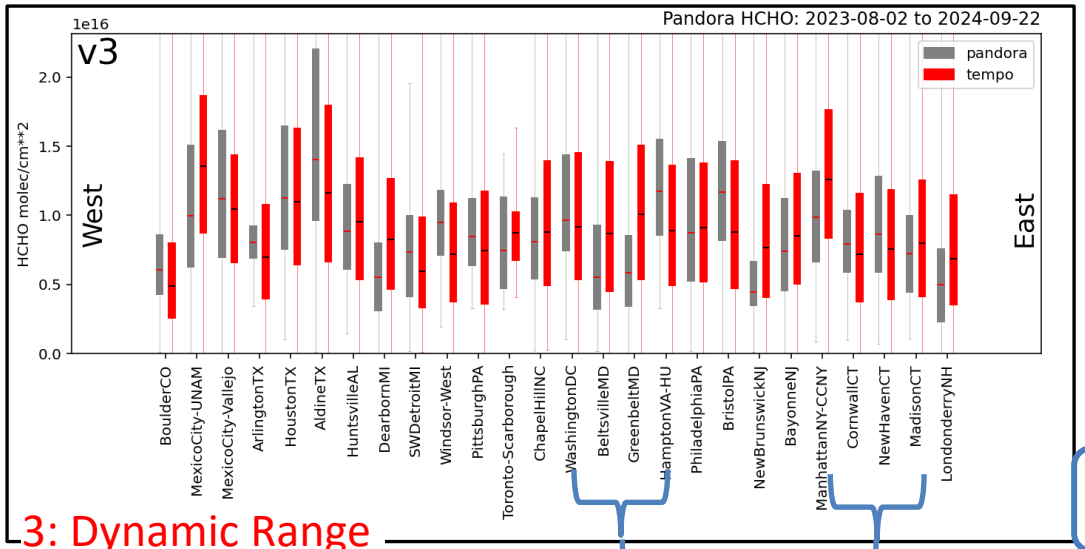


TEMPO HCHO Agrees well with Pandora

TEMPO L2 vs Pandora Total HCHO

1: Spatial Variability





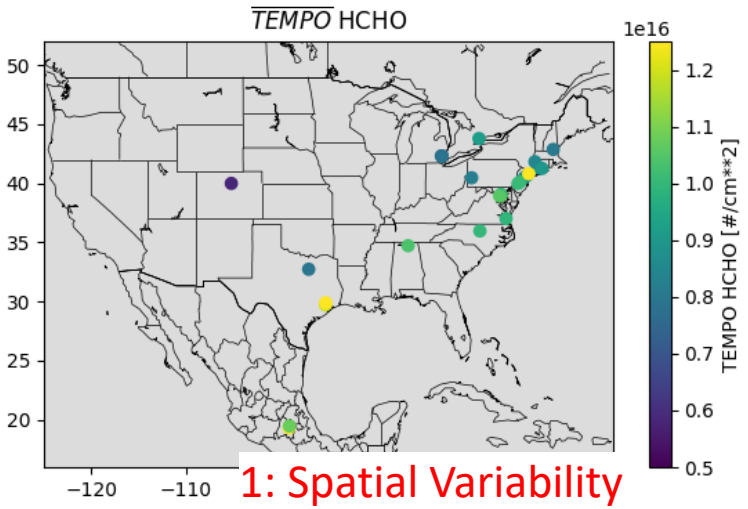
3: Dynamic Range

Using direct sun with pixel averaging

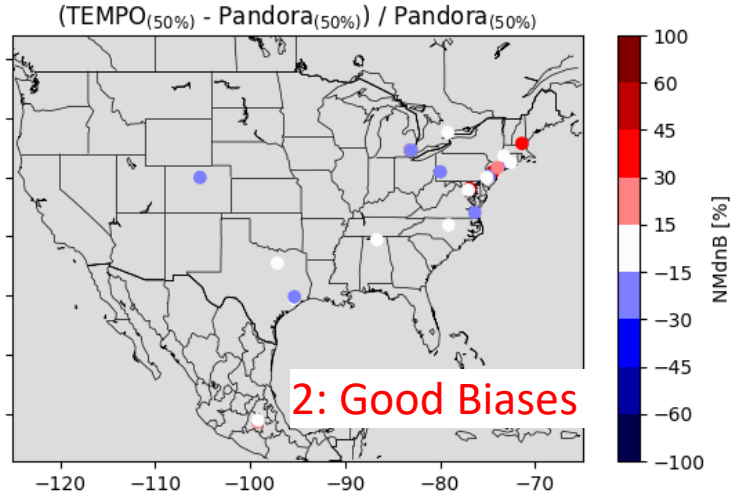
- Site selection: direct sun vs sky scan
- *See Prajjwal Rawat for more details*

Compared to Pandora, TEMPO:

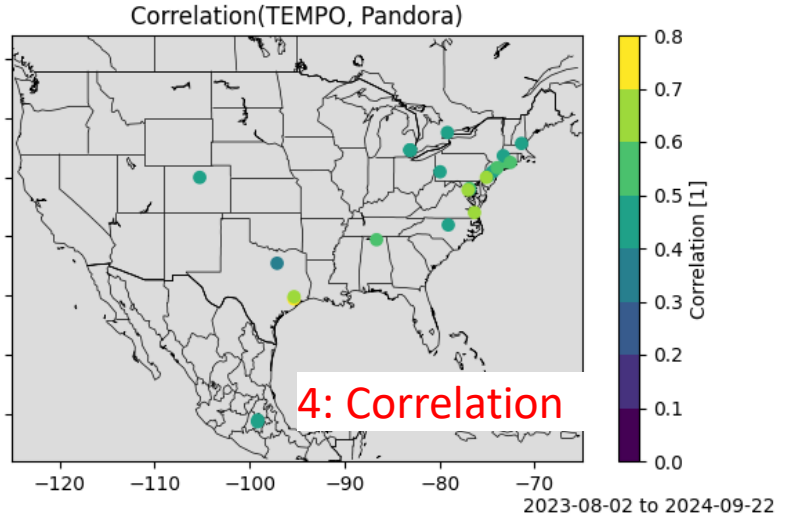
1. Correlates at the site-level
2. Has reasonable bias with some individual sites needing investigation.
3. Captures regional-specific dynamic range.
4. Site-specific time correlation.
5. Intra-regional site-level gradients are challenging, perhaps due to pixel averaging



1: Spatial Variability



2: Good Biases

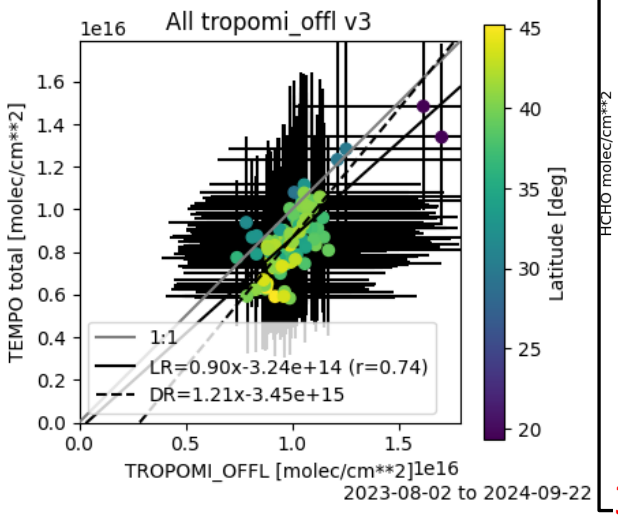


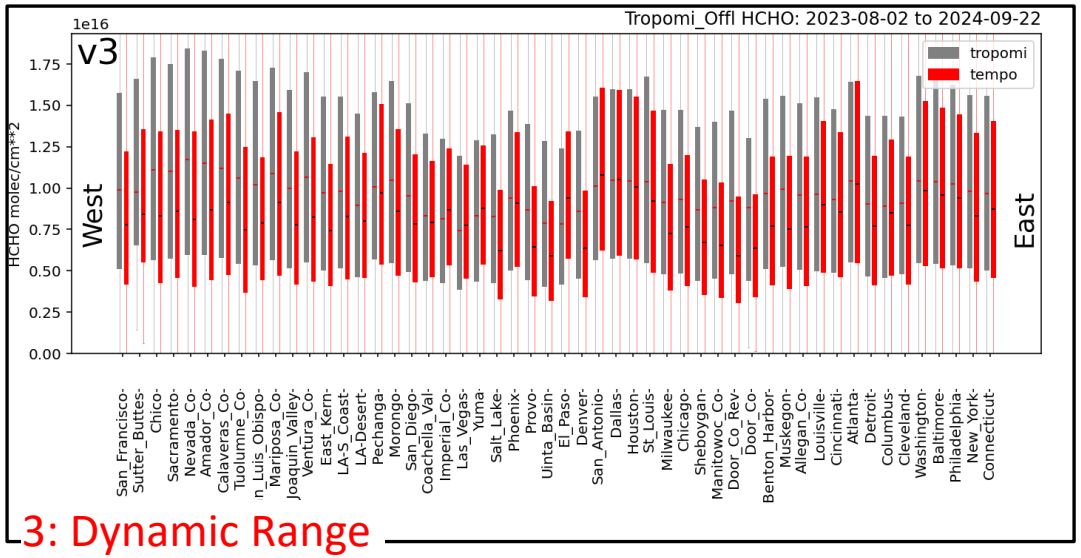
4: Correlation

Example Routine Evaluation Analysis

TEMPO L2 vs TropOMI Tropospheric HCHO

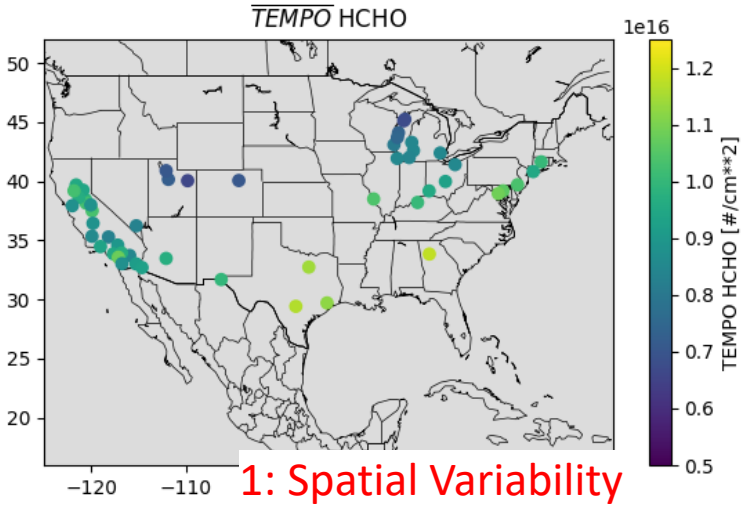
1: Spatial Variability



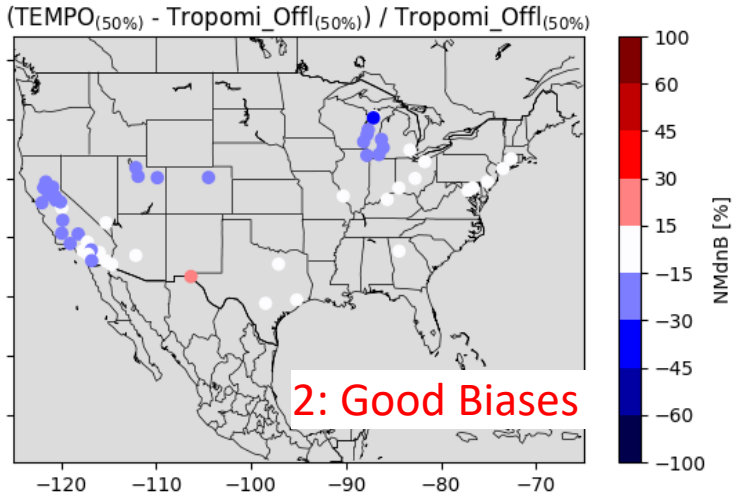


3: Dynamic Range

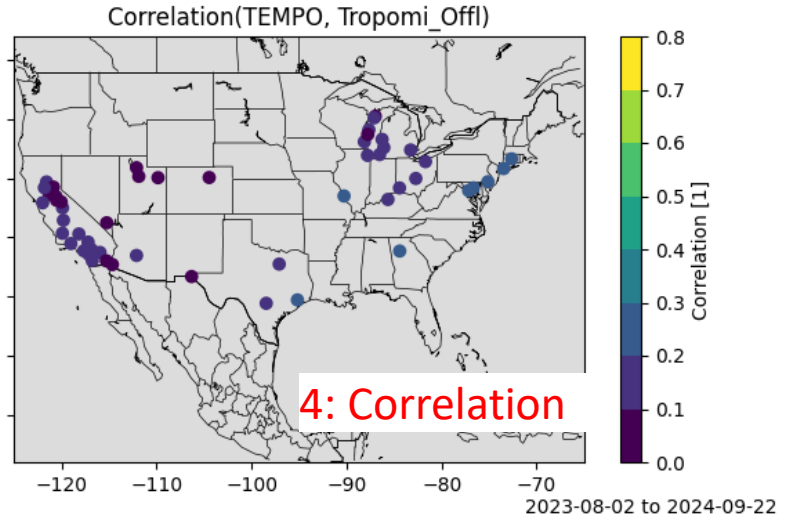
- TropOMI correlation is useful because we don't have Pandora everywhere.
- Here we explore comparisons at Ozone Nonattainment Areas
- Unlike NO2, the diurnal cycle of HCHO is not strong many places which implicitly makes temporal correlation more challenging.



1: Spatial Variability



2: Good Biases



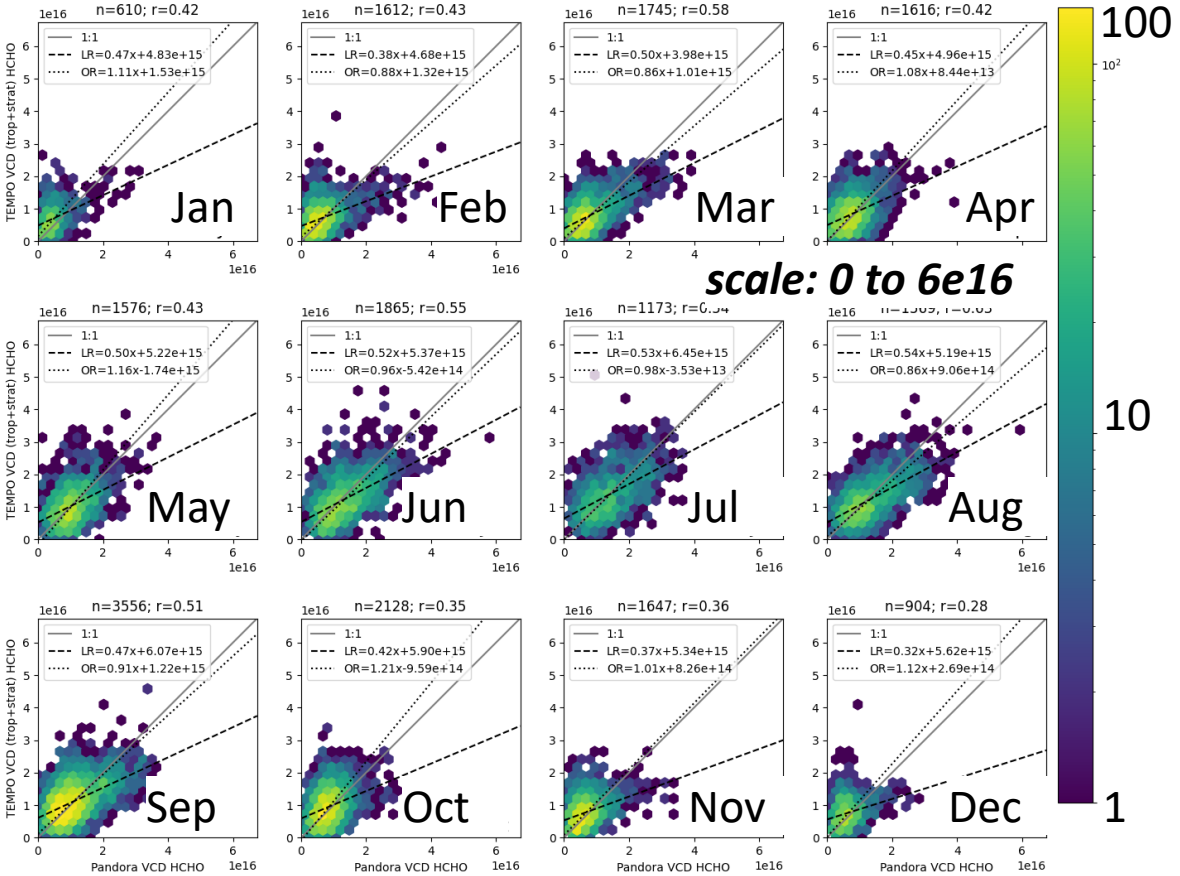
4: Correlation

Seasonal and Diurnal Performance is Consistent

TEMPO L2 vs Pandora Total HCHO

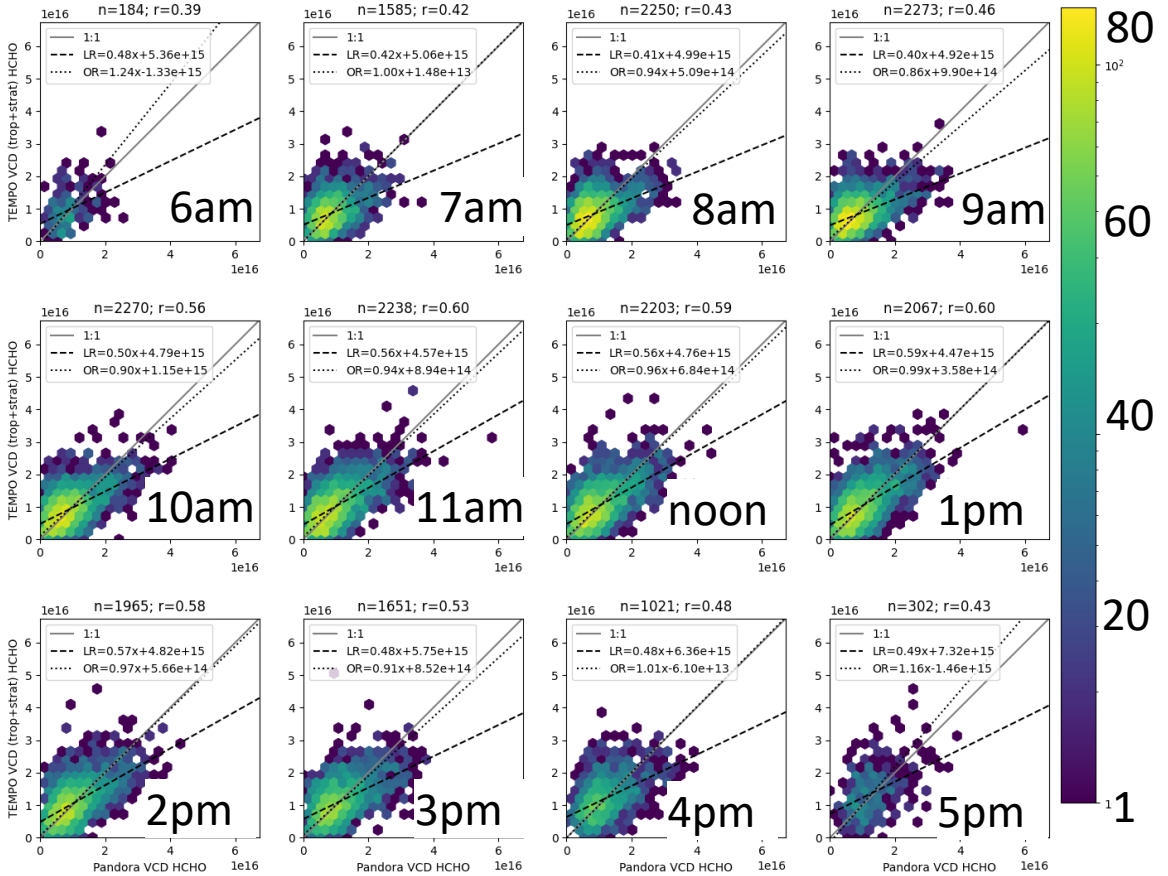
Consistent monthly performance

- Dynamic range varies by month as expected
- Orthogonal slopes consistent



Consistent diurnal performance

- Dynamic varies less by time of day
- Orthogonal important due airmass sampling.

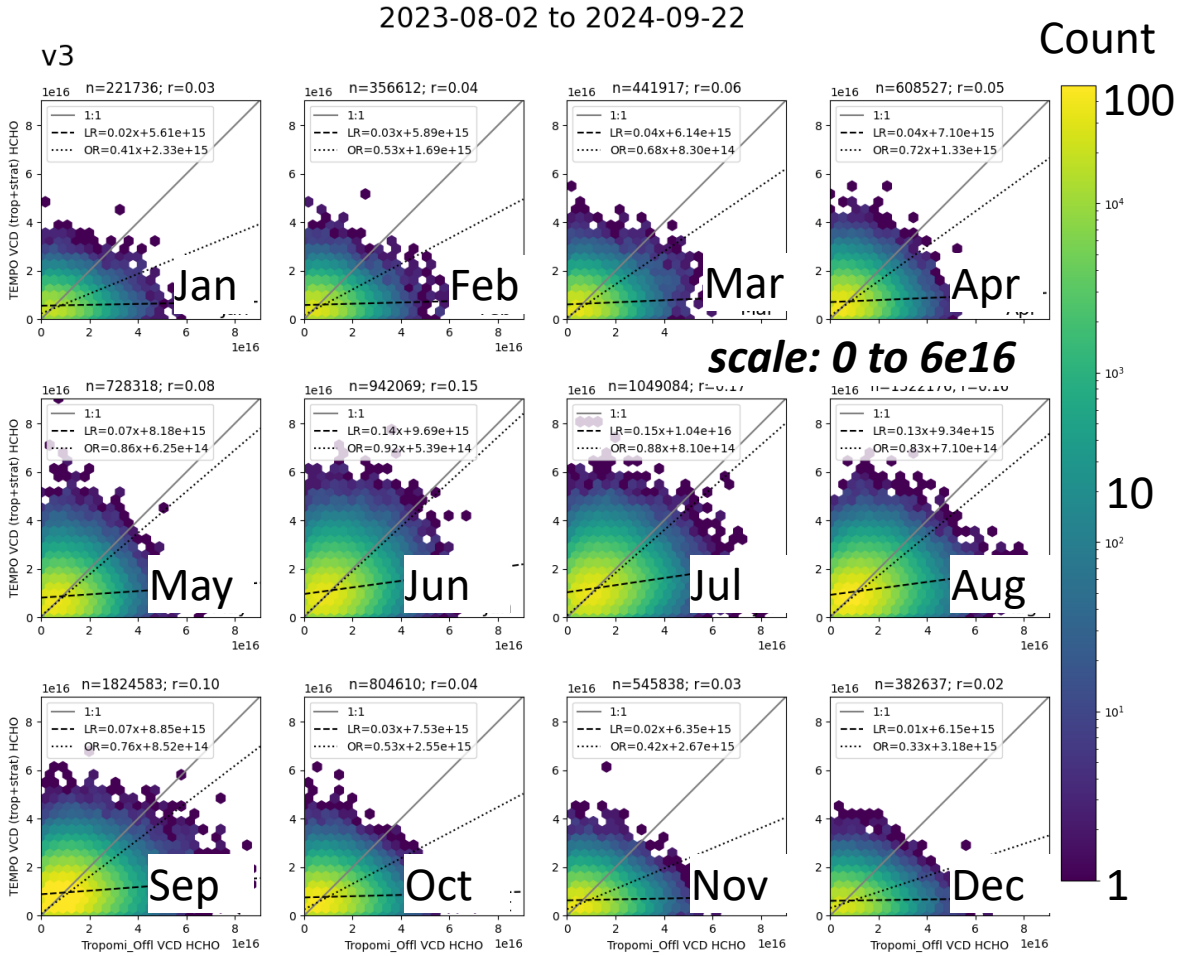


Seasonal and Diurnal Performance is Consistent

TEMPO L2 vs TropOMI Total HCHO

Better Agreement in Summer

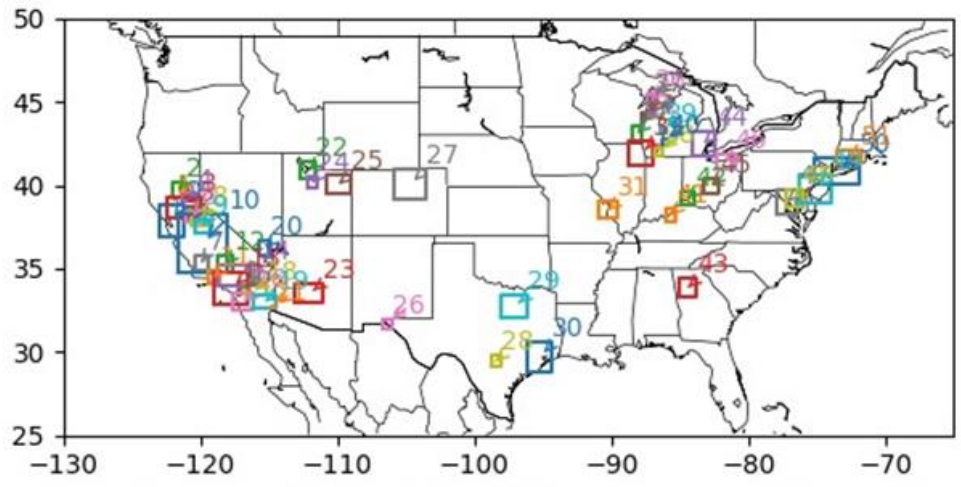
- Dynamic range varies by month as expected
- Larger seasonal changes in TEMPO than TropOMI.
- Orthogonal slopes lowest in winter
  - Steadily increasing from January to May
  - Decreasing after August
- By comparison, Pandora slopes were quite consistent.
- Suggest looking into potential TropOMI high-bias in Winter/Spring

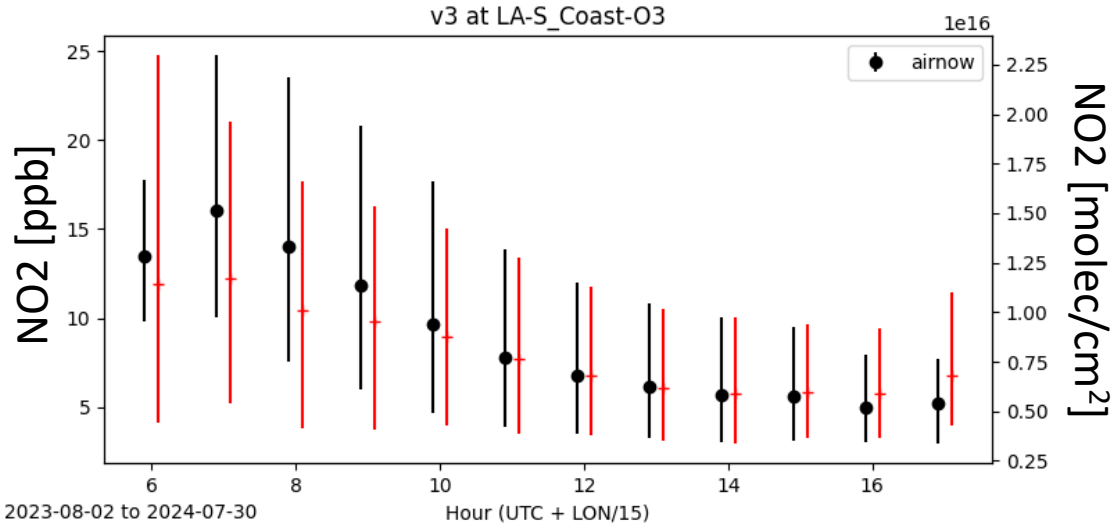


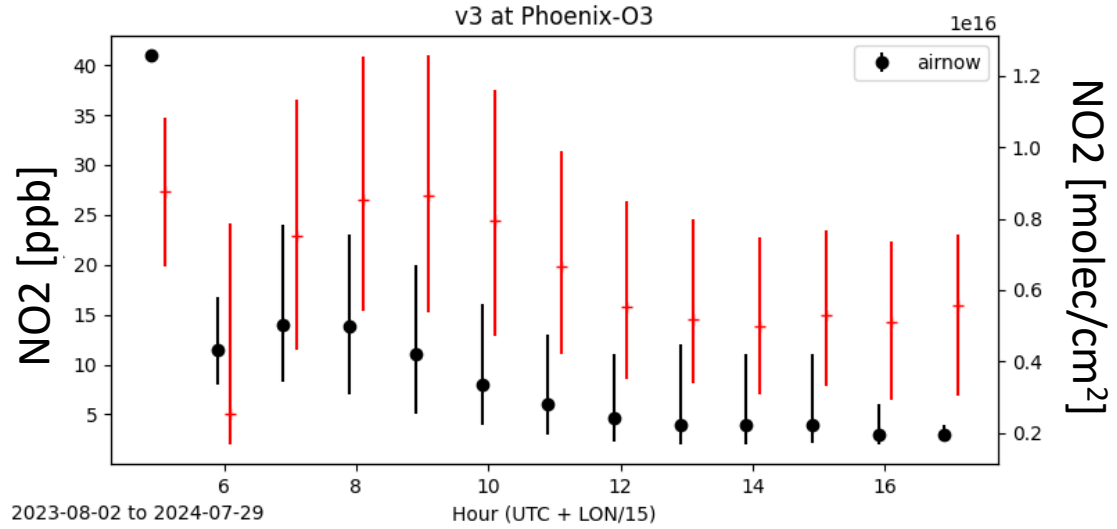
Connecting TEMPO to Air Quality Management

TEMPO L2 vs AirNow Surface NO_2

- Looking towards future applications.
  - We know that columns and surface concentrations shouldn't always correlate well.
  - Where do they correlate well enough and why?
- How can we transform columns to better correlate with surface?
- How can this be useful for nonattainment or near-realtime mapping? What about annual mean surfaces for exposure?







Summary of Validation

Henderson.Barron@epa.gov

- Thanks to:
  - Kelly, SAO Team, and NASA TEMPO Project Team for delivering on the promises of TEMPO!
  - NASA LaRC ASDC for assistance to connect TEMPO to RSIG APIs and increase accessibility!
  - Pandonia Global Network and State and Local agencies for working with EPA to expand Pandora measurements!
  - Research groups and researchers who have contributed their time and analysis in support of TEMPO validation!

- Given the short timeline for TEMPO baseline mission, early data access to support a community led validation effort was critical.

- Nitrogen dioxide and formaldehyde results contribute to both the beta and provisional maturity levels outlined in the validation plan.
  - Assessing bias, precision and uncertainty (NO2-02, NO2-04, HCHO-02 and HCHO-04)
  - Inter-site gradients contributes to urban/rural gradient assessments (NO2-01 and HCHO-01)

- EPAs automated validation software will continue to assess TEMPO L2 products!

Slides at: