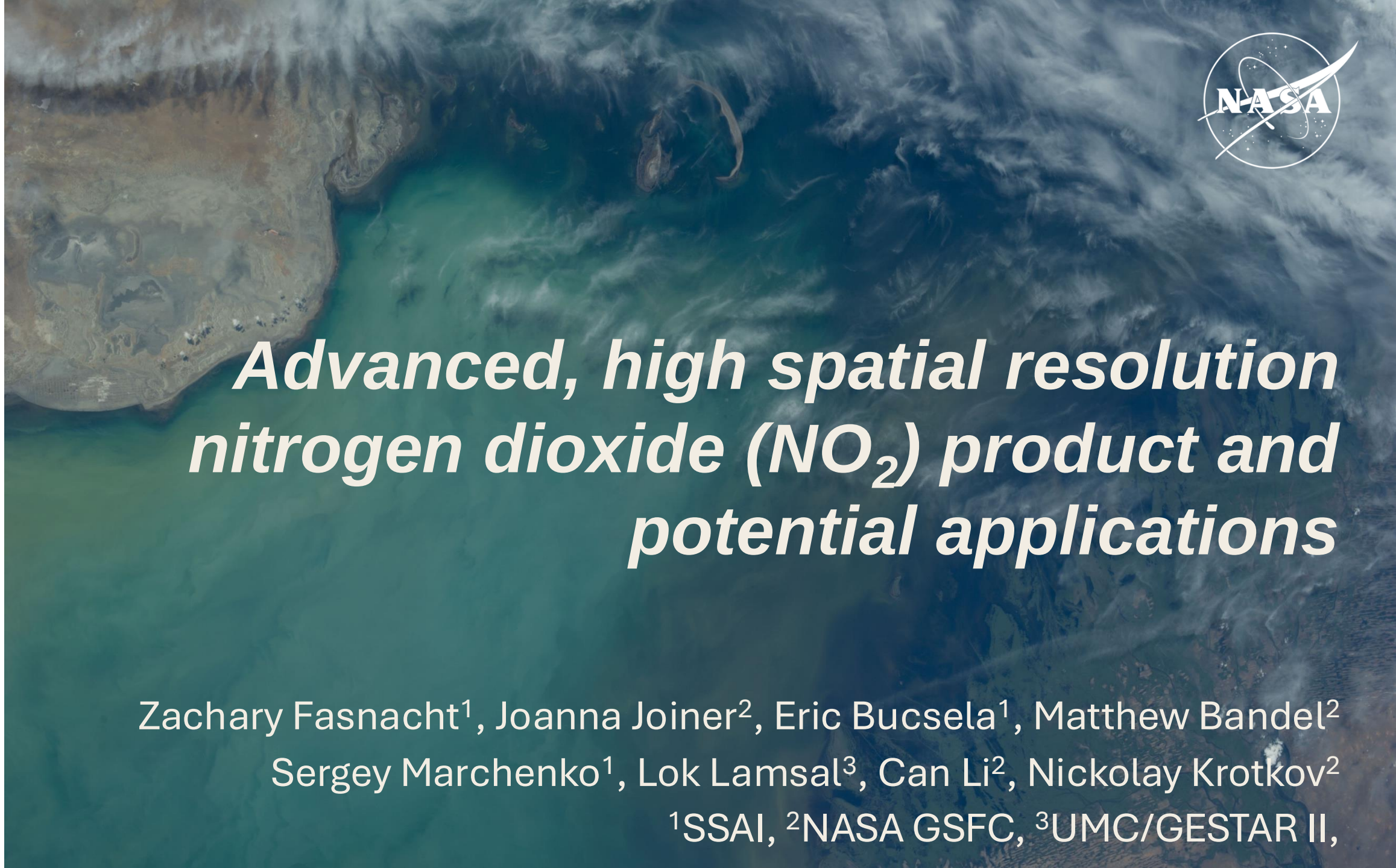


Advanced, high spatial resolution nitrogen dioxide (NO_2) product and potential applications

Zachary Fasnacht[1], Joanna Joiner[2], Eric Bucsela[1], Matthew Bandel[2]
Sergey Marchenko[1], Lok Lamsal[3], Can Li[2], Nickolay Krotkov[2]
[1]SSAI, [2]NASA GSFC, [3]UMC/GESTAR II,

Motivation

- NO_2 sources are both natural (wildfires, soil, lightning) and anthropogenic (burning of fossil fuels, biomass burning)
- NO_2 is a pollutant (adverse health effects) and climate agent (contributes to the formation of aerosols and tropospheric ozone)
- NO_2 impacts ocean color algorithms. Errors under high loading ($1x10^{16}$ mol cm^{-2}) of 10-20% in water leaving radiance (Ahmad et al., 2007).

2021 annual averaged TROPOMI troposphere NO_2 column (courtesy Lok Lamsal)

Can we retrieve NO_2 accurately with PACE OCI and if so, can it provide value-added data for AQ and atmospheric chemistry communities (for downscaling emissions, etc)?

GODDARD EARTH SCIENCES

Heritage Trace Gas (NO_2) Instruments

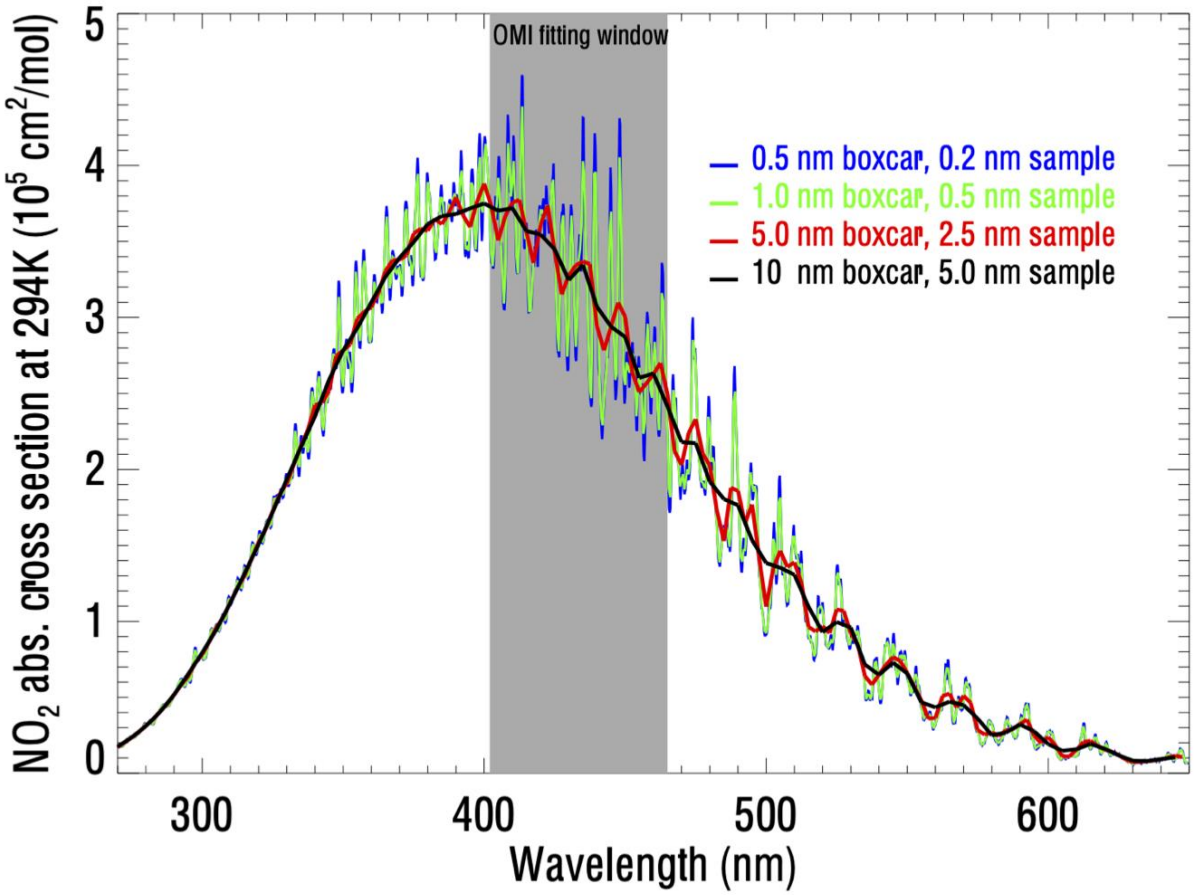
- Traditional trace gas satellite instruments (OMI, TROPOMI, TEMPO) have lower spatial resolution (at least 10x coarser) than PACE OCI, but higher spectral resolution
- Previous ocean color multi-spectral instruments such as MODIS and VIIRS have spectral resolution of 20nm+, too coarse for NO_2 retrievals

	Spatial Res.	Spectral Res.	Spectral Range	Orbit
OMI	13x24km^2	0.42-0.63nm	290-500nm	Polar
TROPOMI	3.5x5.5km^2	0.25-0.55nm	267-499nm 661-786nm 2.3-2.389um	Polar
TEMPO	2x4.7km^2	0.6nm	290-490nm 540-740nm	Geo
PACE OCI	1km^2	5nm	315-895nm	Polar

GODDARD EARTH SCIENCES

NO_2 Absorption Cross Sections

- With traditional trace gas sensors, NO_2 slant columns densities (SCD) are typically retrieved using high frequency structure in the range 400-465 nm
- With spectral resolution of PACE OCI (red), there is still some high frequency structure in range 400-500 nm
- Can we utilize a wider spectral range with PACE OCI to retrieve accurate NO_2 (SCD or vertical column density)?
- Machine learning trained on TROPOMI or TEMPO retrievals may be a fast and effective strategy



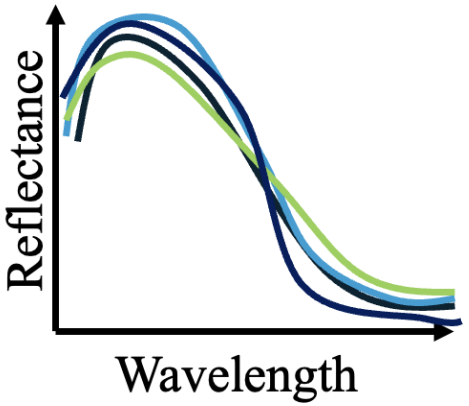
UV (more Rayleigh scattering, less surface sensitivity)

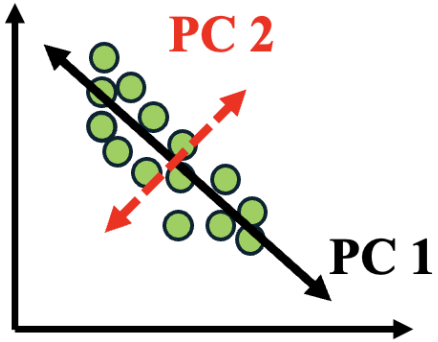
Blue/green (less Rayleigh scattering, more surface sensitivity)

GODDARD EARTH SCIENCES

Basic approach

Measured Reflectances Decomposed into PCs

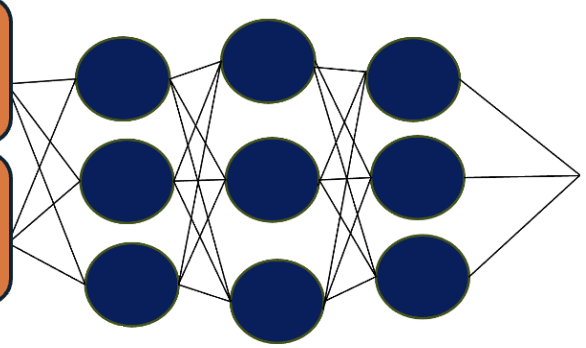




Neural Network Trained to Learn Relationships between PCs and Co-located NO_2

Solar Zenith Angle

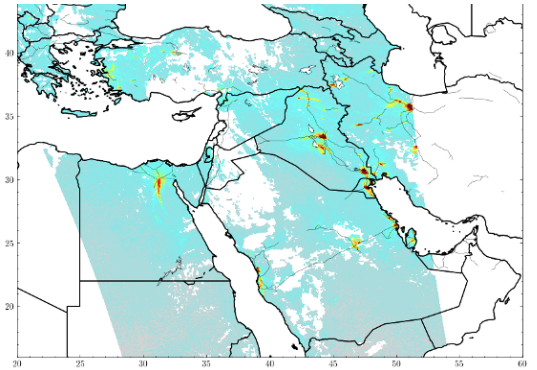
Coefficients of PCs

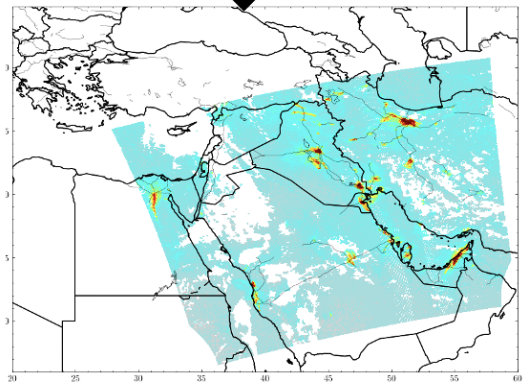


Optionally profile data can be used, but not currently used

TROPOMI NO_2 Co-located to PACE

Use 5km PACE OCI L1b data collocated with TROPOMI data binned to 5 km



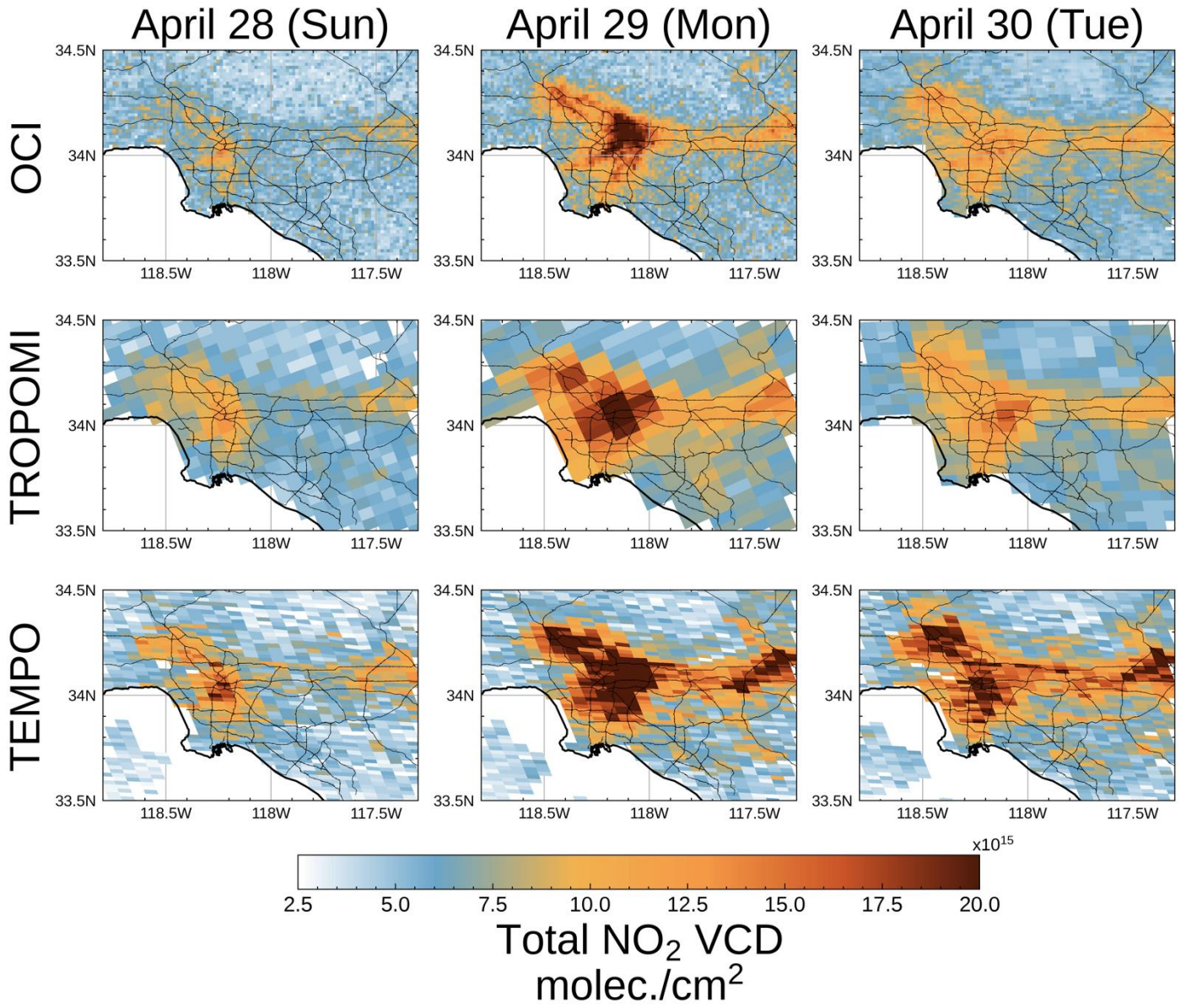


Apply to 1km PACE OCI L1b data

GODDARD EARTH SCIENCES

Weekend vs Weekday NO_2 in LA Metro

- Air quality in LA region is heavily dominated by vehicular traffic leading to a significant weekend/weekday effect as seen in NO_2 retrievals on right
- Unlike TROPOMI and TEMPO, with PACE OCI spatial resolution we can begin to see individual highways, particularly in heavy vehicular traffic such as Monday April 29



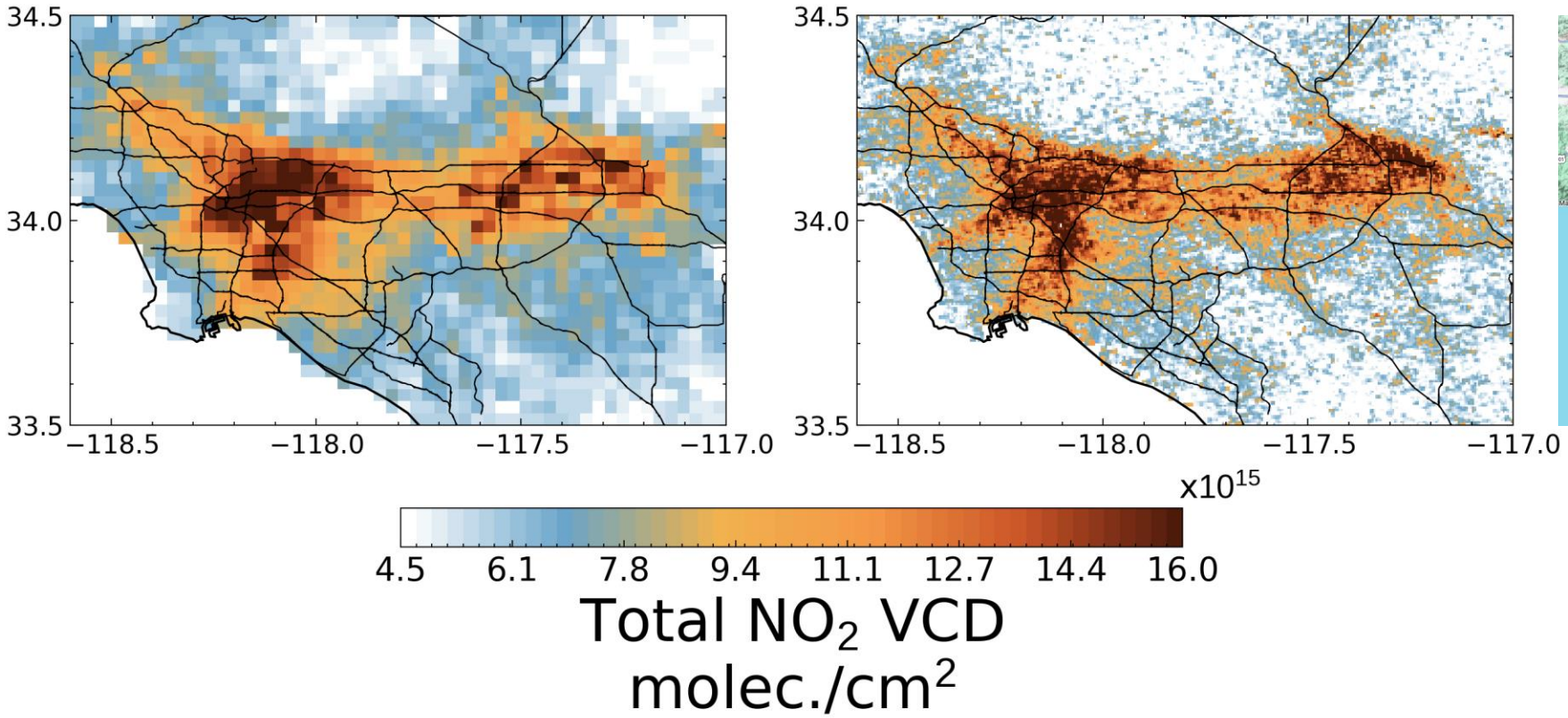
GODDARD EARTH SCIENCES

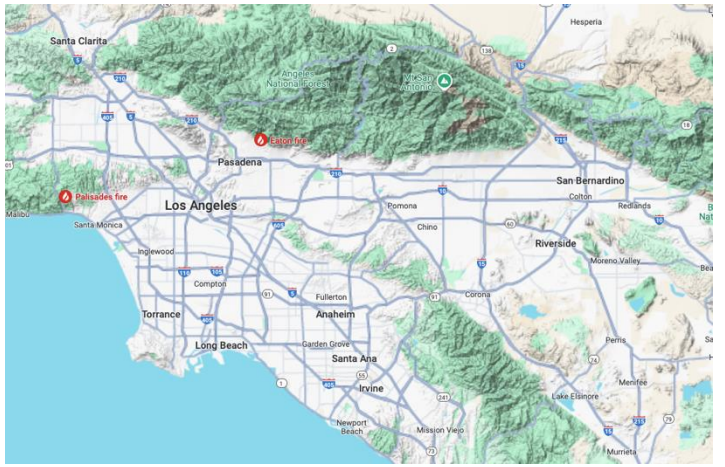
Multi-Day Average for Upscaling

Thu Sep 26-28

TROPOMI ~3km Resolution

PACE OCI ~500m Resolution

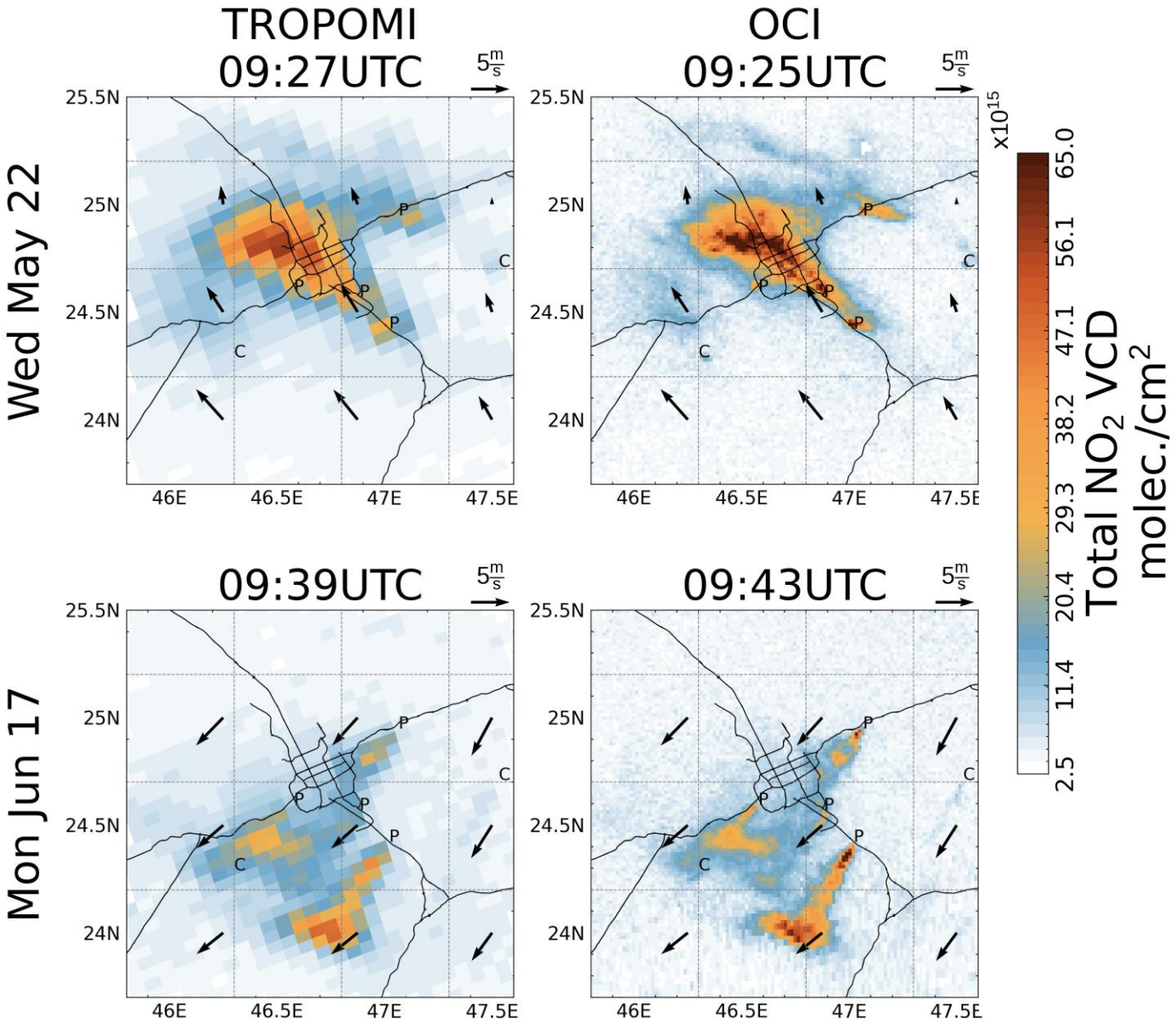




- High resolution measurements from PACE allow for upscaling of NO_2 within a few days to spatial resolution < 500m
- Example above from LA shows many localized features such as mountain ranges, highways, and localized neighborhoods

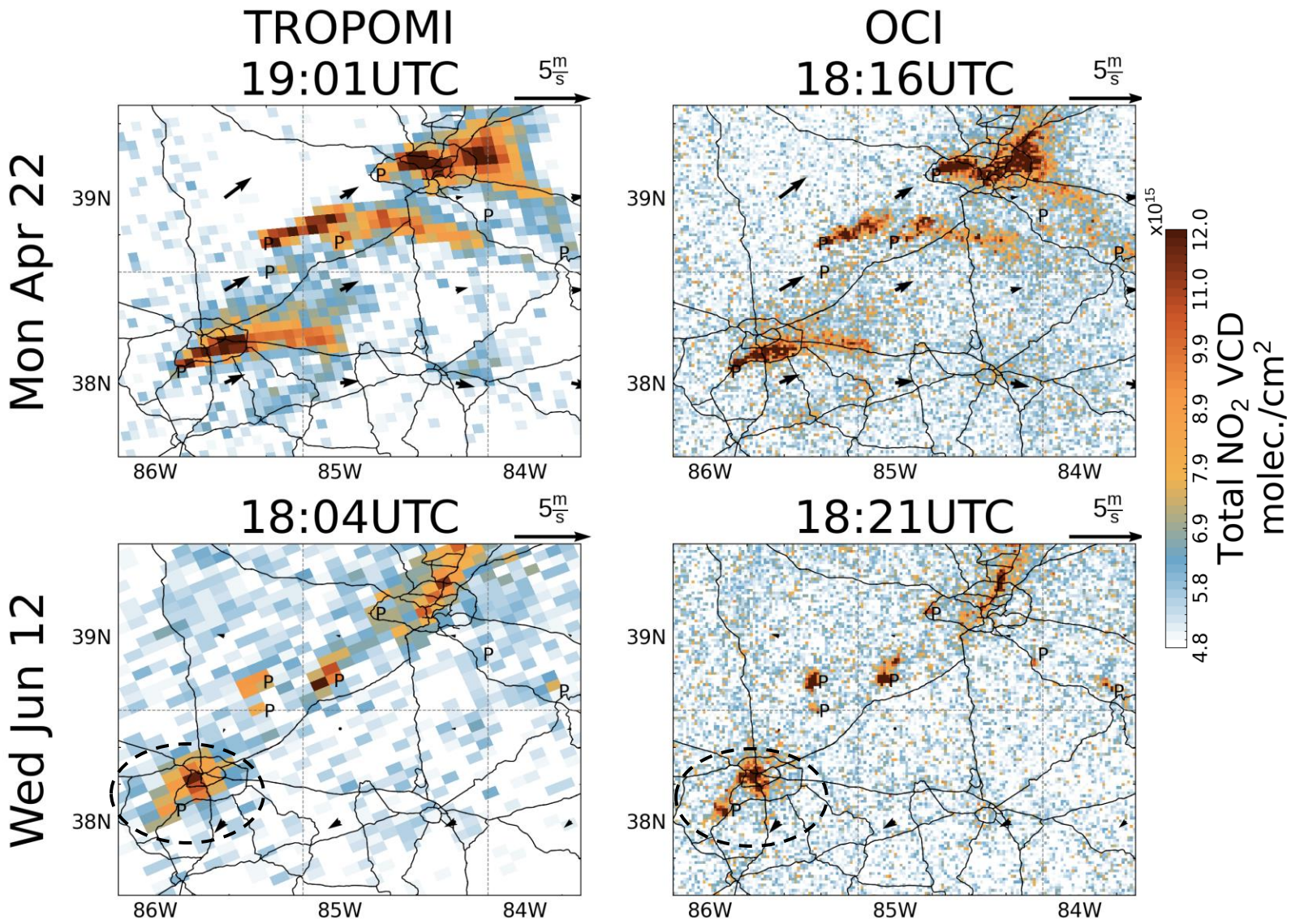
NO_2 in Riyadh, Saudi Arabia

- Air quality in Riyadh is dominated by industrial emissions from power and manufacturing plants such as cement factories (on right Power Plants labeled as “P” and cement factories labeled as “C”)
- The enhanced spatial resolution of PACE OCI provides better defined snapshots of the individual NO_2 plumes
- Large impact of winds on plumes



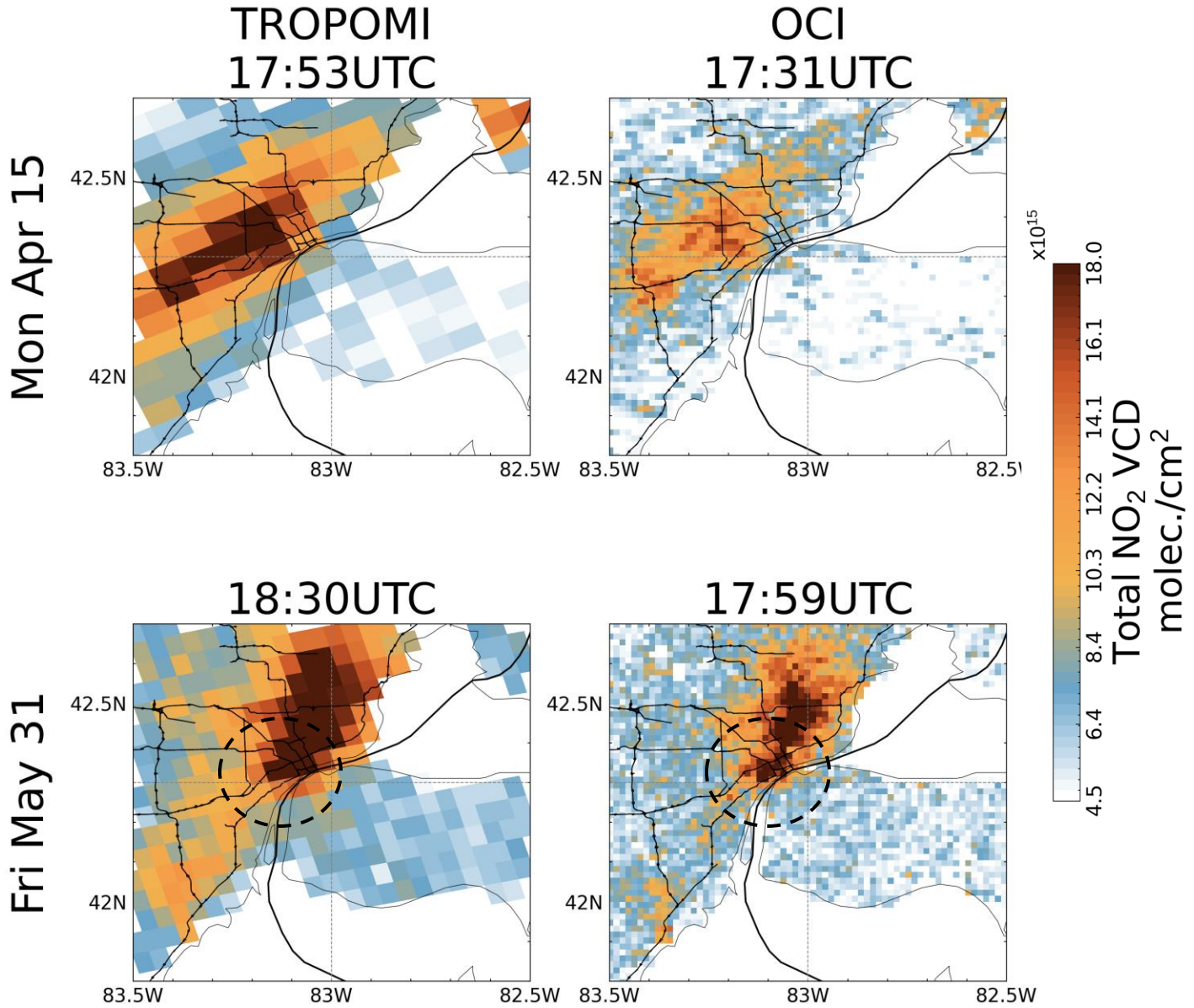
NO_2 in Ohio River Valley

- Several coal burning power plants lie along the Ohio River between Cincinnati, OH and Louisville, KY
- NO_2 plumes from the coal plants are better defined from PACE OCI NO_2 retrievals than TROPOMI
- On June 12, PACE shows two distinct NO_2 plumes from Mill Creek power plant and Louisville vehicular emissions, whereas TROPOMI shows one region of elevated NO_2 (dashed circle)



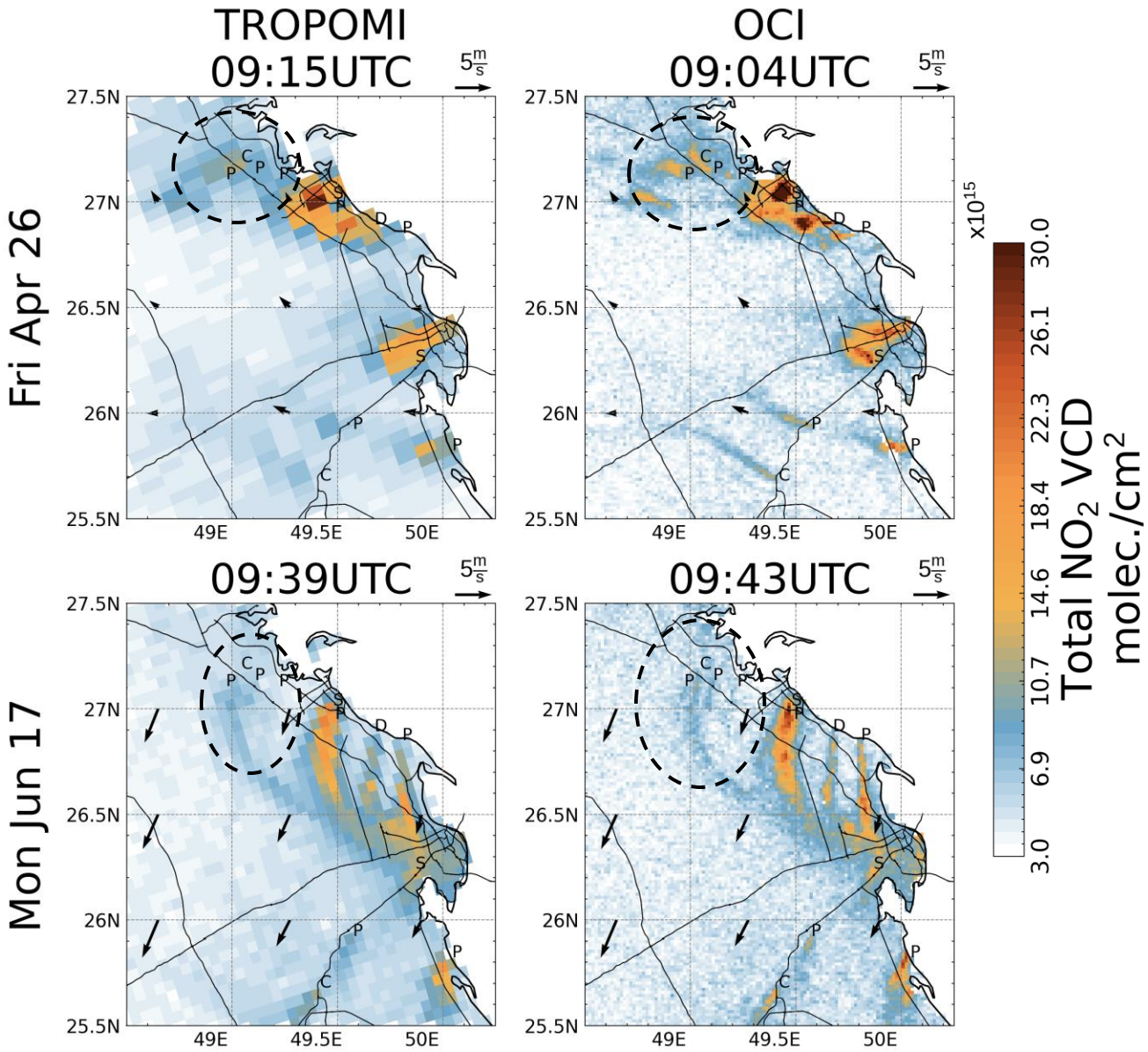
NO_2 in Detroit

- NO_2 emissions from Detroit are primarily from vehicular emissions in the city and emissions from plants such as Ford motor company to the south in Dearborn
- PACE shows a sharper plume of NO_2 running N-S in Detroit on May 31 along the main thruway
- The Dearborn plant to the south of Detroit is clearly distinguished as a separate NO_2 plume in PACE OCI, particularly on May 31, whereas TROPOMI shows one large plume of NO_2 over Detroit



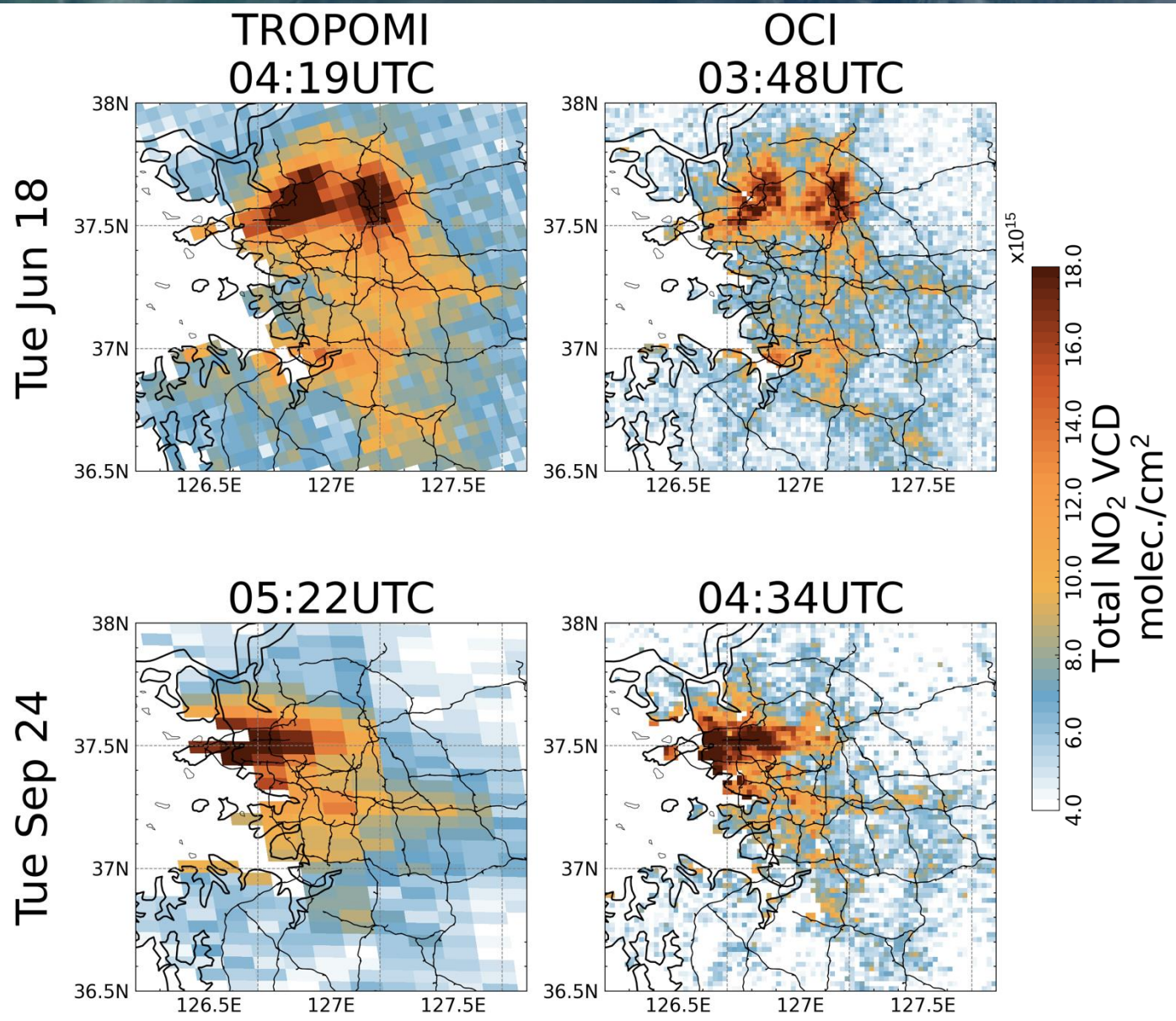
NO_2 in Eastern Saudi Arabia

- NO_2 in eastern Saudia Arabia is elevated due to many power plants and manufacturing plants in the region
  - P: Power Plant
  - C: Cement Factory
  - D: Desalination Plant
  - S: Steel Factory
- PACE OCI shows better defined NO_2 plumes such as to the north where there are two power plants and a cement factory (dashed circle)



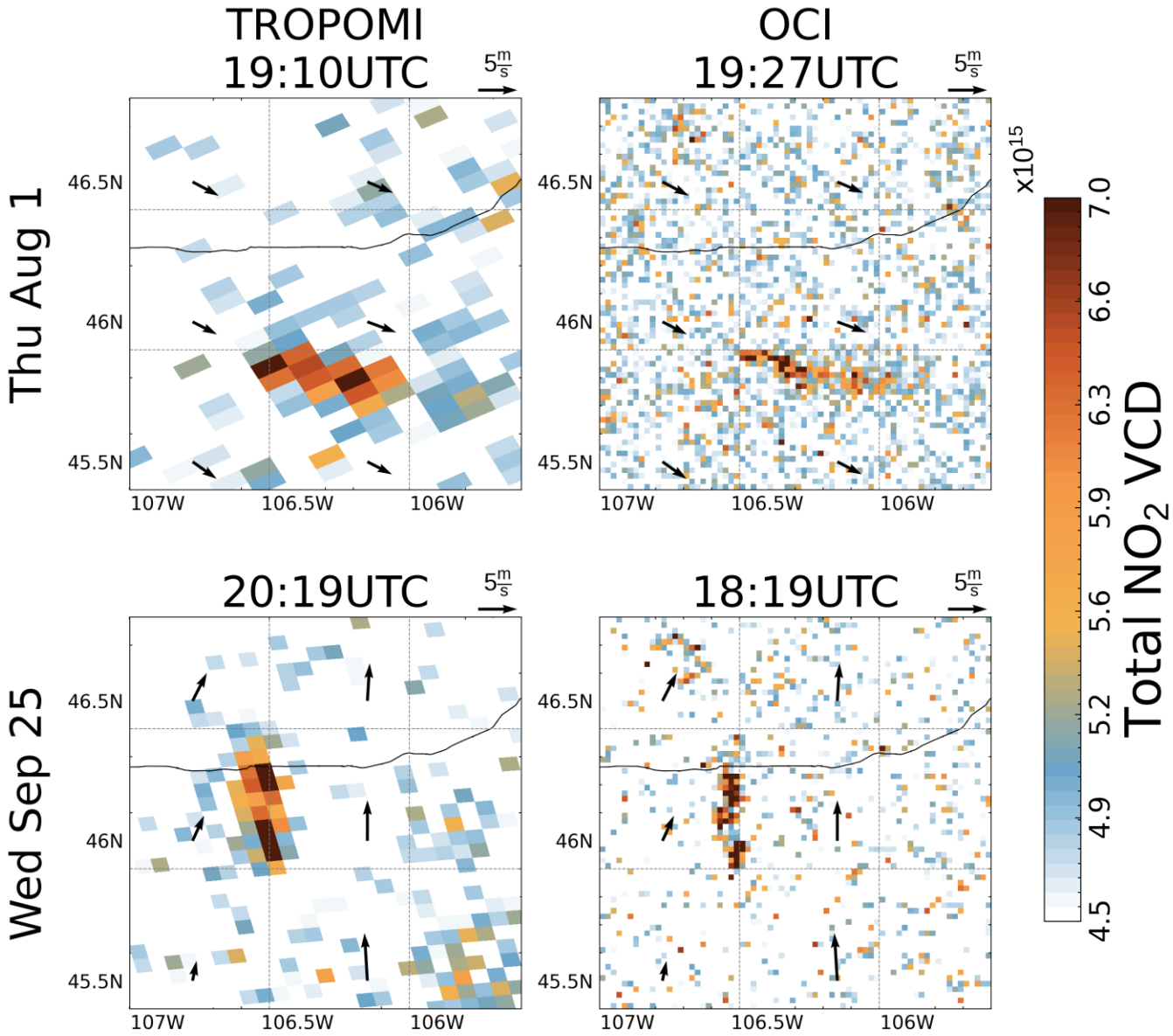
NO_2 in Seoul

- Seoul has elevated NOx emissions because of diesel emissions from vehicles
- NO_2 from PACE shows regional hot spots including highways, whereas TROPOMI coarser spatial resolution just shows generally elevated NO_2



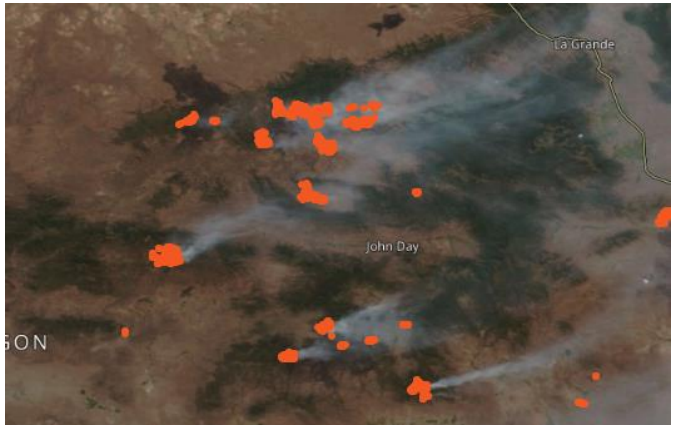
Colstrip Power Plant in Montana

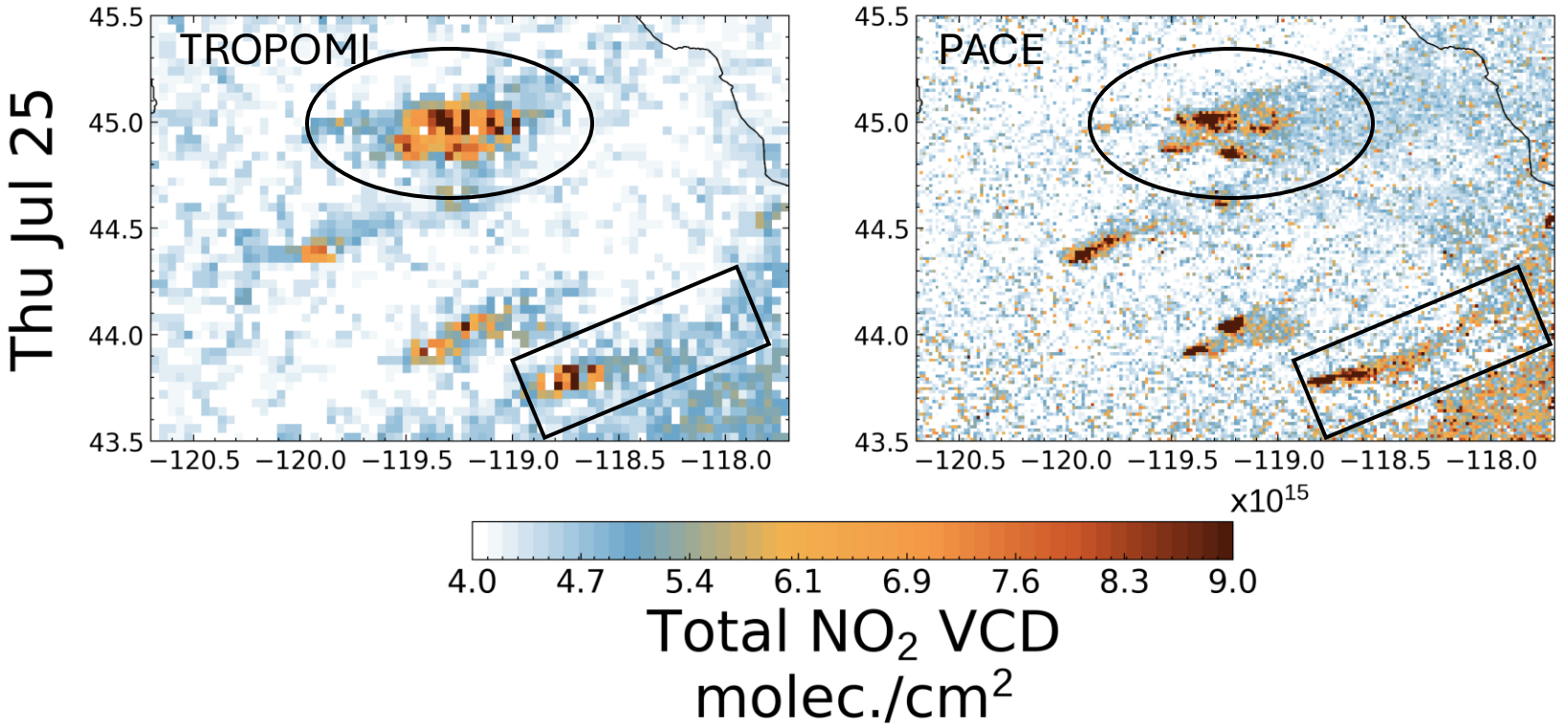
- Colstrip is a coal-fired power plan in SE Montana that emits ~10,000 tons of NOx annually (based on 2023 EIA report, https://www.eia.gov/electricity/data/emissions/)
- PACE retrieval provides more well-defined plume information'
- On Sep 25, TROPOMI would suggest plume traveled NNW, but PACE shows N track of plume that is consistent with MERRA-2 winds



July 2024 Oregon Wildfires

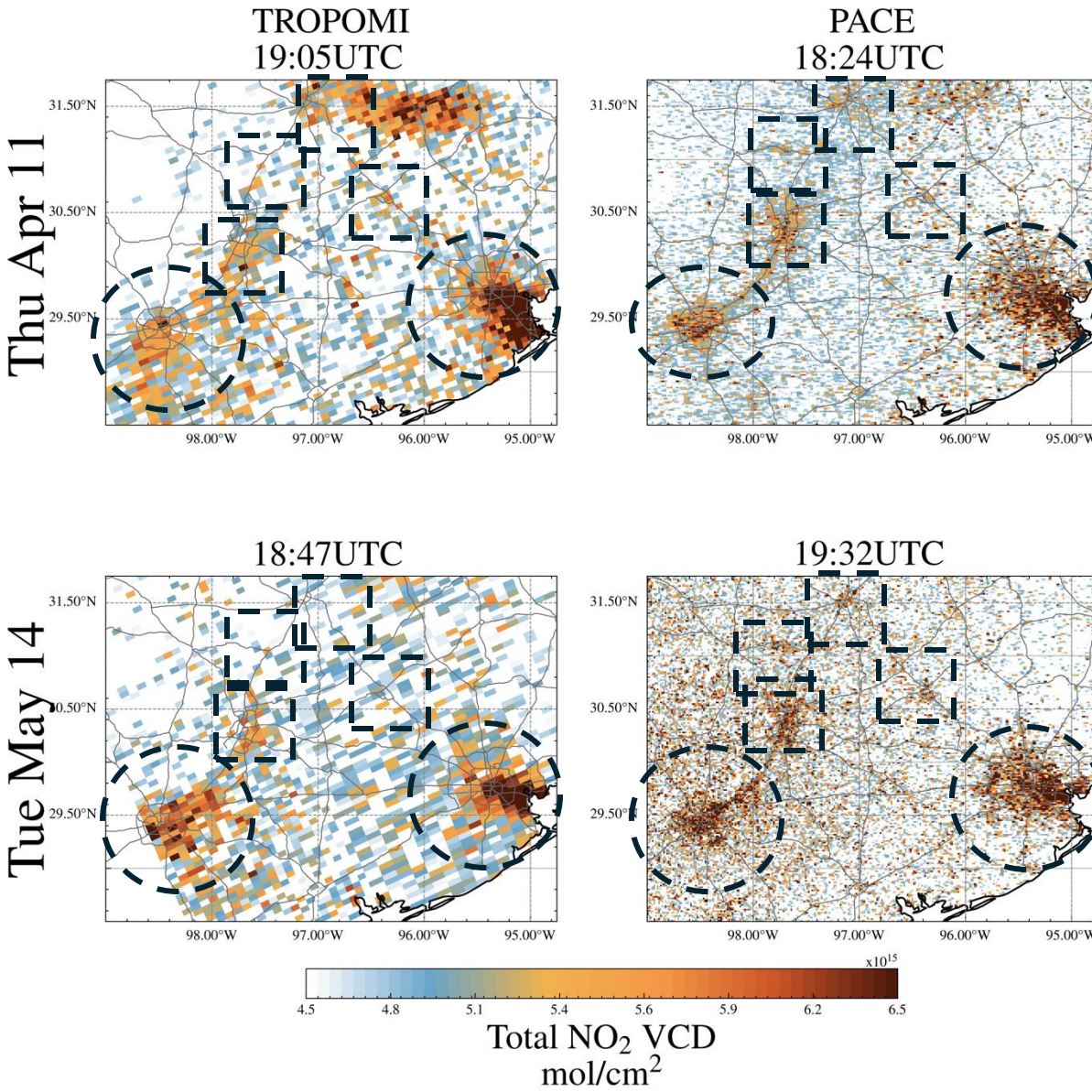
- Numerous wildfires in July 2024 burned hundreds of thousands of acres of land in Oregon
- High resolution NO_2 from PACE shows better ability to detect individual wildfires, particularly in circled region
- PACE also shows more well-defined plume for fire in the SE, shown in the rectangle





NO_2 in Southeast Texas

While the cities of San Antonio and Houston can be seen easily with TROPOMI (dashed circles), smaller cities such as Austin, Waco, Killeen, and College Station can be seen from the PACE OCI NO_2 measurements (dashed squares)



Sample PACE NO2 Data

- Processed 3 months of test data for users to explore
- Test data covers North America and the Middle East from April-June 2024
- Data are in .nc4 format similar to PACE file format and include the following fields:
  - Total vertical column NO_2
  - U10M, V10M from GMAO
  - Latitude, Longitude
- Additional data could be produced upon request
- Future plans to process full PACE mission globally

```
netcdf PACE_NO2_Gridded_NAmerica_2024m0401 {
dimensions:
        nlat = 2667 ;
        nlon = 4000 ;
variables:
        int nlat(nlat) ;
                nlat:valid_min = 1 ;
                nlat:valid_max = 5000 ;
                nlat:long_name = "number of latitudes" ;
                nlat:comment = "The dimension representing the along track positions." ;
                nlat:units = "1" ;
        int nlon(nlon) ;
                nlon:valid_min = 1 ;
                nlon:valid_max = 3000 ;
                nlon:long_name = "number of longitudes" ;
                nlon:comment = "The dimension representing the along-track scan-line number." ;
                nlon:units = "1" ;

// global attributes:
                :title = "PACE OCI Level-3 Data NO2" ;
                :product_name = "PACE_NO2_Gridded_NAmerica_2024m0401.nc" ;
                :processing_version = "1.0.0" ;
                :Conventions = "CF-1.8" ;
                :instrument = "OCI" ;
                :date_created = "2024-12-19T12:36:59.110439" ;
                :institution = "NASA/GSFC" ;
                :spatial_resolution = "1500m" ;
                :spatial_coverage = "-130W to -70W, 20N to 60N" ;
                :date = "2024-04-01T00:00:00.000000" ;
                :PlatformShortName = "PACE" ;

group: geophysical_data {
  variables:
        float nitrogen_dioxide_total_vertical_column(nlon, nlat) ;
                nitrogen_dioxide_total_vertical_column:_FillValue = -999.f ;
                nitrogen_dioxide_total_vertical_column:valid_min = -999.f ;
                nitrogen_dioxide_total_vertical_column:valid_max = 1.e+30f ;
                nitrogen_dioxide_total_vertical_column:long_name = "Total vertical column nitrogen dioxide" ;
                nitrogen_dioxide_total_vertical_column:source = "ML" ;
                nitrogen_dioxide_total_vertical_column:units = "molecules/cm2" ;
        float U10M(nlon, nlat) ;
                U10M:_FillValue = -999.f ;
                U10M:valid_min = -999.f ;
                U10M:valid_max = 1.e+30f ;
                U10M:long_name = "10-m Eastward Wind" ;
                U10M:source = "NASA Global Modeling and Assimilation Office GEOS-5 Forward Processing for Instrument Teams" ;
                U10M:units = "m s-1" ;
        float V10M(nlon, nlat) ;
                V10M:_FillValue = -999.f ;
                V10M:valid_min = -999.f ;
                V10M:valid_max = 1.e+30f ;
                V10M:long_name = "10-m Northward Wind" ;
                V10M:source = "NASA Global Modeling and Assimilation Office GEOS-5 Forward Processing for Instrument Teams" ;
                V10M:units = "m s-1" ;
  } // group geophysical_data
```

Downloading Sample Data

- Data have been made available at NASA's Aura Validation Data Center (AVDC) https://avdc.gsfc.nasa.gov/pub/tmp/PACE_NO2/
- Can be easily downloaded with simple wget or curl commands, no login needed
- Example:

  wget https://avdc.gsfc.nasa.gov/pub/tmp/PACE_NO2/NO2_L3_Gridded_NAmerica/PACE_NO2_Gridded_NAmerica_2024m0401.nc

Potential Applications and Future Work

Applications

- Improved spatially resolved emissions estimates
- Better resolved exposure estimates
- Improved ocean color retrievals
- Improved chemistry-transport modeling (for air quality)
- Spatial downscaling of TEMPO hourly measurements (complementary)

Future Work

- Finetuning the training and integration into PACE processing system
- More validation with aircraft as well as ground-based

GODDARD EARTH SCIENCES