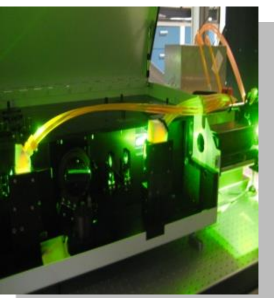
# TOLNet

*Tropospheric Ozone LIDAR Network*

# Measuring the Spatio-temporal Distribution of Pollution with Tropospheric Emissions: Monitoring of Pollution (TEMPO) Geostationary Satellite Observations and Ground-based Tropospheric Ozone Lidar Network (TOLNet) Ozone/Aerosol Differential Absorption Lidar (Ozone/Aerosol DIAL).

Transportation, Air Quality, and Health Symposium
February 18-20, 2019
Austin, TX


**Michael Newchurch[1]**, Kelly Chance[11], Shi Kuang[1], Ali Akan[2,3], Raul Alvarez II[4], Timothy Berkoff[3], Gao Chen[3], Guillaume Gronoff[2,3], Matthew Johnson[5], Andrew Langford[4], Thierry Leblanc[6], Barry Lefer[7], Thomas McGee[8], Christoph Senff[4,9], Michael Shook[3], Kevin Strawbridge[10] , John Sullivan[9], Bo Wang[1], Emily Berndt[12], Aaron Neager[1]

*[1]UAH, [2]SSAI, [3]NASA/LaRC, [4]NOAA/ESRL, [5]NASA/ARC, [6]Caltech/JPL, [7]NASA/HQ, [8]NASA/GSFC, [9]CU/CIRES, [10]ECCC, [11]SAO, [12]NASA/MSFC*


THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

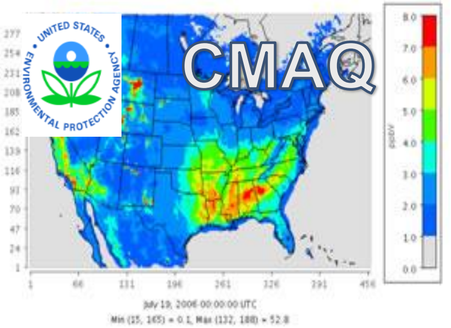
http://nsstc.uah.edu/atmchem/
https://www-air.larc.nasa.gov/missions/TOLNet/

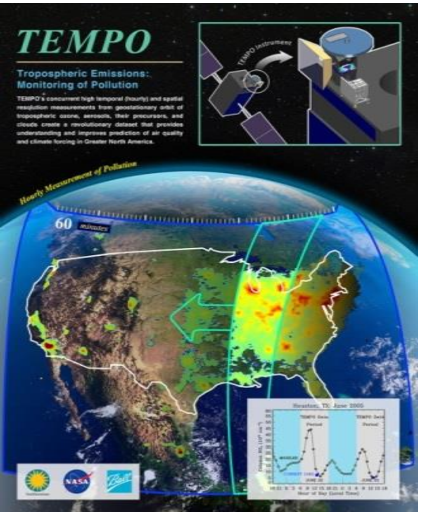
# TOLNet Objectives

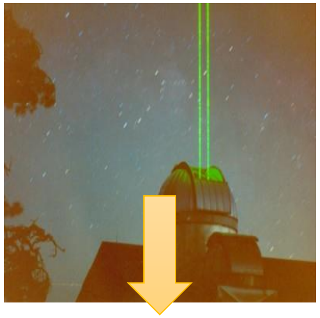
(1) **Provide high-resolution time-height measurements** of ozone and aerosols at a few sites from near surface to upper troposphere for air-quality/photochemical models and satellite retrieval validation;

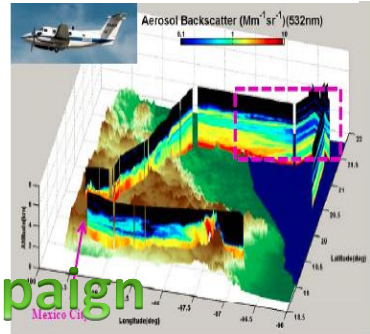
(2) **Support field campaigns and existing networks** (e.g., DISCOVER-AQ, SOAS, SENEX, SEAC$^4$RS) to advance understanding of processes controlling regional air quality and chemistry;

(3) **Develop recommendations** for lowering the cost and improving the robustness of such systems to better enable their possible use in future national networks to address the needs of NASA, NOAA, EPA and State/local AQ agencies.



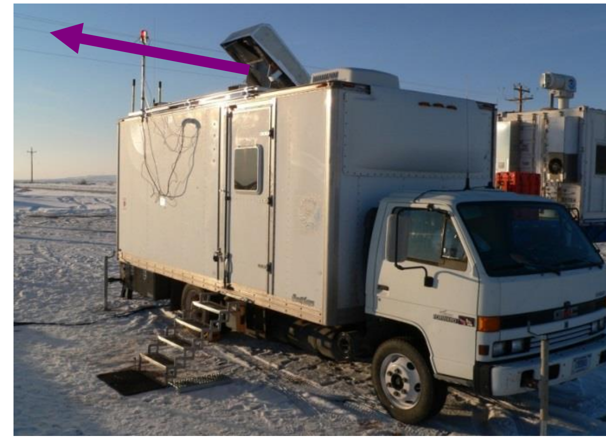



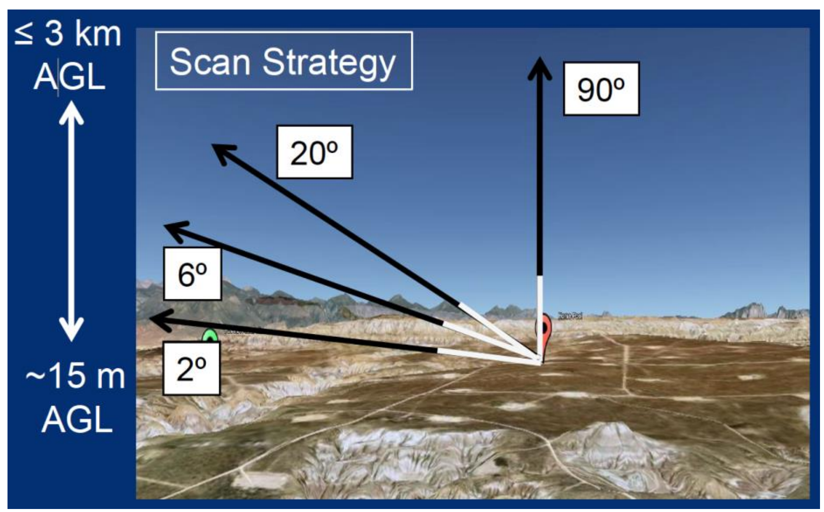



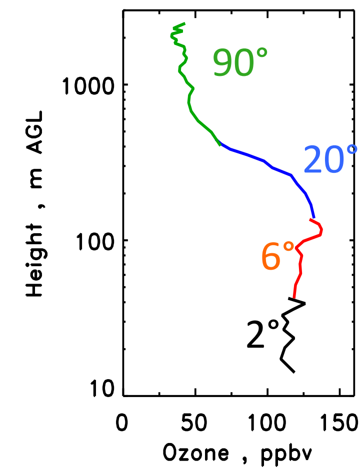
# NOAA Mobile Ozone Lidar

| Name | TOPAZ (Tunable Optical Profiler for Aerosol and oZone) lidar |
|---|---|
| Affiliation | NOAA/ESRL |
| Host location | Boulder, CO |
| Set-up | Mobile |
| Transmitter type | Quadruple Nd:YLF pumped Ce:LiCAF laser (tunable wavelength) |
| Wavelength (nm) | Typically 287, 291, 294 |
| Receiver size (cm) | 50 |
| Measurable range (km AGL) | 0-3 |
| Reference | [Alvarez et al., 2011] |

- Tunable UV ozone DIAL
- O3 and aerosol backscatter profiles from ~15 m up to 3 km AGL





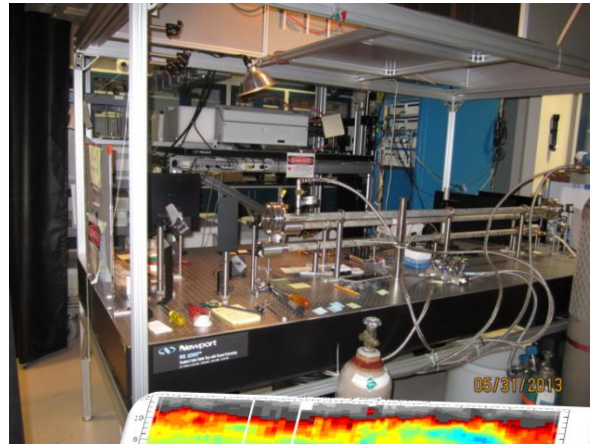




Composite vertical profiles every 5 min

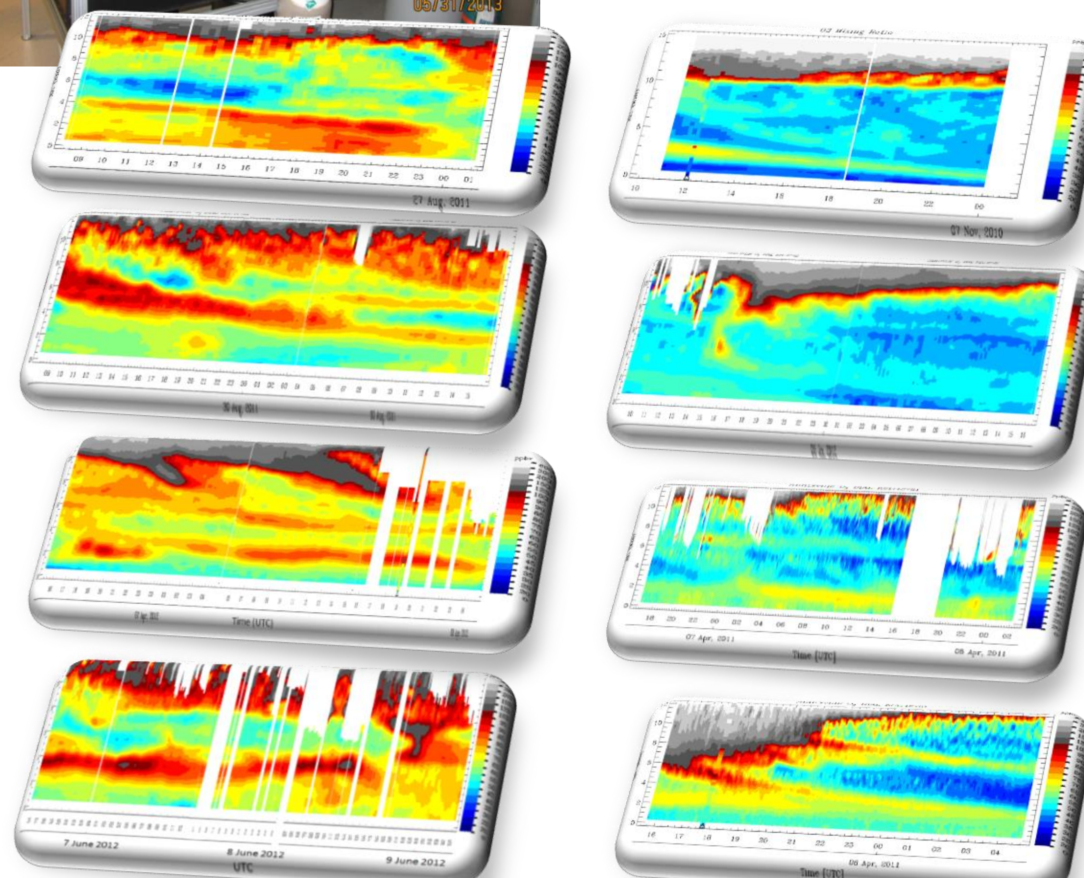
# UAH Ground-based O3 lidar

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

| | |
|---|---|
| **Name** | **RO$_3$QET (Rocket-city O3 Quality Evaluation in theTroposphere) lidar** |
| **Affiliation** | UAH |
| **Host location** | Huntsville, AL |
| **Set-up** | Fixed-location |
| **Transmitter type** | Quadruple Nd:YAG pumped Raman laser |
| **Wavelength (nm)** | 289, 299 |
| **Receiver size (cm)** | 40, 10, 2.5 |
| **Measurable range (km AGL)** | 0.1-12 |
| **Reference** | [Kuang et al., 2011, 2013] |



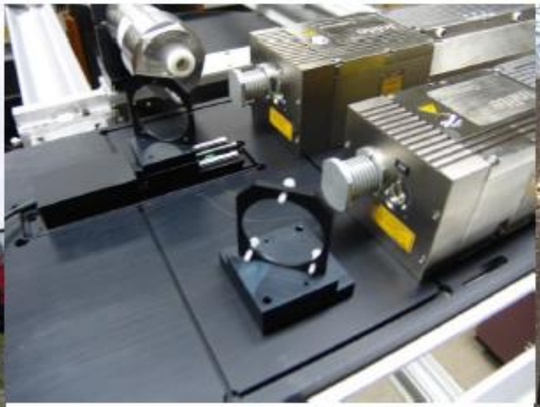

Raman shifted 289/299



**Examples**


Environment Canada    Environnement Canada    Canada

# Autonomous ozone and aerosol lidar measurements: a synergistic approach to air quality



**Kevin Strawbridge**

Air Quality Processes Section, Environment Canada

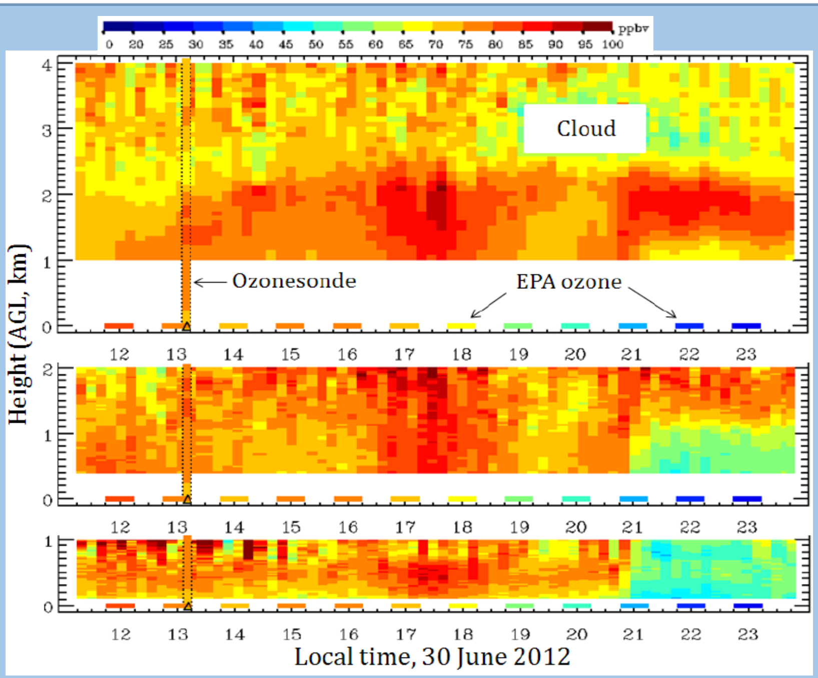
email: Kevin.Strawbridge@ec.gc.ca

# 3 TOLNet lidars Measuring Ozone Below 100 m

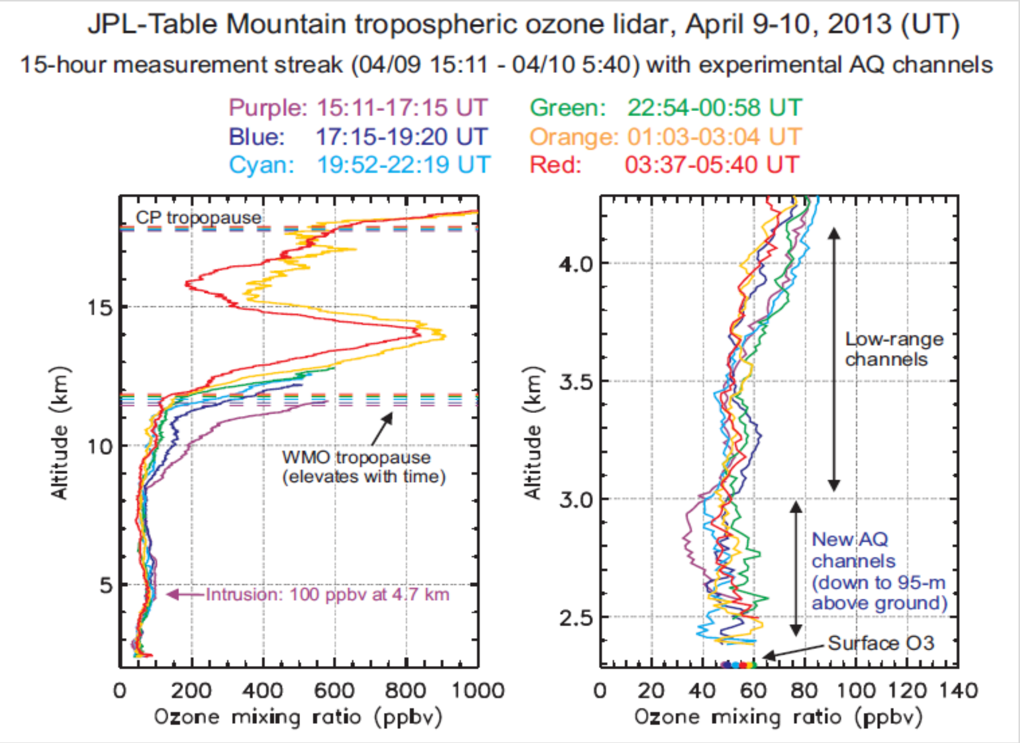
TOLNet is an emerging ground-based network making the first ozone lidar profiles from < 100 m to the stratosphere.

Mike Newchurch[1], Raul Alvarez[2], Russell DeYoung[4], Mike Hardesty[2], Shi Kuang[1], Andy Langford[2], Thierry Leblanc[5], Stuart McDermid[5] , Tom McGee[3], Christoph Senff[2], John Sullivan[3]

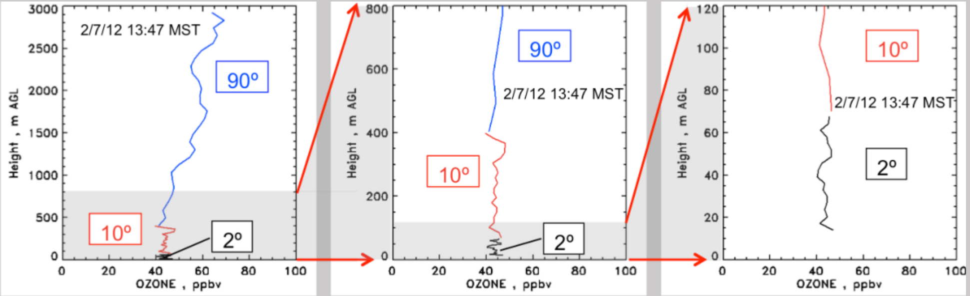
**5 TOLNet Stations:** *[1]UAHuntsville, [2]NOAA/ESRL, [3]NASA/GSFC, [4]NASA/LaRC, [5]NASA/JPL*


UAH Ozone lidar retrievals from the 3 lowest altitude channels compared with ozonesonde (marked by black triangle at 13:10 launch time) and EPA (~16 km away) hourly surface measurements. A 4th channel (not shown) measures the middle and upper troposphere.




The NOAA/ESRL two-axis scanning lidar is installed in a truck. By using the scanner to direct the beam to low elevation angles, measurements are obtained to within a few meters of the surface. Azimuth scanning provides horizontal structure of ozone.

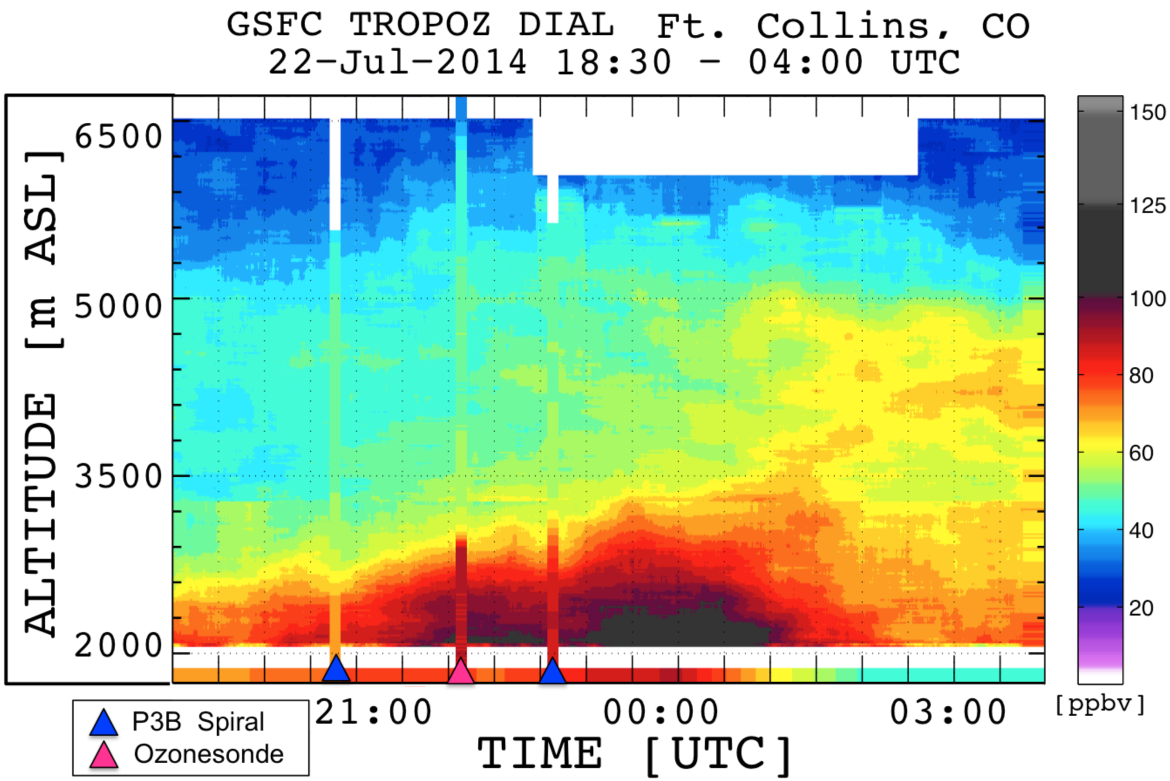



Lidar observations were made at elevation angles of 2°, 10°, 90° and pieced together to create a profile with higher vertical resolution near the surface.

# TOLNET

*Tropospheric Ozone LIDAR Network*


## GSFC TROPOZ Observations from DISCOVER-AQ July 22-23 2014 at Ft. Collins, CO

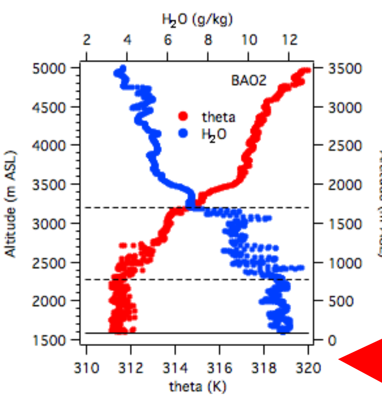



- GSFC TROPOZ DIAL observations on July 22 and 23 2014 compare well with the NASA P3B Spiral-down and co-located ozonesondes.
- The surface monitor is shown in the lowest bin of the figure, which indicates the greatest enhancement near 0 UTC (18 MDT) and quickly becomes less polluted at the surface.
- However, aloft ozone concentrations remain elevated and are characterized with extended TROPOZ measurements

- This elevated ozone event was delayed from the typical diurnal maximum during the DISCOVER AQ campaign period by several hours.
- Further analysis has shown that the increase in near surface (1570m ASL) ozone was correlated with a convectively driven upslope – downslope flow transition, which subsequently converged over Ft. Collins, CO.

# Multiple lidar probing of wave dynamics and entrainment of the morning residual layer (RL) at the Boulder Atmospheric Observatory (BAO) during DISCOVER-AQ/FRAPPÉ: An example from July 29, 2014.

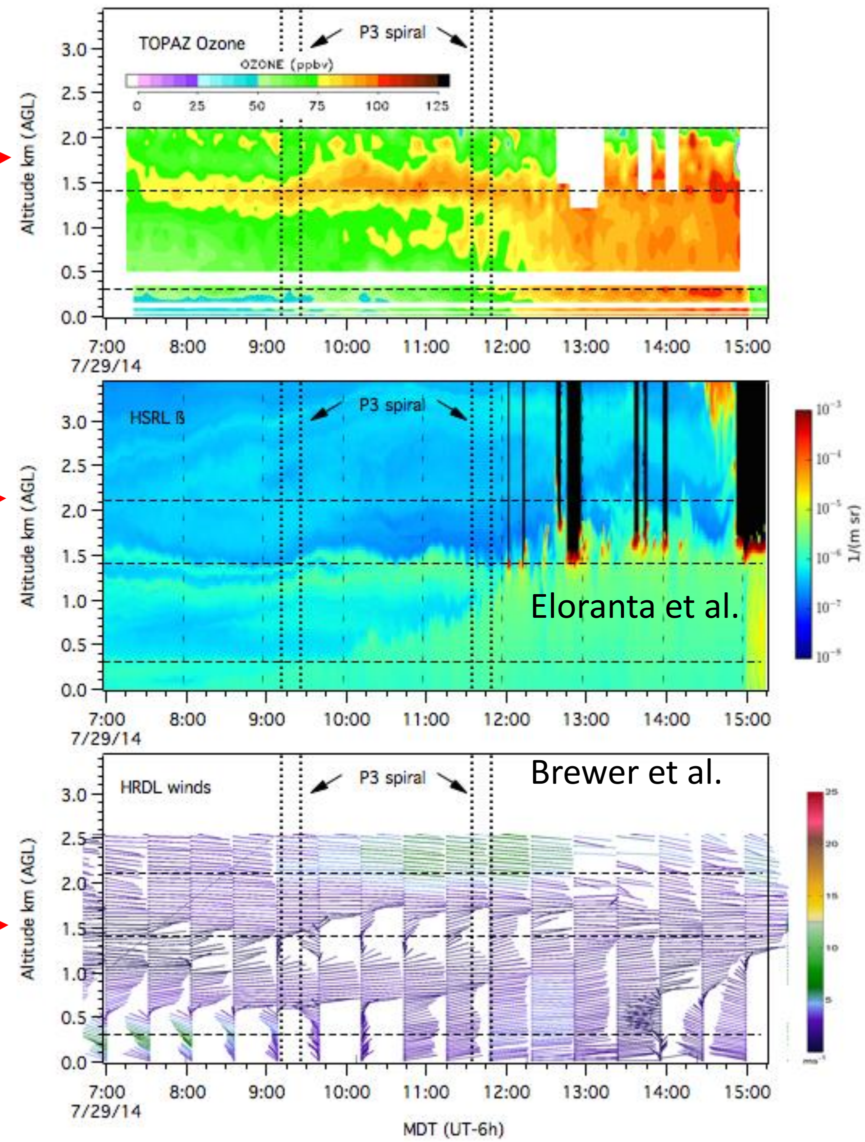
Measurements from the NOAA TOPAZ lidar show a narrow morning RL with 75-90 ppbv of $O_3$ that is enveloped by the growing convective boundary layer (CBL) near midday. The P3 showed this RL extending over a large area. The observations were ended by T-storms near 1500 MDT.




The aerosol distribution from the collocated U Wisc HSRL (High Spectral Resolution Lidar) shows similar structures with gravity wave (GW) activity in the RL between 1000 and 1200 MDT.

The water vapor profile from the second BAO spiral also show this wave activity.

NOAA HRDL (High Resolution Doppler Lidar) located nearby shows predominately easterly winds with directional shear in the RL during late morning that may have triggered GWs. T-storm outflow causes low level winds to rotate to WNW in afternoon.




**A.O. Langford, NOAA ESRL ARS**

# Horizontal Lidar Measurements of Near-surface Ozone

Shi Kuang, Mike Newchurch, Bo Wang, Paula Tucker, Kristen Pozsonyi, Ankur Shah *U. of Alabama in Huntsville*

TOLNET
Tropospheric Ozone LIDAR Network

## Background:

- Small-scale horizontal $O_3$ gradients occur due to inhomogeneous air pollution emissions, varying surface vegetation and complicated physical mixing and chemical reactions. High-resolution horizontal $O_3$ measurements are critical for urban-scale air-quality models and, however, were rarely conducted.

## Analysis:

- The UAH scanning lidar measured $O_3$ (*Fig. 1*) at ~20m AGL with a 2-min temporal resolution on the solar eclipse day, 8/22/2017. The lidar is ~10km, ~25km, and ~60km away from the Huntsville, Decatur, and Muscle Shoals EPA stations, respectively.

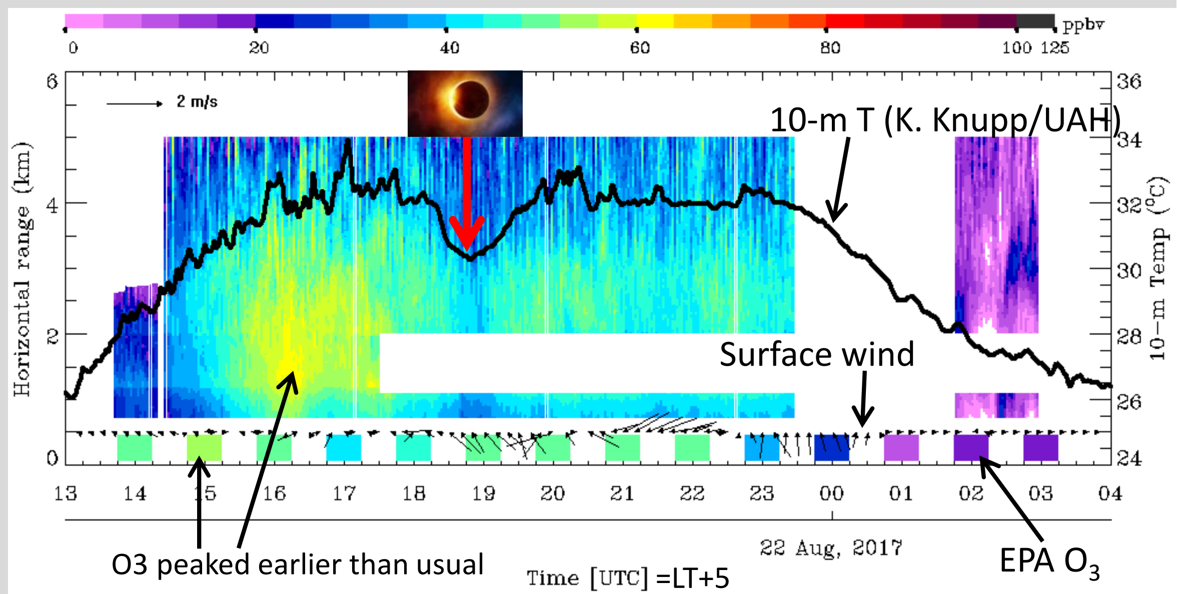



*Fig. 1. Horizontal $O_3$ lidar curtain and the Huntsville EPA $O_3$ measured on the solar eclipse day (8/22/2017).*

## Findings:

- Both the lidar and EPA $O_3$ peaked earlier than usual due to termination of increase of solar radiation, similarly as T.
- Lidar curtain reveals noticeable horizontal $O_3$ gradients during daytime consistent with the $O_3$ differences among the 3 EPA stations, up to 10 ppbv (*Fig. 2*).
- Lower lidar-O3 at all ranges during the solar eclipse (~2pm LT), behind the surface local low (12LT), suggesting surface is a sink for this location.

## Significance:

- The scanning lidar measurements can evaluate high-resolution atmospheric numerical models (e.g., LES models) and improve our understanding on small-scale air-quality problems.

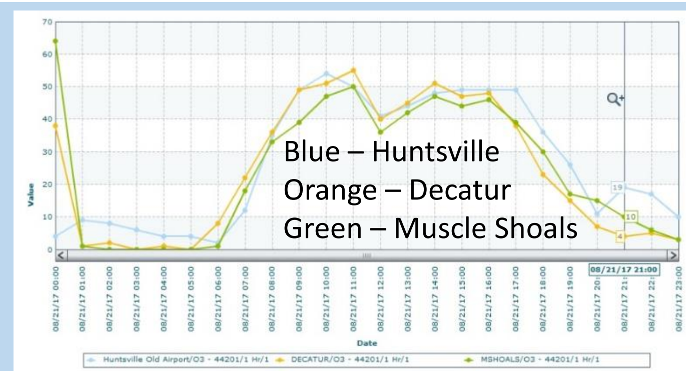
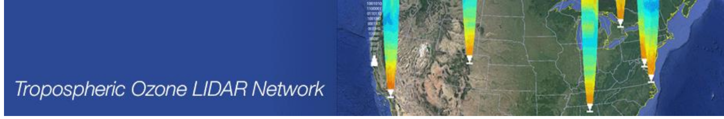



*Fig. 2. Surface $O_3$ measured at 3 EPA stations 10-60km away from the lidar site (AirNow).*

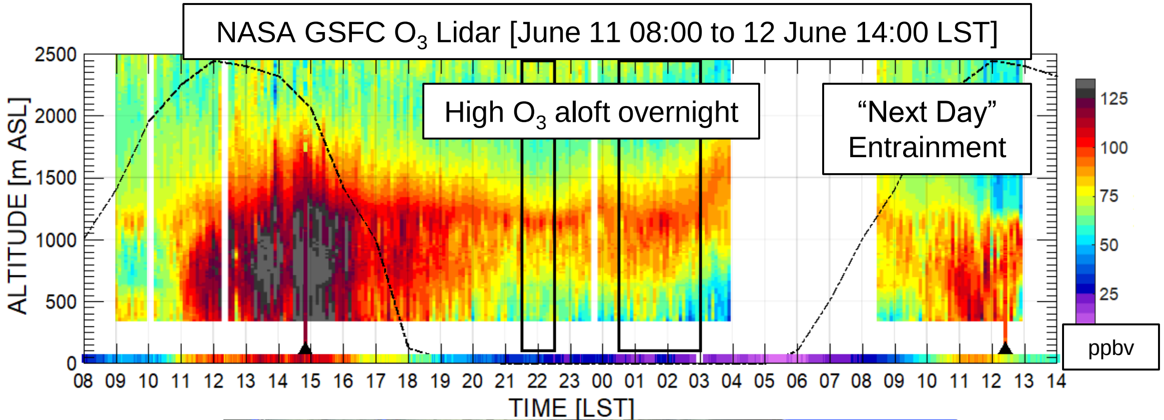
# TOLNet Observations Revealing "Next Day" Pollution Episodes




*John Sullivan, Thomas McGee et al., Atmos. Env. Vol 158.* *DOI:10.1016/j.atmosenv.2017.03.039*

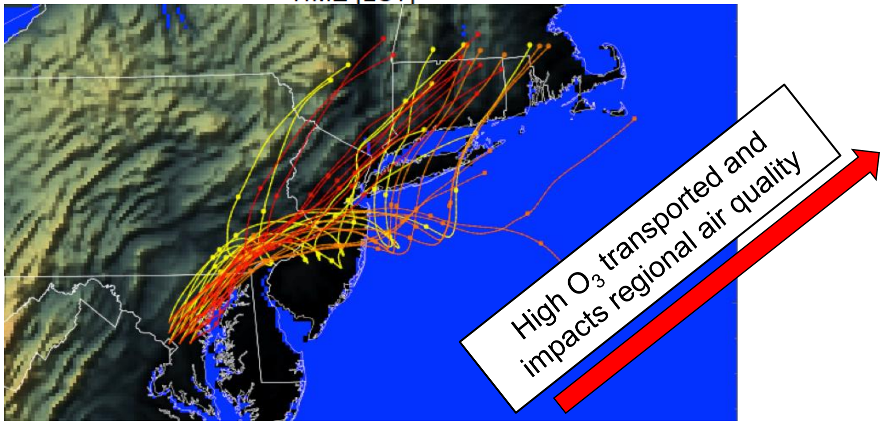
**Background:**

- TOLNet (Tropospheric Ozone Lidar Network) comprises 6 lidars dedicated to studying air quality, tropospheric ozone variability, and satellite validation.
- June 2015: The GSFC TOLNet lidar deployed to Beltsville, MD to support regional air-quality forecasts




**Analysis:**

- Top figure displays nearly 28 continuous hours of lidar and surface data including 2 sondes
- Bottom figure displays trajectories of the ozone profiles measured by the TOLNet/TROPOZ lidar
- Regional surface monitors assessed the potential impacts of this event




TOLNet/GSFC TROPOZ $O_3$ lidar observes high $O_3$ aloft (top), which is regionally distributed overnight and entrained on the following morning over a broad region (bottom)

**Results:**

- Trajectories indicate the nocturnal residual layer $O_3$ and other pollutants affected broad regions down wind
- Lidar and sondes both observed "Next Day" entrainment verified by surface monitors in the locations of high $O_3$

**Significance:**

*Ozone lidar is the critical measurement platform to identify layers aloft, advection, and vertical mixing of pollutants.*

# TOLNET

*Tropospheric Ozone LIDAR Network*



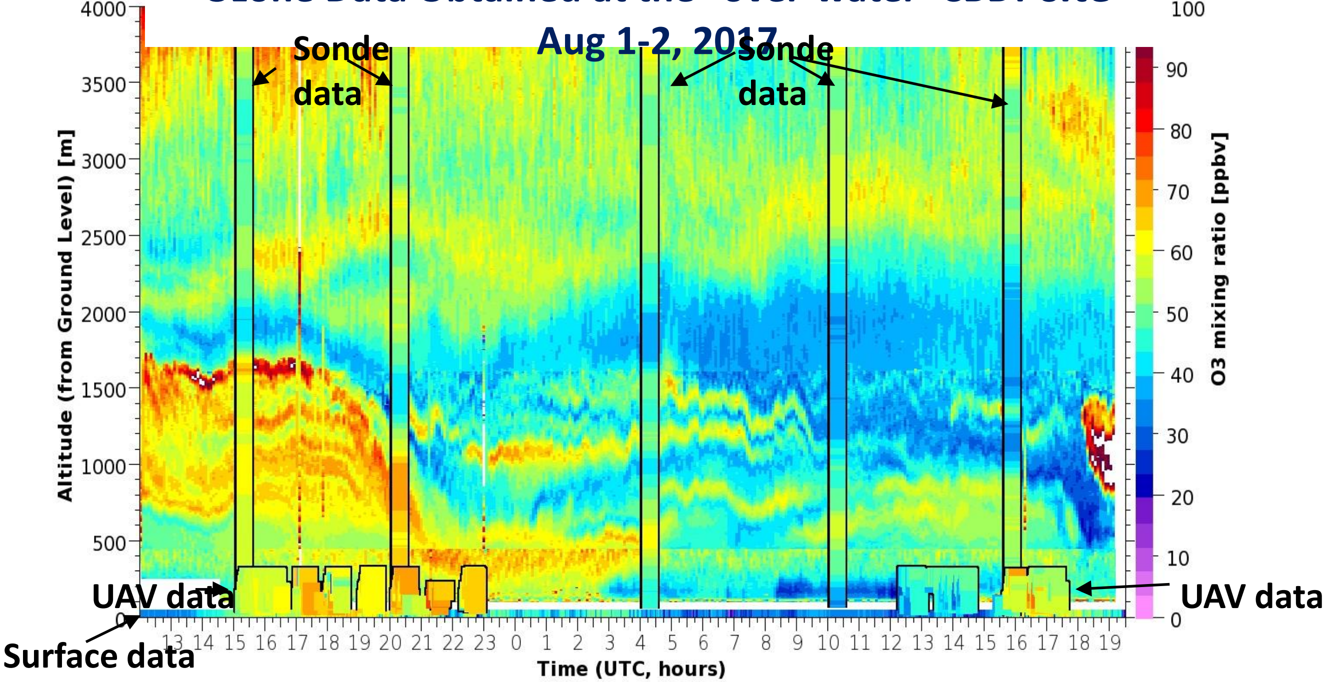


http://www-air.larc.nasa.gov/missions/TOLNet/

**TOLNet Langley Mobile Ozone Lidar: Preliminary Data**

**Ozone Data Obtained at the "over-water' CBBT site**

**Aug 1-2, 2017**



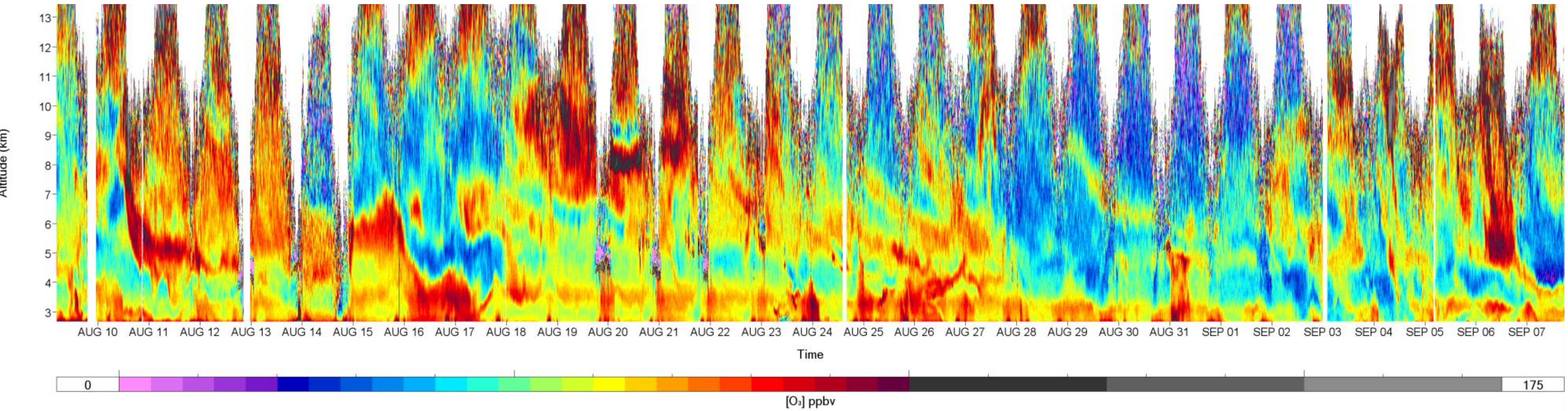

**During the Summer 2017 Ozone Water Land Environmental Transition Study (OWLETS) in the Tidewater region of Southern Virginia, ozone profile data were obtained at the third island of the Chesapeake Bay Bridge Tunnel, 7.5 miles off-shore. On Aug 1-2, the Langley Mobile Ozone Lidar (LMOL) ran for 30+ hours capturing diurnal cycle ozone dynamics resulting from the collapse of the Aug 1 daytime boundary layer and resultant residual layers leading into Aug 2. Also highlighted are the ozonesonde launches and data collected by a UAV/drone carrying an in-situ ozone sensor. The UAV/drone sensor provided the ability to investigate near-range variability, and helped to validate the capabilities of a new near-surface lidar channel on LMOL. This data when combined with other OWLETS measurements will help evaluate ozone transition behavior from land to water in complex coastal scenes where large gradients in ozone can occur.**

# TOLNET

*Tropospheric Ozone LIDAR Network*


ECCC continuous, atonomous observations at SCOOP:
31 days including the BlueCut fire TMF evacuation

*Courtesy of K. Strawbridge*

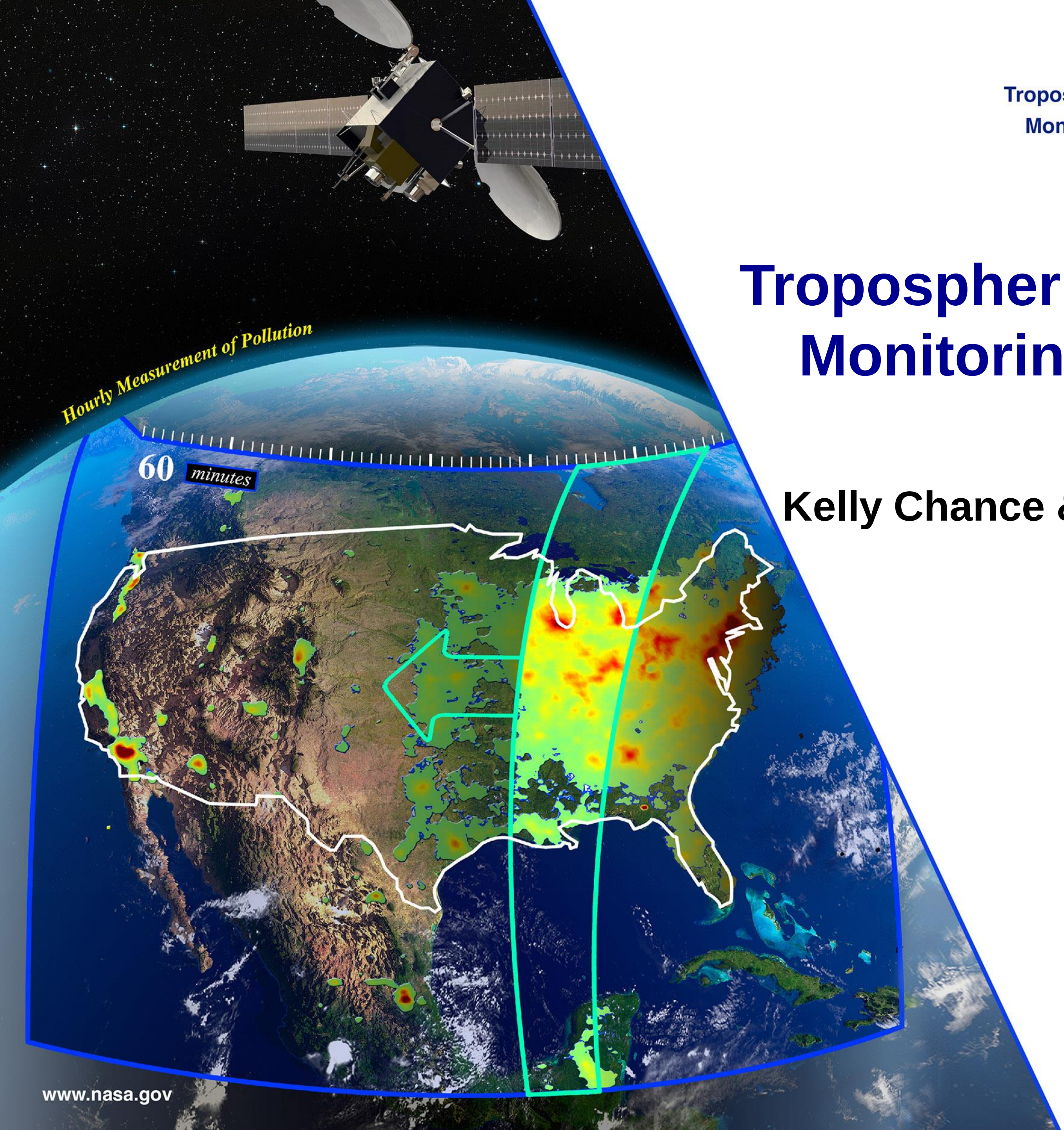


# TOLNet

*Tropospheric Ozone LIDAR Network*



**5th Annual TOLNet Meeting with NCACC**
**7-11 May 2018**
**Huntsville, AL USA**




Tropospheric Emissions:
Monitoring of Pollution

# Tropospheric Emissions: Monitoring of Pollution (TEMPO)

Kelly Chance & the TEMPO Team

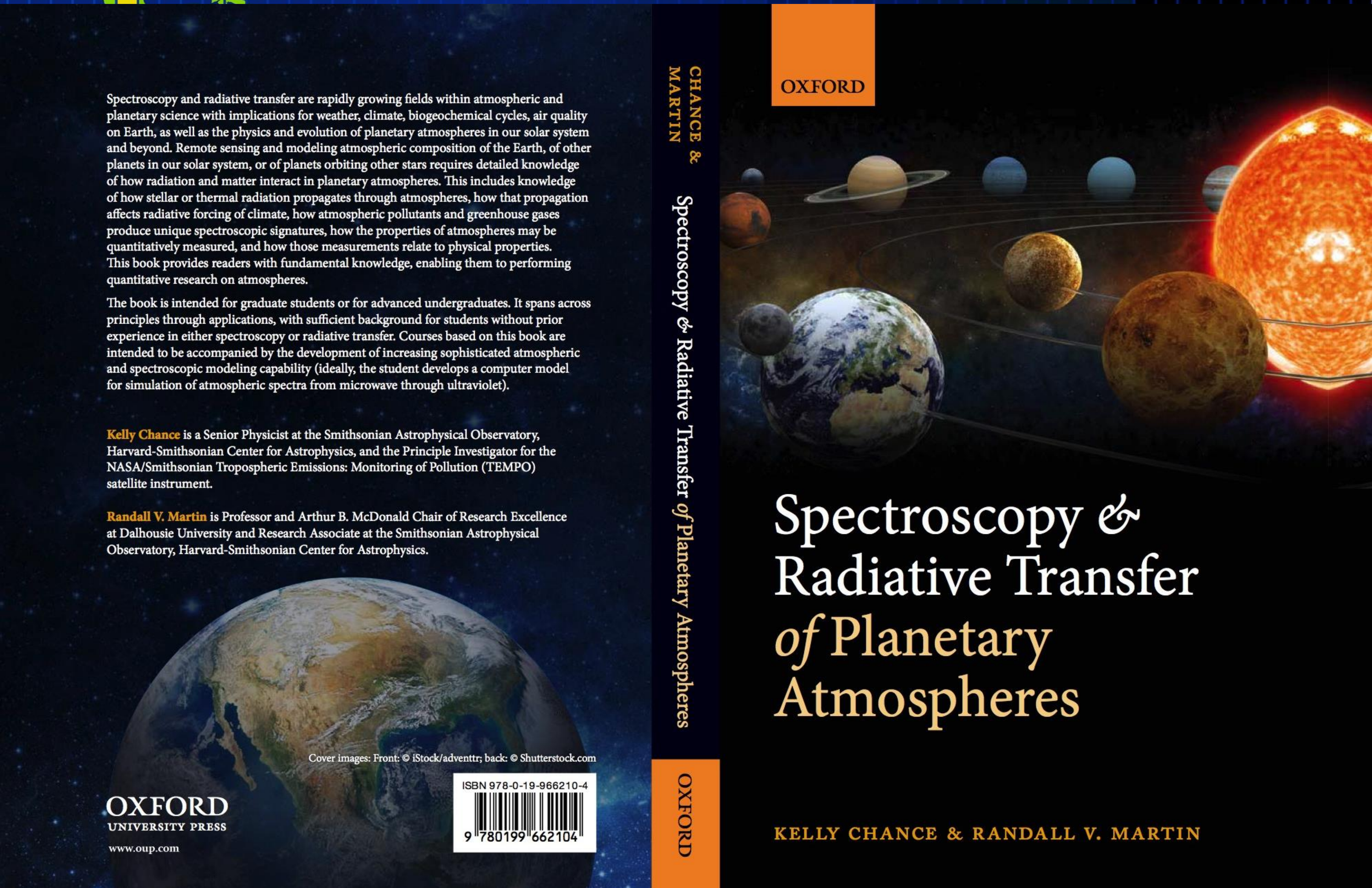
April 19, 2013

Smithsonian

TEMPO

# Now in press!

Smithsonian



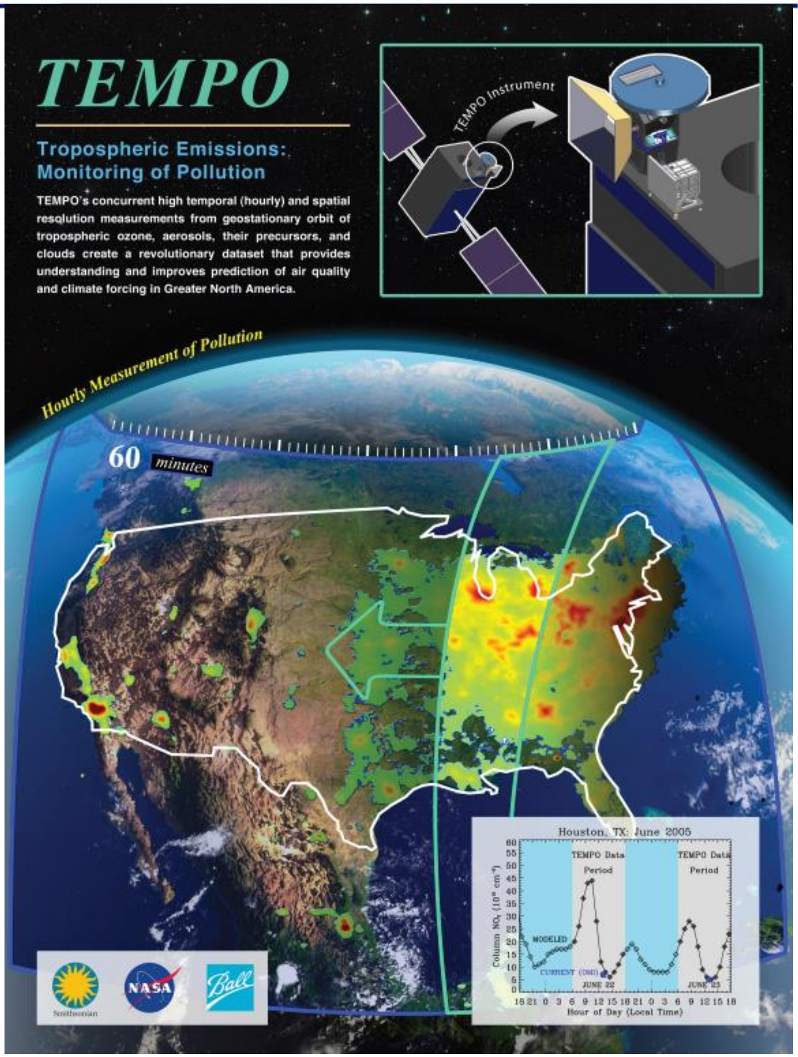
# Hourly atmospheric pollution from geostationary Earth orbit

**PI:** Kelly Chance, Smithsonian Astrophysical Observatory
**Deputy PI:** Xiong Liu, Smithsonian Astrophysical Observatory
**Instrument Development:** Ball Aerospace
**Project Manager: Wendy Pennington,** NASA LaRC
**Project Scientist:** Dave Flittner, LaRC; **Deputy PS:** Jay Al-Saadi, LaRC
**Other Institutions:** NASA GSFC (led by Scott Janz), NOAA, EPA, NCAR, Harvard, UC Berkeley, St. Louis U, U Alabama Huntsville, U Nebraska
**International collaboration:** Korea, ESA, Canada

**Selected Nov. 2012 through NASA's first Earth Venture Instrument solicitation**
- **Currently Instrument delived**
- **NASA will arrange hosting on commercial geostationary communications satellite with expected ~2021 launch**

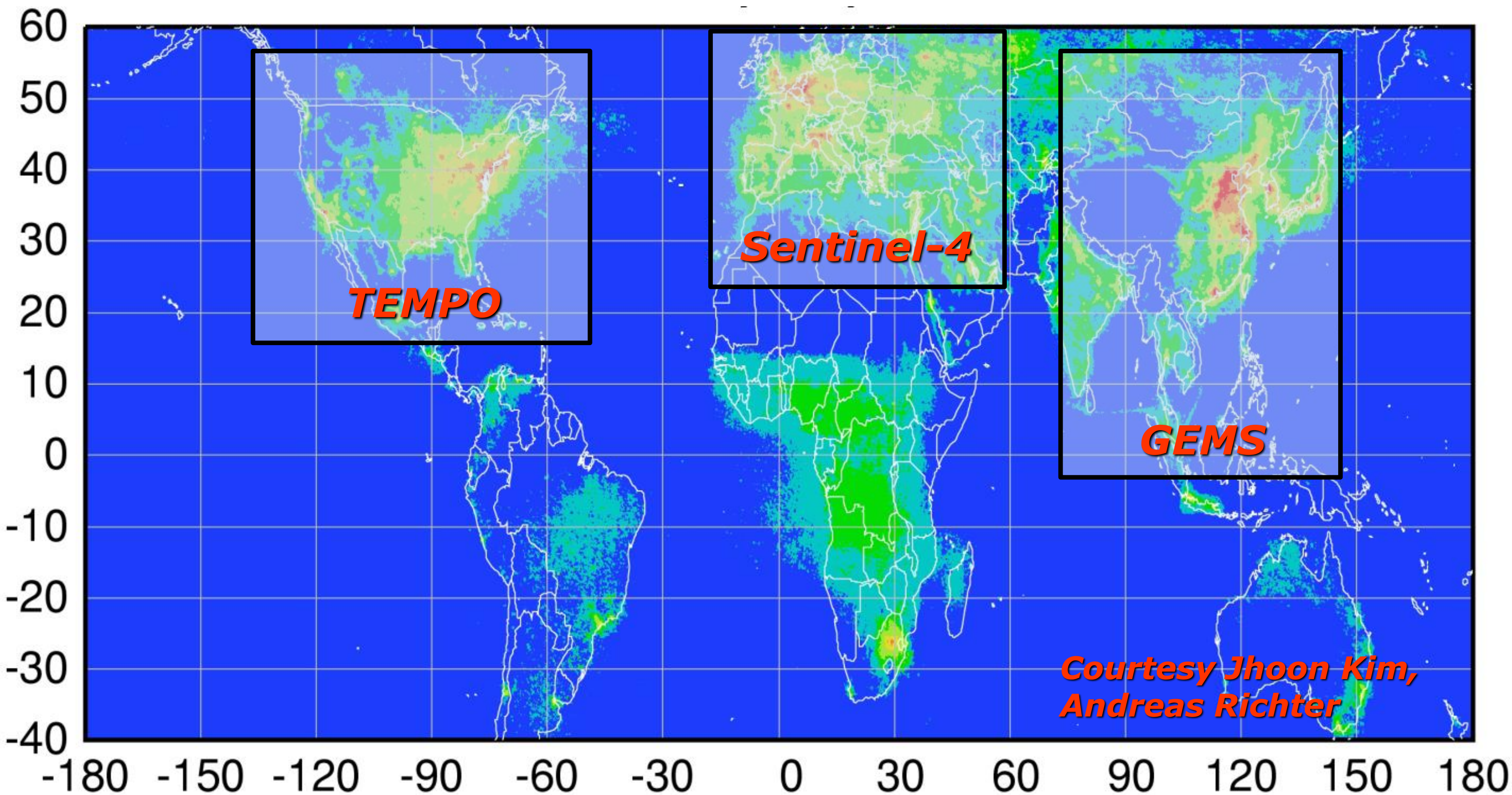
**Provides hourly daylight observations to capture rapidly varying emissions & chemistry important for air quality**
- UV/visible grating spectrometer to measure key elements in tropospheric ozone and aerosol pollution
- Exploits extensive measurement heritage from LEO missions
- Distinguishes boundary layer from free tropospheric & stratospheric ozone

**Aligned with Earth Science Decadal Survey recommendations**
- Makes most of the GEO-CAPE atmosphere measurements
- Responds to the phased implementation recommendation of GEO-CAPE mission design team




***The North American geostationary component of an international constellation for air quality monitoring***

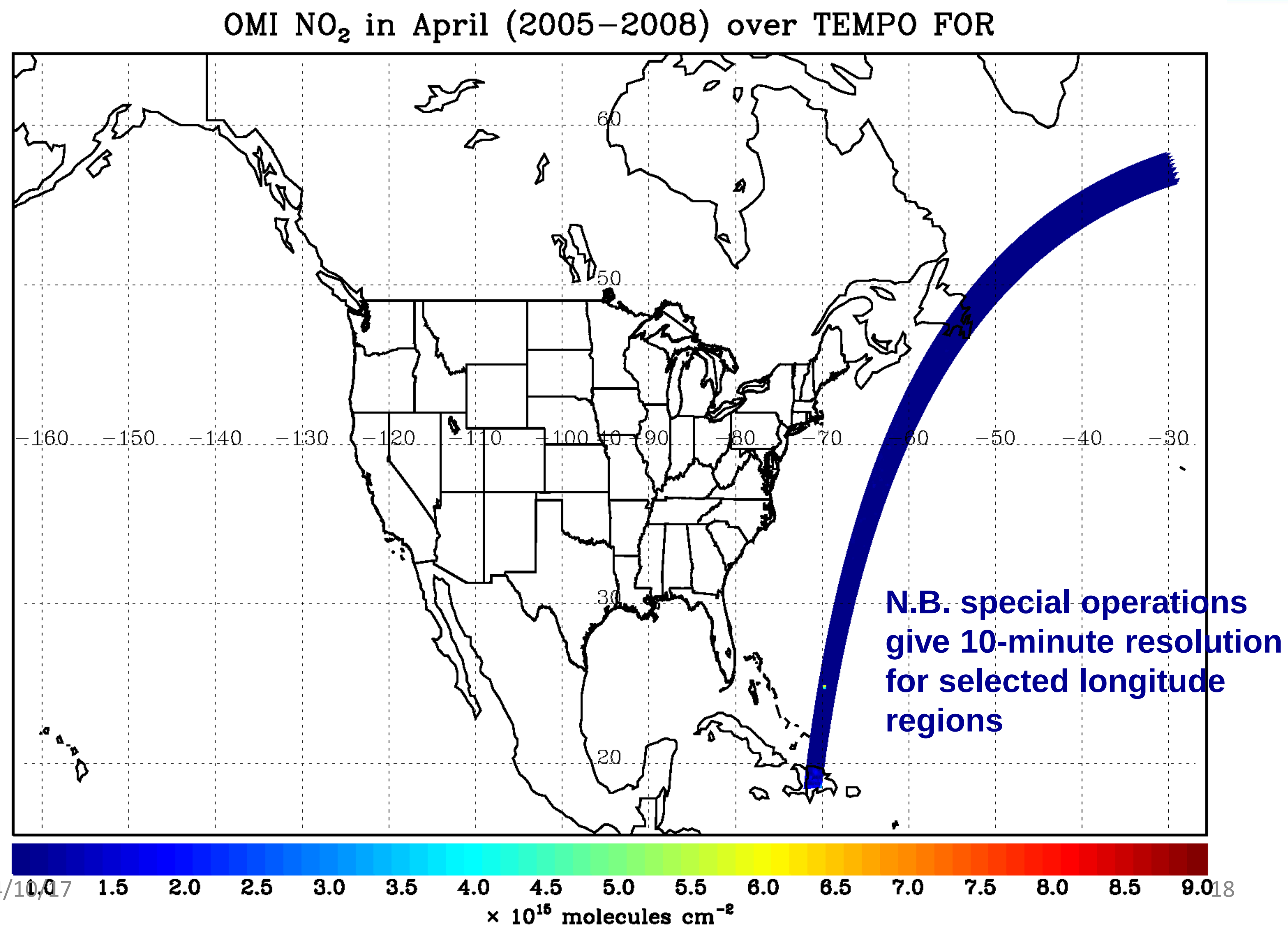
# Geostationary constellation coverage




**Policy-relevant science and environmental services enabled by common observations**

- **Improved emissions, at common confidence levels, over industrialized Northern Hemisphere**
- **Improved air quality forecasts and assimilation systems**
- **Improved assessment, *e.g.*, observations to support the United Nations Convention on Long Range Transboundary Air Pollution**

# TEMPO hourly $NO_2$ sweep

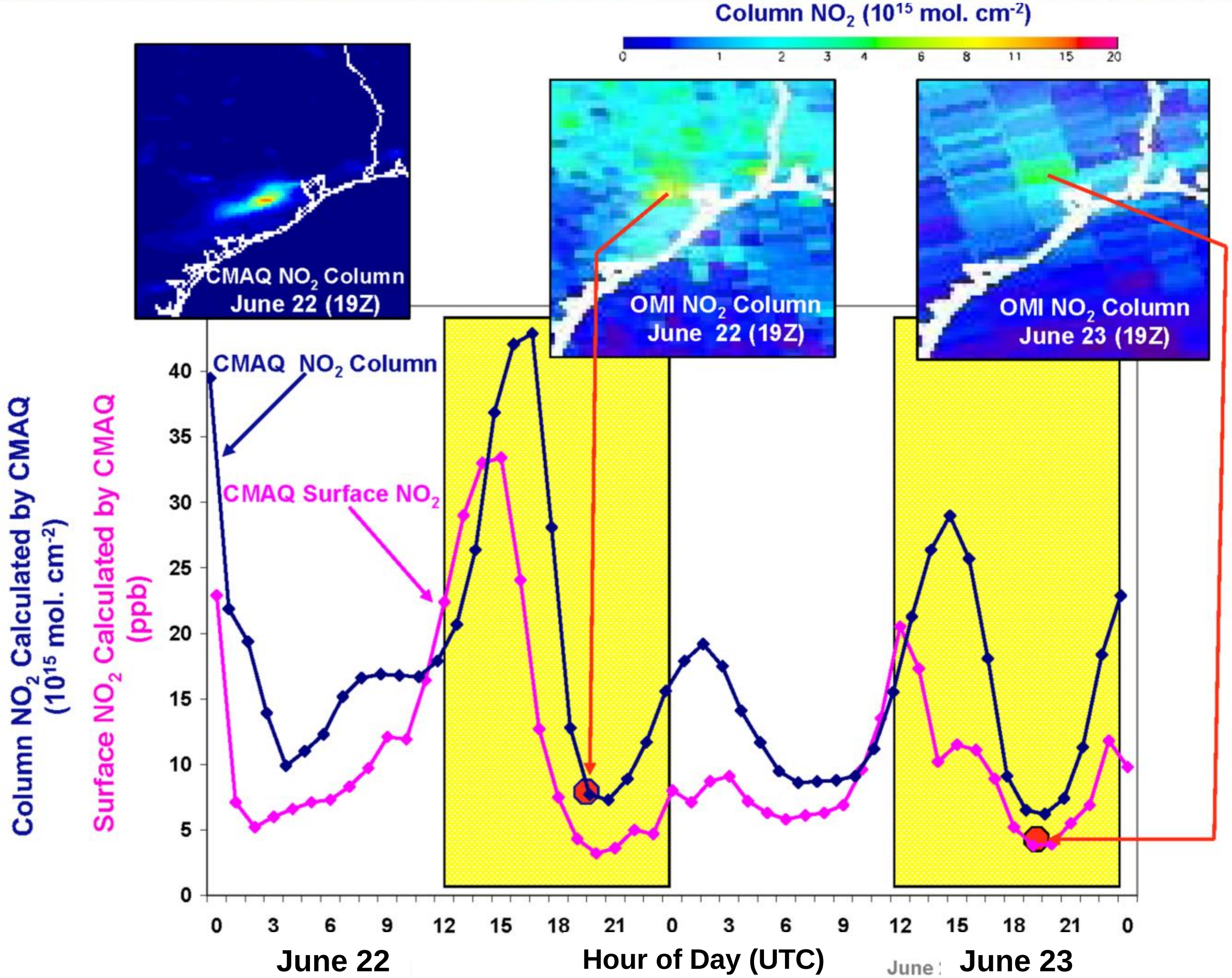


# TEMPO science questions

1. What are the temporal and spatial variations of **emissions** of gases and aerosols important for air quality and climate?
2. How do physical, chemical, and dynamical **processes** determine tropospheric composition and air quality over scales ranging from urban to continental, diurnally to seasonally?
3. How does air pollution drive **climate** forcing and how does climate change affect air quality on a continental scale?
4. How can observations from space improve **air quality forecasts and assessments** for societal benefit?
5. How does **intercontinental transport** affect air quality?
6. How do **episodic events**, such as wild fires, dust outbreaks, and volcanic eruptions, affect atmospheric composition and air quality?

# Why geostationary? High temporal and spatial resolution

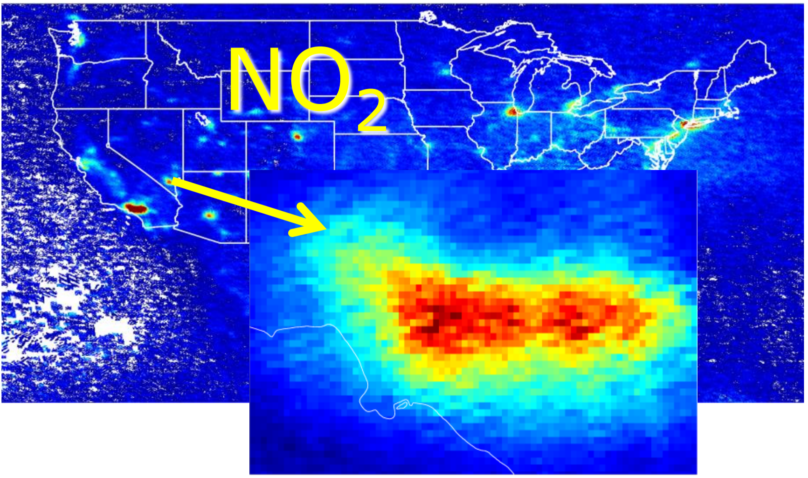
**Hourly $NO_2$ surface concentration and integrated column calculated by CMAQ air quality model: Houston, TX, June 22-23, 2005**

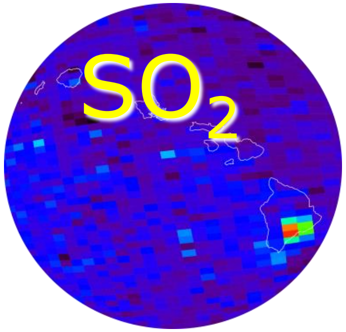



**LEO observations provide limited information on rapidly varying emissions, chemistry, & transport**

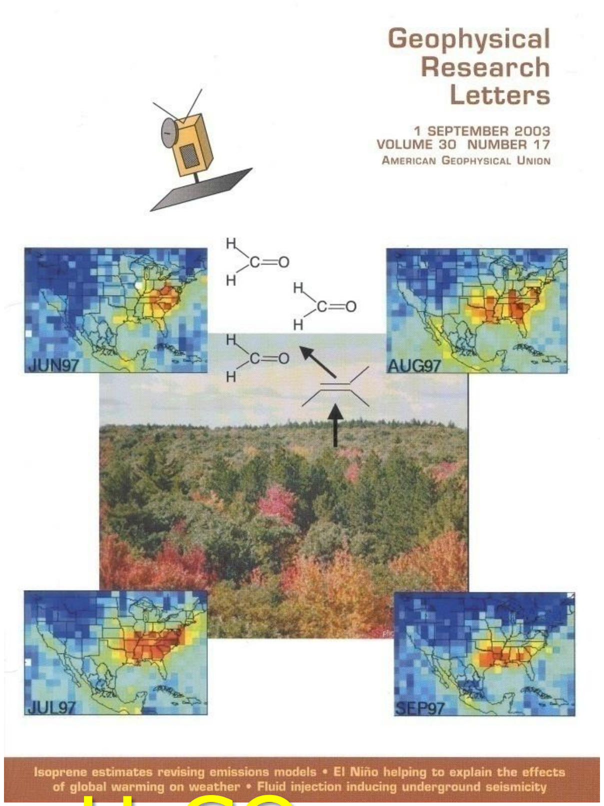
**GEO will provide observations at temporal and spatial scales highly relevant to air quality processes**

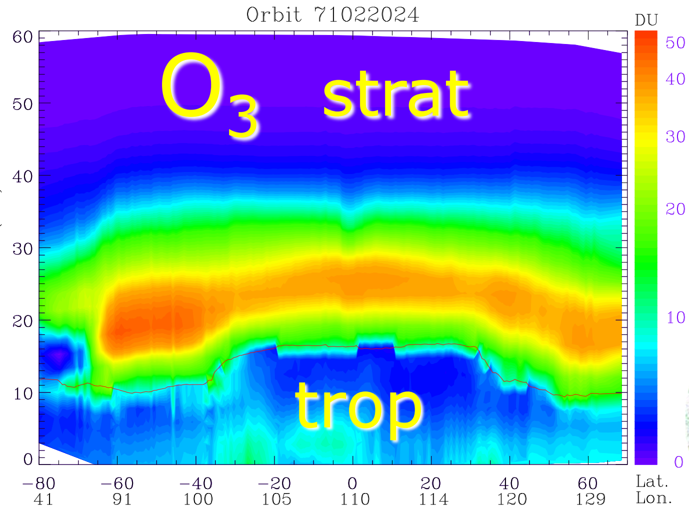
# GOME, SCIA, OMI examples

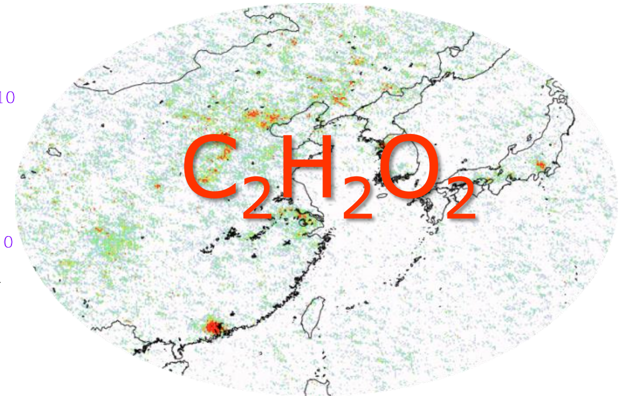


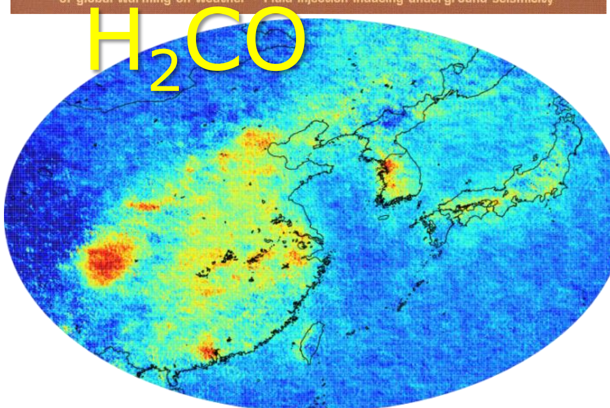




Kilauea activity, source of the VOG event in Honolulu on 9 November 2004



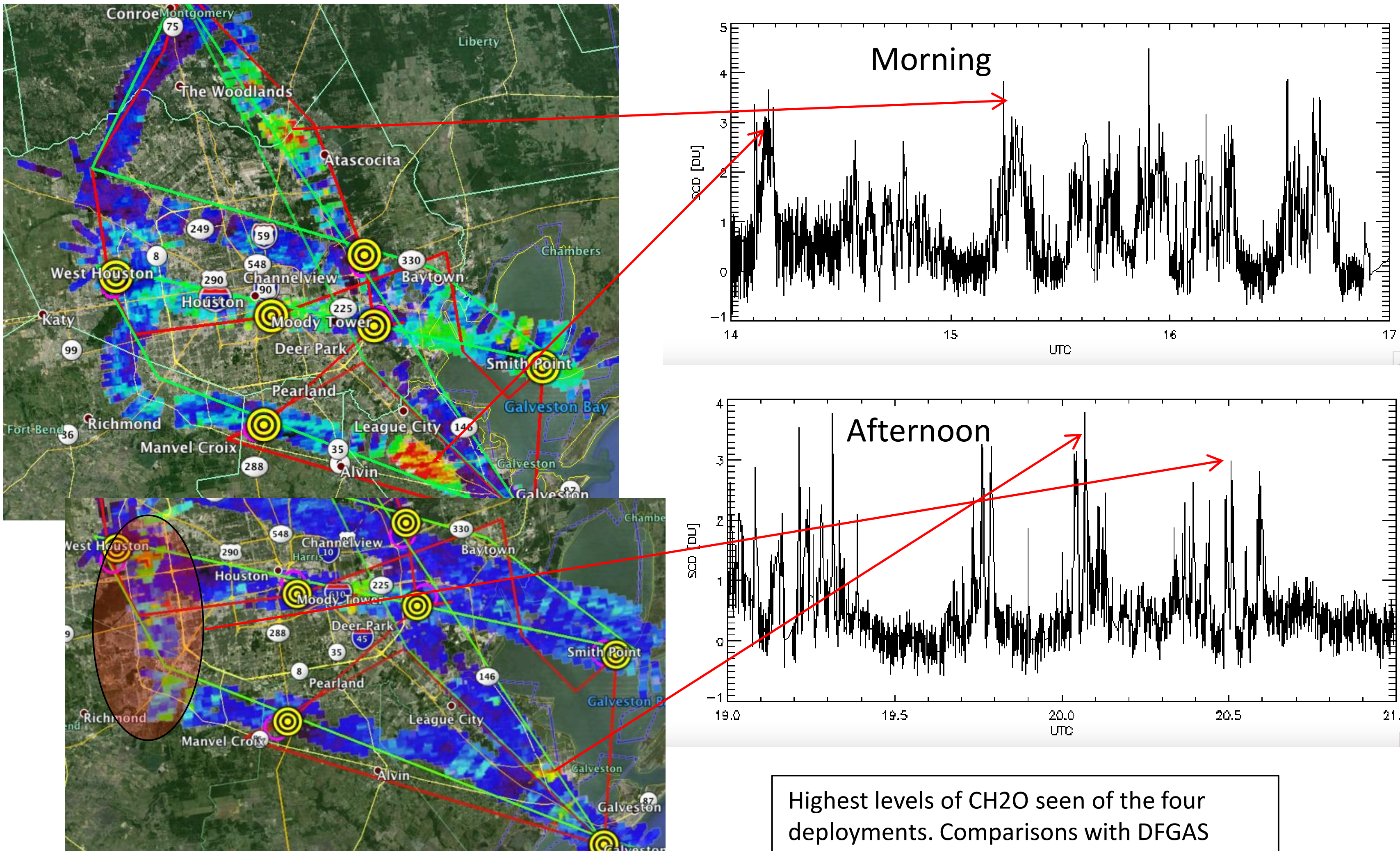



# TEMPO Aircraft Simulator: GCAS $CH_2O$ Sept. 24th

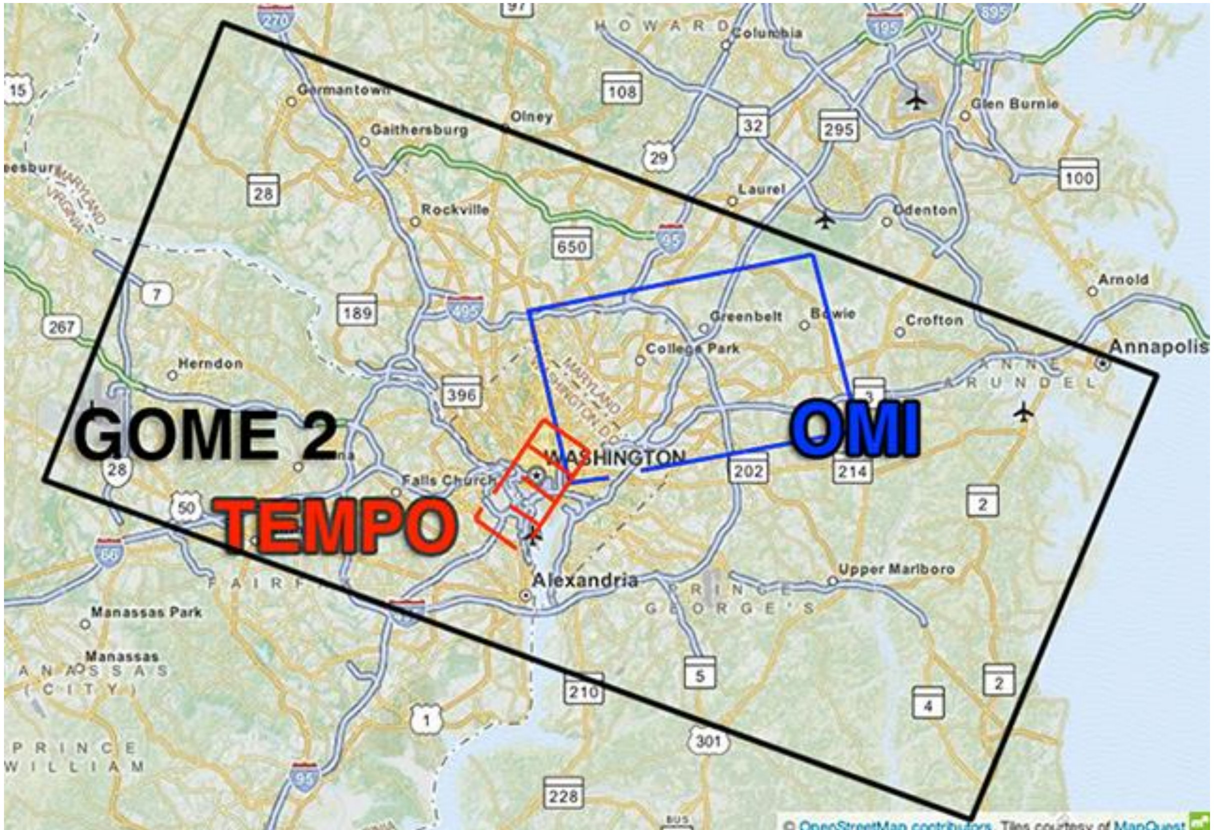
## Houston deployment




Highest levels of CH2O seen of the four deployments. Comparisons with DFGAS complicated by cloud interference.

# Coverage comparisons

- **Spatial resolution: allows tracking pollution at sub-urban scale**
  - **GEO at 100°W: 2.1 km N/S × 4.7 km E/W = 9.8 km$^2$ (native) at center of FOR (36.5°N, 100°W)**
  - **Full resolution for $NO_2$, HCHO, total $O_3$ products**
  - **Co-add 4 N/S pixels for $O_3$ profile product: 8.4 km N/S × 4.7 km E/W**

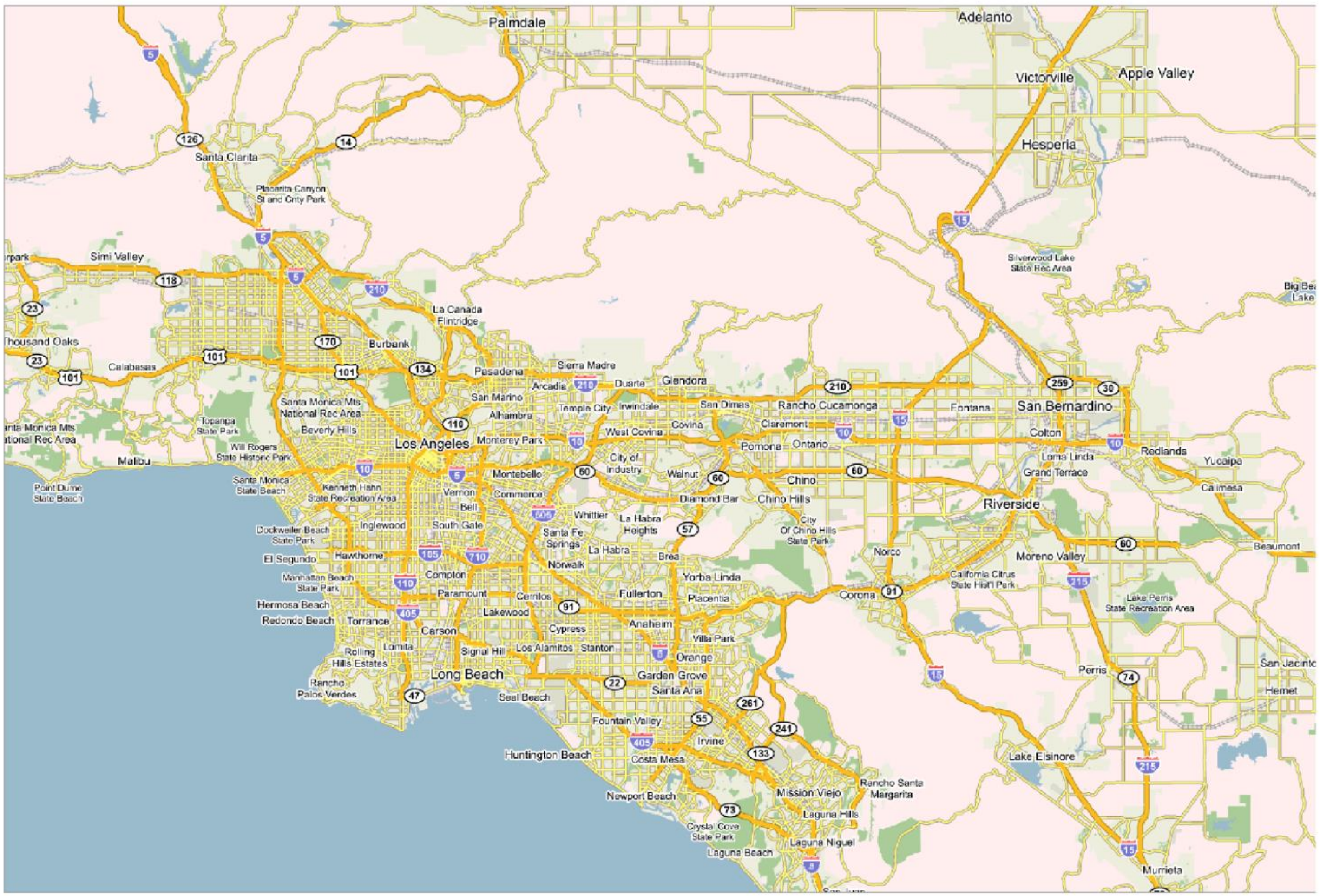



**~ 1/300 of GOME-2**

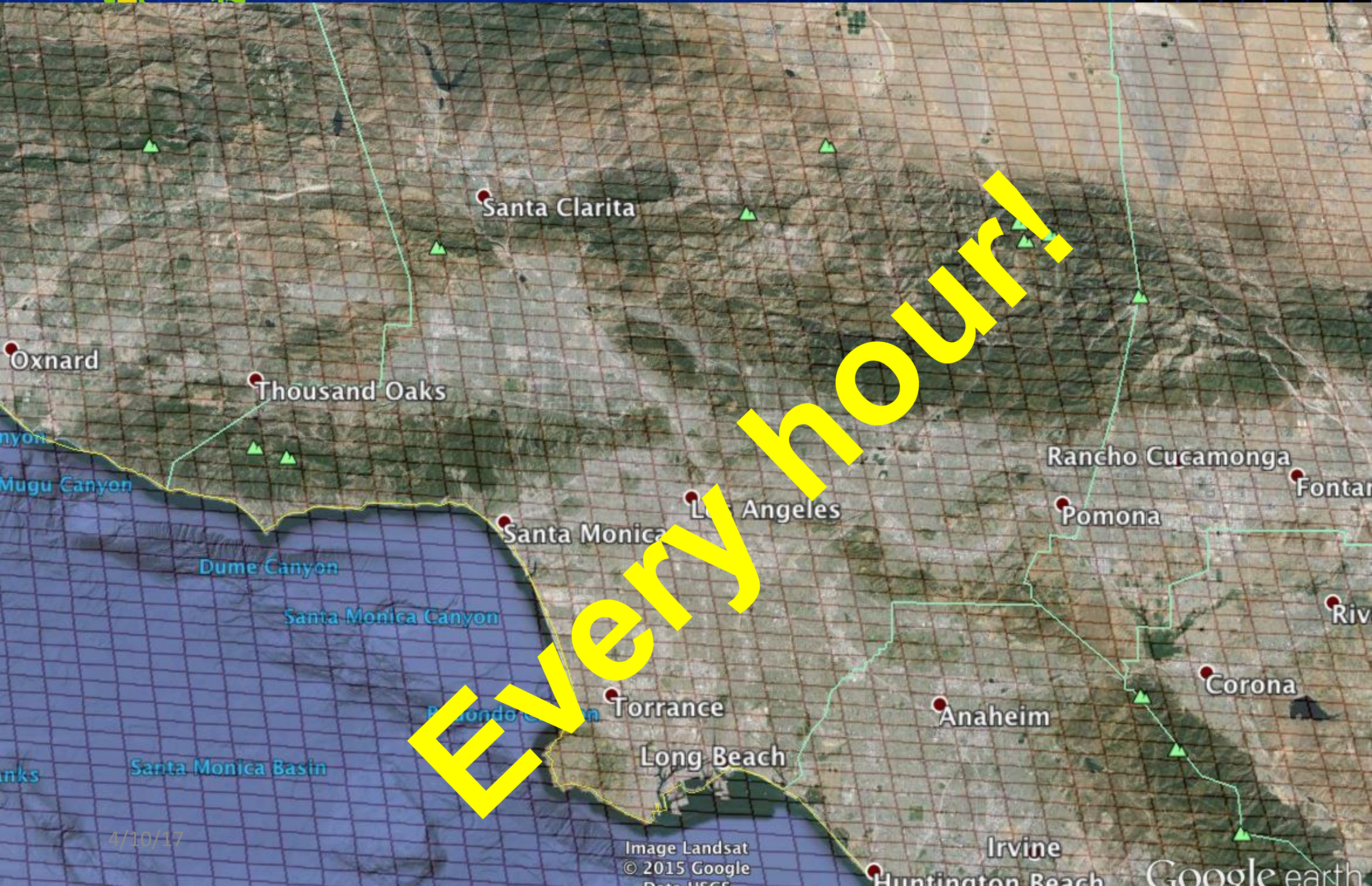
**~ 1/30 of OMI**

TEMPO

# $NO_2$ over Los Angeles



# Los Angeles coverage




**Every hour!**

TEMPO

# Mexico City coverage

Smithsonian NASA

# LEO measurement capability

**A full, minimally-redundant, set of polluting gases, plus aerosols and clouds is now measured to very high precision from satellites. Ultraviolet and visible spectroscopy of backscattered radiation provides $O_3$ (including profiles and tropospheric $O_3$), $NO_2$ (for $NO_x$), $H_2CO$ and $C_2H_2O_2$ (for VOCs), $SO_2$, $H_2O$, $O_2$-$O_2$, $N_2$ and $O_2$ Raman scattering, and halogen oxides (BrO, ClO, IO, OClO). Satellite spectrometers planned since 1985 began making these measurements in 1995.**

# Experimental Opportunities

1. Up to 25% of observing time can be devoted to non-standard ops
2. Two types:
   1. Events (e.g., eruptions, fires, dust storms, etc.)
   2. Experiments (non standard scan patterns to explore phenomena)
3. TEMPO team will work with experimenters concerning Image Navigation and Registration (i.e., pointing resolution and accuracy)
4. Experiments could occur during commissioning phase
5. Hope to include $SO_2$, aerosol, and $C_2H_2O_2$ as operational products.
6. Can initiate a non-standard, pre-loaded scan pattern within 1 hour
7. Send your ideas into a TEMPO team member

# Traffic, biomass burning

**Morning and evening higher-frequency scans** The optimized data collection scan pattern during mornings and evenings provides multiple advantages for addressing TEMPO science questions. The increased frequency of scans coincides with peaks in vehicle miles traveled on each coast.

**Biomass burning** The unexplained variability in ozone production from fires is of particular interest. The suite of $NO_2$, $H_2CO$, $C_2H_2O_2$, $O_3$, and aerosol measurements from TEMPO is well suited to investigating how the chemical processing of primary fire emissions effects the secondary formation of VOCs and ozone. For particularly important fires it is possible to command special TEMPO observations at even shorter than hourly revisit time, probably as short as 10 minutes.

TEMPO

# $NO_x$ studies

**Lightning $NO_x$** Interpretation of satellite measurements of tropospheric $NO_2$ and $O_3$, and upper tropospheric $HNO_3$ lead to an overall estimate of 6 ± 2 Tg N y-1 from lightning [Martin et al., 2007]. TEMPO measurements, including tropospheric $NO_2$ and $O_3$, can be made for time periods and longitudinal bands selected to coincide with large thunderstorm activity, including outflow regions, with fairly short notice.

**Soil $NO_x$** Jaeglé et al. [2005] estimate 2.5 - 4.5 TgN $y^{-1}$ are emitted globally from nitrogen-fertilized soils, still highly uncertain. The US a posteriori estimate for 2000 is 0.86 ± 1.7 TgN $y^{-1}$. For Central America it is 1.5 ± 1.6 TgN $y^{-1}$. They note an underestimate of NO release by nitrogen-fertilized croplands as well as an underestimate of rain-induced emissions from semiarid soils.

TEMPO is able to follow the temporal evolution of emissions from croplands after fertilizer application and from rain-induced emissions from semi-arid soils. Higher than hourly time resolution over selected regions may be accomplished by special observations. Improved constraints on soil $NO_x$ emissions may also improve estimated of lightning $NO_x$ emissions [Martin *et al*. 2000].

# Air quality and health



TEMPO's hourly measurements allow better understanding of the complex chemistry and dynamics that drive **air quality on short timescales**. The density of TEMPO data is ideally suited for data assimilation into chemical models for both air quality forecasting and for better constraints on emissions that lead to air quality exceedances. Planning is underway to combine TEMPO with regional air quality models to **improve EPA air quality indices and to directly supply the public with near real time pollution reports and forecasts through website and mobile applications**. As a case study, an OSSE for the Intermountain West was performed to explore the potential of geostationary ozone measurements from TEMPO to improve monitoring of ozone exceedances and the role of background ozone in causing these exceedances (Zoogman *et al*. 2014).

# Clouds and aerosols

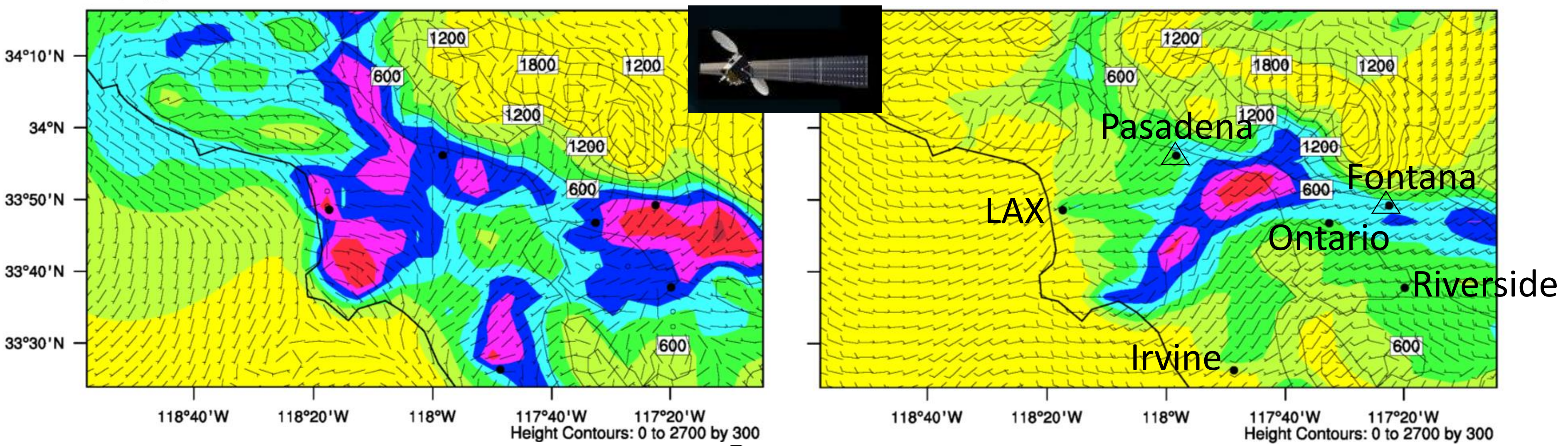
**Clouds** The launch cloud algorithm is be based on the rotational Raman scattering (RRS) cloud algorithm that was developed for OMI by GSFC. Retrieved cloud pressures from OMCLDRR are not at the geometrical center of the cloud, but rather at the optical centroid pressure (OCP) of the cloud. **Additional** cloud products are possible using the $O_2$-$O_2$ collision complex and/or the $O_2$ *B* band.

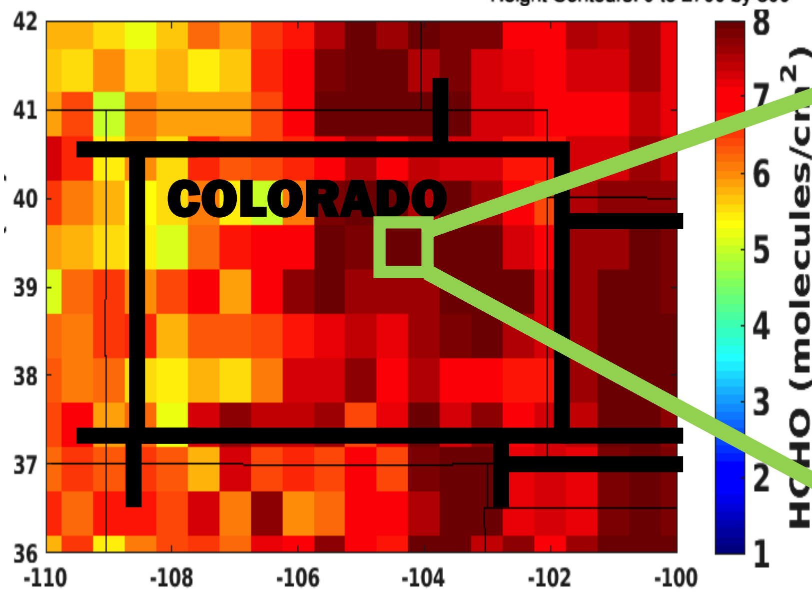
**Aerosols** TEMPO's launch algorithm for retrieving aerosols will be based upon the OMI aerosol algorithm that uses the sensitivity of near-UV observations to particle absorption to retrieve Absorbing Aerosol Index (AAI), aerosol optical depth (AOD) and single scattering albedo (SSA). TEMPO may be used together with the advanced baseline imager (ABI) instruments on the NOAA GOES-R and GOES-S satellites, particularly the 1.37μm bands, for aerosol retrievals, reducing AOD and fine mode AOD uncertainties from 30% to 10% and from 40% to 20%.

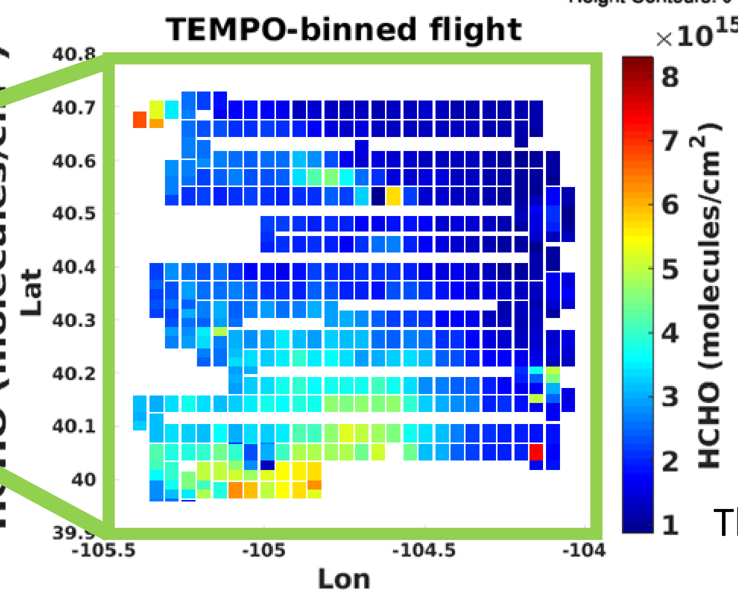
# TEMPO synthetic observations

Si-Wan Kim et al.

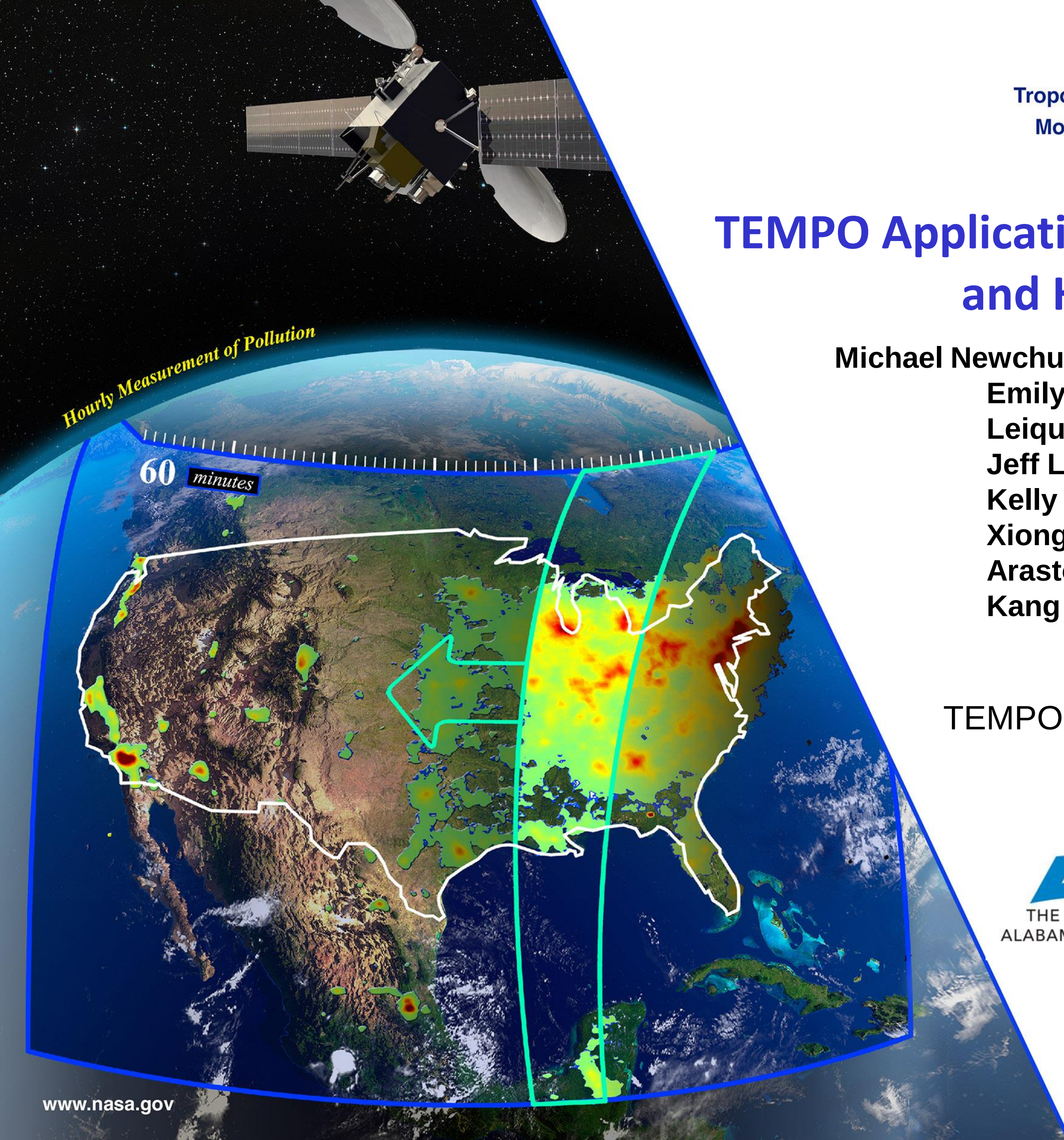
NO$_2$ columns modeled at approximate TEMPO resolution




Frank Keutsch, Mitchell Thayer, et al.




Tropospheric Emissions: Monitoring of Pollution

TEMPO

# TEMPO Applications to Air-Quality and Health

**Michael Newchurch, Aaron Naeger, Emily Berndt, Susan Alexander, Leiqui Hu, Matthew Johnson, Jeff Luvall, Christopher Miller, Kelly Chance, Arlindo da Silva, Xiong Liu, Tom Moore, Arastoo Pour-Biazar, Kang Sun, Bradley Zavodsky**

April 10, 2018

TEMPO Early Adopters Workshop

Fort Collins, CO

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

SPORT

Smithsonian

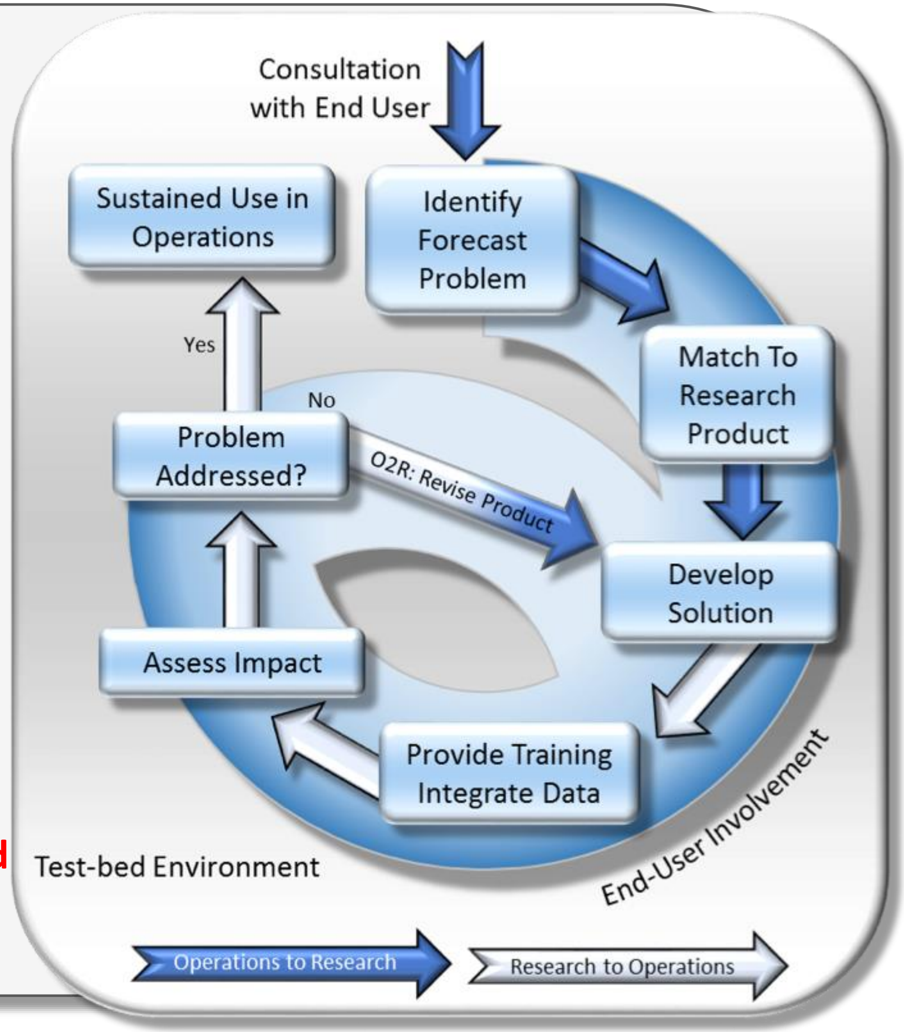
NASA

TEMPO

# Short-term Prediction Research and Transition (SPoRT)

- **Over the past 15 years, SPoRT has successfully transitioned unique observations from more than 40 satellite datasets to operational end users**
- **Established research-to-operations/operations-to-research paradigm that engages in solving specific forecast problems**
- **SPoRT plans to use this successful approach to prepare the user community for TEMPO data**

**See NASA SPoRT talk (Emily Berndt and Aaron Naeger) – SPoRT R2O Paradigm: preparing end users for next-generation satellite missions before day 1 operations**




https://weather.msfc.nasa.gov/sport/

SPORT

# Pilot Project: Public Health



- How can TEMPO be used to assess the impact of air pollutant exposure on hospital readmission rates for cardiopulmonary disorders?
- Collaboration with Alabama Department of Public Health and Alacare Home Health & Hospice
- TEMPO proxy products will be used to build the readmission rate prediction model
- The spatial/temporal resolution of air pollutants from TEMPO offer the capacity to assess environmental risk factors on health and provide critical time and space information to healthcare end users for mitigation actions

**See S. Alexander/UAH talk**

# TEMPO Data Products: Health Applications

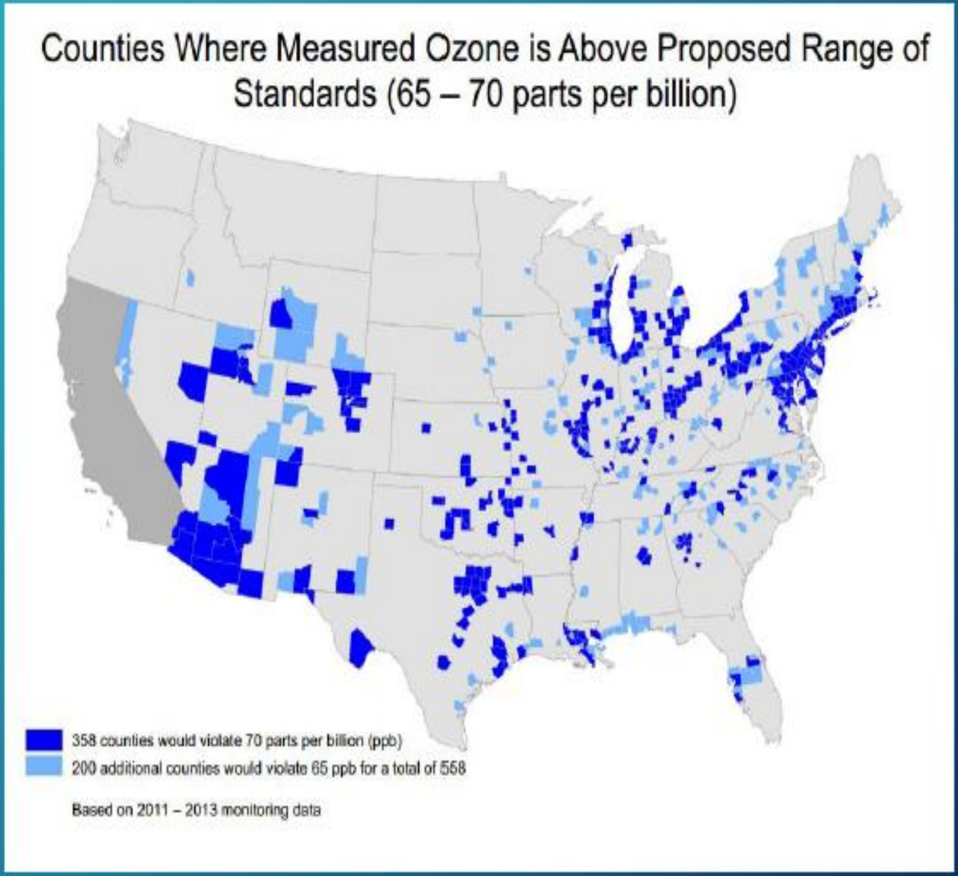
Susan Alexander, DNP, ANP-BC, ADM-BC
Mike Newchurch, PhD
Aaron Kaulfus, MS

# Clinical Interests

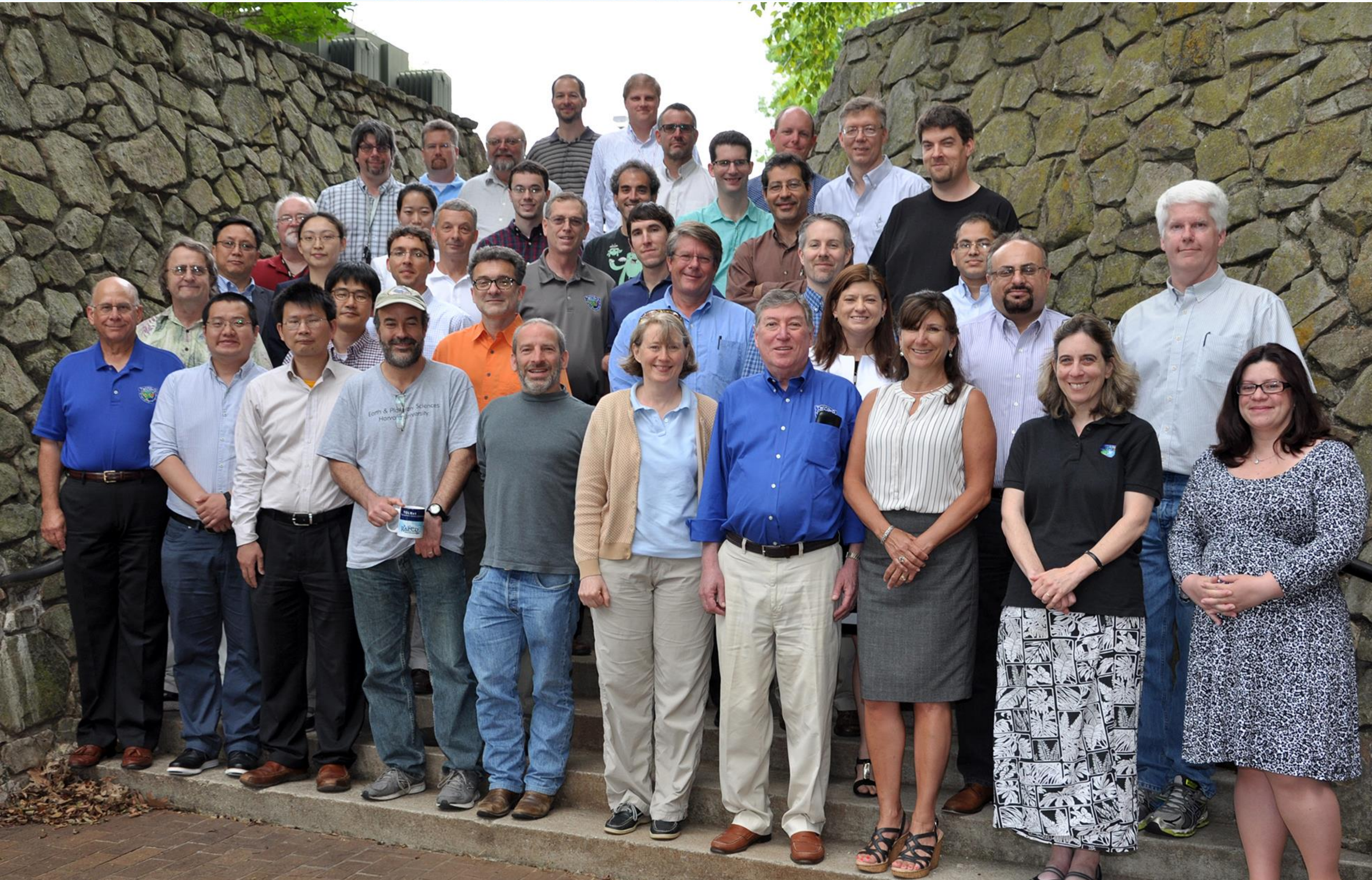
- Vulnerable populations
- Morbidity/mortality
- Costs
  - Financial (resource utilization, facility risk, HCP P4P)
  - Social
  - Emotional

# Ozone—health impact

- Additive
- Lung function
- Respiratory disorders
- morbidity
- mortality



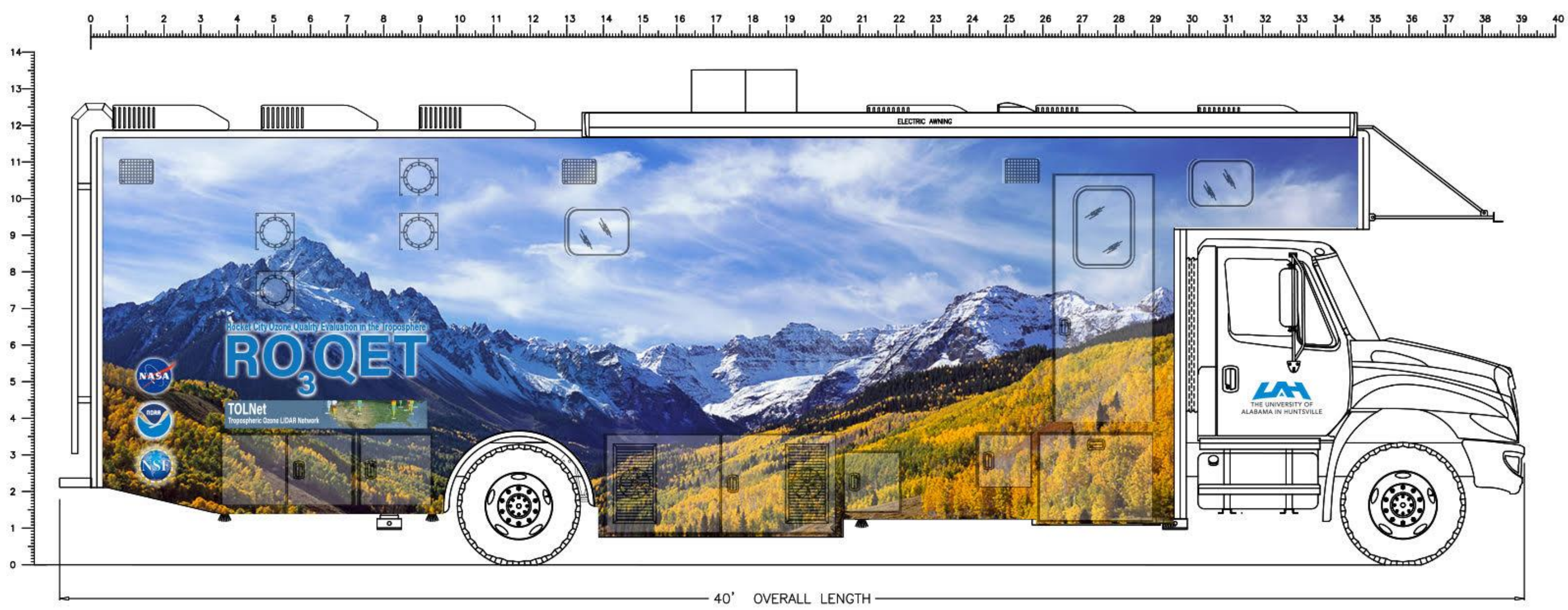
# TEMPO Science Team



# TOLNET

Tropospheric Ozone LIDAR Network


## Rocket-City Ozone Quality Evaluation in the Troposphere: $RO_3QET$




STATUS

*GRAPHICS TEMPLATE*
*ALL DIMENSIONS ARE APPROXIMATIONS*

**MBF Industries, Inc.**
*ENGINEERED FOR LIFE*
210 TECH DRIVE SANFORD, FL 32771
www.MBFindustries.com
P:407-323-9414 F:407-330-2068

DRAWING NUMBER 1470 GRAPHICS TEMPLATE 9/19/18
DRAWING TYPE GRAPHICS
DATE 9/19/18
VEHICLE TYPE INTERNATIONAL 4400 – MODULAR

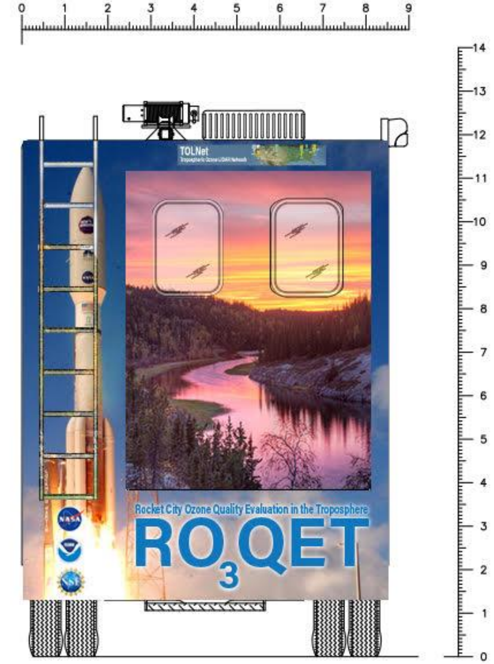
These drawings and/or specifications are the proprietary property and trade secrets of MBF Ind. and are issued in strict confidence. No reproduction or use is to be made without written consent of MBF Ind.

TITLE UNIVERSITY of ALABAMA HUNTSVILLE RO3QET INSTRUMENT CONTAINER
VIEW EXTERIOR CURBSIDE ELEVATION
DRAWN BY GAJ
SCALE N/A
SIZE B
SHEET 1 of 3

# TOLNET

*Tropospheric Ozone LIDAR Network*


## Rocket-City Ozone Quality Evaluation in the Troposphere: $RO_3QET$


STATUS

***GRAPHICS TEMPLATE***
***ALL DIMENSIONS***

**MBF Industries, Inc.**
*ENGINEERED FOR LIFE*

| | |
|---|---|
| DRAWING NUMBER 1470 GRAPHICS TEMPLATE 9/19/18 | TITLE UNIVERSITY of ALABAMA HUNTSVILLE RO3QET INSTRUMENT CONTAINER |
| DRAWING TYPE GRAPHICS / DATE 9/19/18 | |
| VEHICLE TYPE INTERNATIONAL 4400 – MODULAR | VIEW EXTERIOR FRONT AND REAR ELEVATIONS |
| These drawings and/or specifications are the proprietary property and trade | DRAWN BY GAJ / SCALE / SIZE |