

Unveiling urban pollution patterns from a bird's-eye view

Laura Judd, NASA LaRC

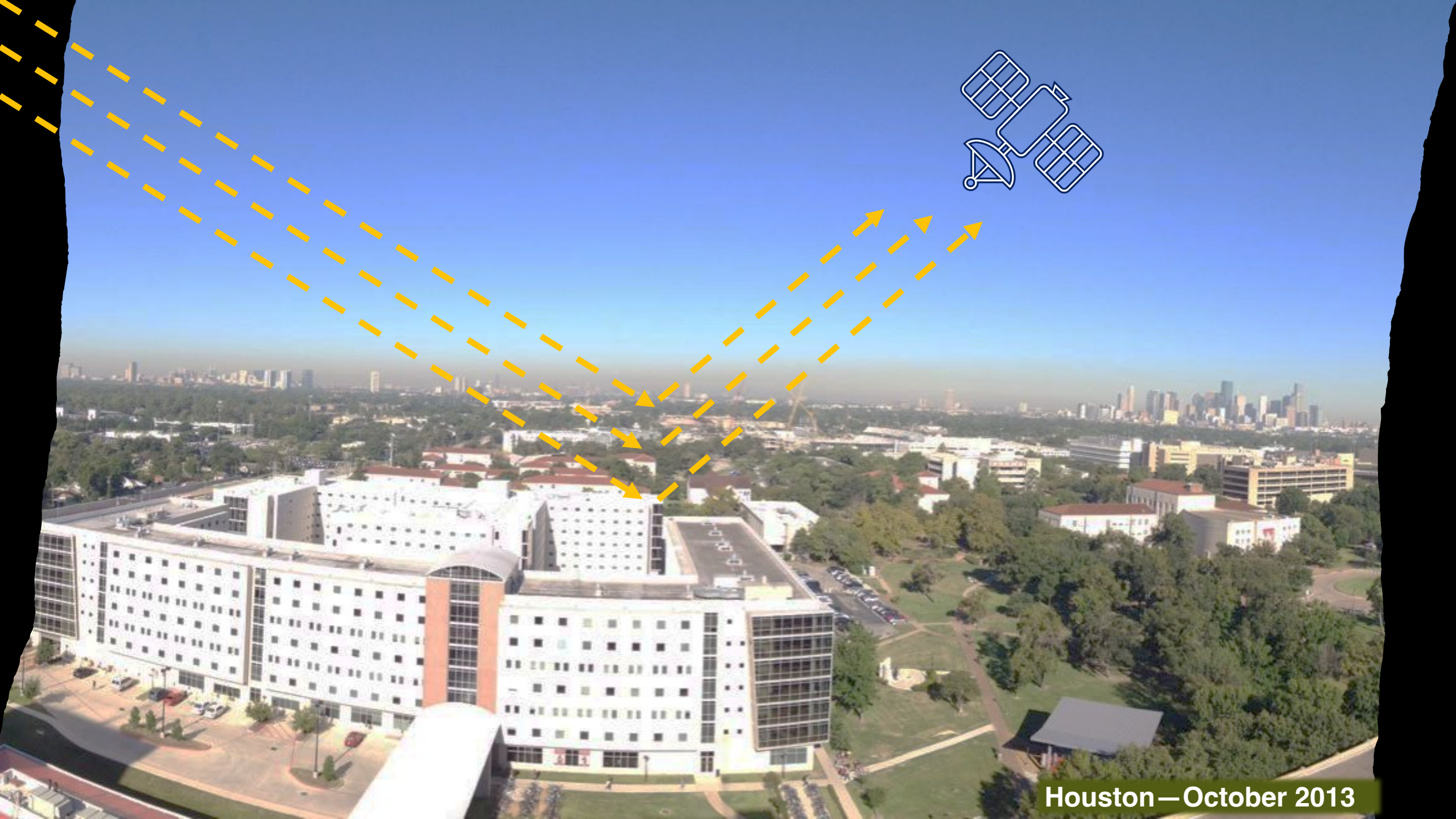


Regulated by the EPA Clean Air Act, though more indirectly controlled through the Ozone and PM2.5 National Ambient Air Quality Standards (NAAQS)

NO₂ pollution exposures can lead to exacerbation of respiratory diseases and has even been linked with the development of millions of pediatric asthma cases annually. Though incidence has declined over the last few decades. (Anenberg et al. 2022).

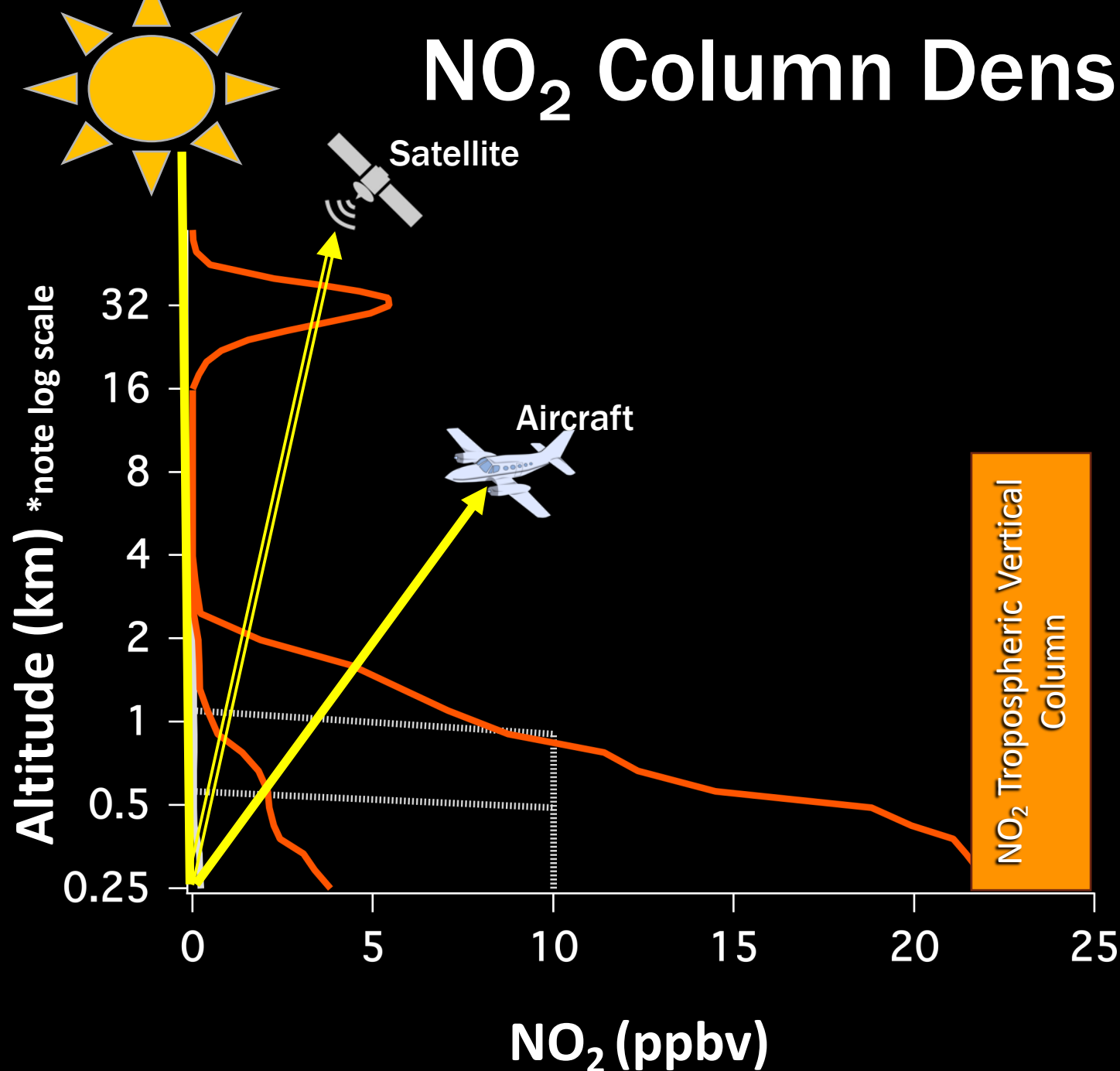
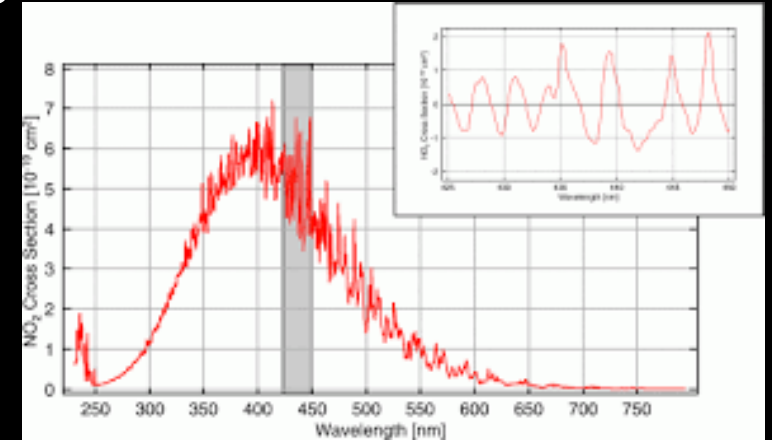


Houston — October 2013



Houston — October 2013

NO₂ Column Density



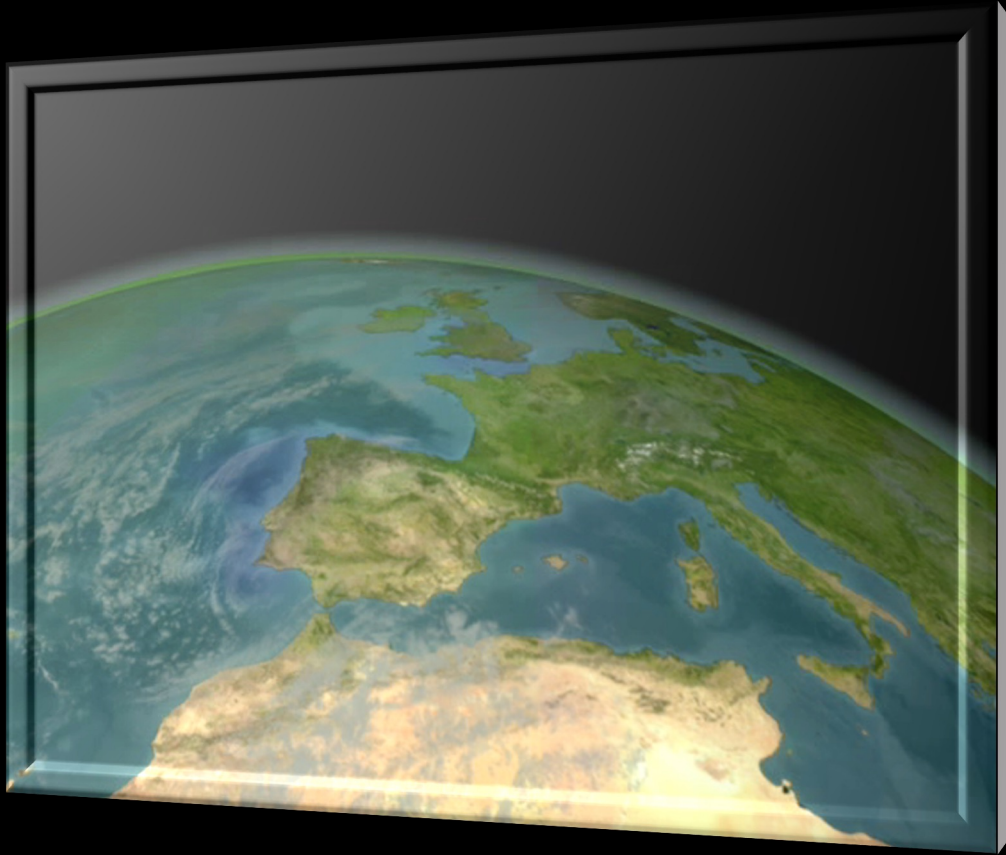
Satellites and GeoTASO/GCAS can only 'remotely sense' NO₂ columns by looking at its absorption signatures in the blue part of the light spectrum (via Differential Optical Absorption Spectroscopy¹).

Surface NO₂: molecular density or mixing ratio directly measured at the surface by an in situ monitor

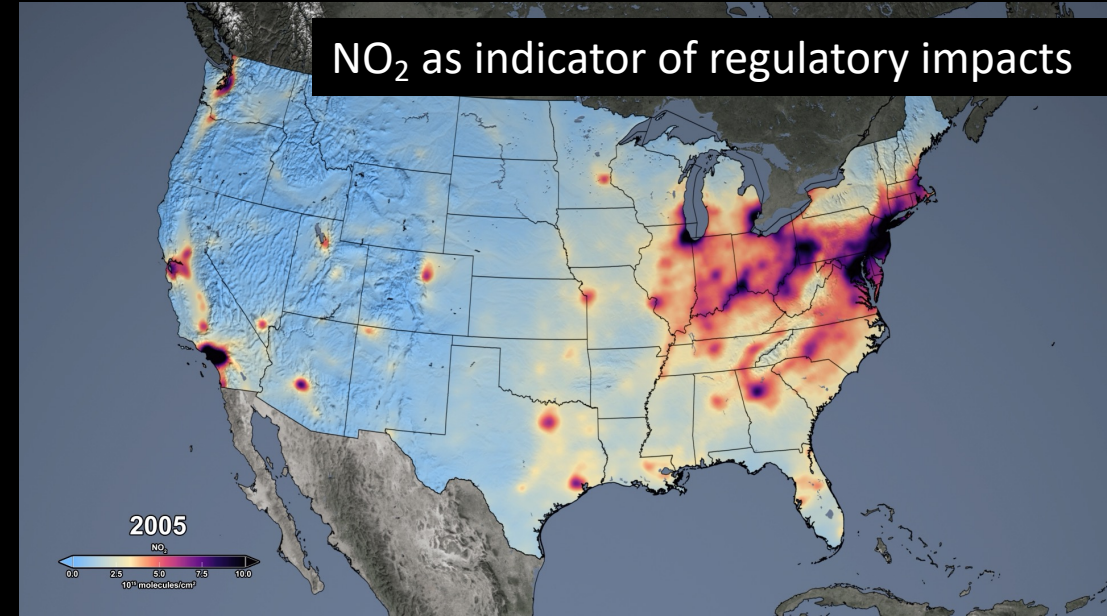
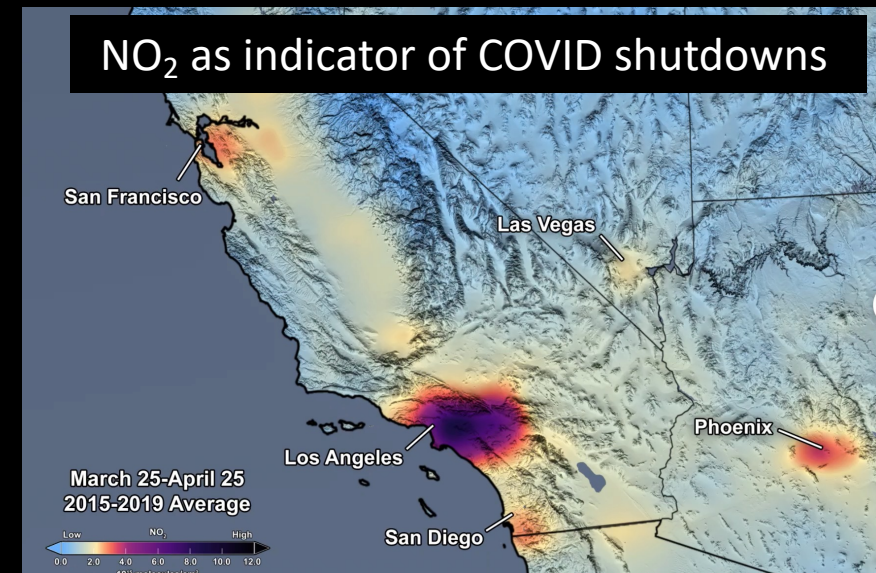
NO₂ Column Density: Integrated molecular density of NO₂ through the vertical

¹: Platt, U., & Stutz, J. (2008). *Differential optical absorption spectroscopy: principles and applications ; with 55 tables*. Berlin: Springer.

Air Quality Measurements with the Ozone Monitoring Instrument (OMI)



UV-VIS Spectrometer operating 2004-present
Overpasses once-per-day typically around 13:30 LT
NO₂ column density is retrieved using the DOAS method
Also retrieves O₃, HCHO, SO₂, etc.

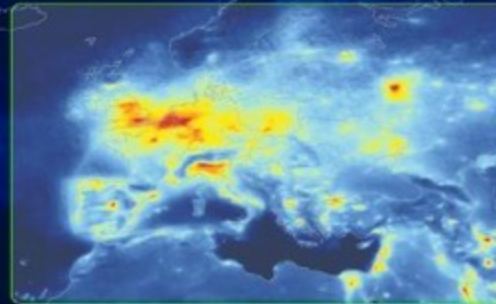


GEO-AQ Constellation

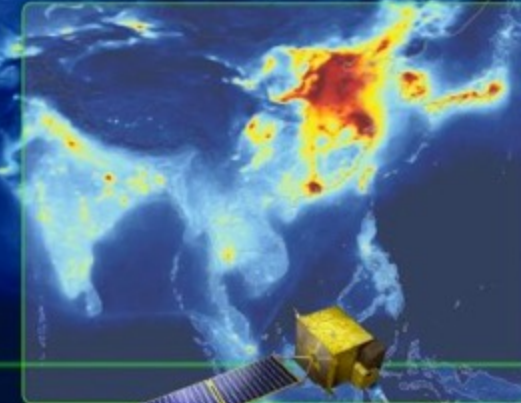
TEMPO (hourly)



Sentinel-4 (hourly)



GEMS (hourly)

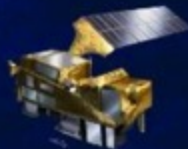


Equator

**Sentinel-5P
(once per day)**



**Sentinel-5
(once per day)**



**OMPS
(once per day)**



**EMI GaoFen-5
(once per day)**





Launching in 2022

TEMPO Mission Leads:

Principal Investigator:

Kelly Chance, Smithsonian Astrophysical Observatory

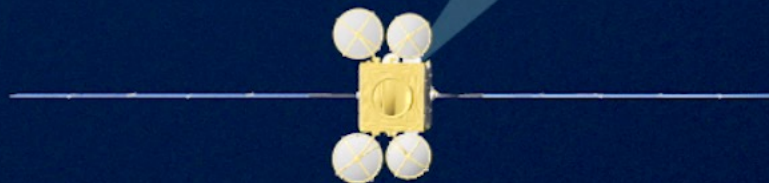
Instrument Development:

Ball Aerospace & Technologies Corporation

Project Management:

NASA/Langley Research Center

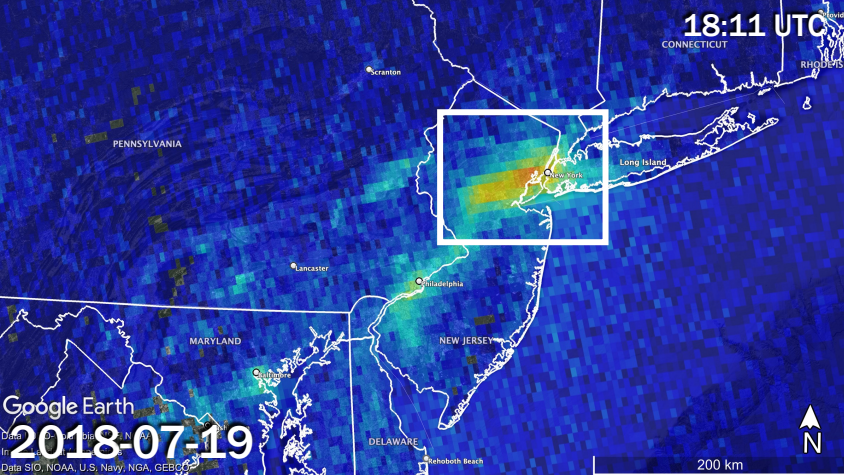
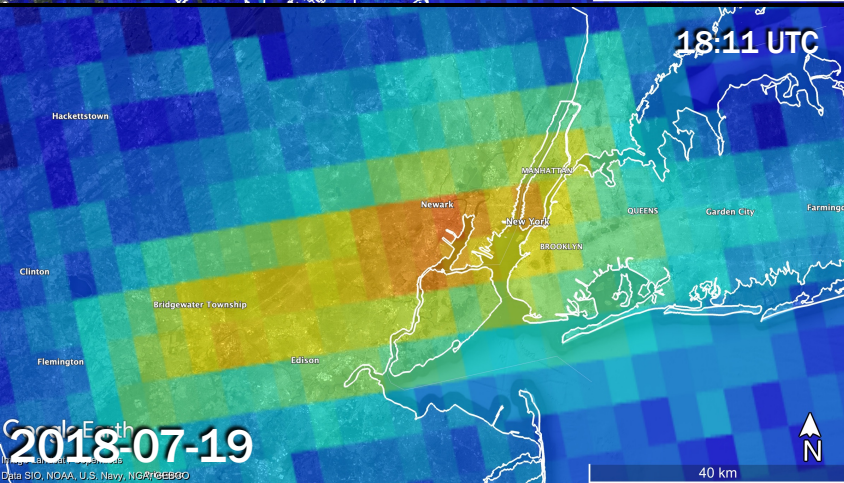
<http://tempo.si.edu/>



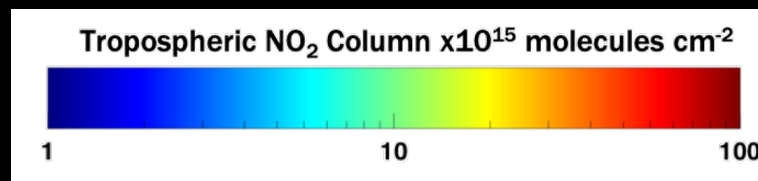
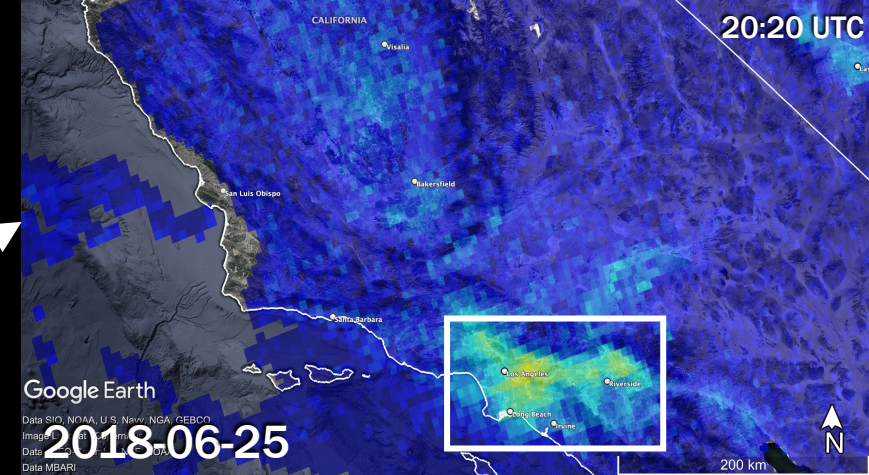
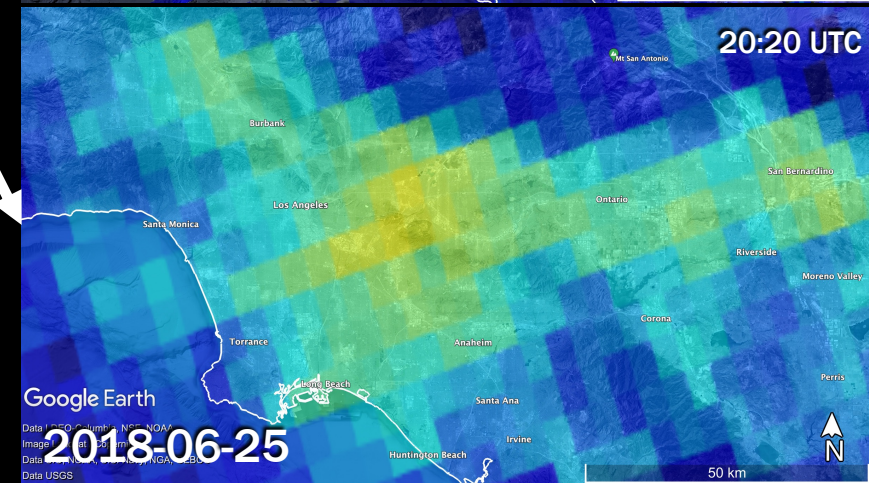
Model-simulated NO₂. Warmer colors indicate larger amounts.

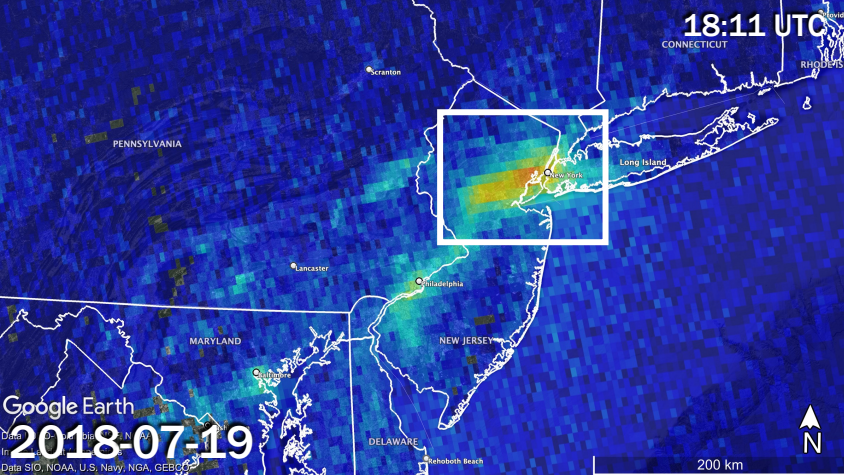
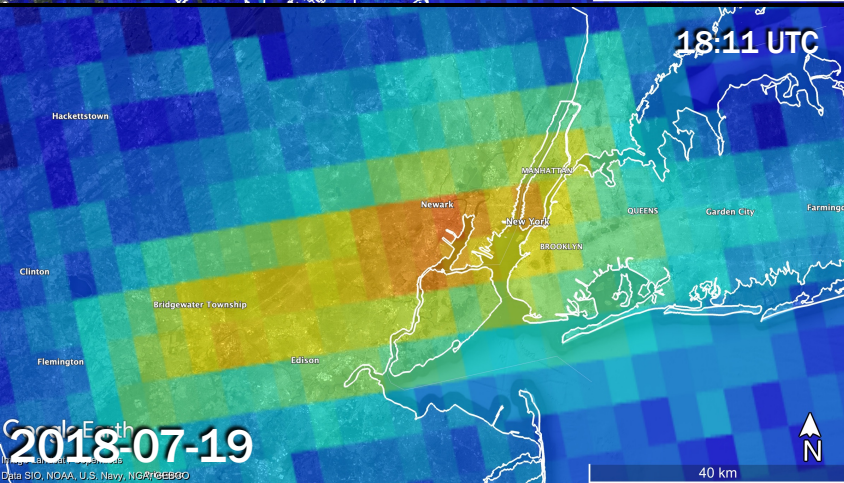
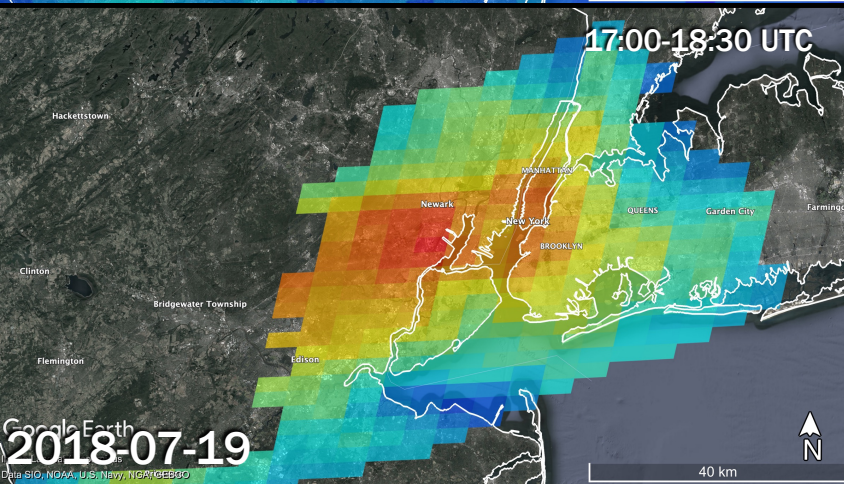
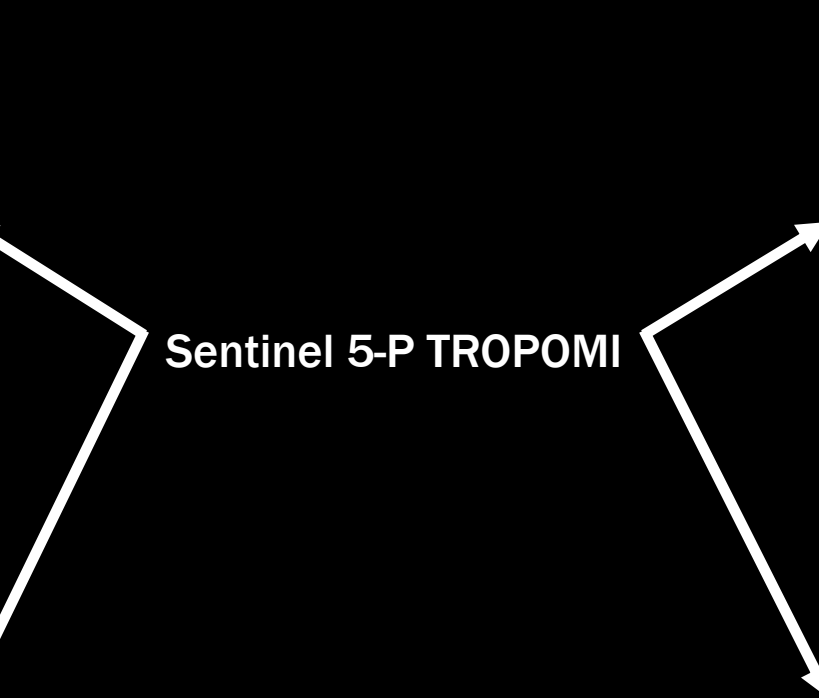
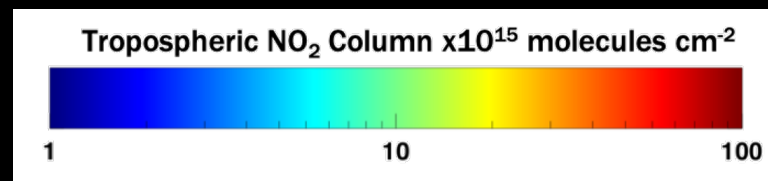
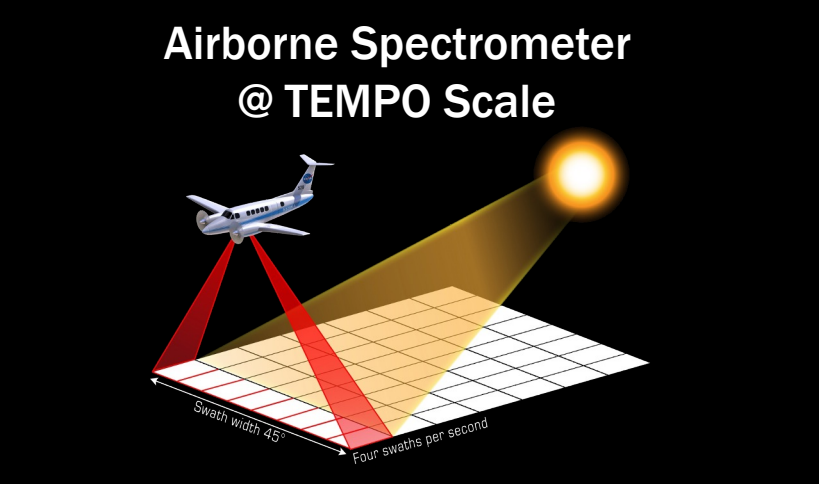
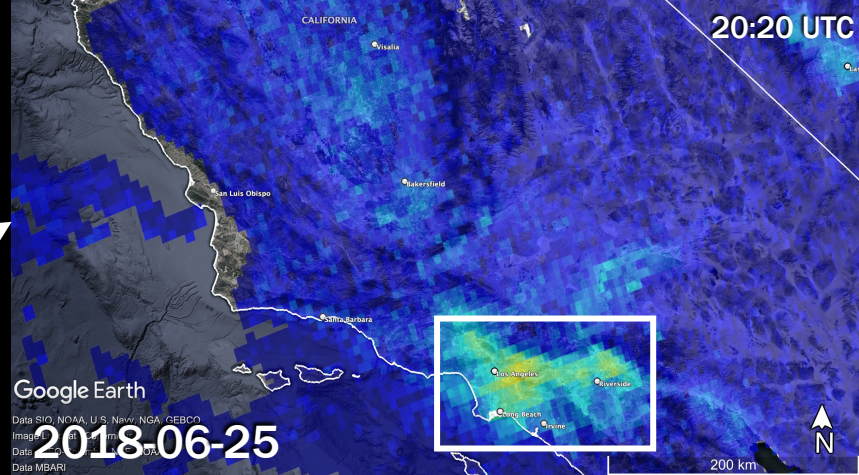
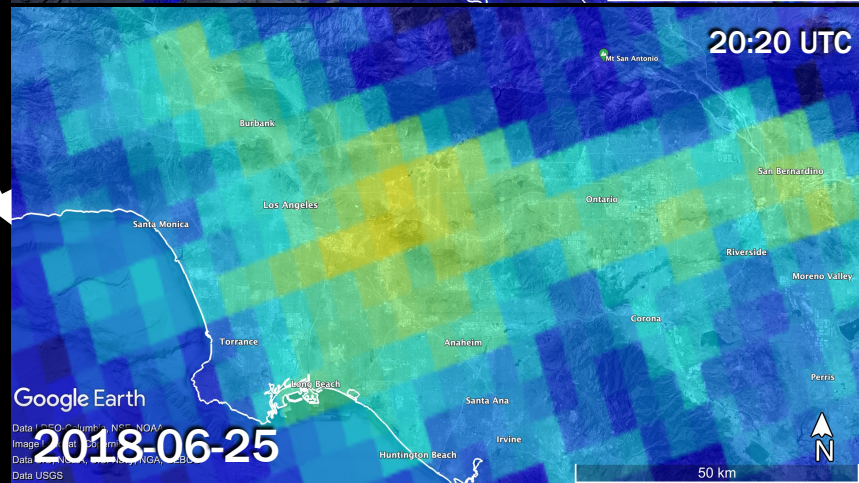
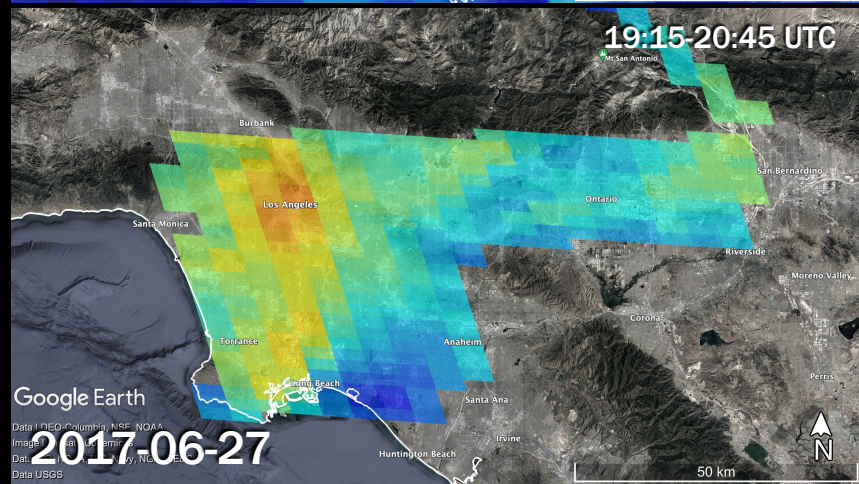
Provides hourly daylight observations to capture rapidly varying emissions & chemistry important for air quality

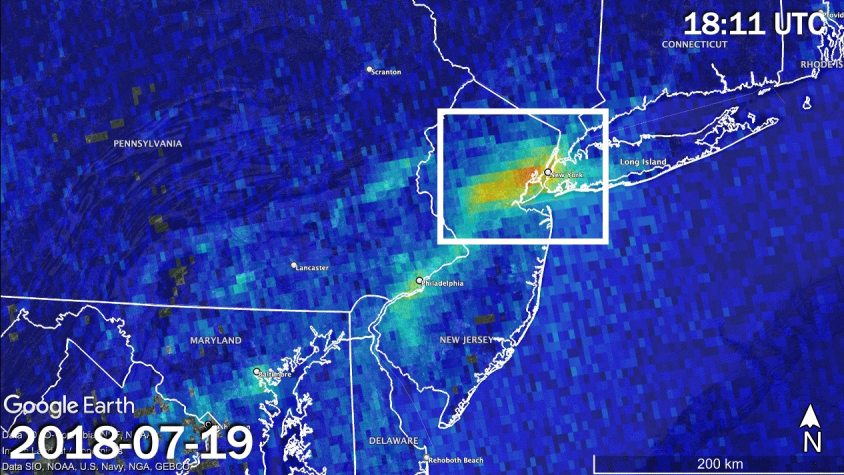
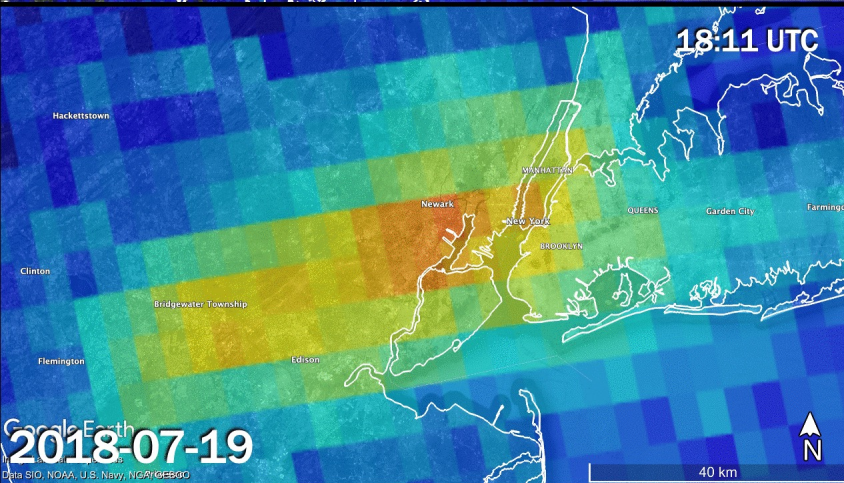
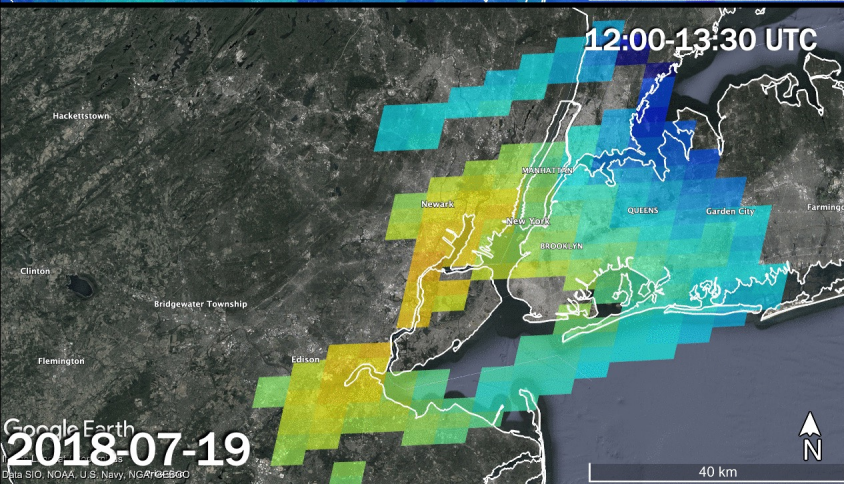
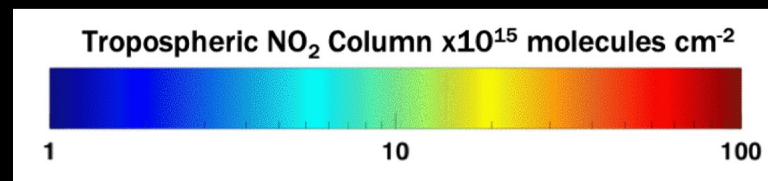
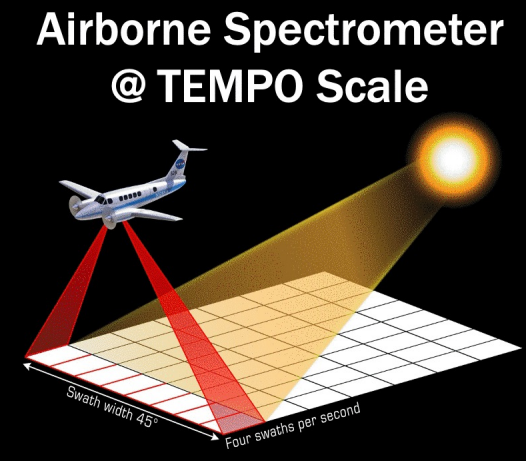
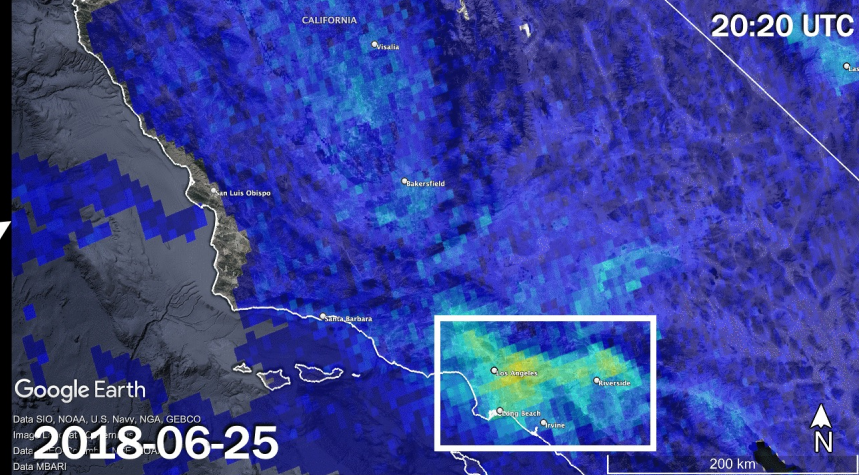
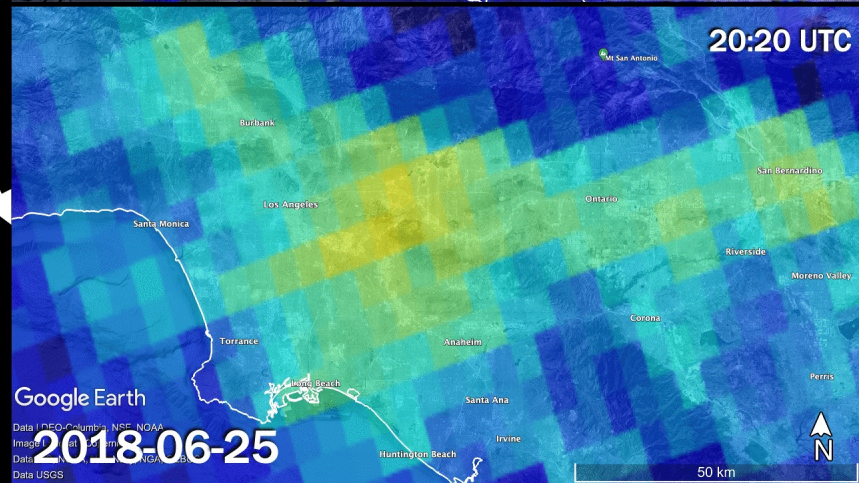
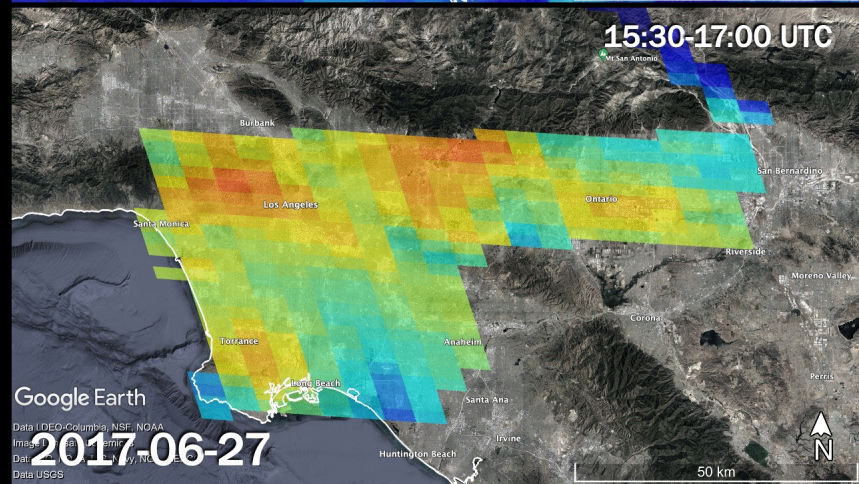
- Key tropospheric pollutants measured
 - Tropospheric ozone
 - Ozone Precursors: **nitrogen dioxide (NO₂)** and formaldehyde (HCHO)
 - Aerosol optical depth
- Distinguishes boundary layer from free tropospheric ozone



Sentinel 5-P TROPOMI

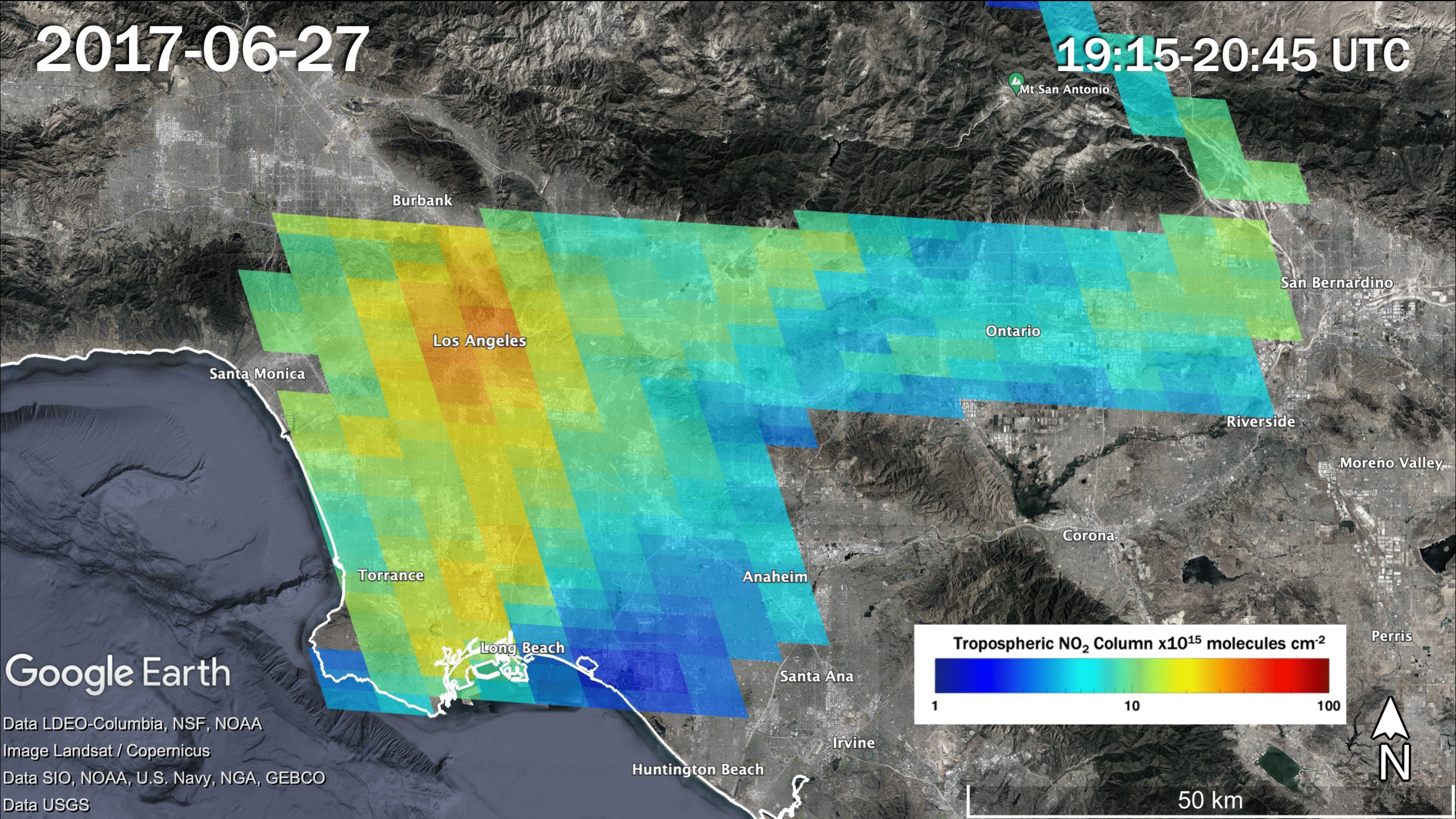






2017-06-27

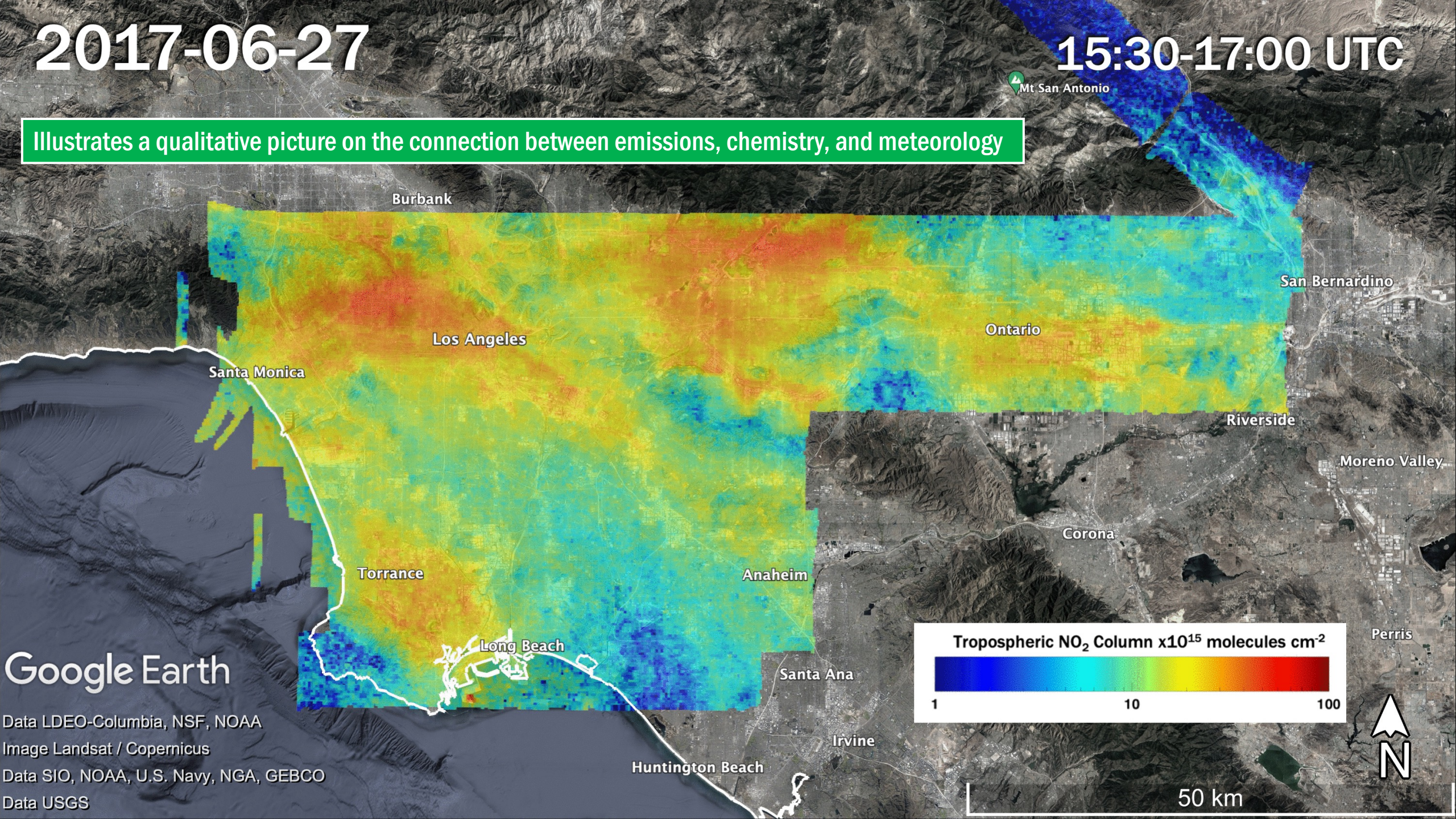
19:15-20:45 UTC



2017-06-27

15:30-17:00 UTC

Illustrates a qualitative picture on the connection between emissions, chemistry, and meteorology



Google Earth

Data LDEO-Columbia, NSF, NOAA

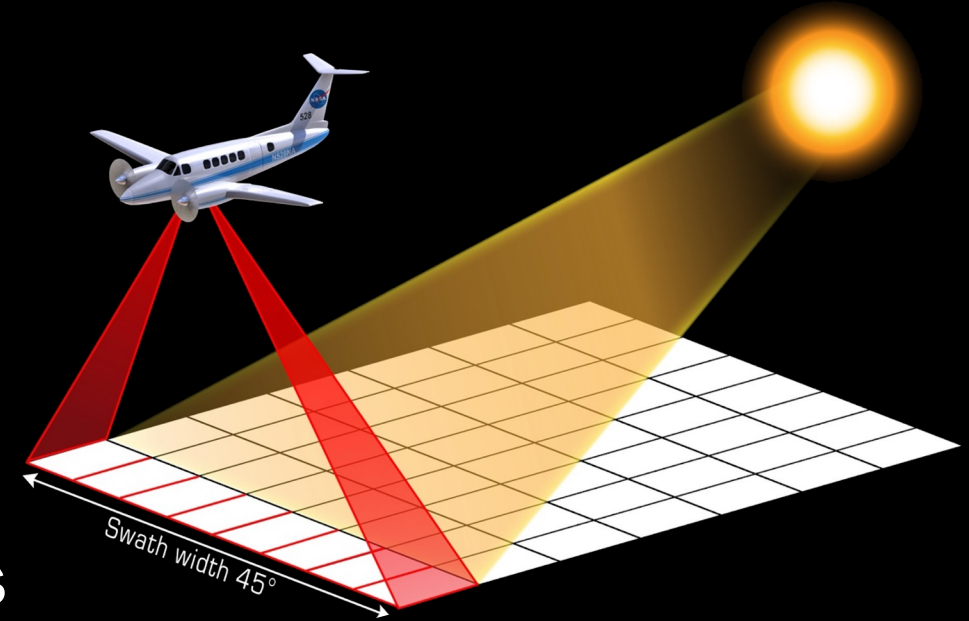
Image Landsat / Copernicus

Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Data USGS

NASA GCAS/GeoTASO Airborne Spectrometers

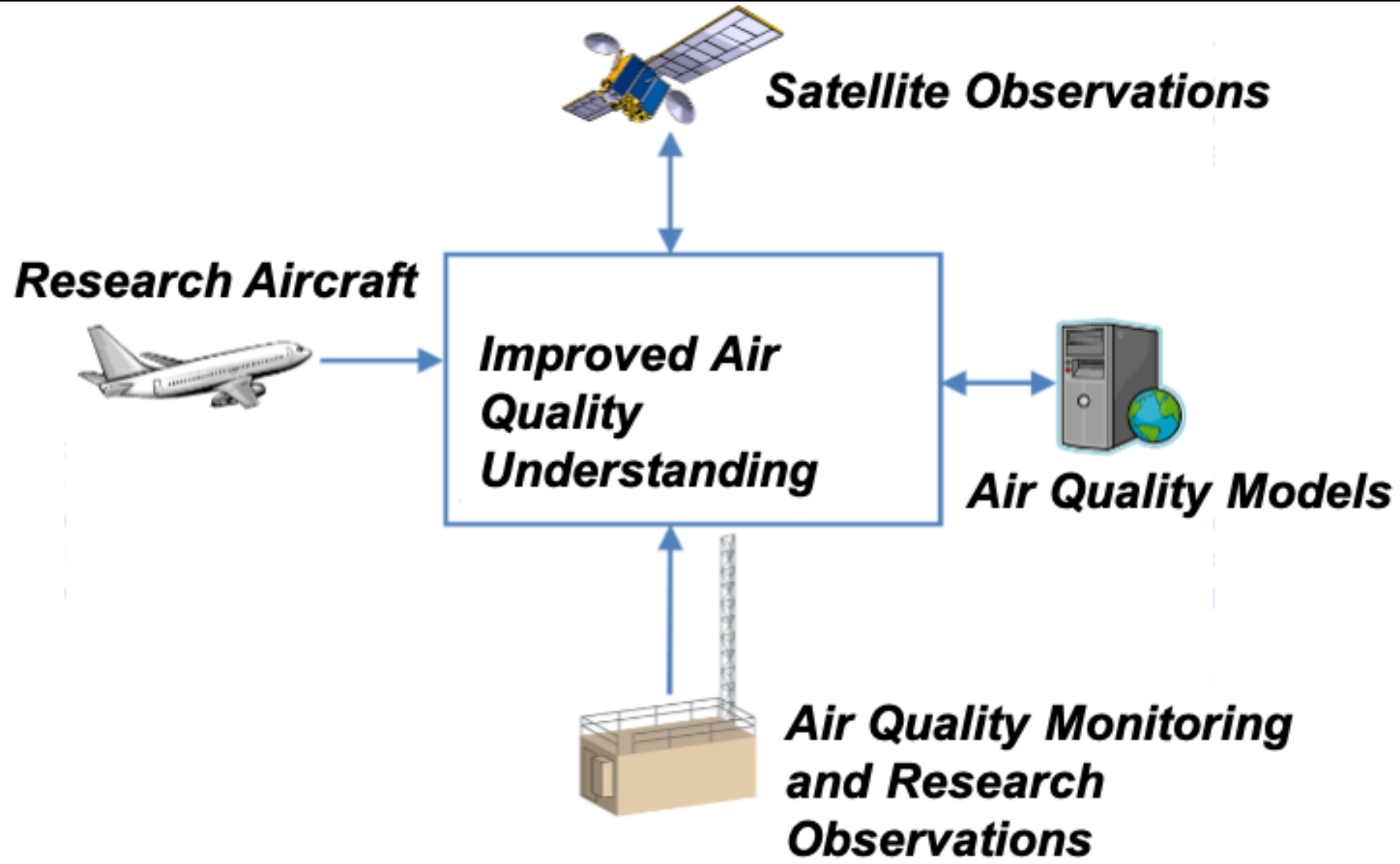
- Think of it as an airborne TEMPO simulator
- Primarily been used to collect preparatory measurements for geostationary air quality observations as well as emissions mapping
- Observes from the bottom of an airplane with a field of view of ~ 7 km at a nominal altitude of 28,000 feet executing gapless mapping over areas of interest
- Measures spectra in the UV-VIS-(NIR) at high spectral and spatial resolution from which trace gas columns can be remotely retrieved (NO_2 and HCHO) (nominally 250 m x 250 m)



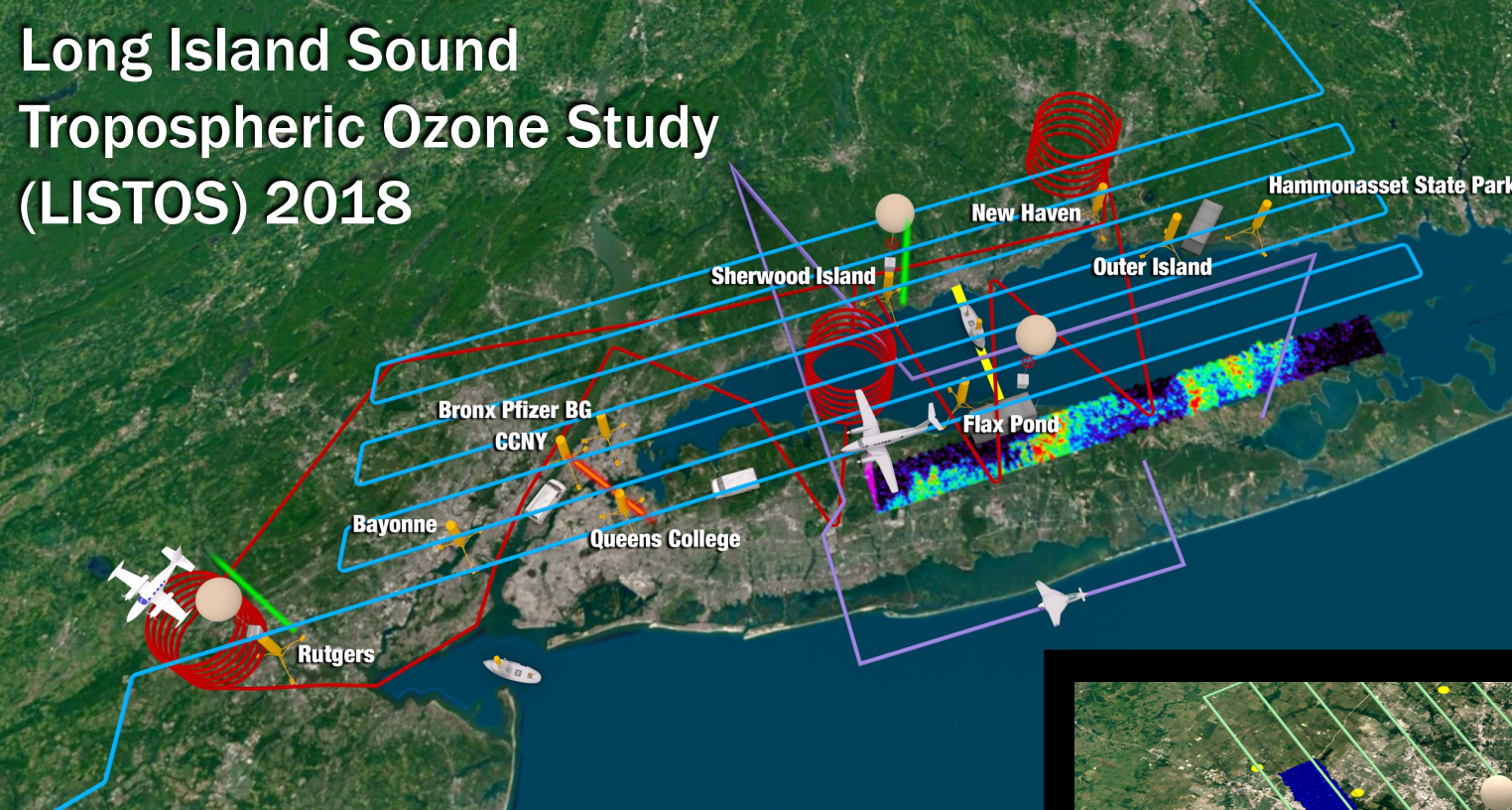
Sampling strategy for the airborne spectrometers operating in a push-broom configuration (adapted from Nowlan et al., 2016)

Some References:

Kowalewski & Janz, 2014: [doi:10.1117/12.2062058](https://doi.org/10.1117/12.2062058)
Leitch et al., 2014: [doi: 10.1117/12.2063763](https://doi.org/10.1117/12.2063763)
Nowlan et al., 2016: [doi:10.5194/amt-9-2647-2016](https://doi.org/10.5194/amt-9-2647-2016)
Nowlan et al., 2018: [doi:10.5194/amt-2018-156](https://doi.org/10.5194/amt-2018-156)
Judd et al., 2019: [doi: 10.5194/amt-12-6091-2019](https://doi.org/10.5194/amt-12-6091-2019)
Judd et al., 2020: [doi: 10.5194/amt-2020-151](https://doi.org/10.5194/amt-2020-151)



Long Island Sound Tropospheric Ozone Study (LISTOS) 2018



Building an integrated observing strategy

1. Column Measurements:

- surface aircraft, satellite

2. Vertical Profile Measurements:

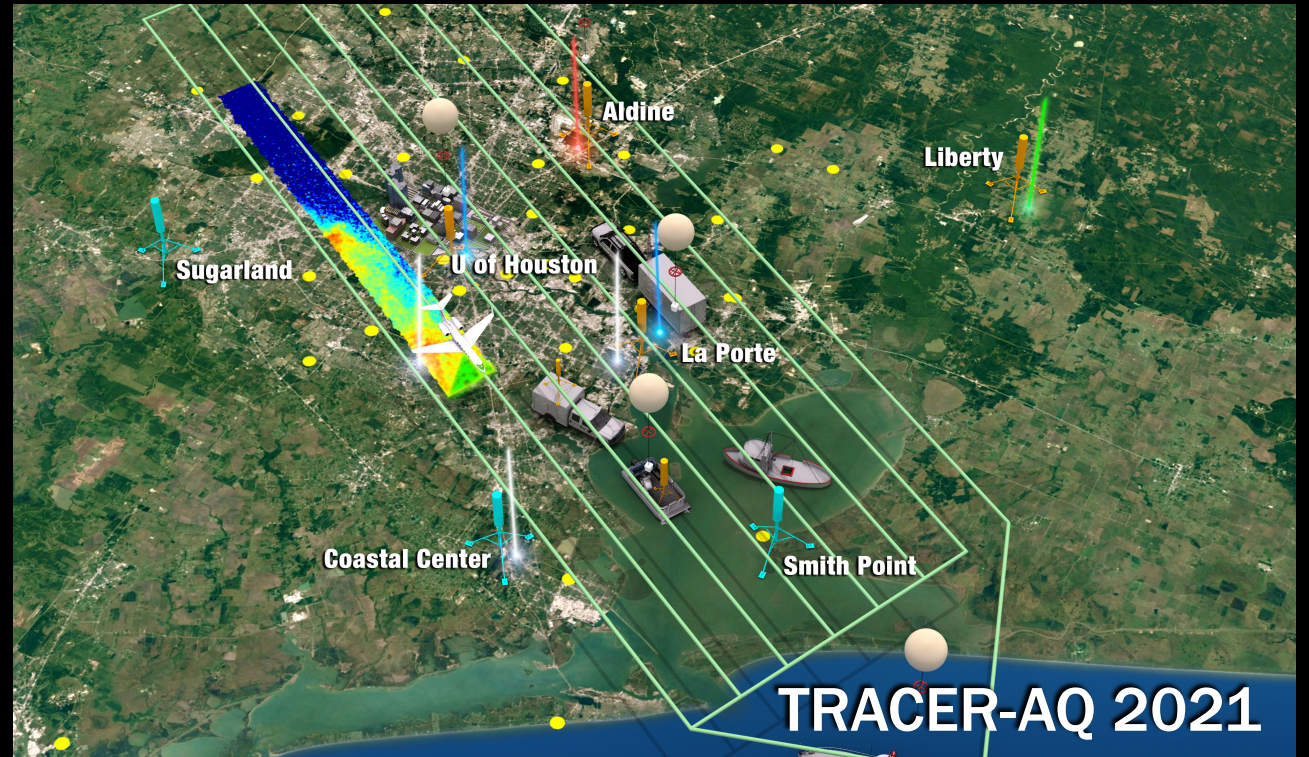
- aircraft, lidars, sondes

3. Nose-level Measurements:

- vehicle, boat, stationary, including regulatory monitors

4. Model Analysis:

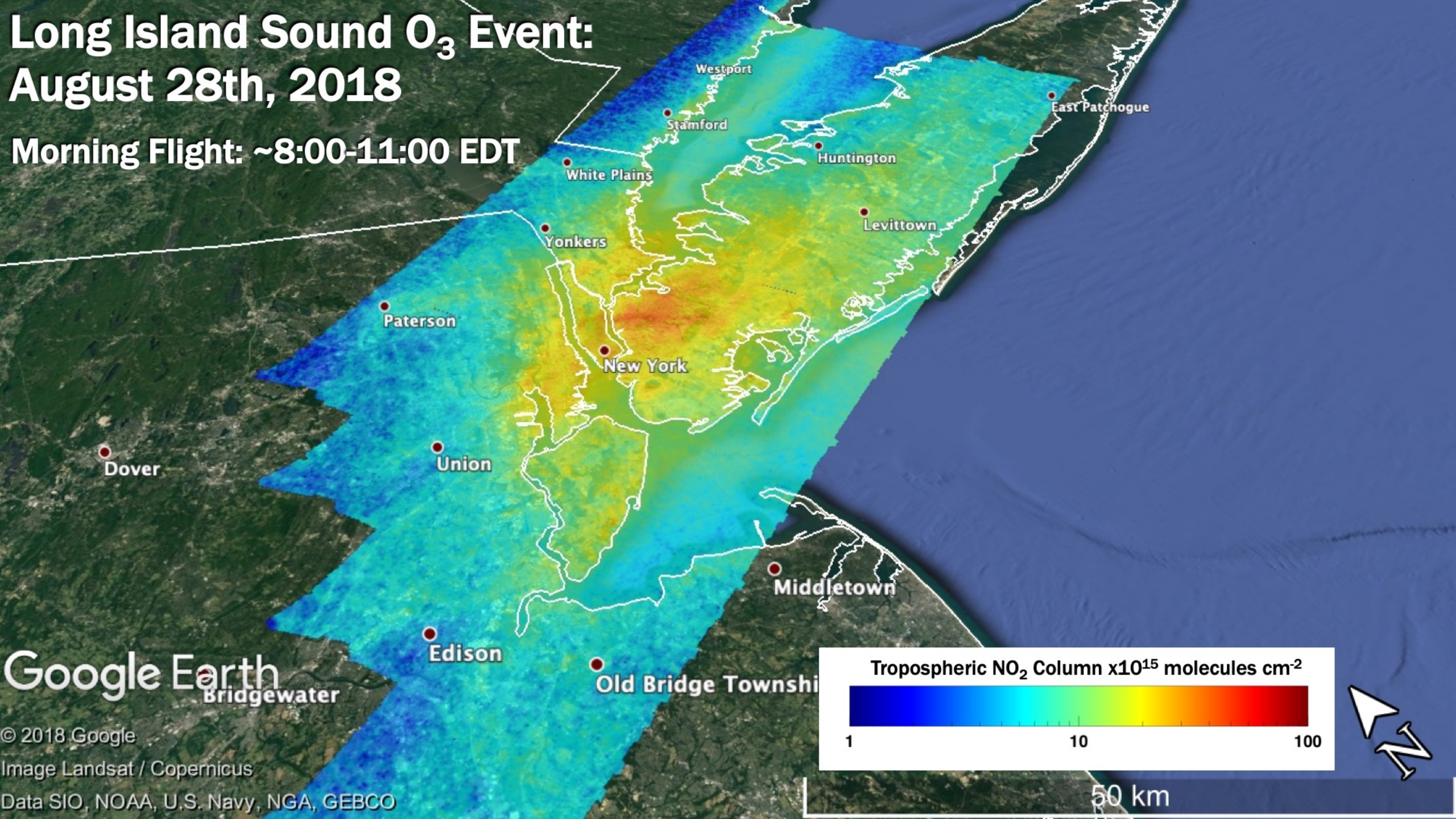
- forecasting & evaluation



TRACER-AQ 2021

Long Island Sound O₃ Event: August 28th, 2018

Morning Flight: ~8:00-11:00 EDT

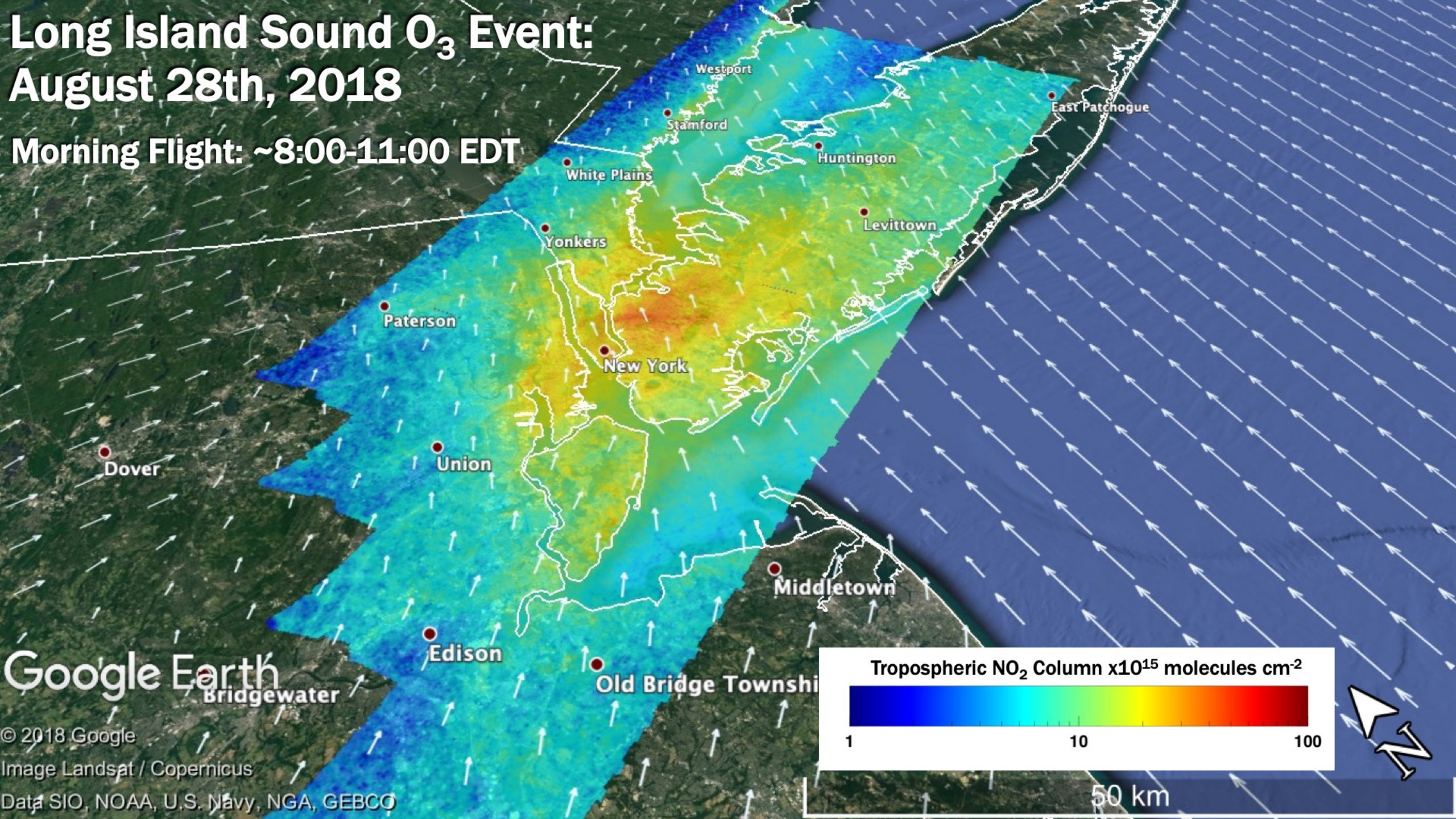


Google Earth
Bridgewater

© 2018 Google
Image Landsat / Copernicus
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Long Island Sound O₃ Event: August 28th, 2018

Morning Flight: ~8:00-11:00 EDT



Google Earth

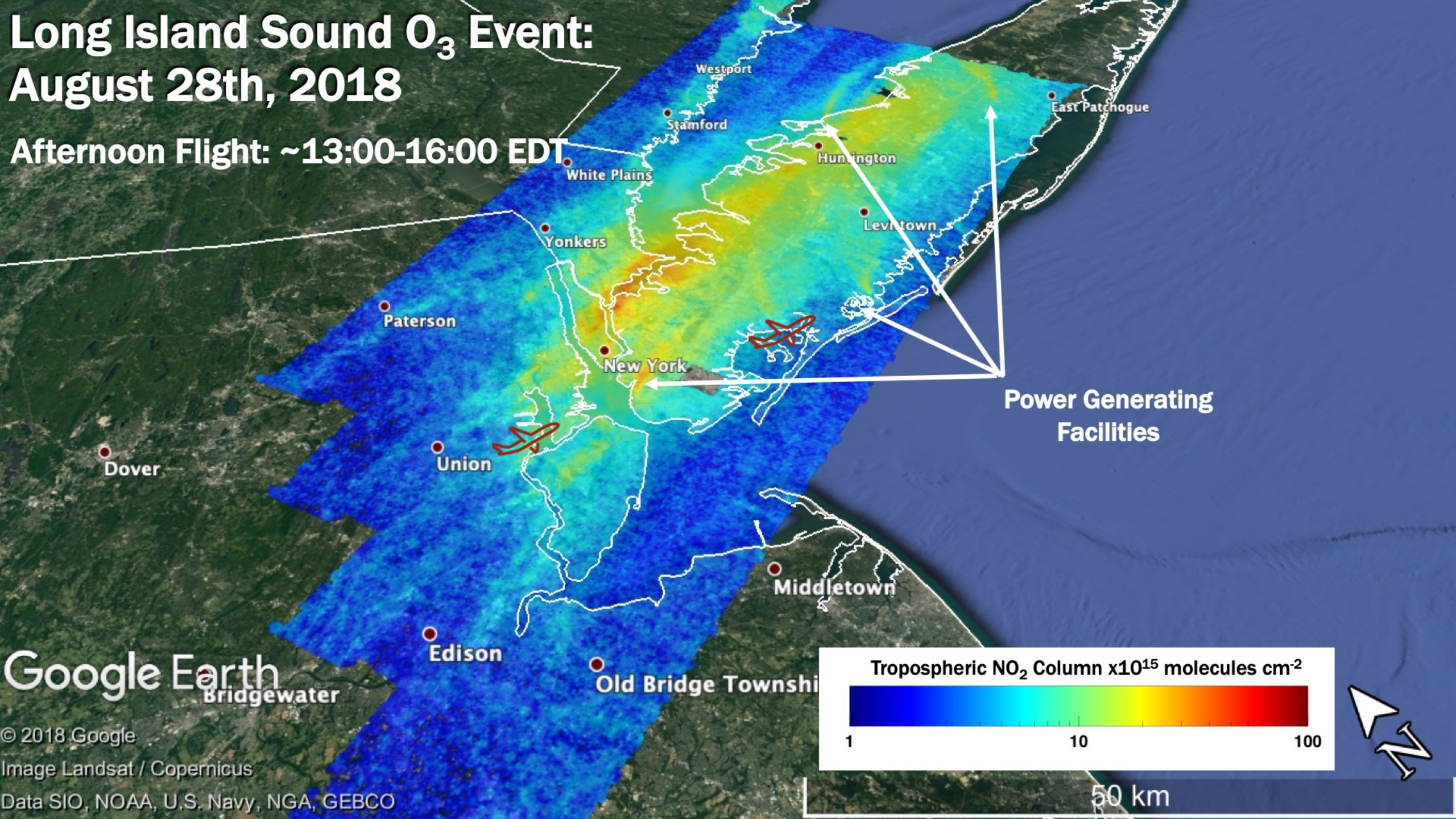
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Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Long Island Sound O₃ Event: August 28th, 2018

Afternoon Flight: ~13:00-16:00 EDT



Google Earth

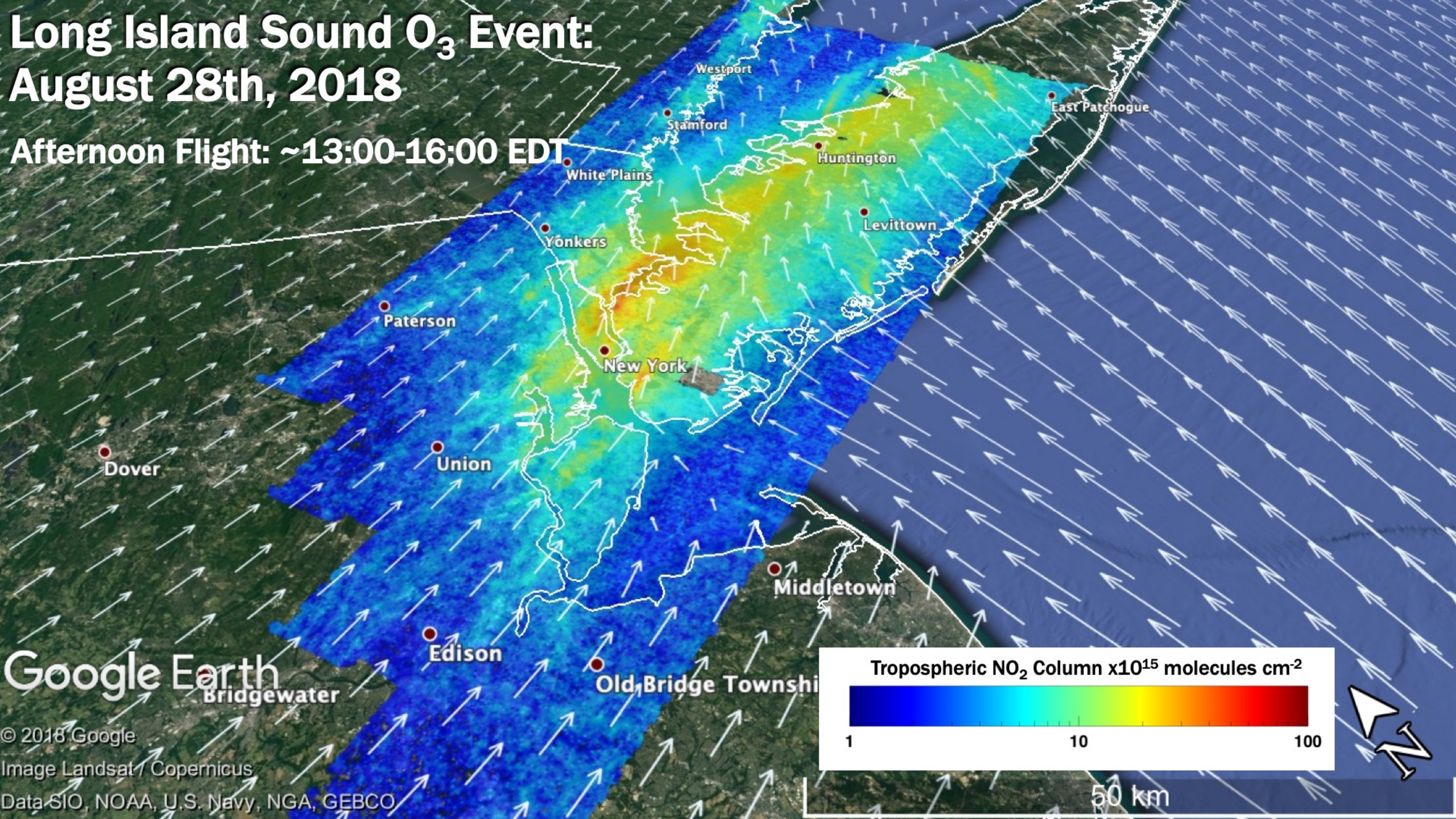
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Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Long Island Sound O₃ Event: August 28th, 2018

Afternoon Flight: ~13:00-16:00 EDT



Google Earth

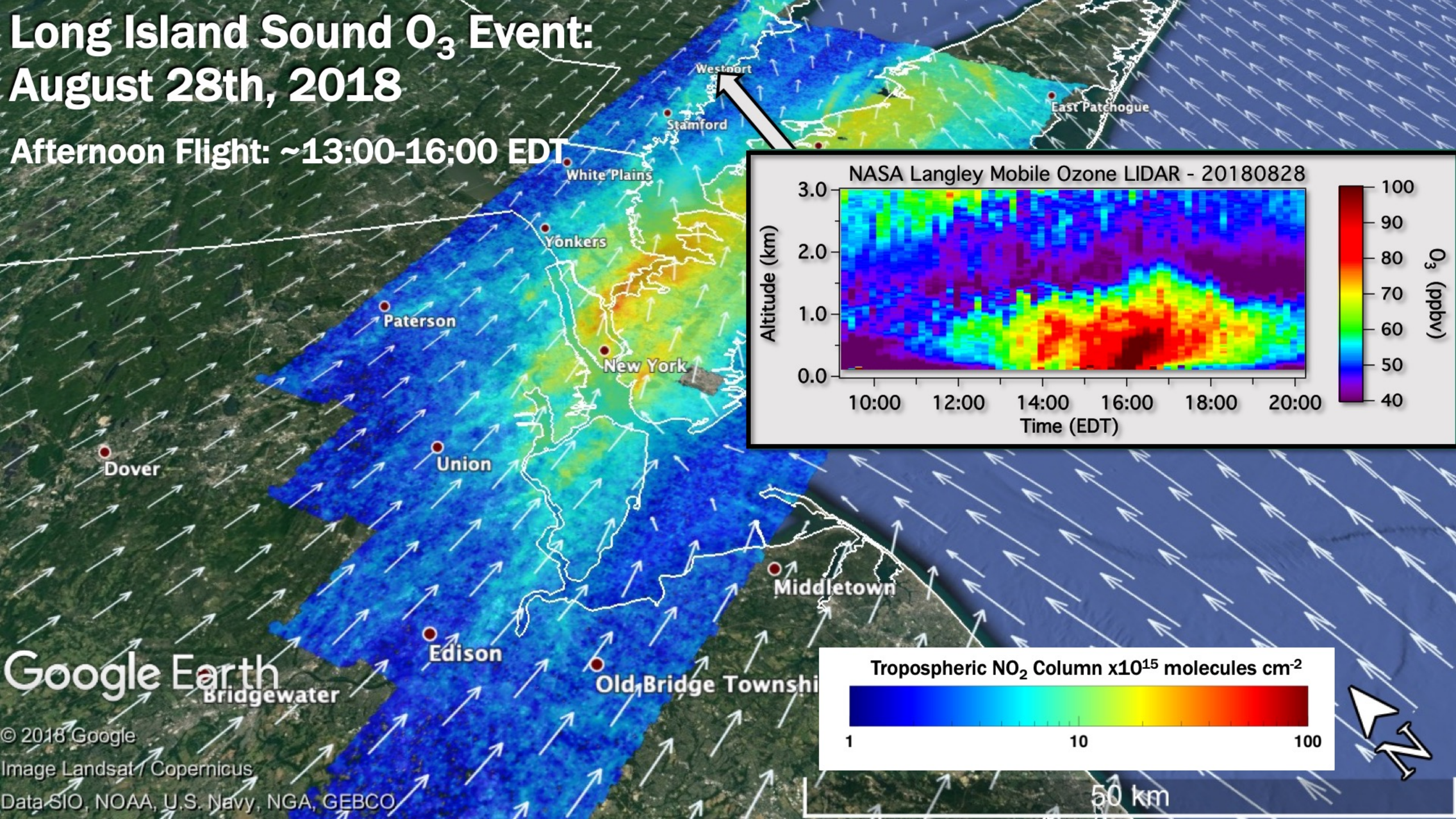
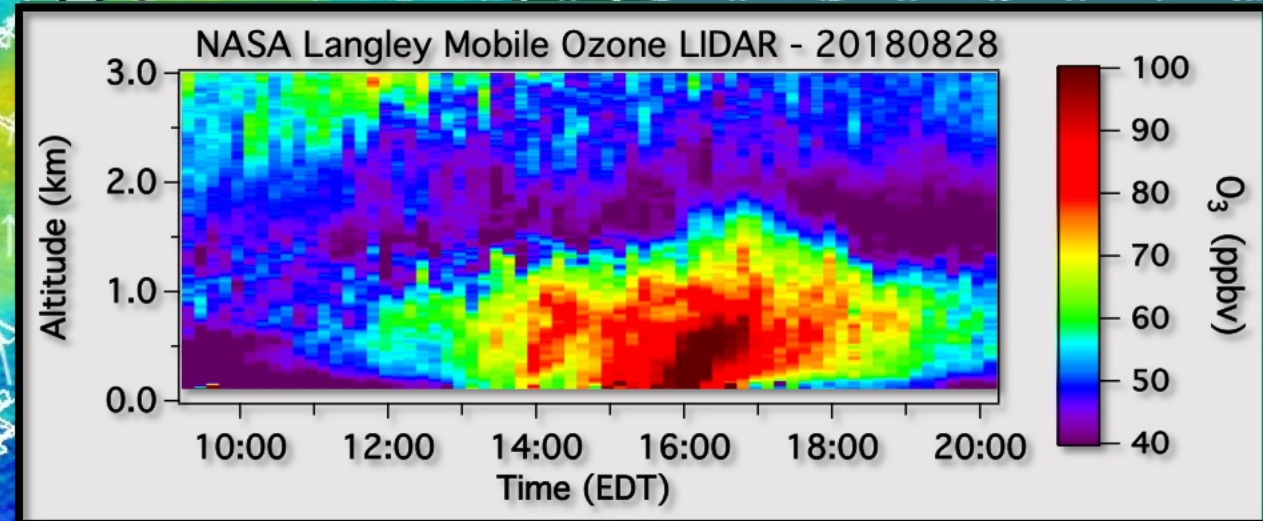
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Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Long Island Sound O₃ Event: August 28th, 2018

Afternoon Flight: ~13:00-16:00 EDT

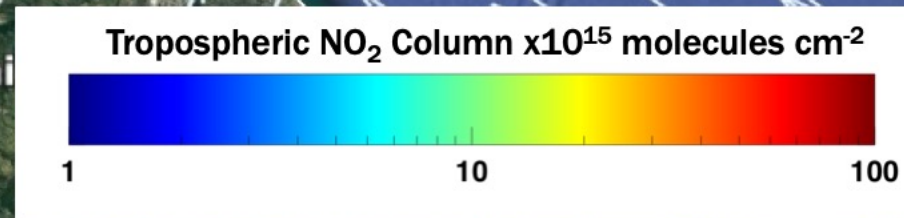


Google Earth

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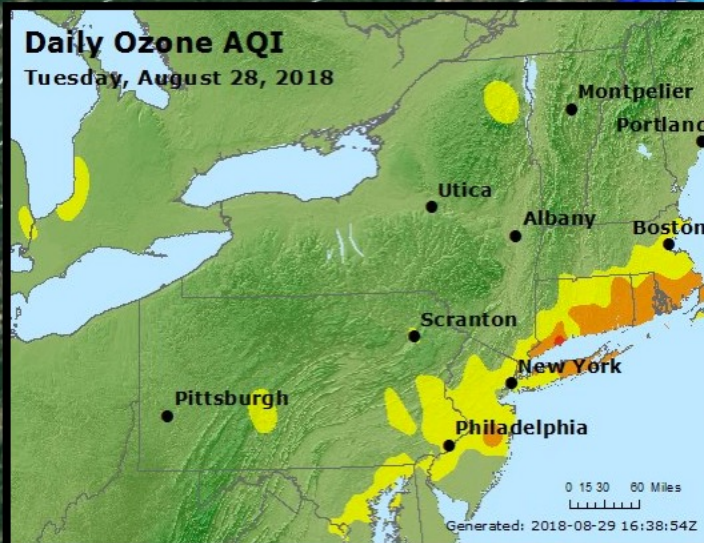
Image Landsat / Copernicus

Data SIO, NOAA, U.S. Navy, NGA, GEBCO



Long Island Sound O₃ Event: August 28th, 2018

Afternoon Flight: ~13:00-16:00 EDT

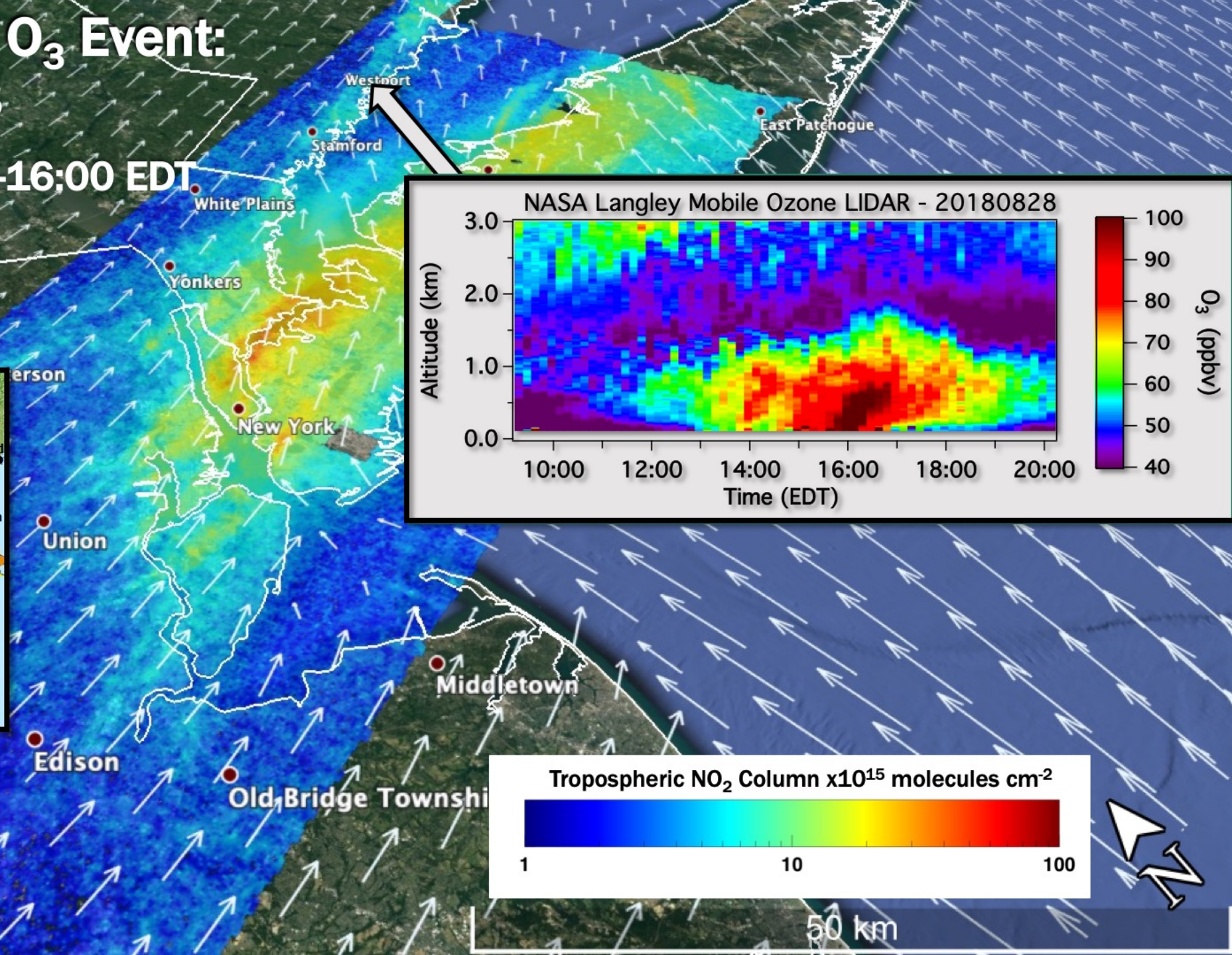


Google Earth

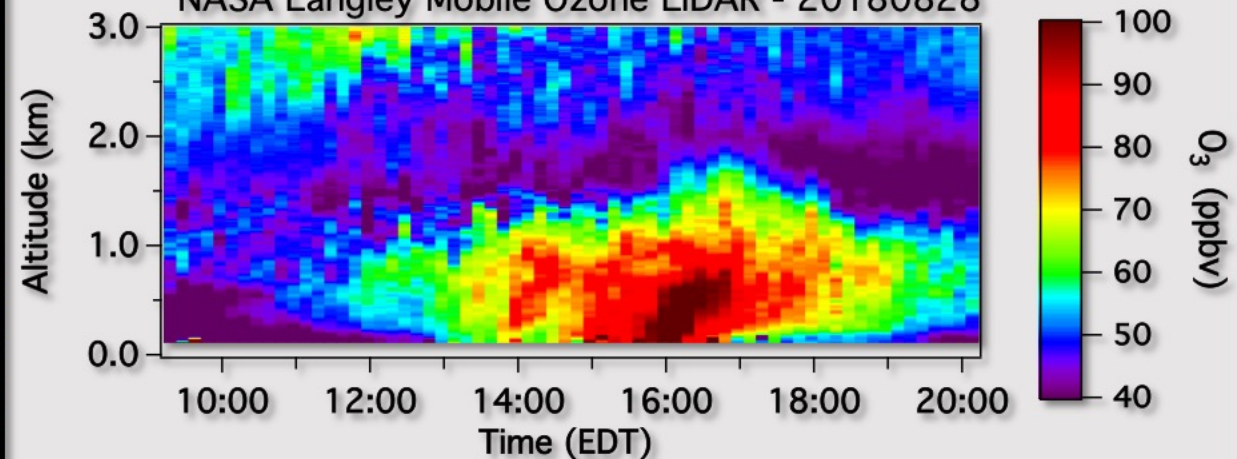
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Image Landsat / Copernicus

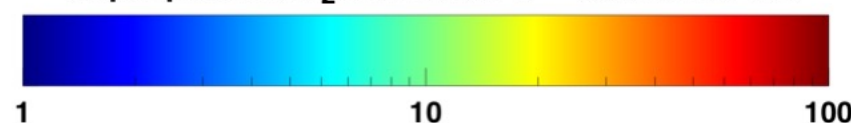
Data SIO, NOAA, U.S. Navy, NGA, GEBCO



NASA Langley Mobile Ozone LIDAR - 20180828



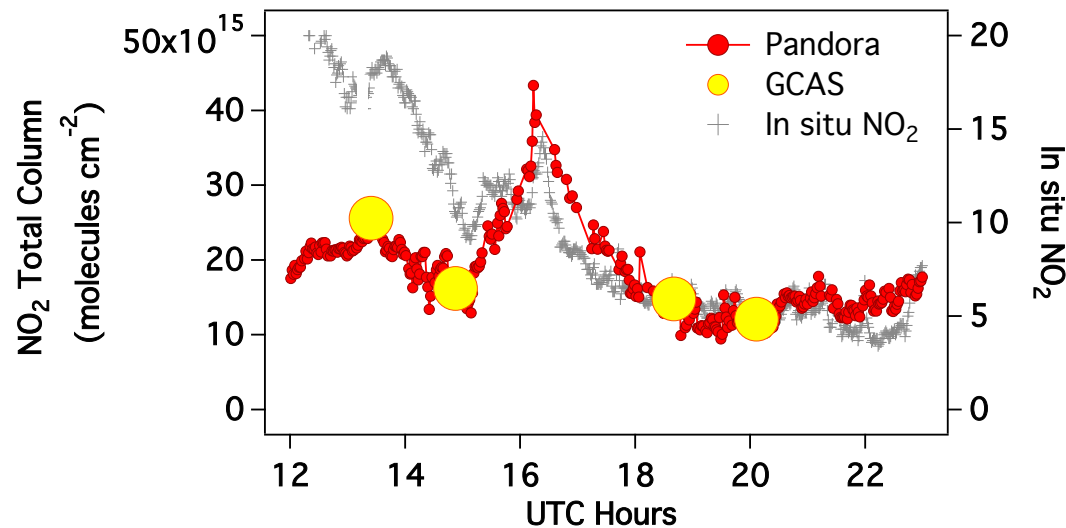
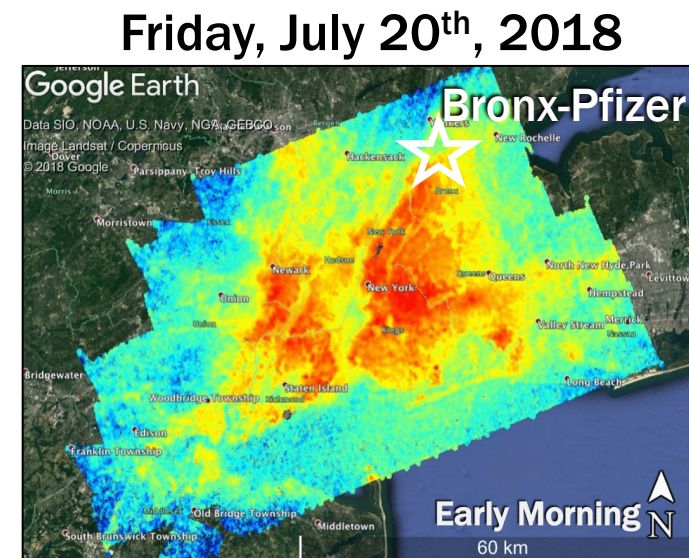
Tropospheric NO₂ Column x10¹⁵ molecules cm⁻²



Surface-to-Column Connections/Challenges

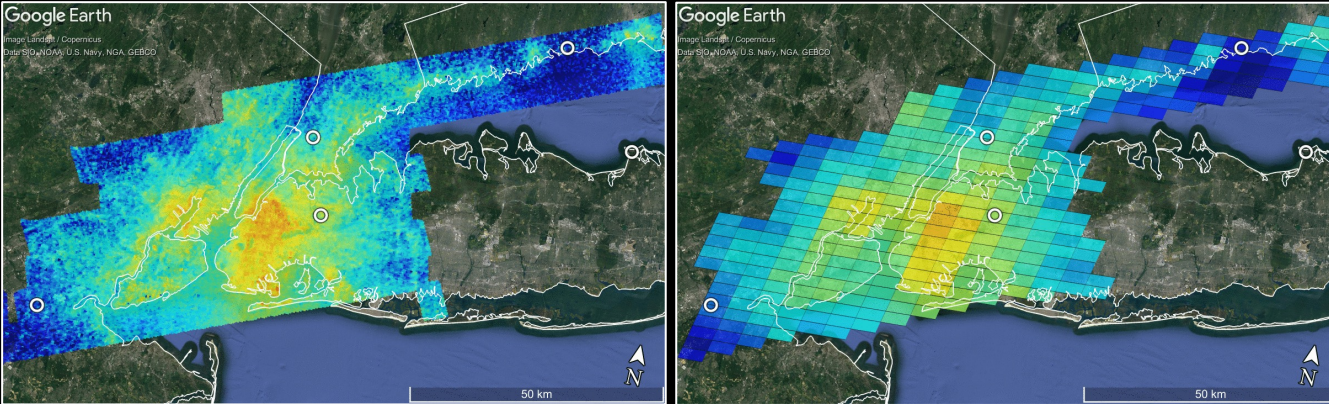
Pandora is a ground-based UV-VIS spectrometer system collecting spectra in which trace-gas column densities can be retrieved continuously throughout the day.

US EPA ORD has been working with state air quality agencies to integrate the column perspective at ground-monitoring locations (currently heavily weighted on the east coast)

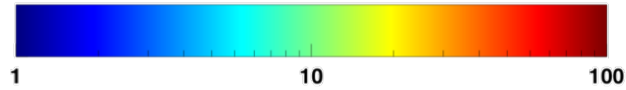


Challenges for Validation/Interpretations: TEMPO

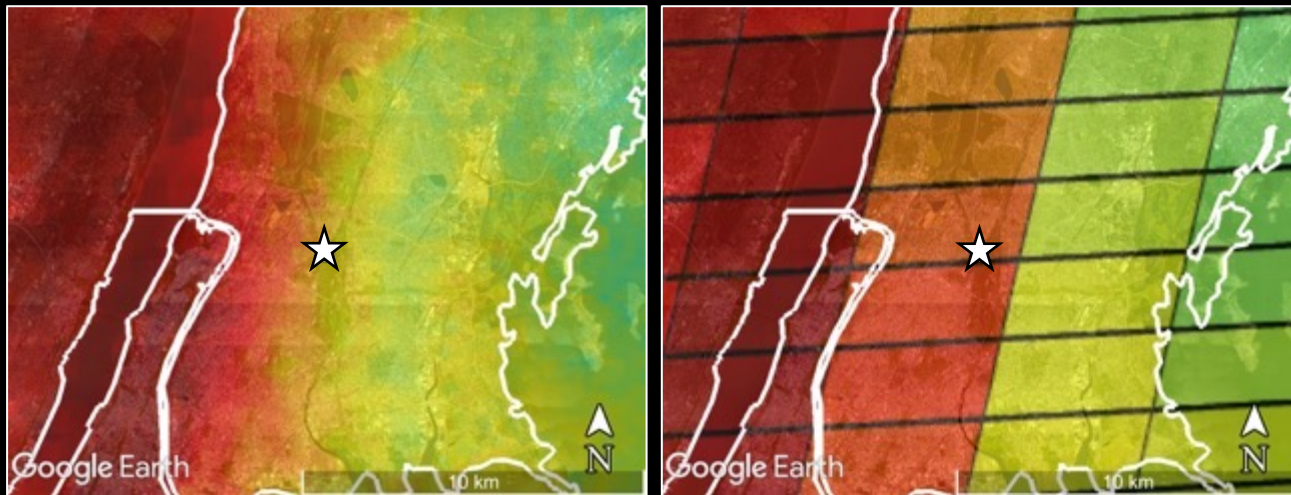
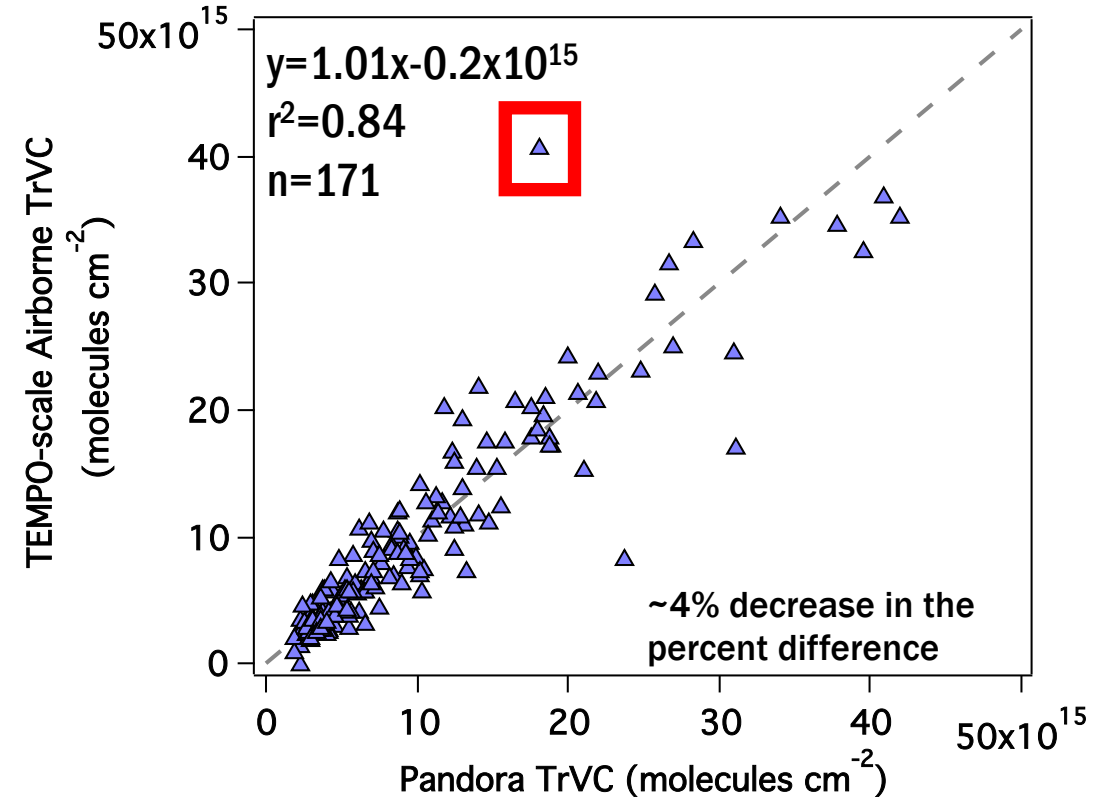
24 August 2018: 4 raster animation



Tropospheric NO₂ Column x10¹⁵ molecules cm⁻²



Bronx Pandora: July 2nd AM



Two Challenges

1. Spatial heterogeneity: Less of an issue than before but still can lead to mis-matches in areas with strong gradients
2. Temporal heterogeneity: the high temporal resolution of Pandora and the hourly measurements from TEMPO could help in identifying large changes over the hour time-frame

Proxy for ground-based ozone

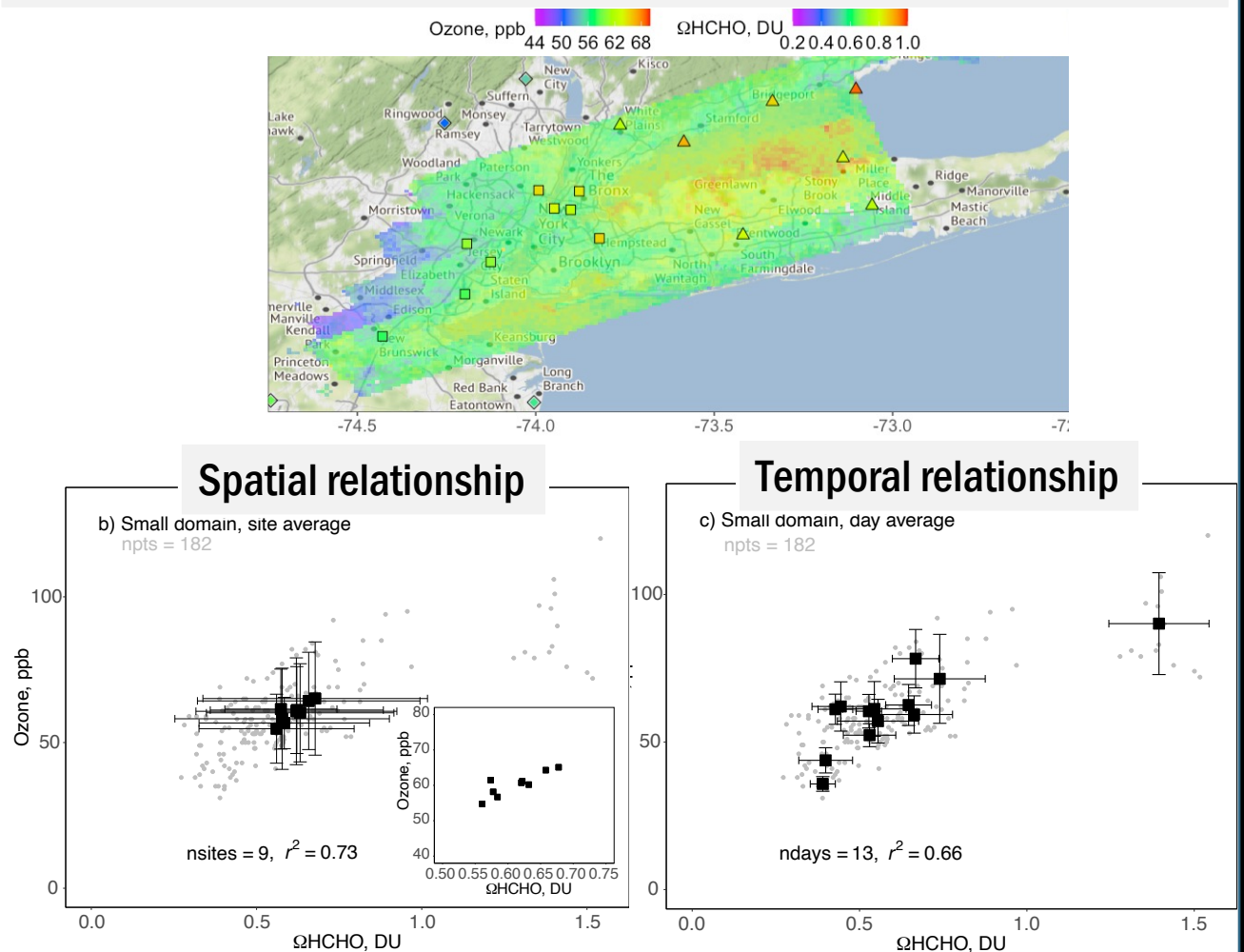
Long Island Sound Tropospheric Ozone Study

What we learned:

Column formaldehyde observations might be able to inform monitoring strategies for ground-level ozone

- Surface level ozone data is NOT available from satellites
 - Column formaldehyde from LISTOS correlates both spatially and temporally with surface ozone.
 - Spatial relationships are more informing toward ozone monitoring strategies employed by the US EPA and air quality management.
 - Emerging datasets collected during TRACER-AQ, the Pandonia Global Network, and TEMPO will provide more clarity on the utility of these relationships.
 - These results were only enabled because of the systematic sampling with the payload on the NASA LaRC B-200
- LaRC B-200 from June-September 2018

Map: Column Formaldehyde from GCAS on board the NASA LaRC B200
Symbols: surface ozone



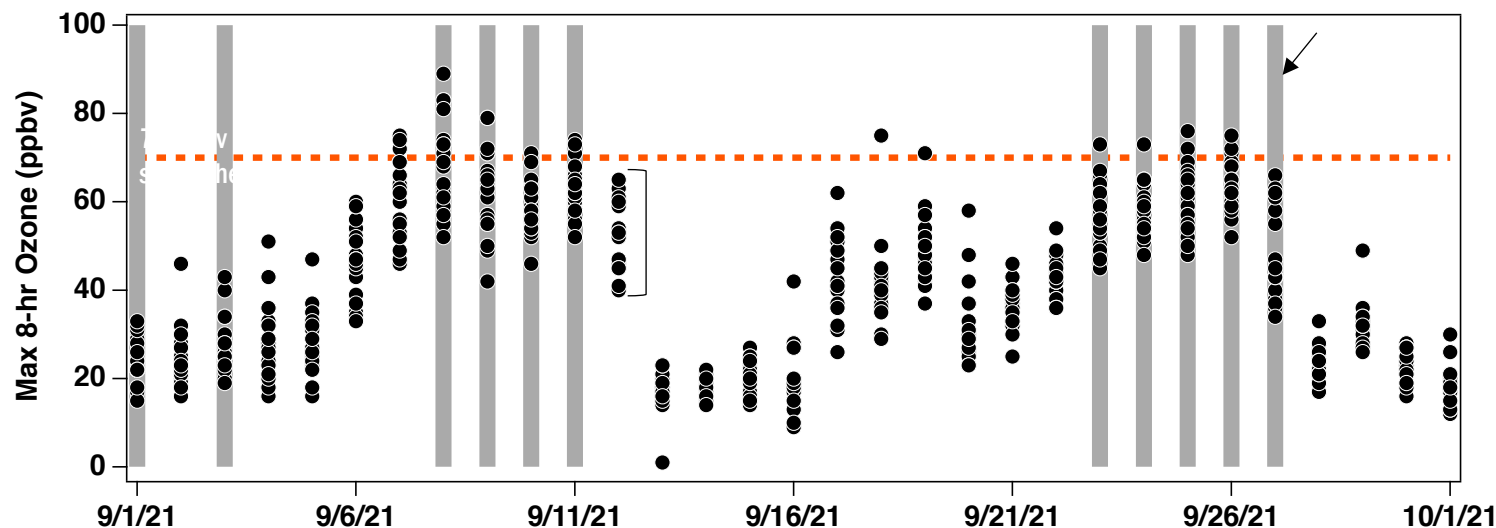
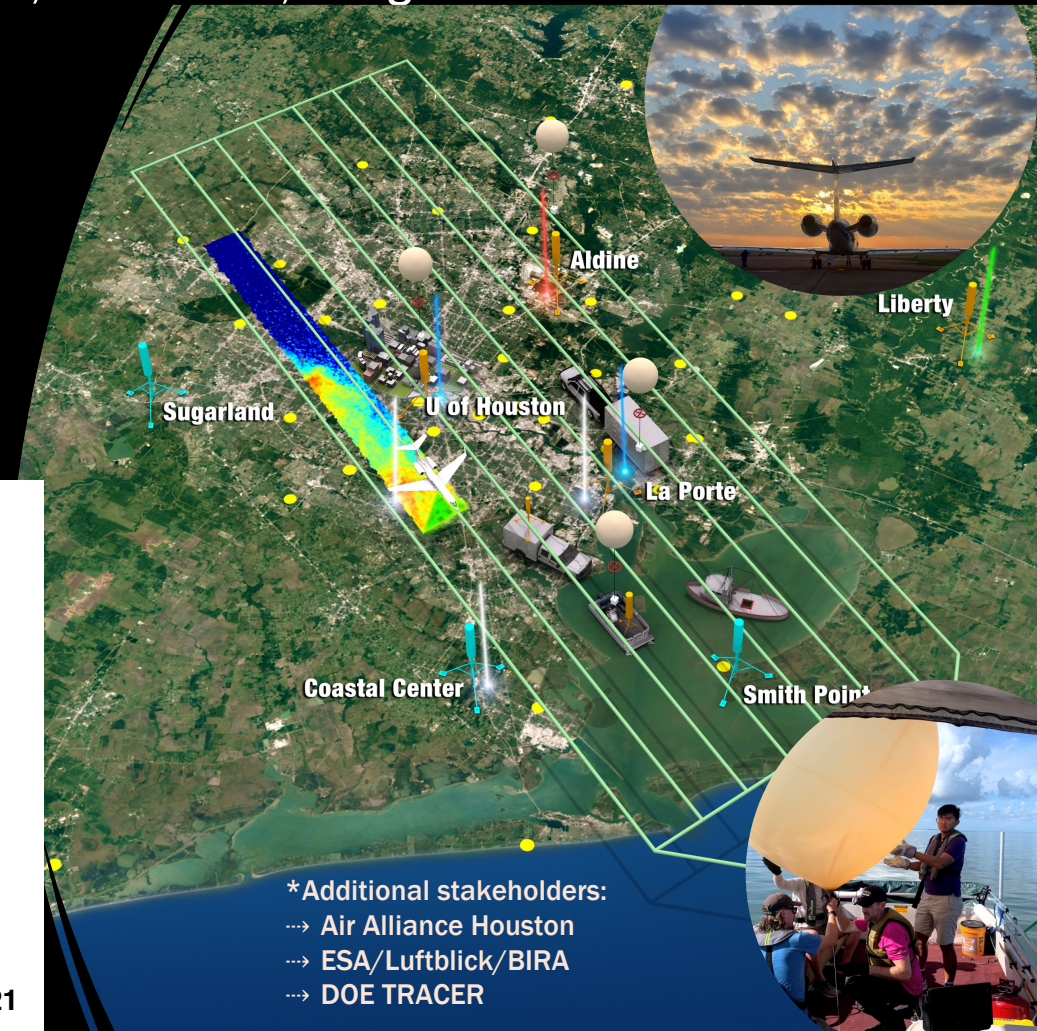
TRACER-AQ – September 2021

Tracking Aerosol Convection interactions Experiment-Air Quality

TRACER-AQ is a NASA-led air quality mission, leveraging DOE's TRACER study, with partners* from the Texas Commission on Environmental Quality (TCEQ) observing Houston pollution from aircraft, boats, mobile labs, and ground sites.

Mission goals jointly developed by NASA/TCEQ include capturing:

1. the current state of emissions and meteorology needed for mandated air quality plan development by the state of Texas
2. to identify pathways for tackling injustices related to pollution exposure in the region



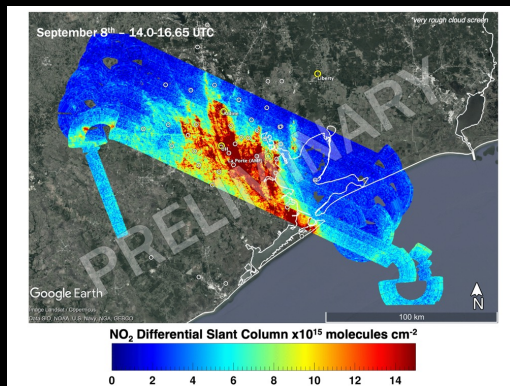
Visualizing chemical weather

Tracking Aerosol Convection interactions ExpeRiment-Air Quality

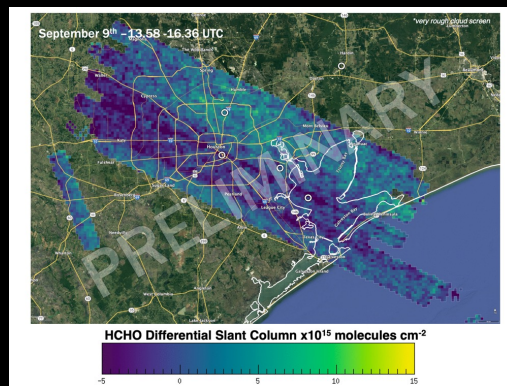
Air quality G-V payload from TRACER-AQ included the GEOCAPE Airborne Simulator and High Spectral Resolution Lidar 2-DIAL

- Spatial scales of these measurements reveal information about these pollution that cannot be captured by a satellites.
- The temporal sampling strategies give us a glimpse of the future with hourly air quality measurements we expect from TEMPO.

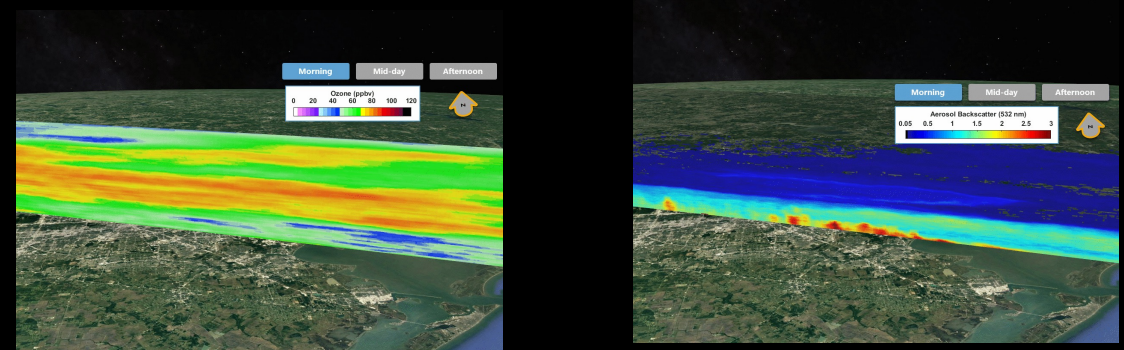
Visualizing emissions from combustion processes in the form of NO₂



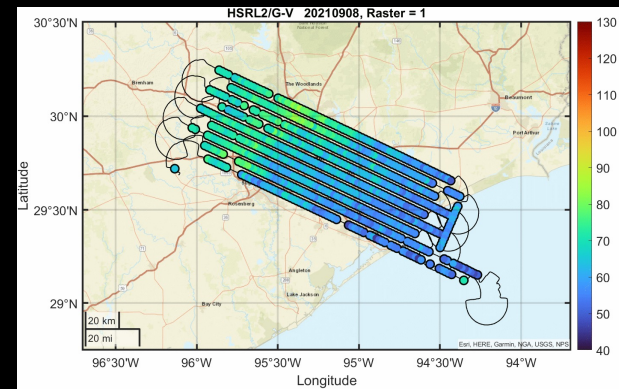
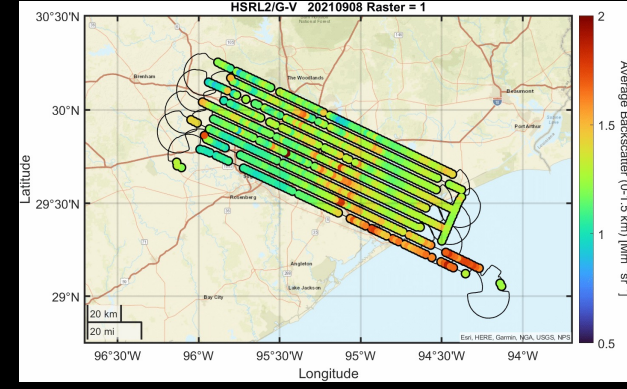
Visualizing the chemical breakdown of volatile organic compounds from industry near the ship channel



Systematically mapped the horizontal and vertical distribution of pollution 27 times during the month of September spanning morning-midday-afternoon. Below is from September 8th.



Near surface ozone and some aerosols are formed chemically as emissions move downwind through the day



TRACER-AQ is a NASA-led air quality mission, leveraging DOE's TRACER study, with main partners in air quality management from the Texas Commission on Environmental Quality (TCEQ) observing pollution from aircraft, boats, mobile labs, and ground sites.



Looking ahead...!



Synergistic TEMPO Air Quality Science (STAQS)

In June-August 2023, STAQS seeks to integrate TEMPO satellite observations with traditional air quality monitoring to improve understanding of air quality science and increase societal benefit.

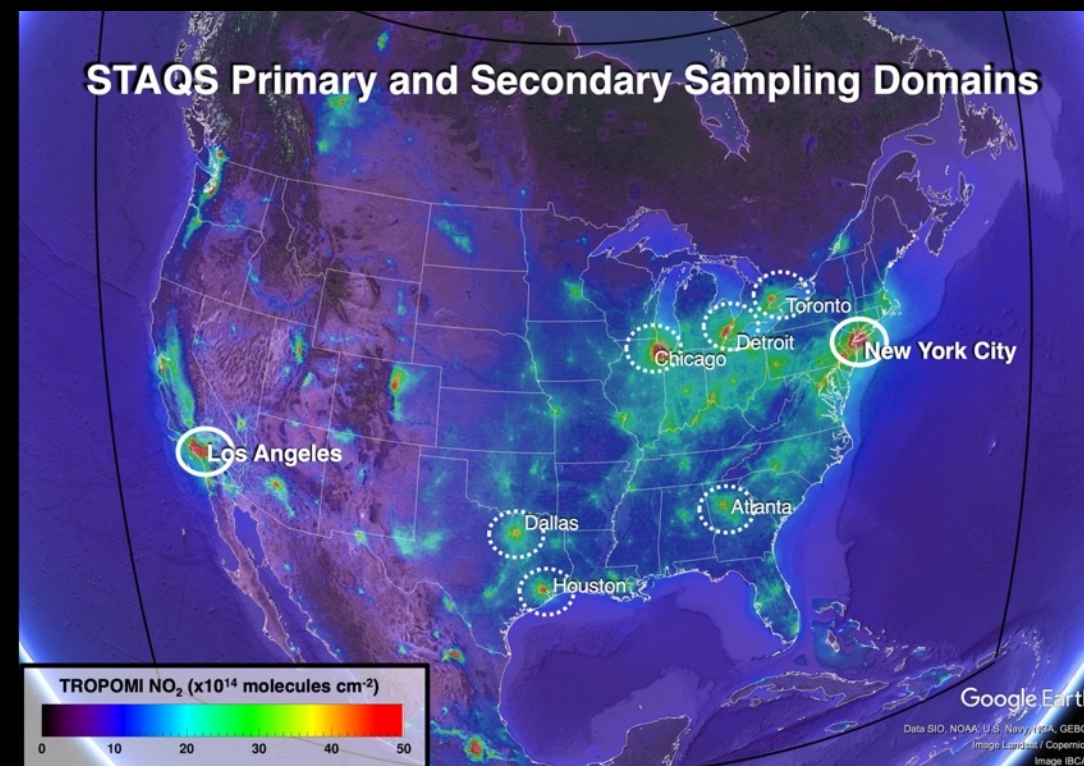
Science Objectives

- 1) Evaluating TEMPO level 2 products geo-physically, spatially, and temporally
- 2) Interpreting the temporal and spatial evolution of air quality events tracked by TEMPO
- 3) Improving temporal estimates of anthropogenic and biogenic trace gas and GHG emissions
- 4) Assessing the benefit of assimilating TEMPO data into chemical transport models
- 5) Linking air quality patterns to socio-demographic data

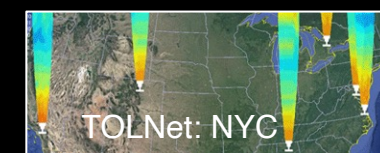
Collaborative activities:

- NOAA Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas (AEROMMA)
- NOAA Coastal Urban Plume Dynamics Study (CUPiDS)
- Greater New York (NY) Oxidant, Trace gas, Halogen, and Aerosol Airborne Mission (GOTHAAM)

Annual average of TROPOMI NO₂ overlaid with the currently planned primary (solid circles) and secondary (dotted circles) sampling domains during STAQS within the TEMPO field of regard (black outline).



Includes deployment of airborne and ground-based remote sensing observations





Thanks for you attention!

Follow up questions? laura.m.judd@nasa.gov

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