Evaluating TEMPO NO_2 over the New York City Metropolitan Area during CUPiDS

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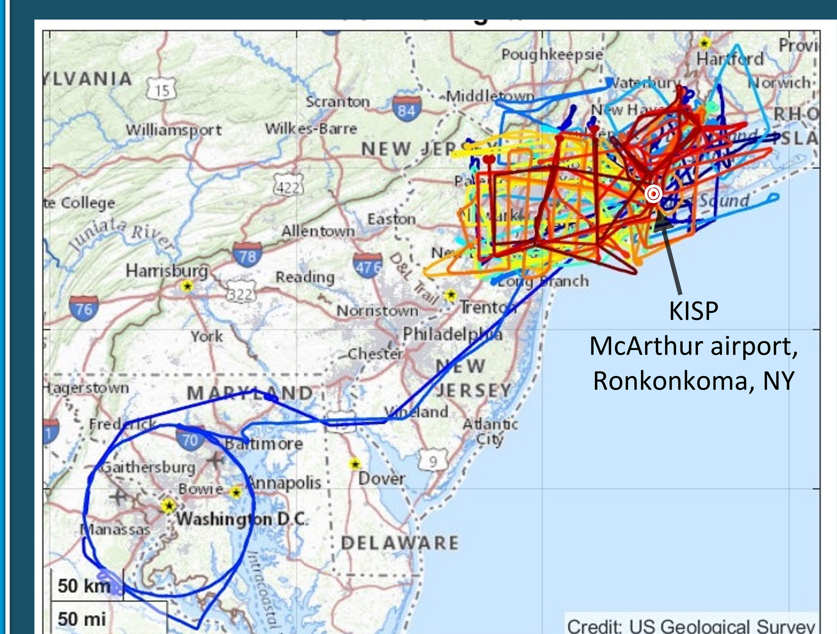
CUPiDS-2022: Scientific Motivation

The Coastal Urban Plume Dynamics Study (CUPiDS, July-Aug 2022) deployed the NOAA TwinOtter as part of the larger AEROMMA study (Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas) to address emerging research needs in urban air quality, marine emissions, climate feedbacks, and atmospheric interactions at the marine-urban interface.



Coastal urban areas face unique air quality challenges due to complex interactions between flows over land and water. CUPiDS flights were focused over the New York Metropolitan Area and Washington, DC (left, see flight tracks) with the following objectives:

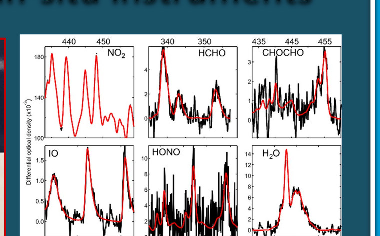
- Quantify reactive nitrogen emissions and O_3 production efficiency.
- Inform future satellite capabilities of monitoring atmospheric composition over North America
- Study spatial structure and temporal evolution of diurnal coastal flows, pollution transport and mixing.

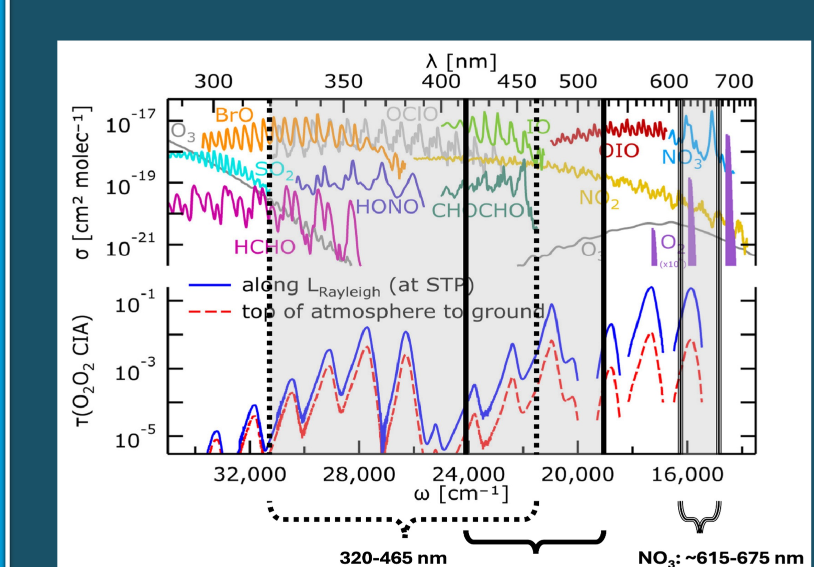
MacArthur Airport, Long Island,
18 Jul – 16 Aug 2023 (24 days in the field)
16 flight days
31 science flights (~100 science flight hours)

CUPiDS Instrument Payload

CUPiDS instruments	Measured Species
Scanning Doppler Lidar	**Wind**, **variance (turbulence)** and aerosol profiles **Boundary layer height**
MAX-DOAS	**NO_2**, formaldehyde, glyoxal columns Profiles during missed approaches
NO_xCaRD	In-situ NO, **NO_2**, NO_y, O_3
Picarro	In-situ CO_2, CH_4, CO, H_2O
Radiometer	Surface albedo at 360, 477, 577, and 630 nm Surface temperature
Filter radiometer	Up and downwelling NO_2 photolysis rate (jNO_2)

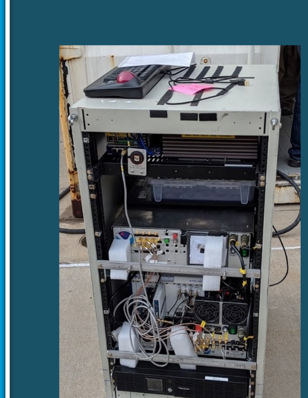
Chemistry + Dynamics measurements
Remote sensing + in-situ instruments





CU Airborne Multi-Axis DOAS

- Trace gas column observations
- Motion stabilized design: Forward, zenith to nadir scanning
- 2x CCD detectors:
  320-465nm
  415-525nm
- FOV: 550 m along track x 20 m cross track (at 4 km), 1-2 sec int. time
- Surface albedo sensor (4-channels: 360, 477, 630, 870 nm) in support of RTM calculations



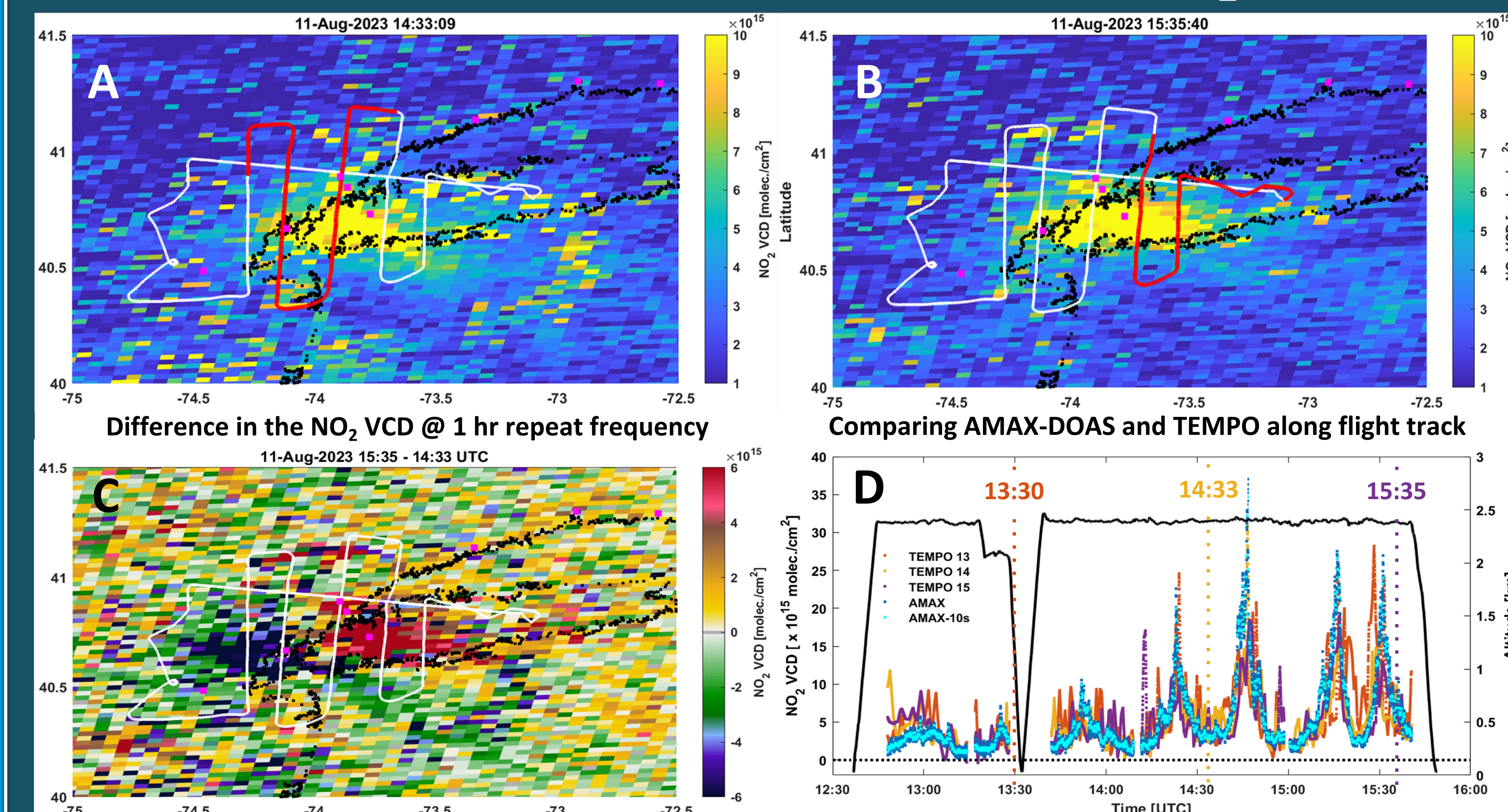
NOAA Scanning Doppler lidar

- Compact motion stabilized design: Look up or down @ 1.5 micron
- Horizontal wind profiles: Scanning 30 deg/s, Beam rate 10 Hz, one sweep every 12s / 720 m along track resolution, 60 m vertical resolution,
- Vertical wind profiles: 10 Hz Beam rate, 6m along track resolution, 60m vertical resolution

NOAA NO_xCaRD

- Cavity Ring Down Spectroscopy

Application #1: Comparison with TEMPO NO_2 (tentative)

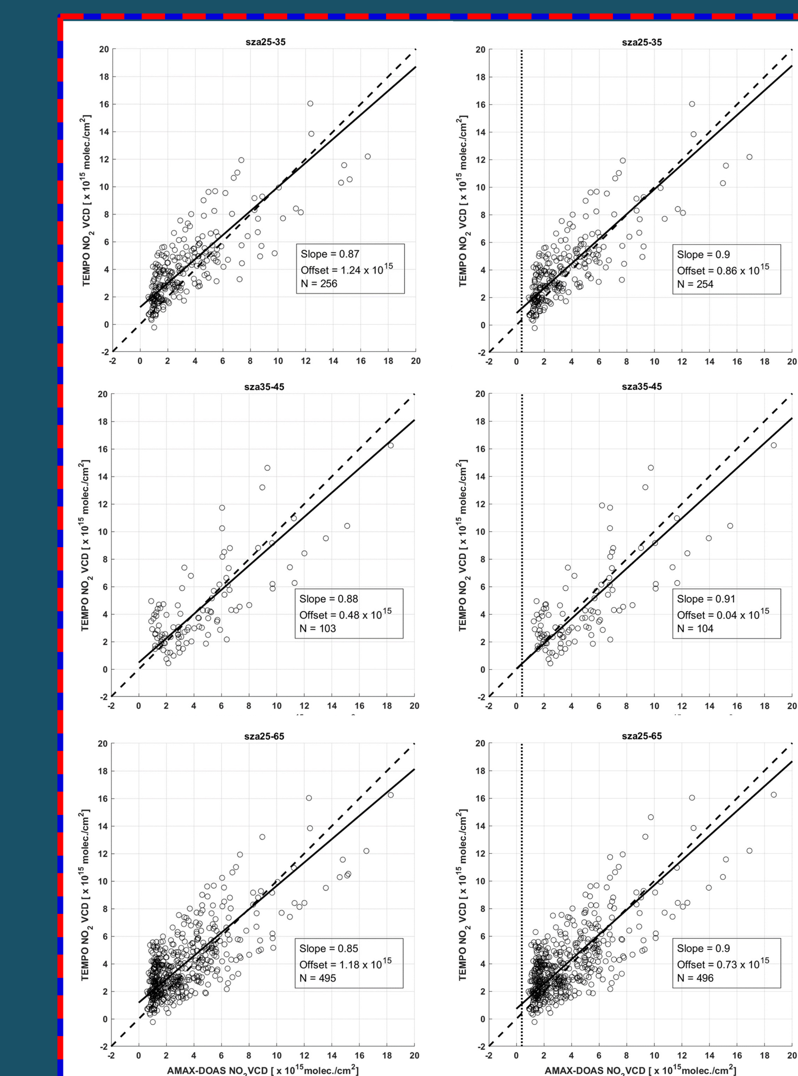


Above: TEMPO tropospheric NO_2 VCDs are compared with AMAX-DOAS for RF25 on 11 Aug 2023

- TEMPO maps at 14:33 UTC (panel A) and 15:35 UTC (B) and their difference (C); (red markers) Pandora sites.
- At a given location, the ΔNO_2 VCD ranges from -6E15 to +6E15 molec cm^{-2} within ~1 hr
- NO_2 VCD along the flight track is compared with hourly TEMPO maps (D)

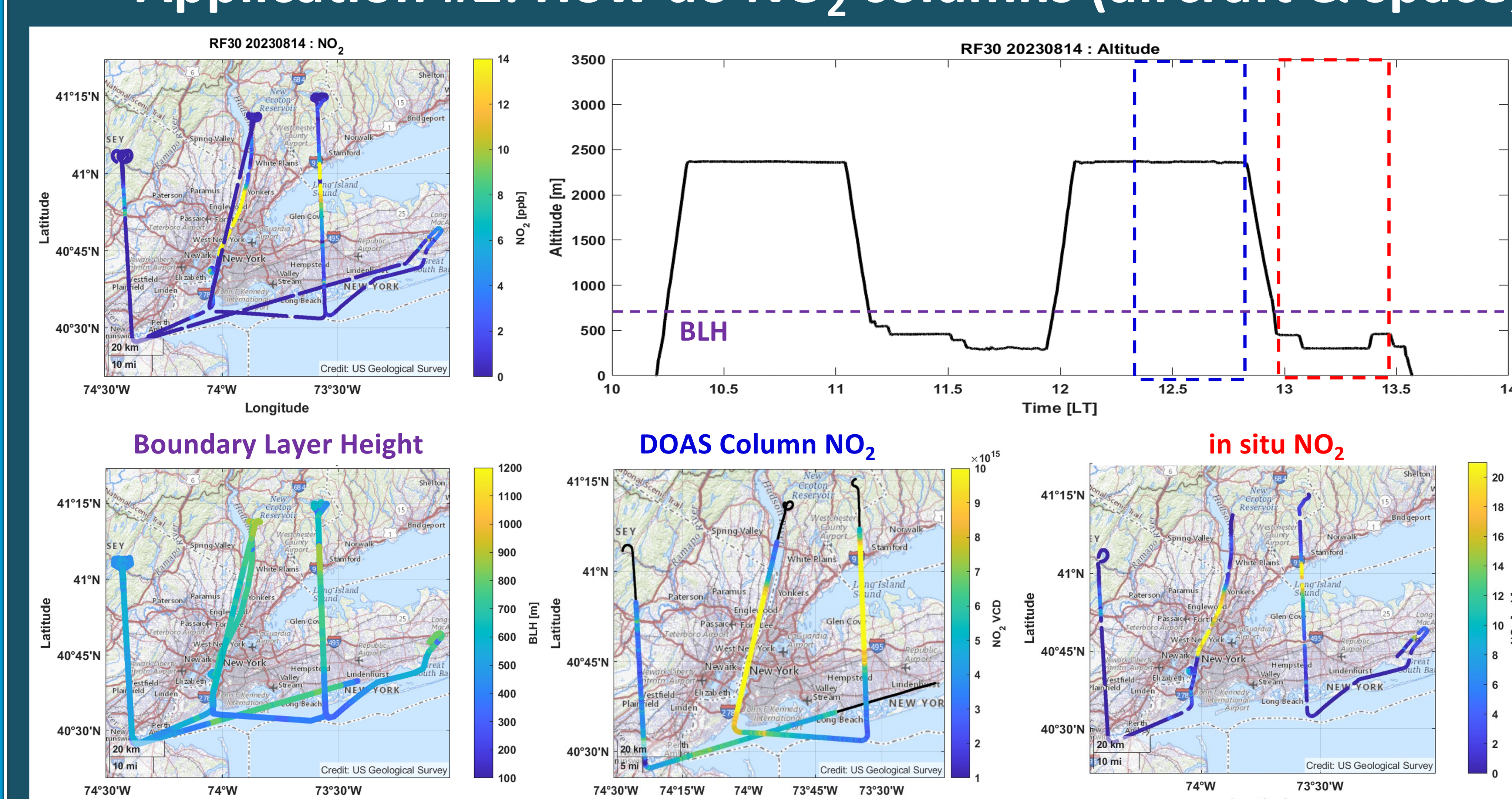
→ NO_2 VCD varies on fine temporal and spatial scales (few 100m / minutes) – TEMPO special obs (10 min frequency) hold promise to address this fundamental sampling challenge!
→ Future deployments are planned over Denver & Utah during summer 2024 (1 Jul – 12 Aug) and hold unique potential to evaluate TEMPO in different environments.

RF23 & RF25

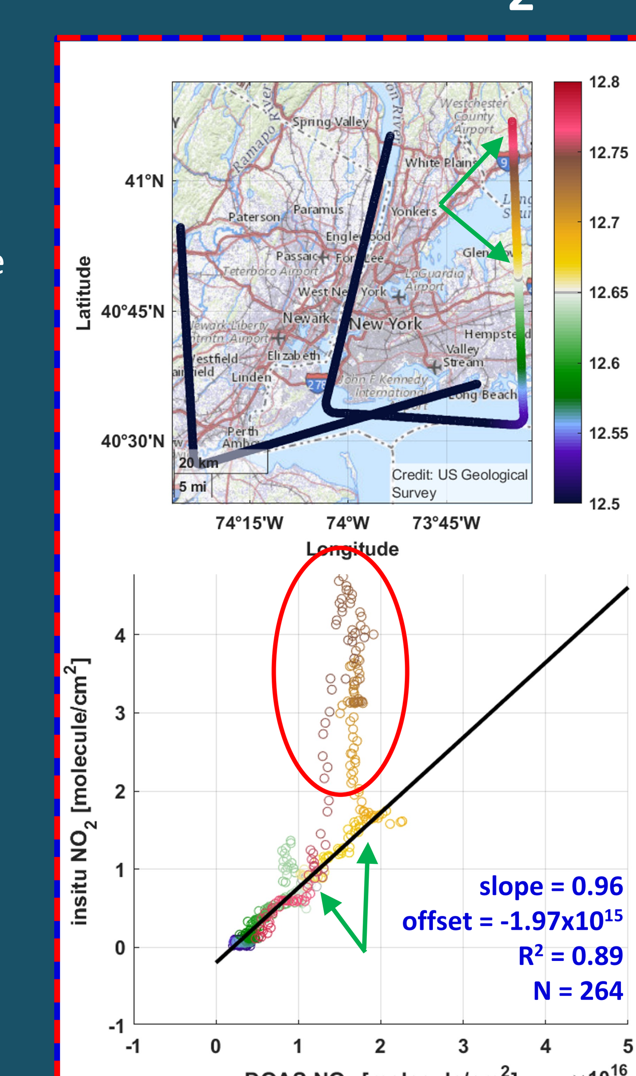


Comparison of RF23 and RF25 data with TEMPO. Criteria: 1) Aircraft above 2km & sampling within 30min (left column); 2) NO_2 above the aircraft added (right, dashed line indicates magnitude of correction); 3) as a function of SZA.

Application #2: How do NO_2 columns (aircraft & space) relate to street level NO_2?



Combining active & passive remote sensing with in-situ observations



Above: Example data from RF30 on 14 Aug 2023 – stacked legs inside and above boundary layer
All data needed to investigate this problem are available from measurements aboard the aircraft

- Over land: very good agreement between NO_2 columns and in-situ NO_2 integrated over boundary layer height
- Coastal domain: strong deviations are observed on fine spatial scales

→ Satellite (i.e., TEMPO, TropOMI) data in coastal environments is complex! Opportunities to advance state-of-the-art.

The above question requires solving a coupled chemistry and dynamics problem. Fine scale gradients at the land-ocean interface are directly observed here and are relevant to public health discussions and exposure assessments. About 40% of the world population is living within 100 km from coasts.

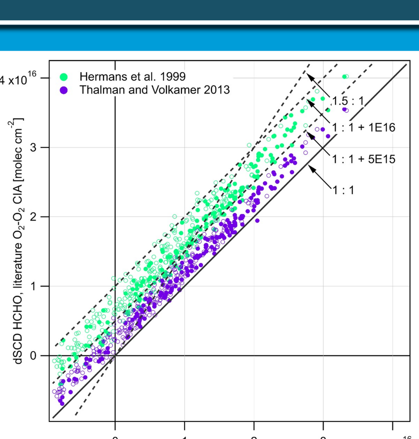


Figure left: DOAS sensitivity study of HCHO slant column fitting (336.5–359 nm) using three sources of O_2-O_2 cross-section data during RF23 (open circles) and RF25 (closed circles): (1) Hermans et al. (1999); (2) Thalman and Volkamer (2013); (3) Finkenzeller and Volkamer (2022); the latter leads to systematically lower HCHO slant columns.

Acknowledgements:

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CUPiDS Coastal Urban Plume Dynamics Study 2023