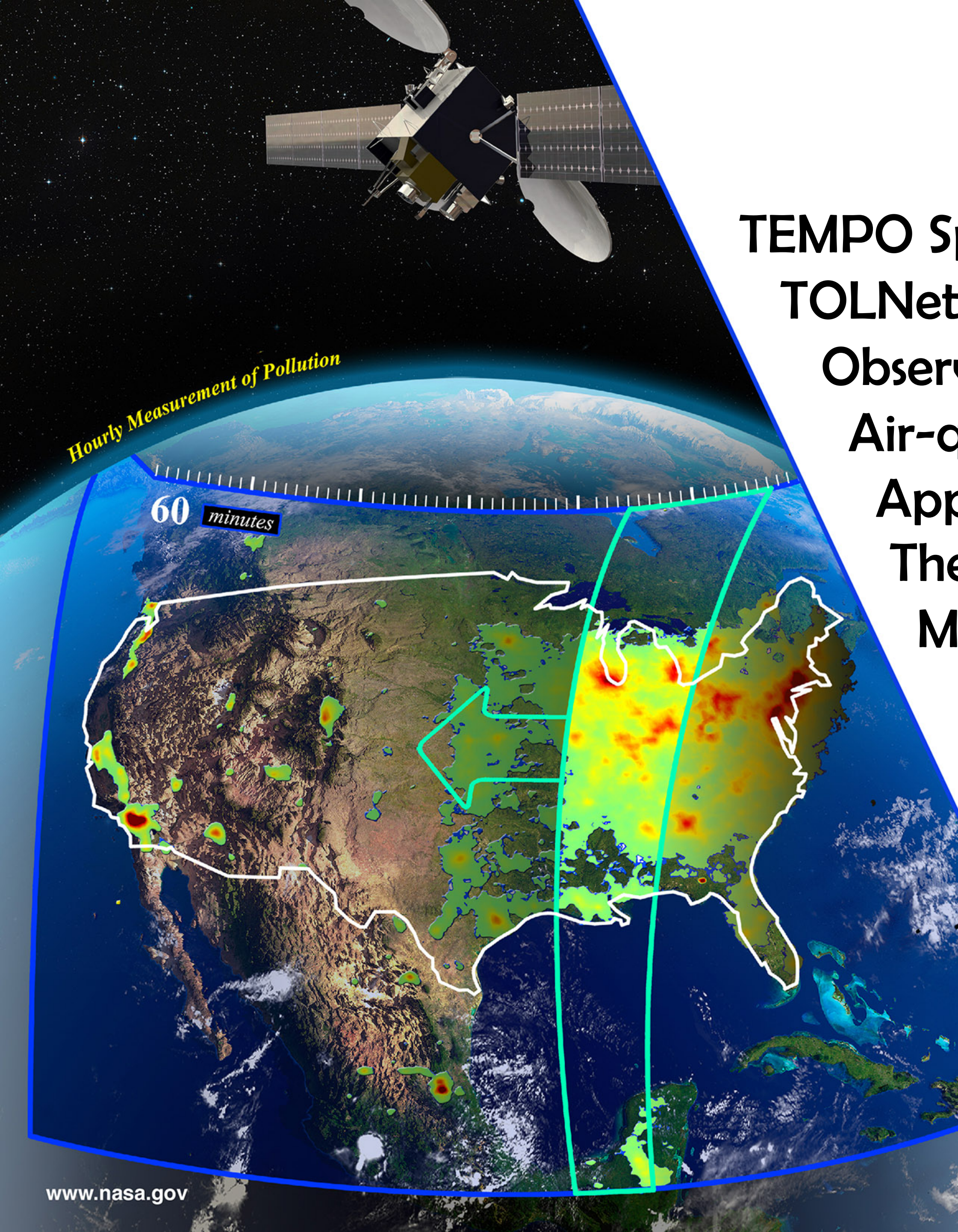


Tropospheric Emissions:
Monitoring of Pollution

TEMPO

TEMPO Space-borne and TOLNet Ground-based Observations for Air-quality Science and Applications: The Future of Air-quality Measurments

Mike Newchurch

with the **TEMPO** and

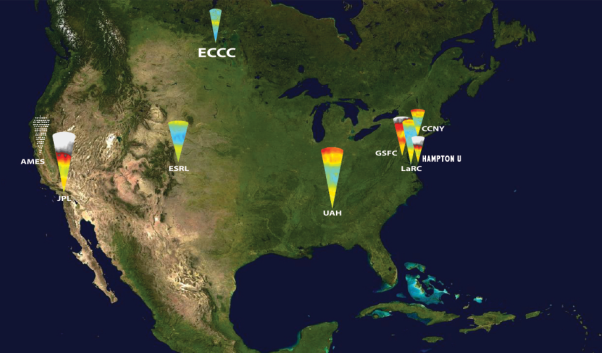
TOLNet Science teams

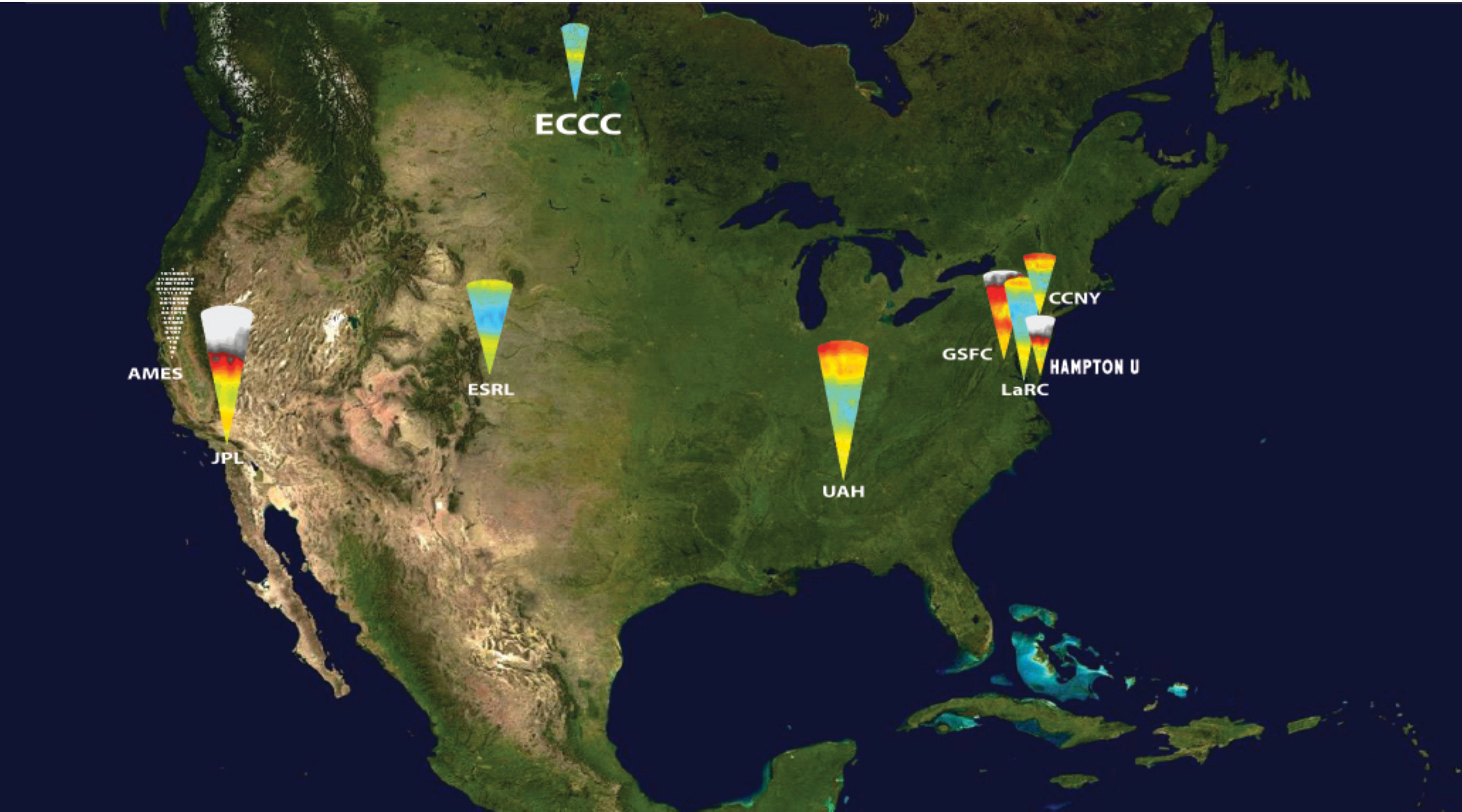
HAQAST6
July 10-12, 2019
Pasadena, California

Ball Smithsonian NASA

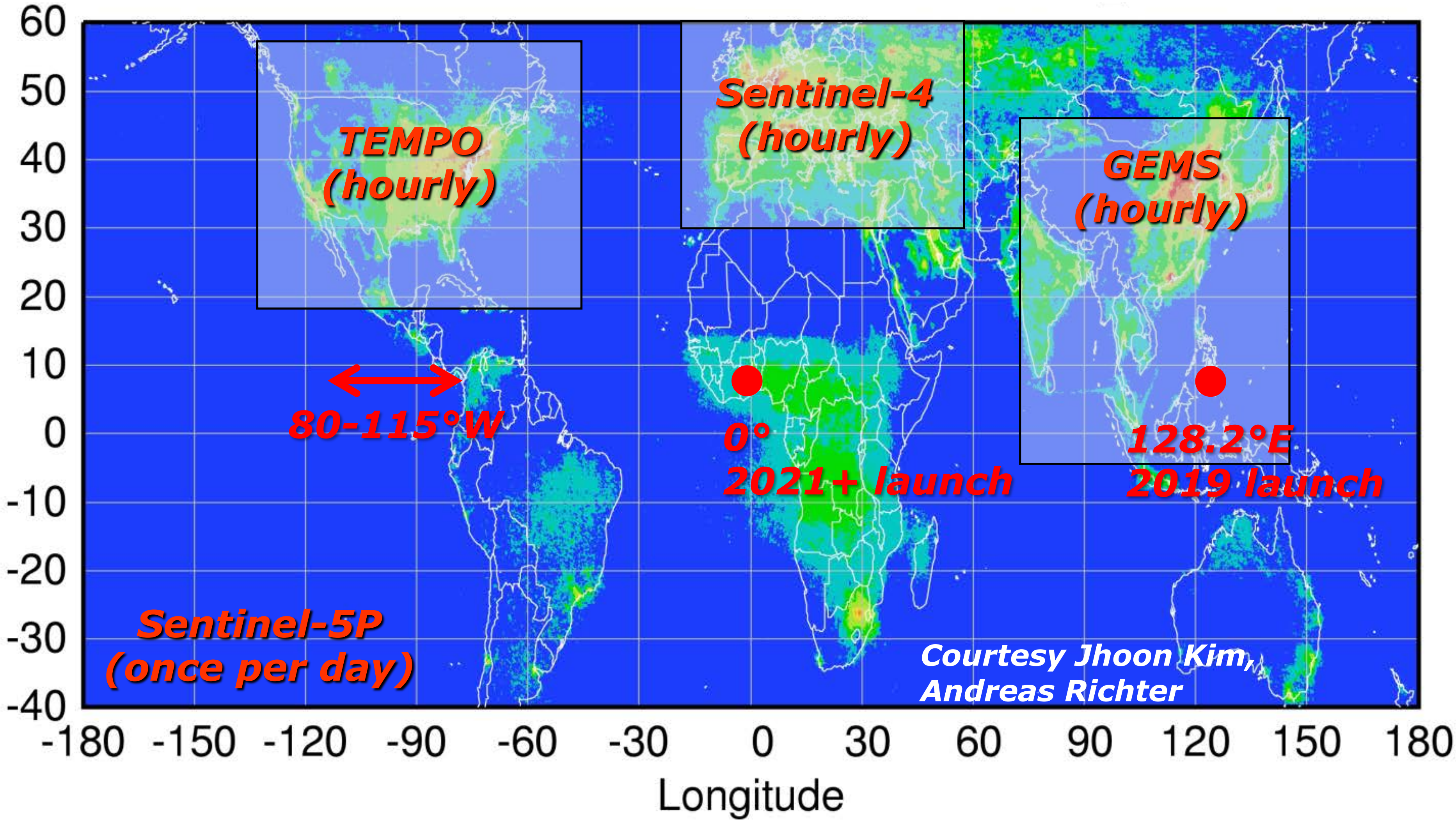
TOLNet

Tropospheric Ozone LIDAR Network

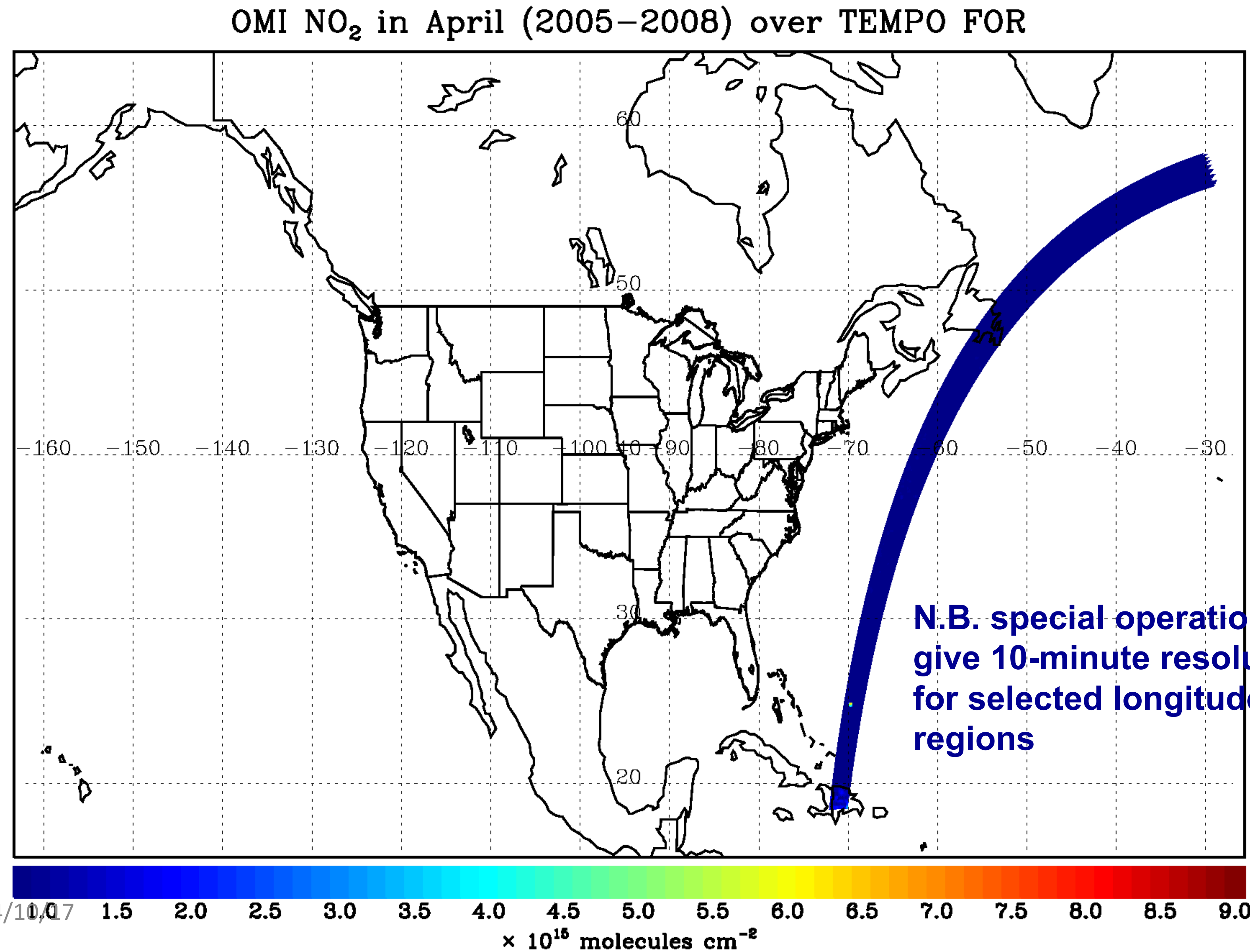




Global pollution monitoring constellation



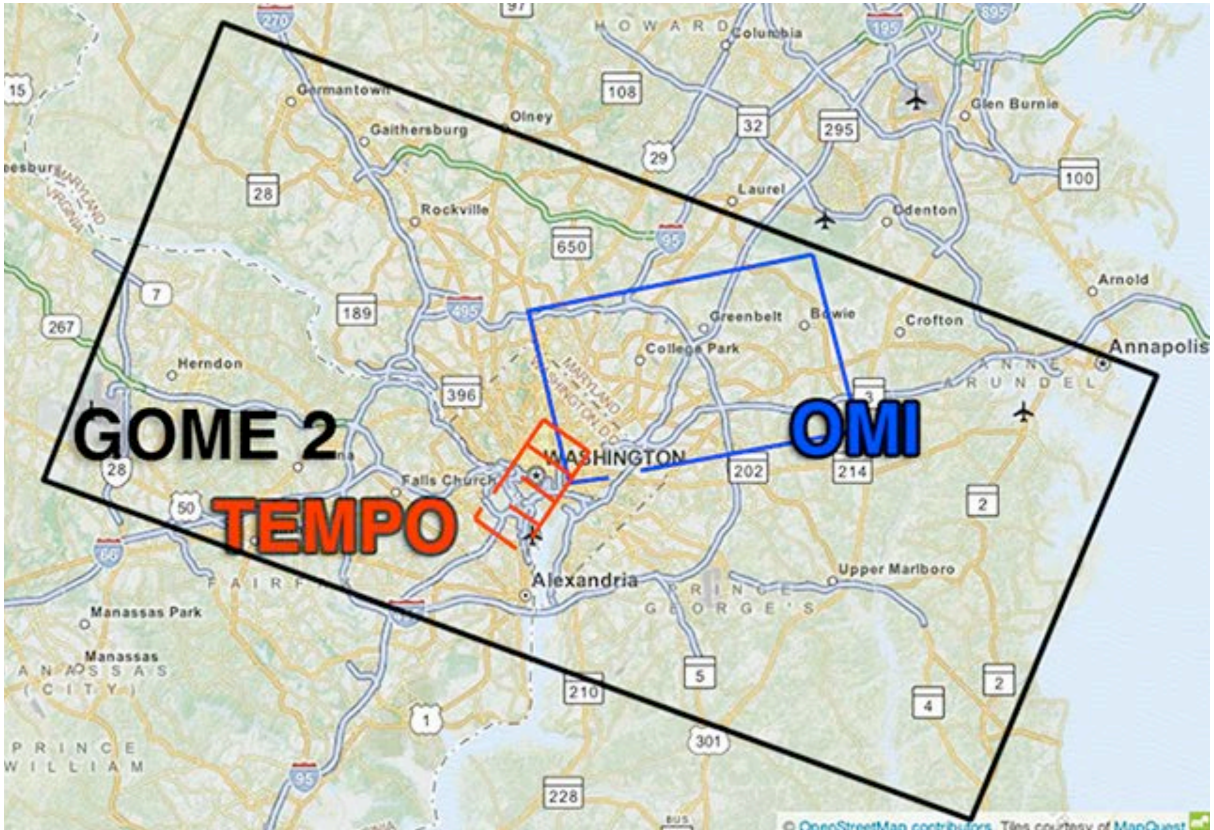
TEMPO hourly NO_2 sweep



N.B. special operations give 10-minute resolution for selected longitude regions

Coverage comparisons

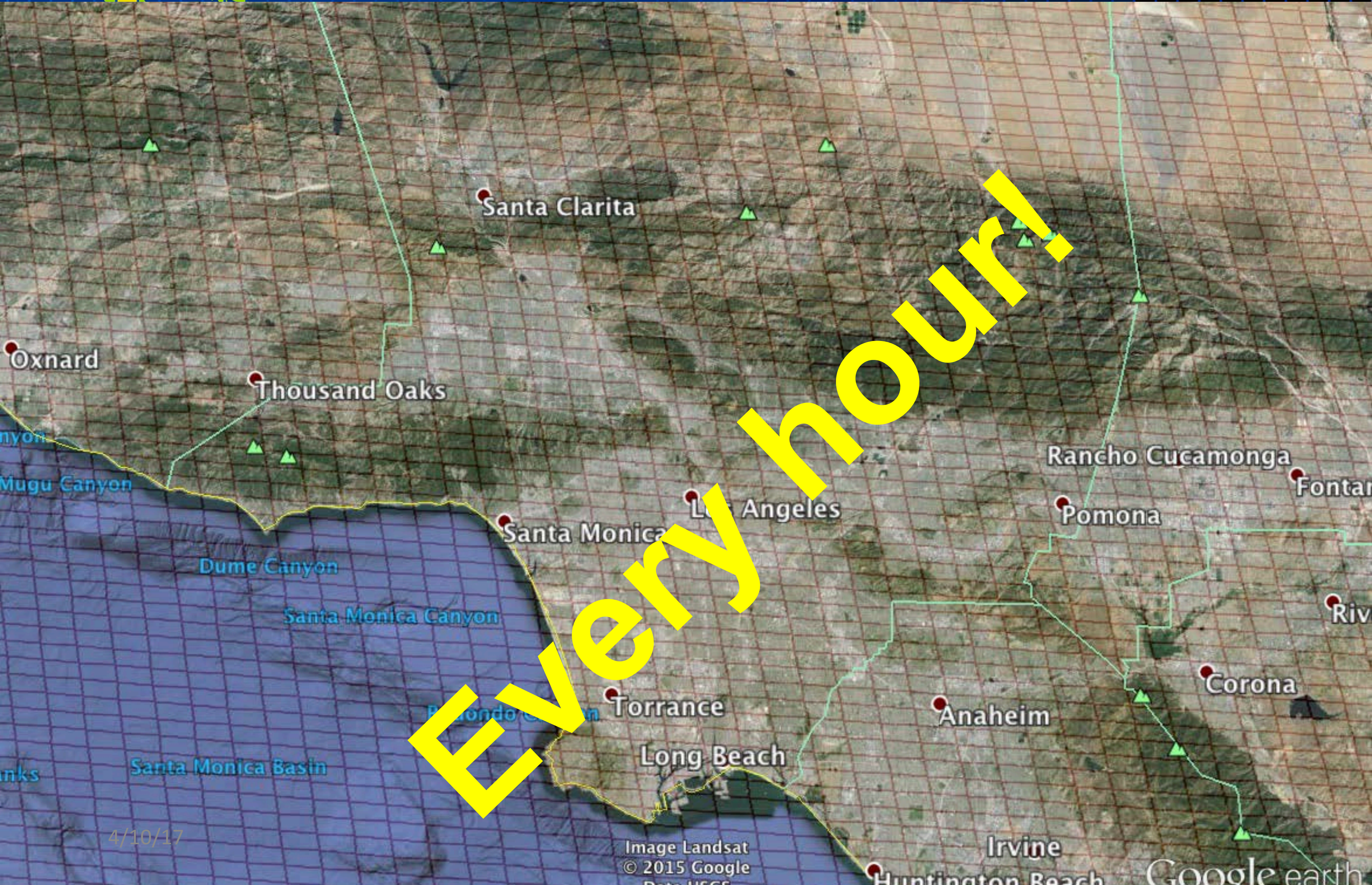
- **Spatial resolution: allows tracking pollution at sub-urban scale**
  - **GEO at 100°W: 2.1 km N/S × 4.7 km E/W = 9.8 km^2 (native) at center of FOR (36.5°N, 100°W)**
  - **Full resolution for NO_2, HCHO, total O_3 products**
  - **Co-add 4 N/S pixels for O_3 profile product: 8.4 km N/S × 4.7 km E/W**



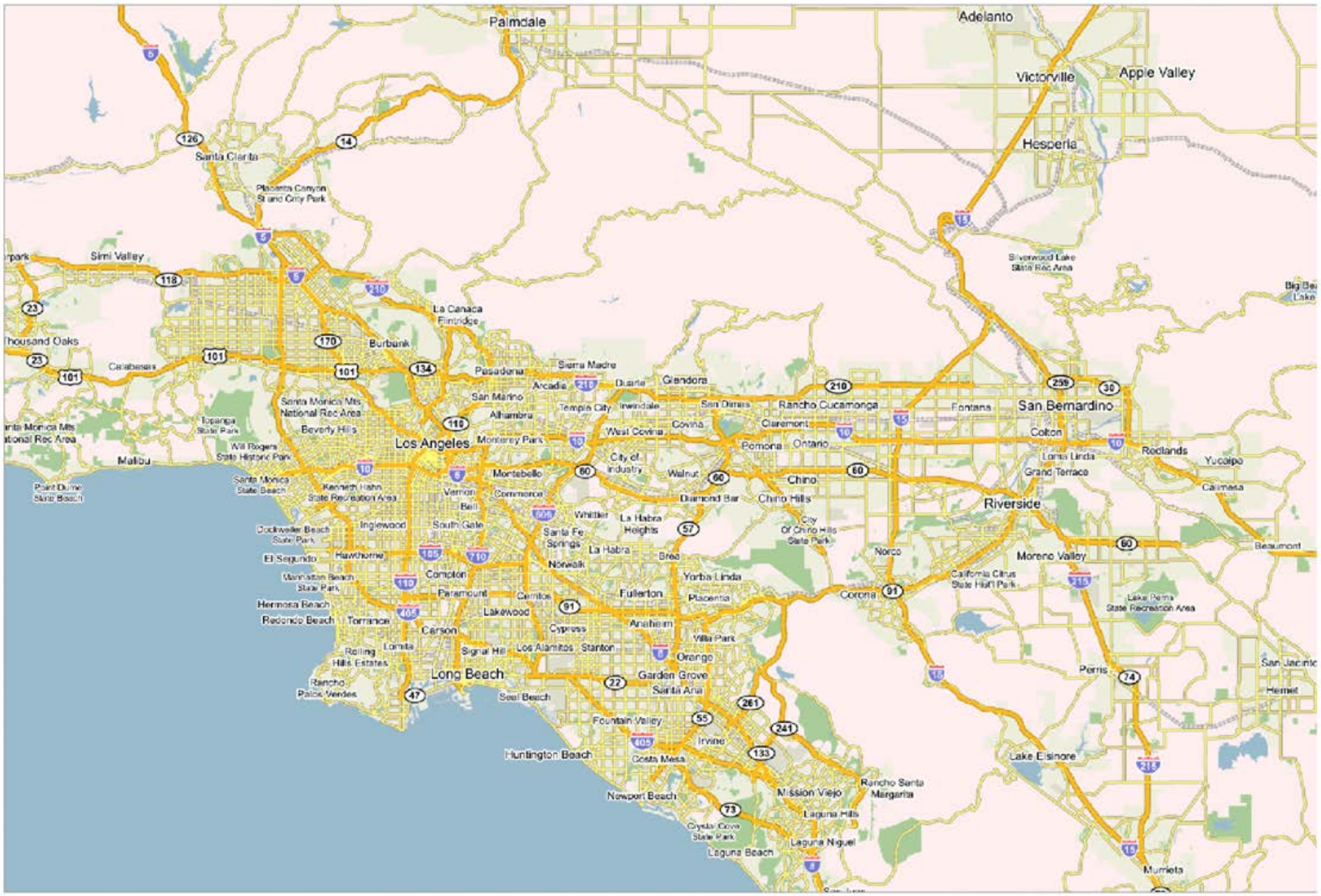
~ 1/300 of GOME-2

~ 1/30 of OMI

Los Angeles coverage



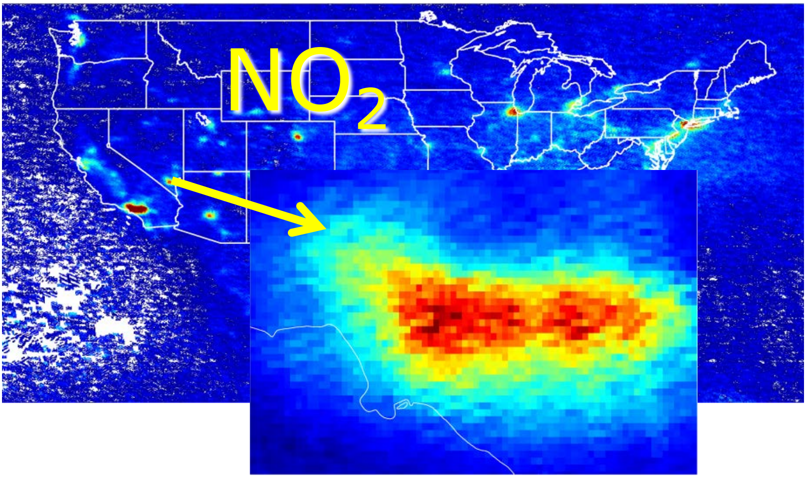
NO_2 over Los Angeles

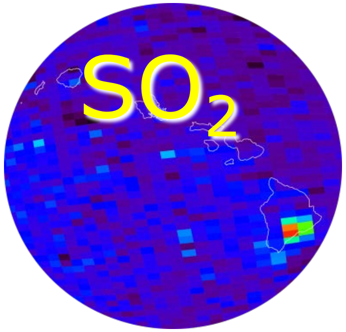


TEMPO science questions

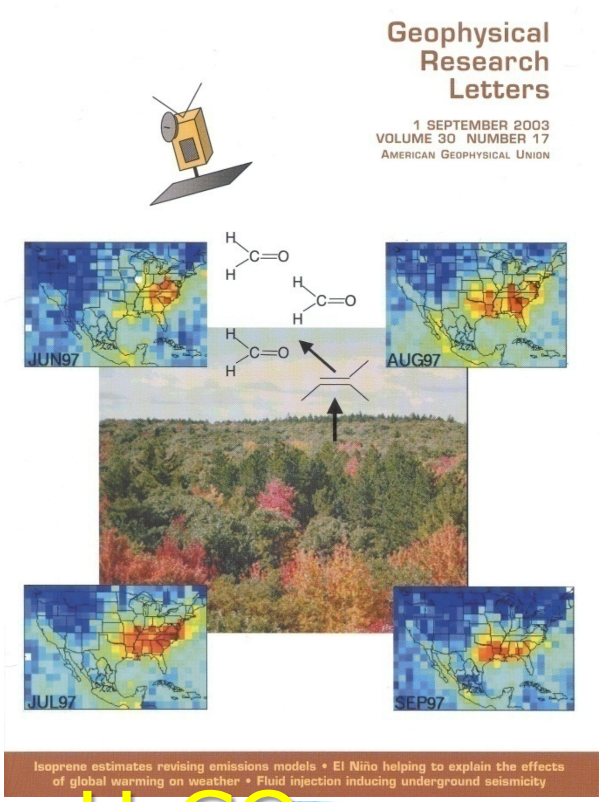
1. What are the temporal and spatial variations of **emissions** of gases and aerosols important for air quality and climate?
2. How do physical, chemical, and dynamical **processes** determine tropospheric composition and air quality over scales ranging from urban to continental, diurnally to seasonally?
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?

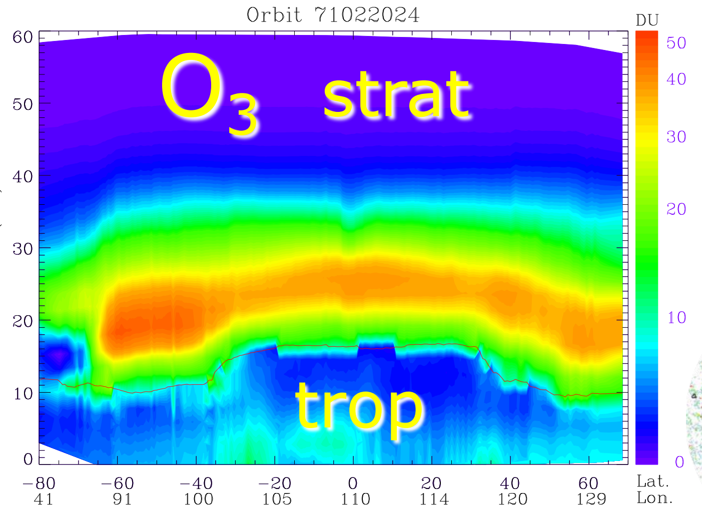
GOME, SCIA, OMI examples

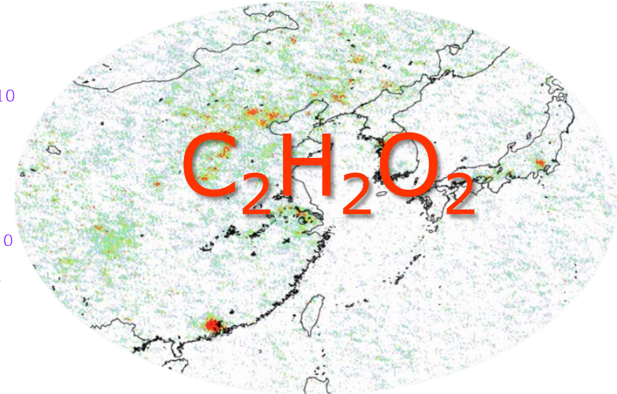


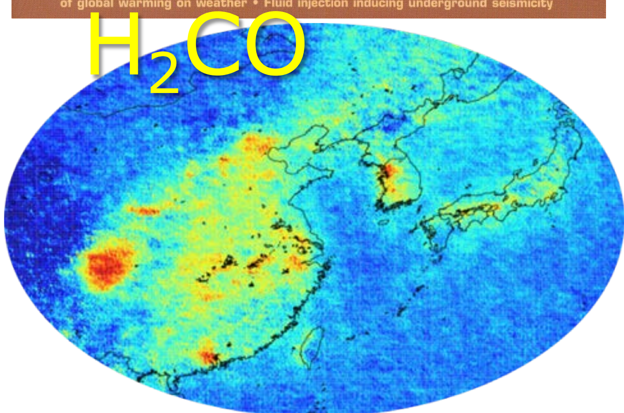


Kilauea activity, source of the VOG event in Honolulu on 9 November 2004



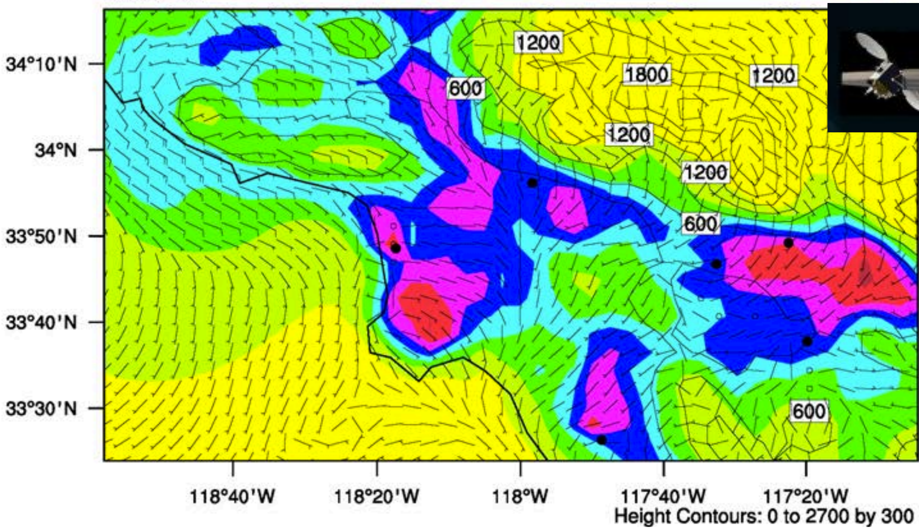


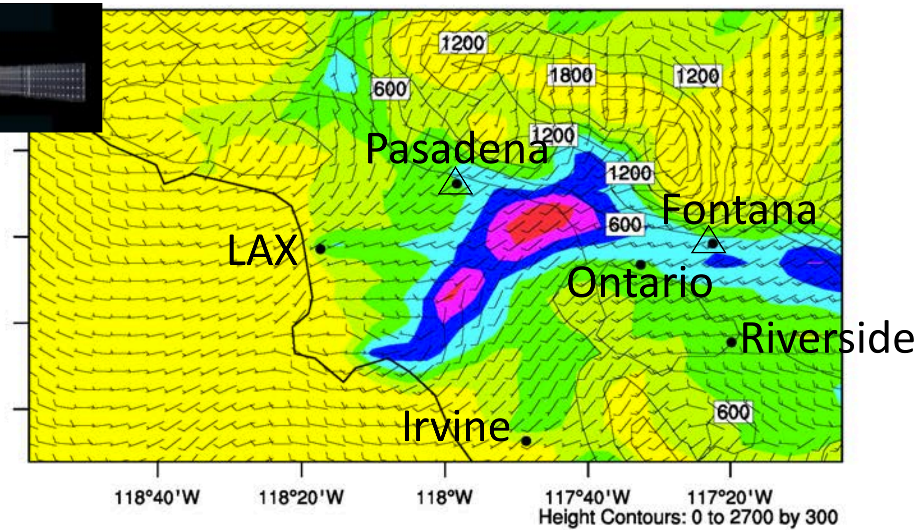


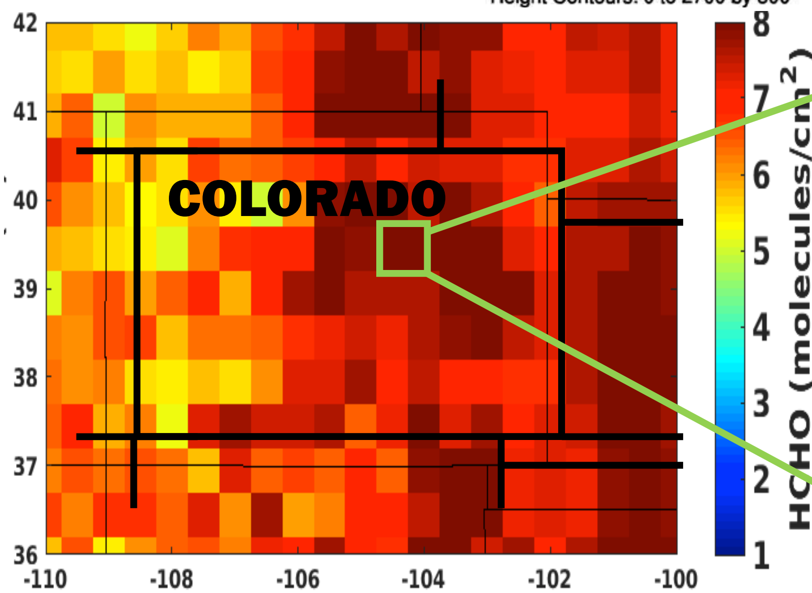


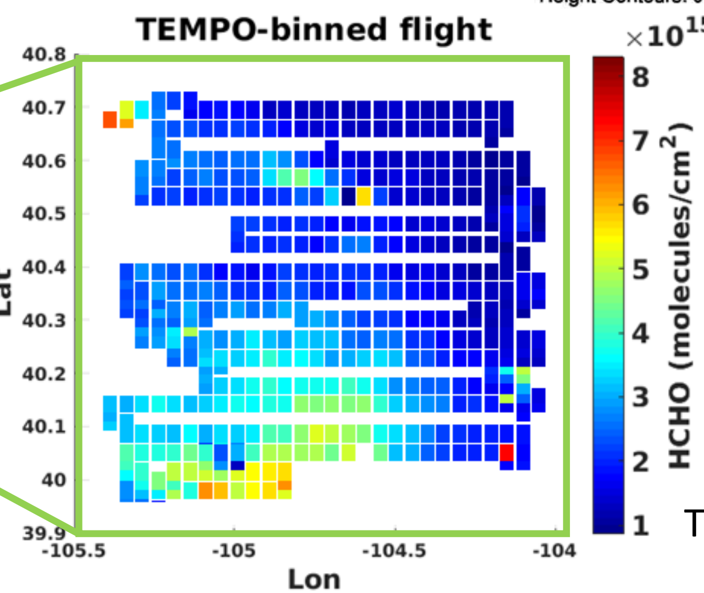
TEMPO synthetic observations

Si-Wan Kim et al. NO$_2$ columns modeled at approximate TEMPO resolution





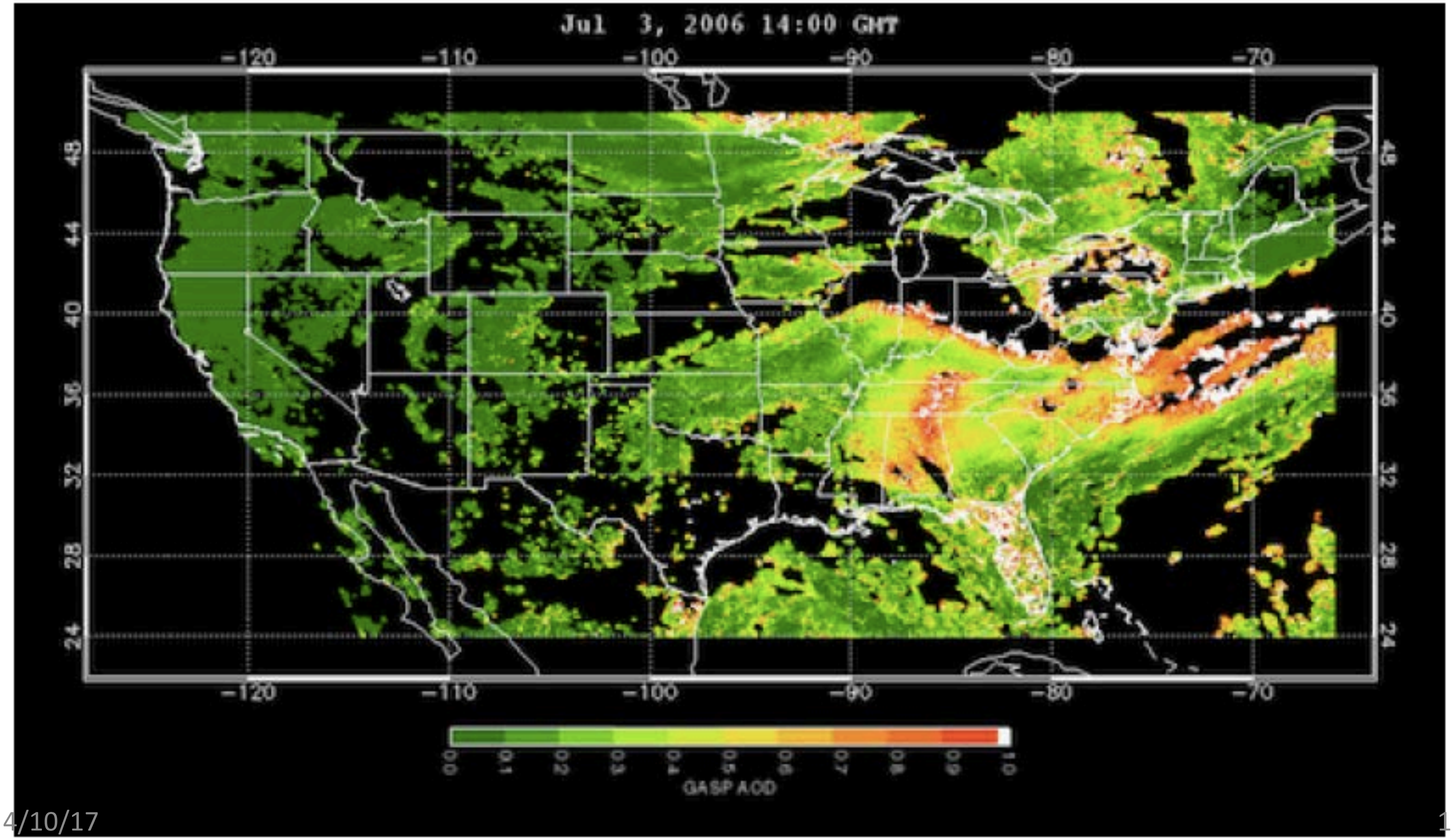




Frank Keutsch, Mitchell Thayer, et al.

www.epa.gov/rsig

TEMPO will use the EPA's Remote Sensing Information Gateway (RSIG) for subsetting, visualization, and product distribution – *to make TEMPO YOUR instrument*



Experimental Opportunities

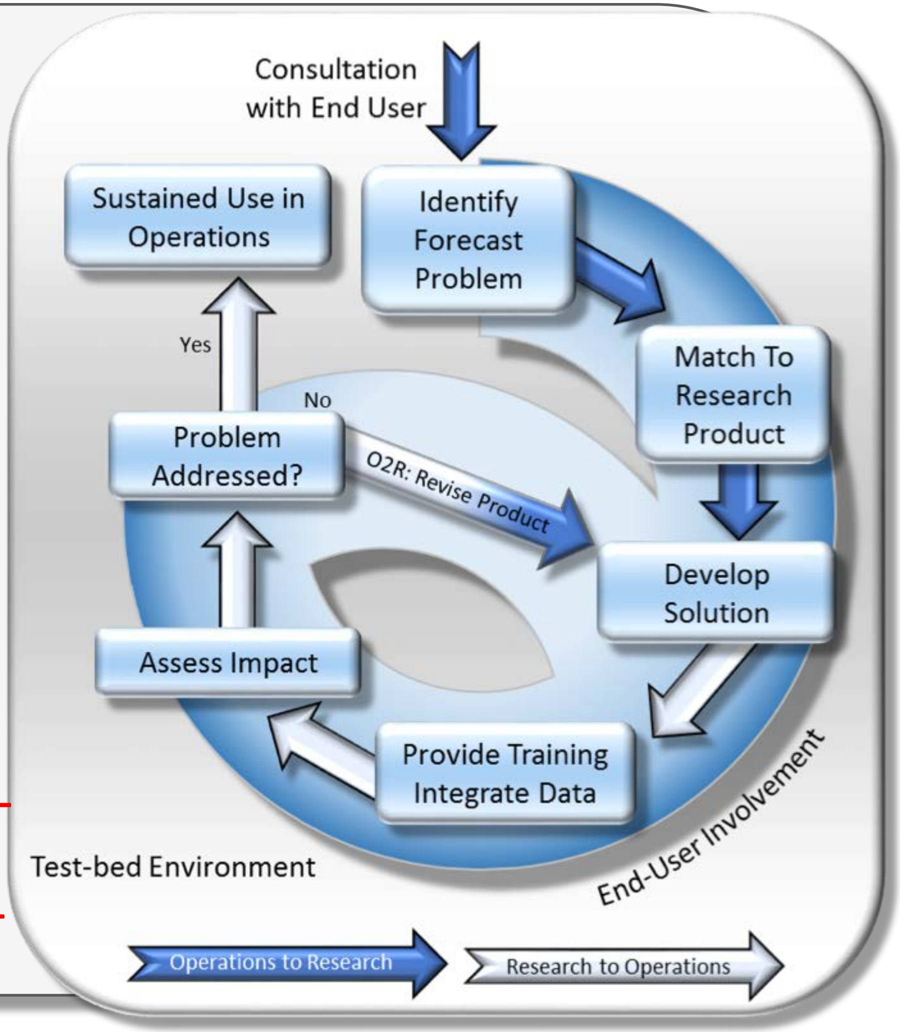
1. Up to 25% of observing time can be devoted to non-standard ops
2. Two types:
    1. Events (e.g., eruptions, fires, dust storms, etc.)
    2. Experiments (non standard scan patterns to explore phenomena)
3. TEMPO team will work with experimenters concerning Image Navigation and Registration (i.e., 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

8. Tempo.si.edu

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

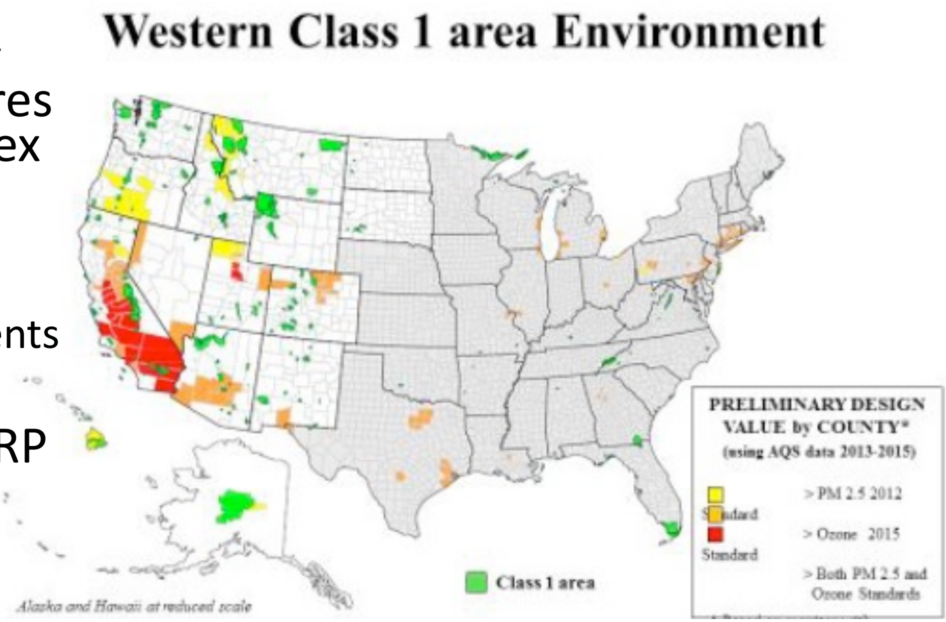
NASA SPoRT: Emily Berndt and Aaron Naeger – SPoRT R2O Paradigm: preparing end users for next-generation satellite missions before day 1 operations



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

Pilot Project: Exceptional Event (Intermountain West)

- How can TEMPO be used to identify exceptional events caused by wildfires or stratospheric intrusions in complex terrain?
  - Distinguish between transport and source events
  - Identify frequency of exceptional events
- Focus on complex terrain in collaboration with WESTAR and WARP
- Can incorporation of proxy data improve PM2.5 and O3 precursor emission estimates used in regional modeling analysis to support planning and decision making to protect both human health and visibility?
- Early testing of data processing infrastructure and assimilation of proxy data in regional models will prepare state/federal agencies for use of TEMPO data quickly after launch



Map of western region showing whether PM2.5 and O3 standards were met from 2013-2015 in each county. Orange where PM2.5 standards not met, Yellow where O3 standards not met, and red where both standards not met

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.

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].

Halogens

BrO will be produced at launch, assuming stratospheric AMFs. Scientific studies will correct retrievals for tropospheric content. **IO** was first measured from space by SAO using SCIAMACHY spectra [Saiz-Lopez *et al*., 2007]. It will be produced as a scientific product, particularly for coastal studies, assuming AMFs appropriate to lower tropospheric loading.

The atmospheric chemistry of halogen oxides over the ocean, and in particular in coastal regions, can play important roles in ozone destruction, oxidizing capacity, and dimethylsulfide oxidation to form cloud-condensation nuclei [Saiz-Lopez and von Glasow, 2012]. The budgets and distribution of reactive halogens along the coastal areas of North America are poorly known. Therefore, providing a measure of the budgets and diurnal evolution of coastal halogen oxides is necessary to understand their role in atmospheric photochemistry of coastal regions. Previous ground-based observations have shown enhanced levels (at a few pptv) of halogen oxides over coastal locations with respect to their background concentrations over the remote marine boundary layer [Simpson et al., 2015]. Previous global satellite instruments lacked the sensitivity and spatial resolution to detect the presence of active halogen chemistry over mid-latitude coastal areas. TEMPO observations together with atmospheric models will allow examination of the processes linking ocean halogen emissions and their potential impact on the oxidizing capacity of coastal environments of North America.

TEMPO also performs **hourly measurements one of the world's largest salt lakes: the Great Salt Lake in Utah**. Measurements over Salt Lake City show the highest concentrations of BrO over the globe. Hourly measurement at a high spatial resolution can improve understanding of BrO production in salt lakes.

Spectral indicators

Fluorescence and other spectral indicators Solar-induced fluorescence (SIF) from chlorophyll over both land and ocean will be measured. In terrestrial vegetation, chlorophyll fluorescence is emitted at red to far-red wavelengths (~650-800 nm) with two broad peaks near 685 and 740 nm, known as the red and far-red emission features. Oceanic SIF is emitted exclusively in the red feature. SIF measurements have been used for studies of tropical dynamics, primary productivity, the length of carbon uptake period, and drought responses, while ocean measurements have been used to detect red tides and to conduct studies on the physiology, phenology, and productivity of phytoplankton. TEMPO can retrieve both red and far-red SIF by utilizing the property that SIF fills in solar Fraunhofer and atmospheric absorption lines in backscattered spectra normalized by a reference (*e.g.*, the solar spectrum) that does not contain SIF.

TEMPO will also be capable of measuring **spectral indices developed for estimating foliage pigment contents and concentrations**. Spectral approaches for estimating pigment contents apply generally to leaves and not the full canopy. A single spectrally invariant parameter, the Directional Area Scattering Factor (DASF), relates canopy-measured spectral indices to pigment concentrations at the leaf scale.

UVB TEMPO measurements of daily UV exposures build upon heritage from OMI and TROPOMI measurements. Hourly cloud measurements from TEMPO allow taking into account diurnal cloud variability, which has not been previously possible. The OMI UV algorithm is based on the TOMS UV algorithm. The specific product is the downward spectral irradiance at the ground (in W m^{-2} nm^{-1}) and the erythemally weighted irradiance (in W m^{-2}).

Air quality and health

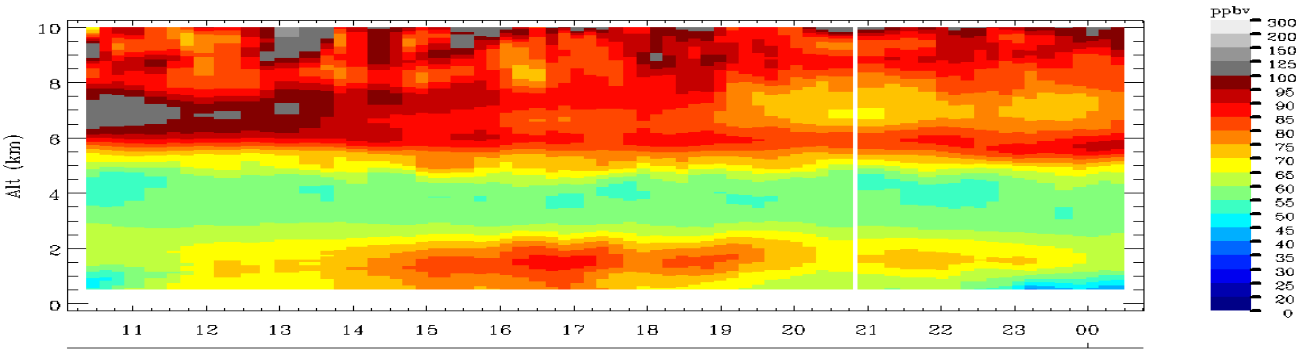
TEMPO's hourly measurements allow better understanding of the complex chemistry and dynamics that drive **air quality on short timescales**. The density of TEMPO data is ideally suited for data assimilation into chemical models for both air quality forecasting and for better constraints on emissions 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

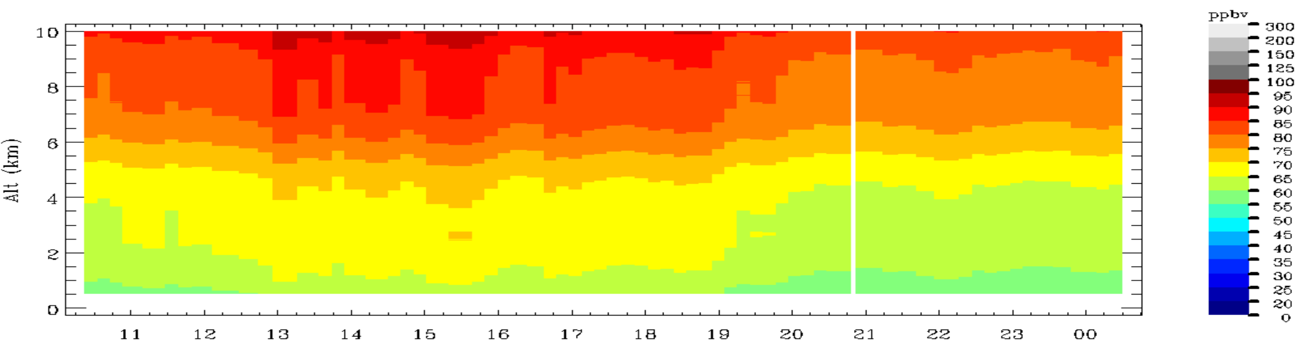
Clouds The launch cloud algorithm is be based on the rotational Raman scattering (RRS) cloud algorithm that was developed for OMI by GSFC. Retrieved cloud pressures from OMCLDRR are not at the geometrical center of the cloud, but rather at the optical centroid pressure (OCP) of the cloud. **Additional** 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%.

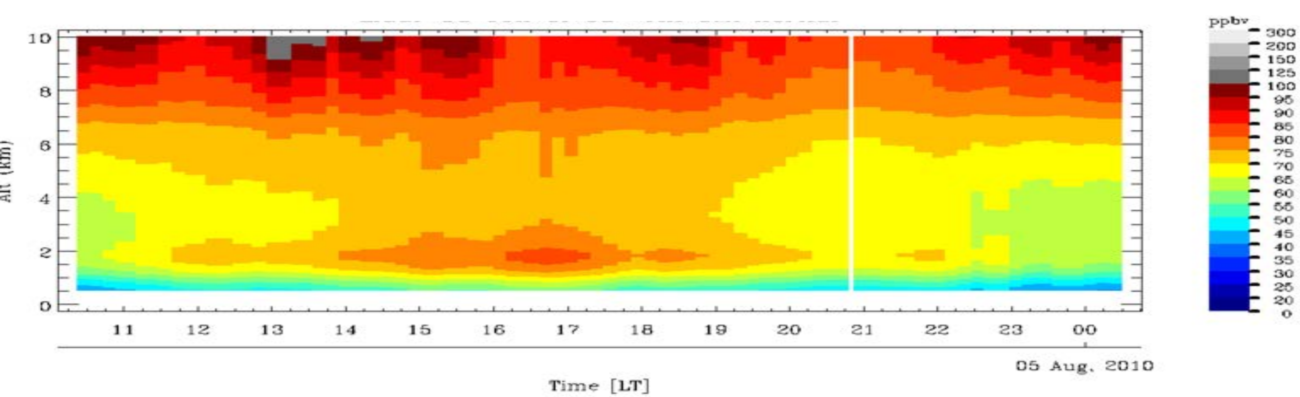
High-resolution PBL lidar observation suggests both UV and Vis radiances required to capture significant PBL signal for satellite



Huntsville lidar observation on Aug. 4, 2010



Lidar obs. convolved with OMI UV averaging kernel----unable to capture the highly variable ozone structure in PBL

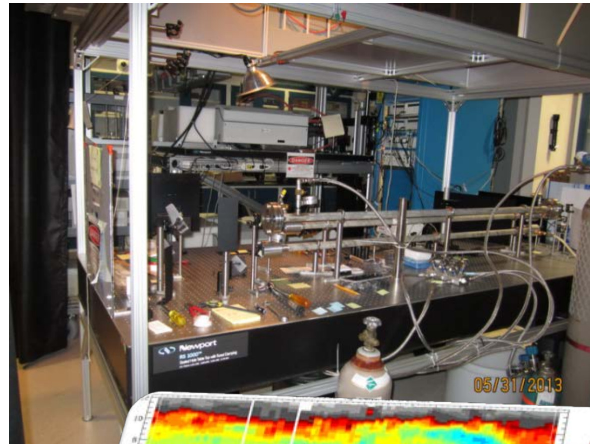


Lidar obs. Convolved with OMI UV-Vis averaging kernel----Captures the PBL ozone structure. X. Liu et al.

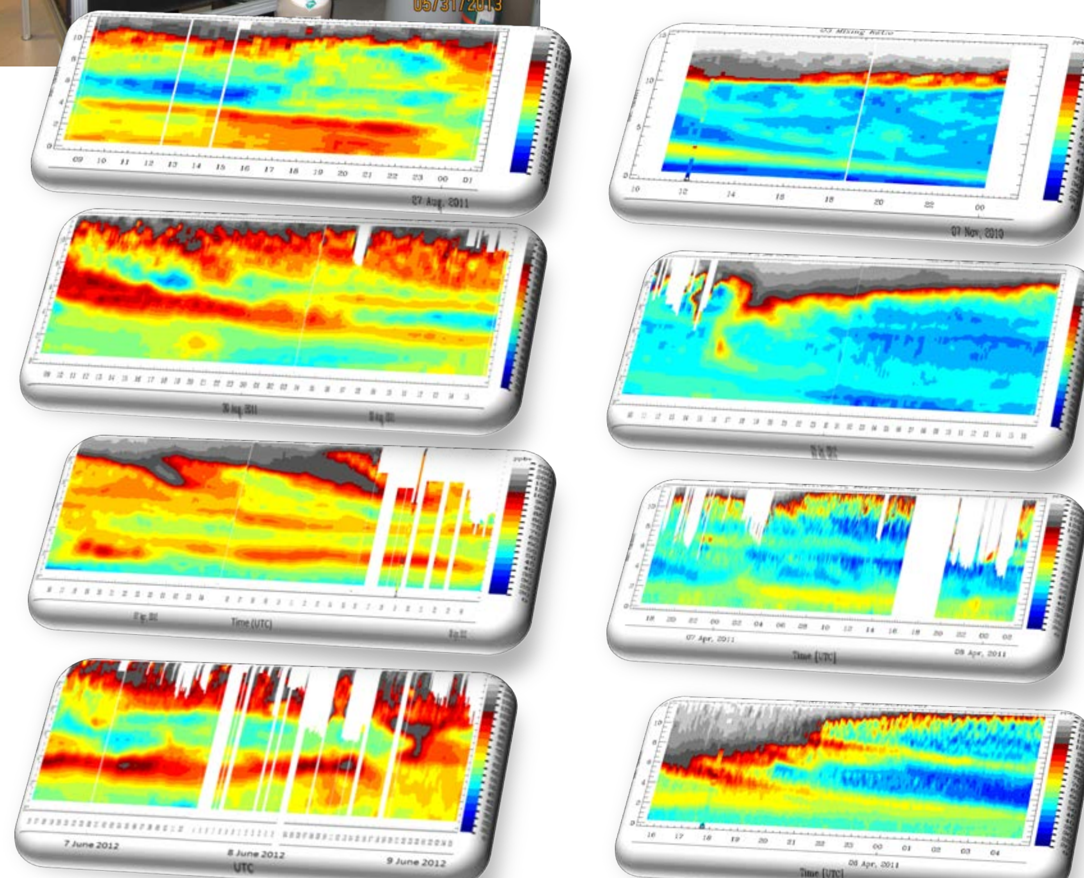
UAH Ground-based O3 lidar

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

Name	RO_3QET (Rocket-city O3 Quality Evaluation in the Troposphere) 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]



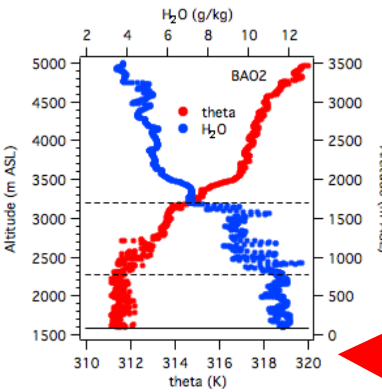
Raman shifted 289/299



Examples

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.

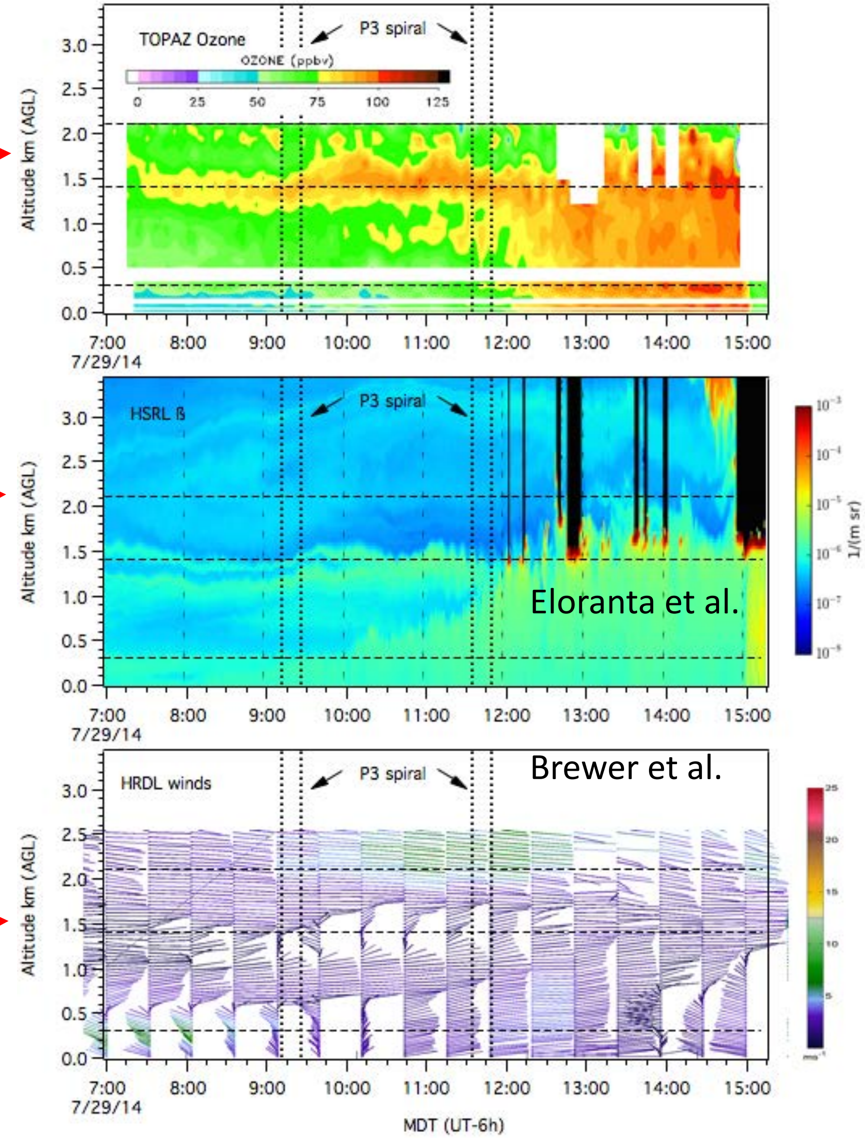
Measurements from the NOAA TOPAZ lidar show a narrow morning RL with 75-90 ppbv of O_3 that is enveloped by the growing convective boundary layer (CBL) near midday. The P3 showed this RL extending over a large area. The observations were ended by T-storms near 1500 MDT.



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.

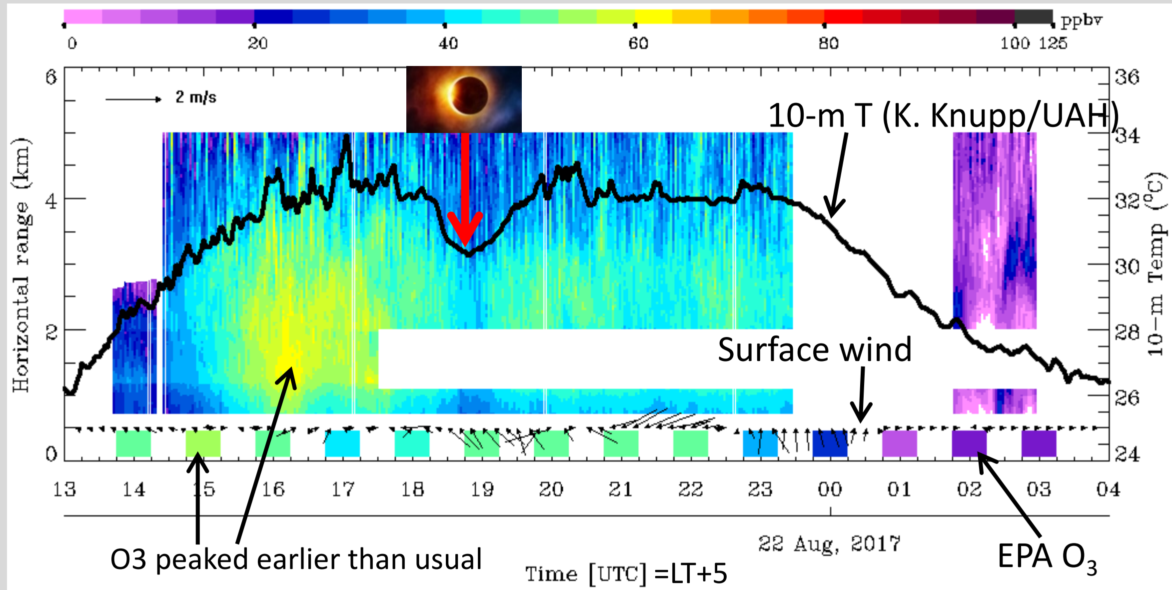


Fig. 1. Horizontal O_3 lidar curtain and the Huntsville EPA O_3 measured on the solar eclipse day (8/22/2017).

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.

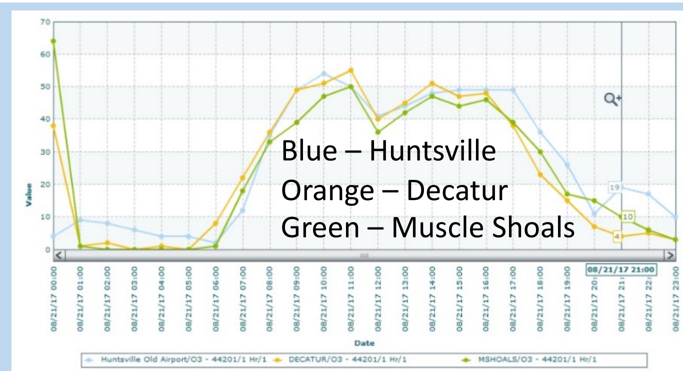


Fig. 2. Surface O_3 measured at 3 EPA stations 10-60km away from the lidar site (AirNow).

Significance:

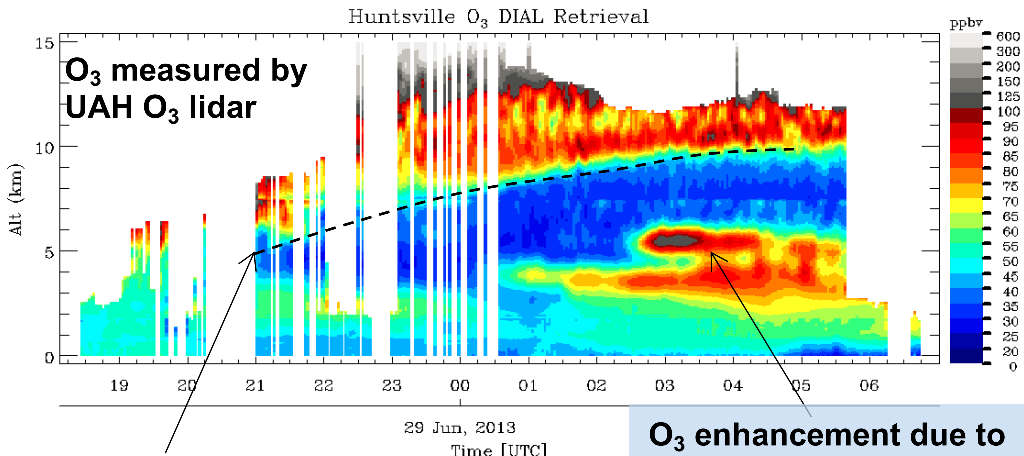
- The scanning lidar measurements can evaluate high-resolution atmospheric numerical models (e.g., LES models) and improve our understanding on small-scale air-quality problems.

TOLNET

Tropospheric Ozone LIDAR Network

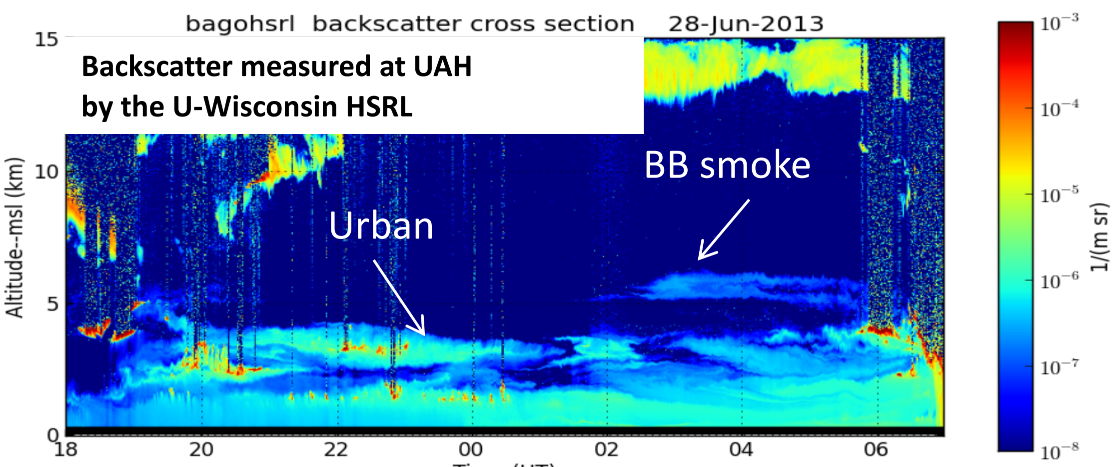
Summertime Tropospheric O_3 Enhancement after a Cold-front Passage Due to Stratosphere-to-Troposphere Transport (STT) and Biomass Burning (BB)

S. Kuang, M. J. Newchurch, J. Burris, E. Eloranta, M. S. Johnson, I. Pollack, T. Ryerson, L. Wang



Upper-air cold front

O_3 enhancement due to both STT & BB influence



28 June 29 June 2013

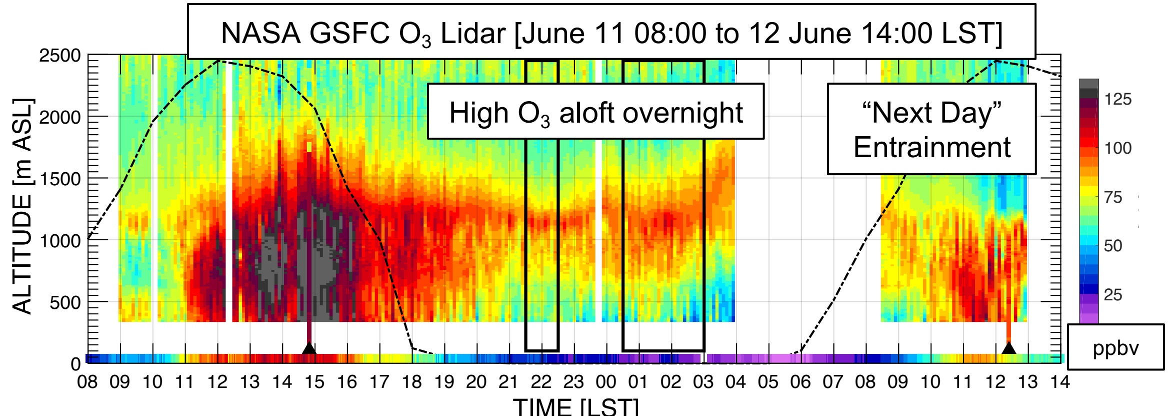
1. Simultaneous ozone and aerosol lidar measurements, rarely available, provide unique information on the sources, interactions, and transport of pollutants.
2. This example reveals the detailed ozone structures associated with a cold-front passage: (1) the large ozone gradients at the upper-air cold front and (2) the large ozone enhancement behind the cold front with mixed sources of STT and BB. The source identification is also confirmed by analysis of simultaneous in-situ, airborne observations.
3. These ozone and aerosol lidar observations provide information to interpret satellite measurements of air pollution in complex environments.

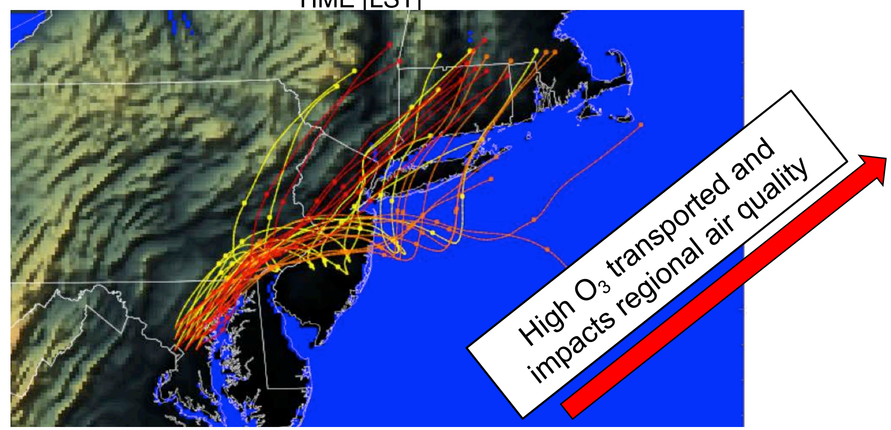
TOLNet Observations Revealing "Next Day" Pollution Episodes

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

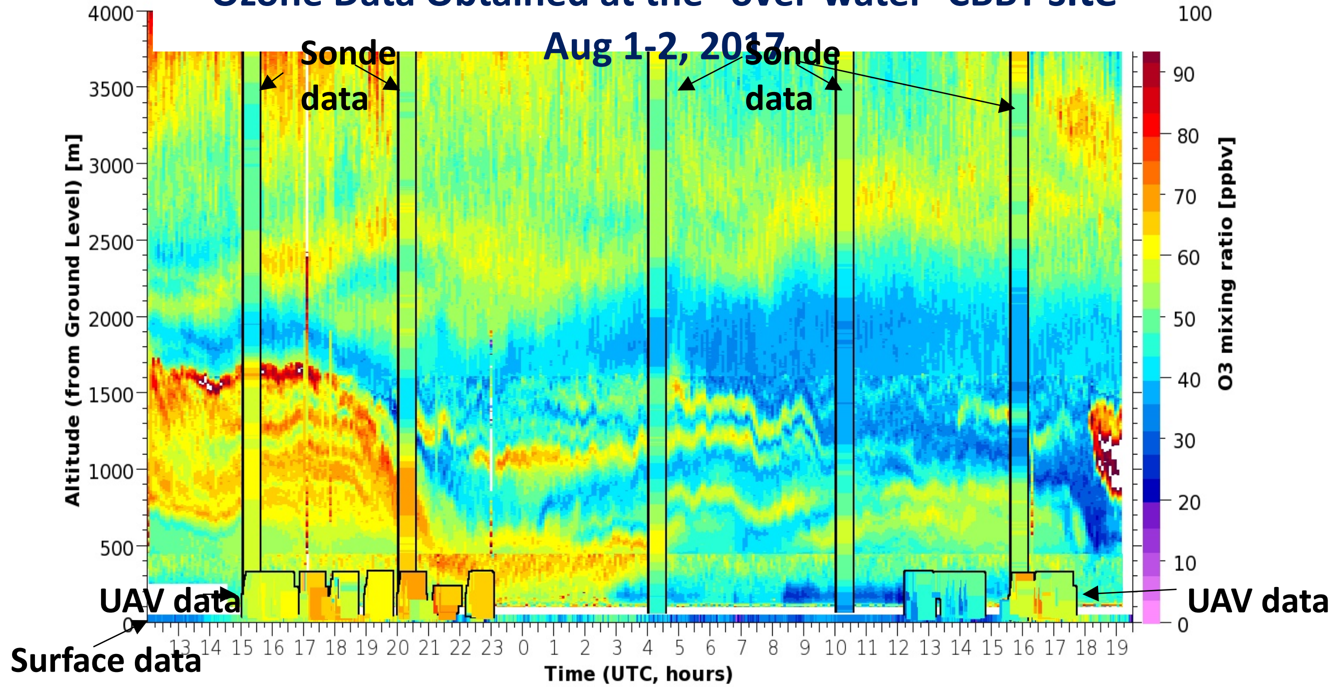
Significance:
Ozone lidar is the critical measurement platform to identify layers aloft, advection, and vertical mixing of pollutants.

TOLNET

Tropospheric Ozone LIDAR Network

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

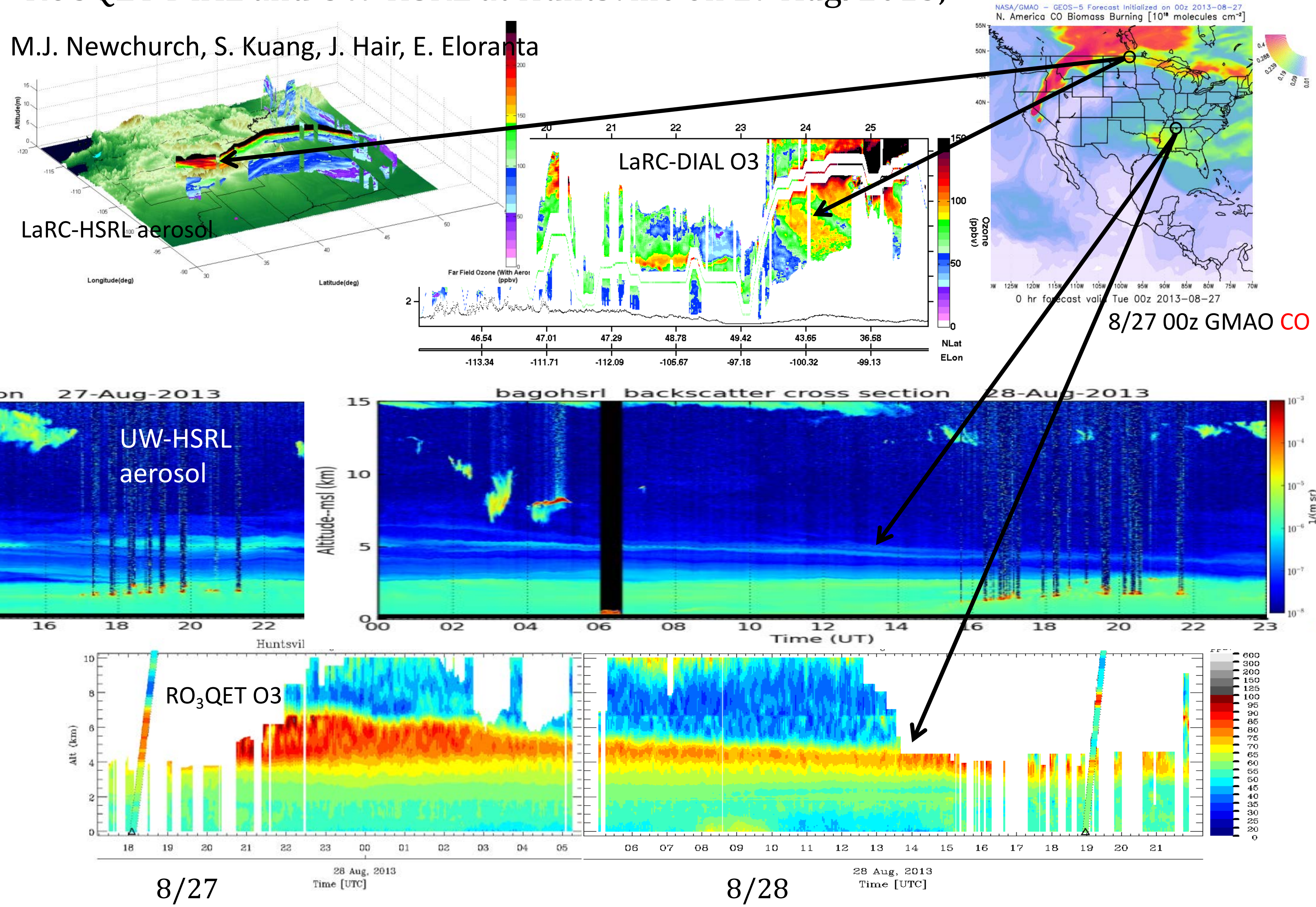
TOLNet Langley Mobile Ozone Lidar: Preliminary Data
Ozone Data Obtained at the "over-water' CBBT site
Aug 1-2, 2017



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.

CA wildfire smoke detected by LaRC airborne DIAL/HSRL above N. Dakota, and RO3QET DIAL and UW-HSRL at Huntsville on 27 Aug. 2013,

M.J. Newchurch, S. Kuang, J. Hair, E. Eloranta



Entrainment of Asian pollution during *FAST*-LVOS

A.O. Langford, R.J. Alvarez II, G. Kirgis[1], and C.J. Senff[1], NOAA ESRL Chemical Sciences Division

[1]*also with CIRES, University Of Colorado, Boulder*

Background:

The Fires, Asian, and Stratospheric Transport-Las Vegas Ozone Study (*FAST*-LVOS) was conducted in Clark County, Nevada during May and June 2017 to investigate the mechanisms by which transported ozone (O_3) is brought to the surface in the Desert Southwest.

Measurements:

The NOAA TOPAZ mobile ozone and aerosol lidar was deployed to the North Las Vegas Airport along with a vertically-staring Doppler lidar to measure mixing heights from May 17 to June 30, 2017. Additional measurements were made by an instrumented aircraft (Scientific Aviation), ozonesondes (NOAA ESRL GMD) and a mobile laboratory (NOAA ESRL CSD).

Results:

TOPAZ acquired 523 hours of lidar measurements on 45 days, with 90 hours of aircraft flights and 30 ozonesondes on 14 of those days. The mobile lab and Doppler lidar operated almost continuously. The profiles in **Figure** 1 show the entrainment of an Asian pollution plume by the mixed layer on June 28, 2017. The plume origin is inferred from the aircraft CH_4 measurements and NOAA HYSPLIT back trajectories.

Significance:

These measurements illustrate the key role of mixed layer entrainment in the capture of stratospheric intrusions and Asian pollution transported over the Sierra Nevada and the creation of a late spring and early summer O_3 maximum in the Desert Southwest.

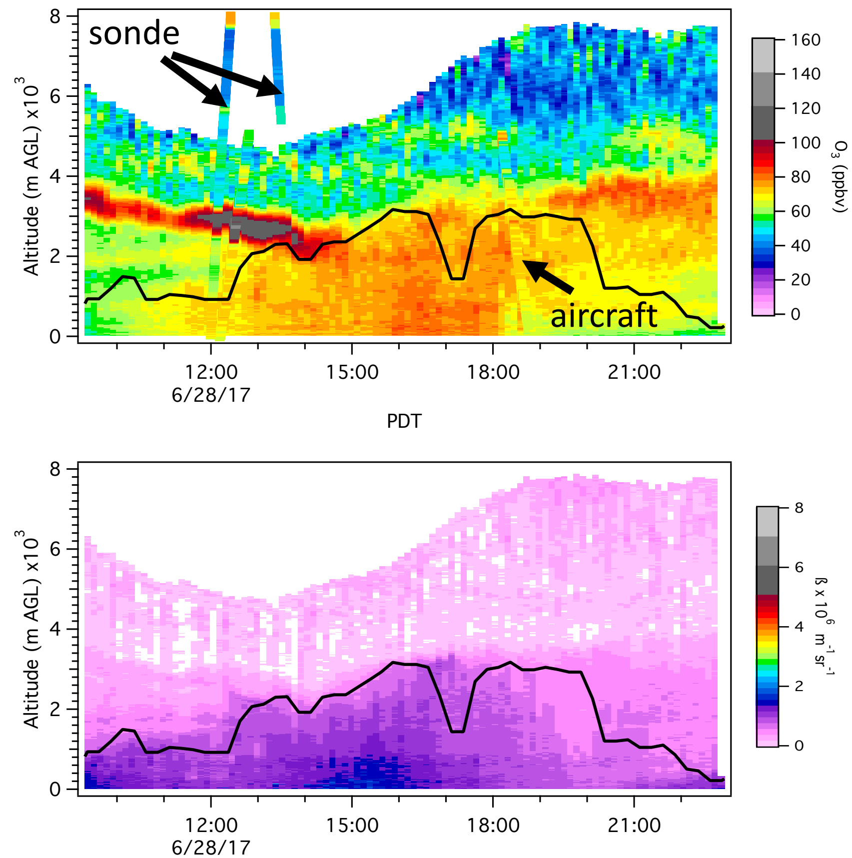
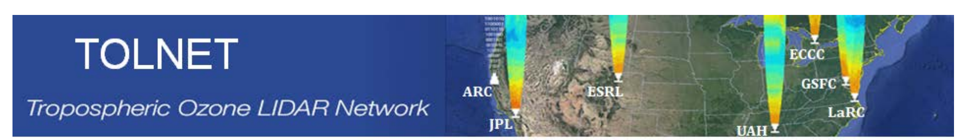


Figure 1. Time-height curtain plots of O_3 (top) and aerosol (bottom) distributions measured by TOPAZ over 14 hours with aircraft and ozonesonde profiles superimposed in the top panel. The solid black line shows the Doppler lidar mixed layer height.



Synchronized Multi-Day Ozone Lidar Measurements in Support of the Ozone-Water Land Environmental Transition Study-2

OWLETS

John Sullivan, T. Berkoff, G. Gronoff, T. McGee, G. Sumnicht, L. Twigg, W. Carrion, J. Sparrow

TOLNET
Tropospheric Ozone LIDAR Network

Background:

- **OWLETS-2** is a follow-on study to better understand the behavior of ozone and related trace gases across the water land transition zone in the upper portion of the Chesapeake Bay
  - ***Fig 1: 4 days of continuous TOLNet measurements from Hart Miller Island (HMI) and University of Maryland, Baltimore County (UMBC)***
- At coastal boundaries, significant water-land gradients can occur due to difference in surface deposition, boundary layer height, and cloud coverage from water to land

Science Questions:

- What are the mechanisms (low boundary layer, chemistry, weather) that produce high ozone over the Chesapeake Bay and lead to high ozone at locations on land near the Chesapeake Bay? ***The synergy of TOLNet lidars, balloon-borne, and surface measurements at HMI and UMBC will directly reveal differences in controlling factors related to air quality episodes***
- How can measurements be better utilized (in conjunction with chemical transport models) to connect ground level pollutants to satellites in the upcoming framework of the NASA TEMPO instrument? ***Repeated high-resolution measurements under a variety of atmospheric conditions will help provide the statistics needed to test and optimize satellite retrievals and comparisons.***

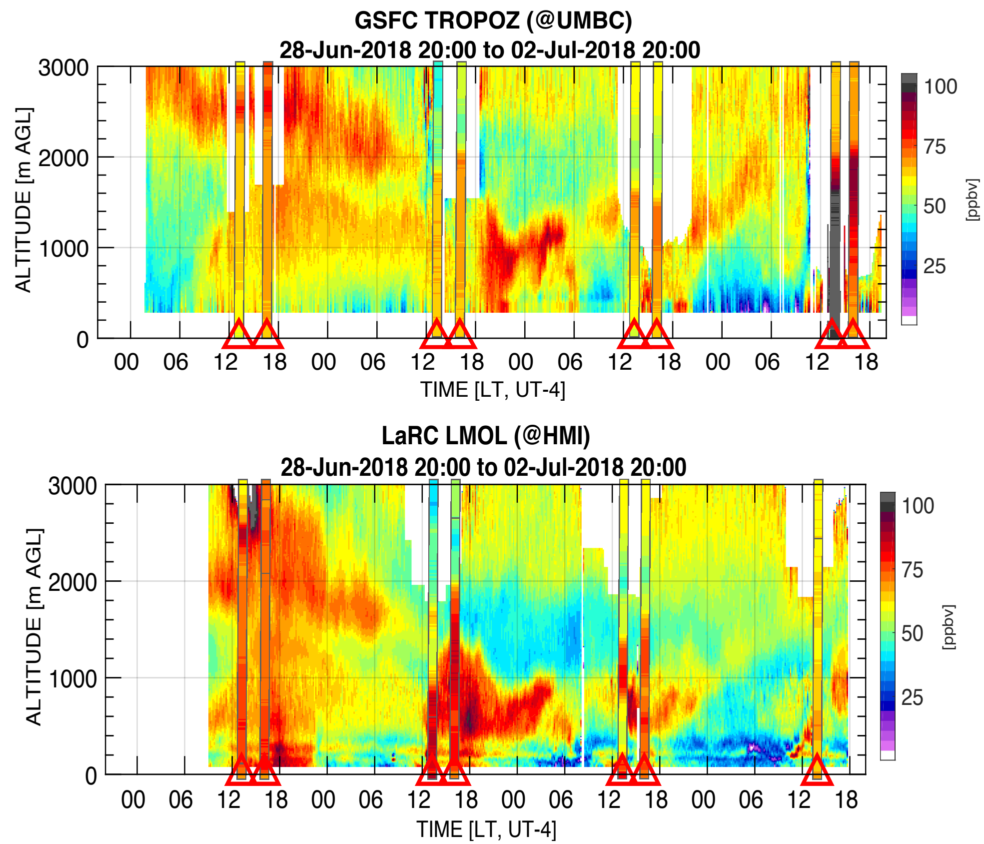


Fig 1: GSFC and LaRC TOLNet lidars operating continuously for 4 days during OWLETS-2 campaign. ***Note: This is preliminary data.***

Validation of the TOLNet Lidars: The Southern California Ozone Observation Project (SCOOP)

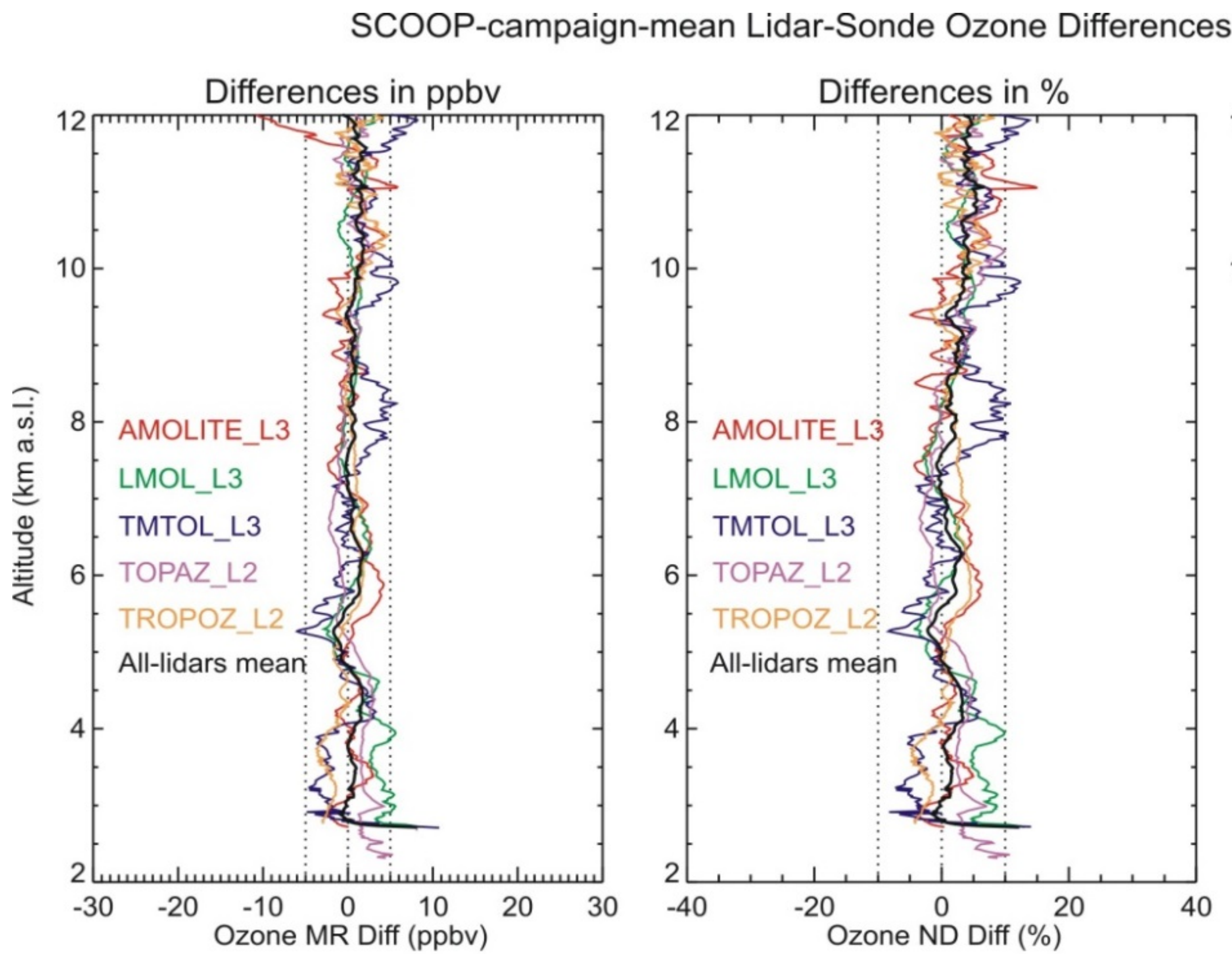
Thierry Leblanc[1], et al., AMT, 2018

Background:
- TOLNet (Tropospheric Ozone Lidar Network) comprises 6 lidars dedicated to air quality and tropospheric ozone variability studies, and to satellite validation.
- Aug 2016: Five of the six TOLNet lidars were deployed at JPL-Table Mountain, CA for a validation campaign (the 6th had already been well validated).

Analysis:
- 18 ECC ozonesondes were launched from TMF in support of validation
- 30-min-averaged lidar profiles coinciding with first 30-min of ECC flights were compared (see figure)
- To facilitate bias detection, the same effective vertical resolution was used for lidars and ECC
  ➔ Preliminary, non-optimized results shown

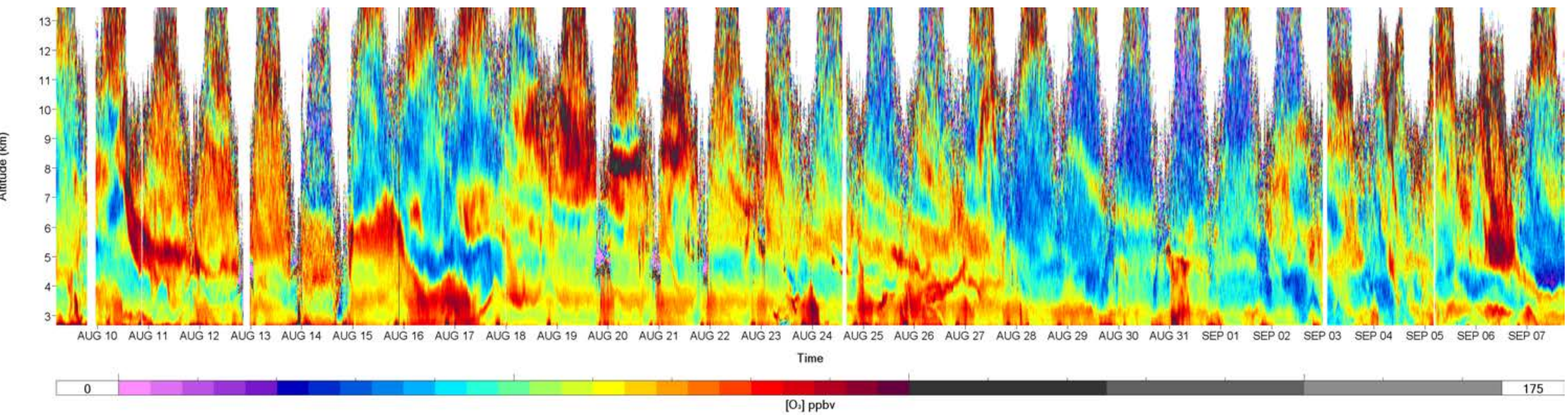
Findings:
- All lidars within +/-1.2 ppbv (+/-2%) of ozonesonde for alt. 3-10 km;
- All lidar-mean bias: +0.1 ppbv (0.6%), RMS: 0.9 ppbv (2%) 3-10 km.
- All differences within reported ECC and lidar combined uncertainties

Significance:
The SCOOP results show that TOLNet lidars now constitute a mature, robust, ground-based reference network



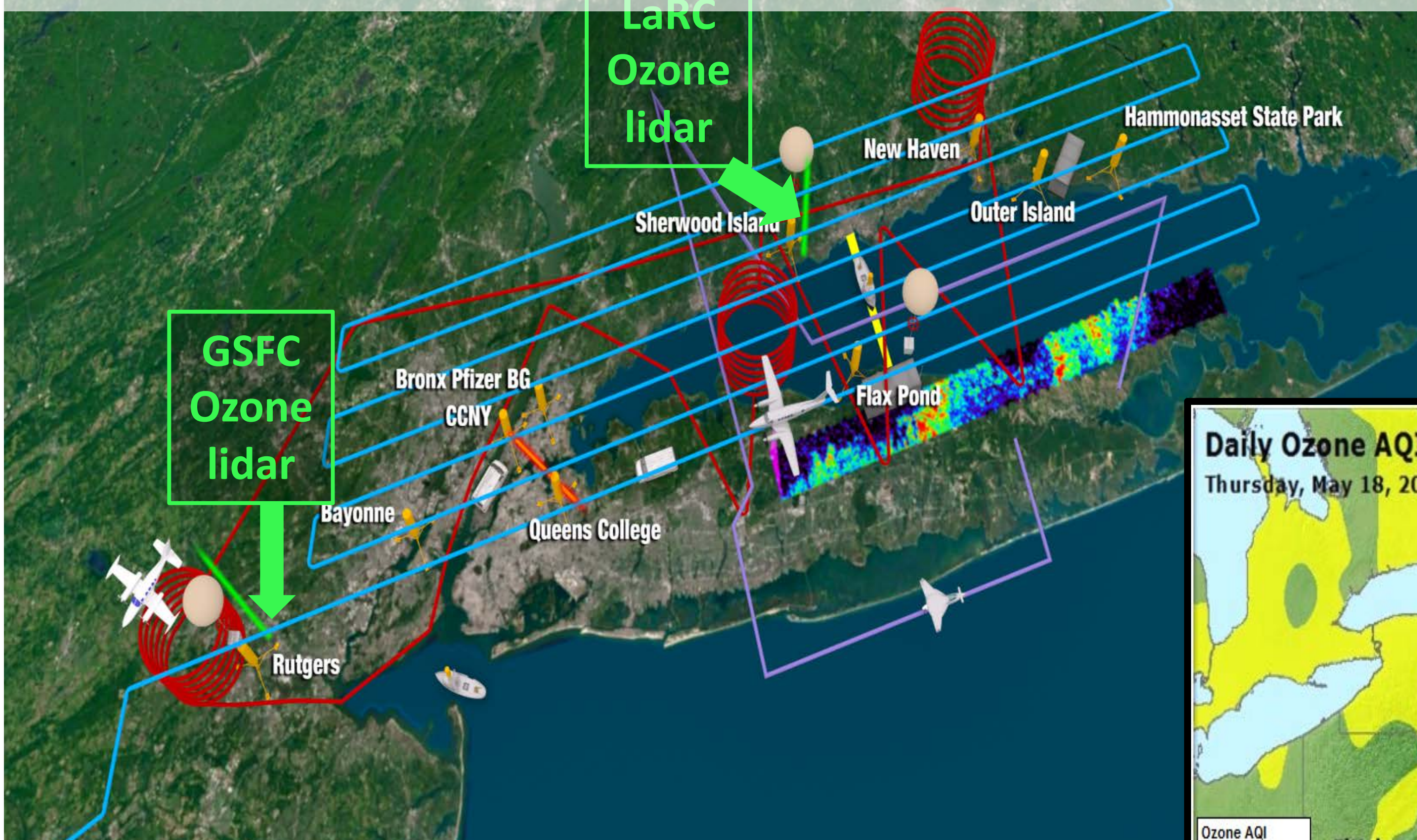
ECCC continuous, atonomous observations at SCOOP:
31 days including the BlueCut fire TMF evacuation

Courtesy of K. Strawbridge



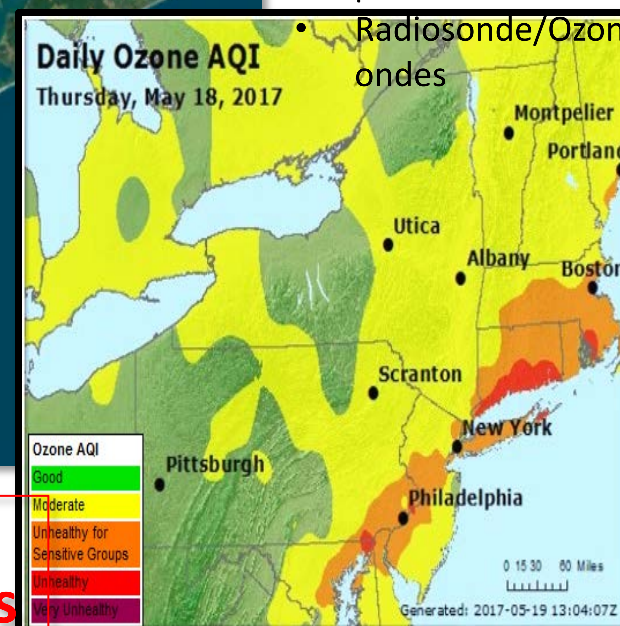
Long Island Sound Tropospheric Ozone Study (LISTOS)

Miller et al., "Overview of the Long Island Sound Tropospheric Ozone Study (LISTOS)", AGU Fall Meeting, 2018



Summer 2018:

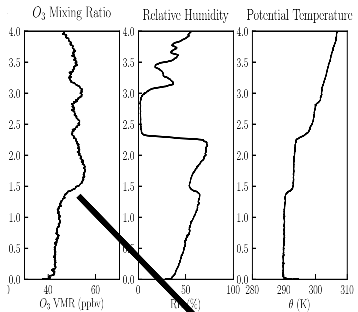
- Multiple aircraft
- Marine vessels
- Automobiles
- Ground lidars
- Sounding systems
- In-situ sensors
- Pandora sun-spectrometers
- Aeronet sun-photometers
- Radiosonde/Ozonesondes



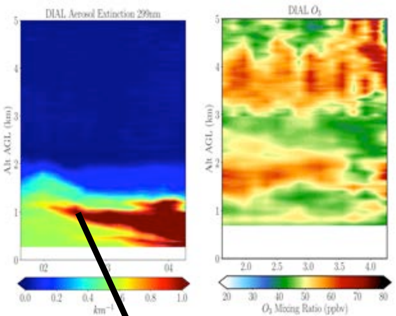
Campaign description website:
http://www.nescaum.org/documents/listos

2016 Southeast Wildfire Impacts

Ozonesonde
O_3 & RH & θ

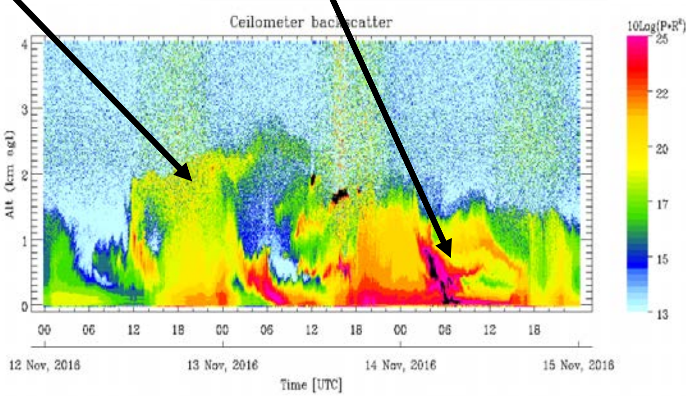


DIAL
Aerosol Extinction & O_3

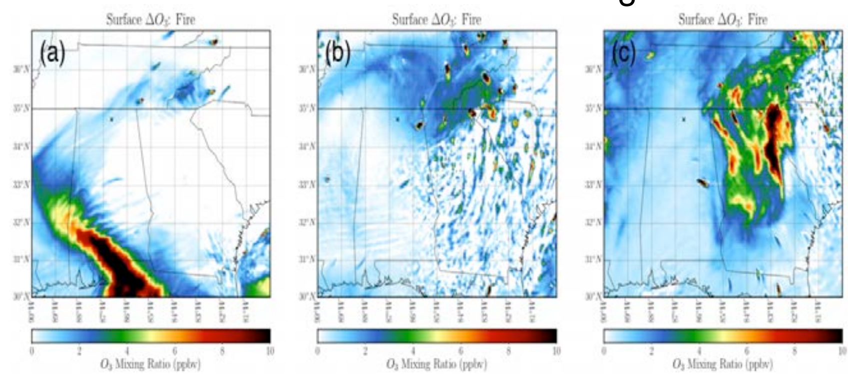


MODIS
Nov. 12-14

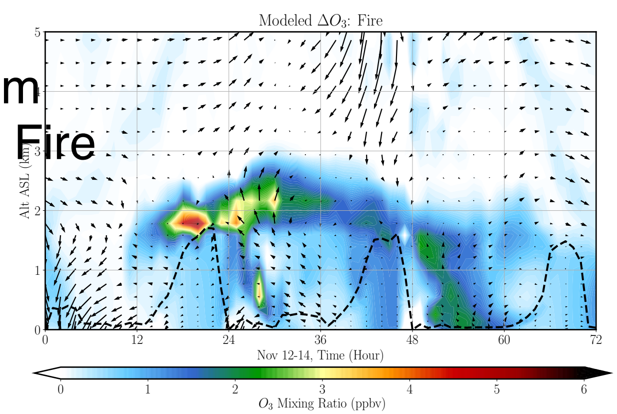
Ceilometer Backscatter



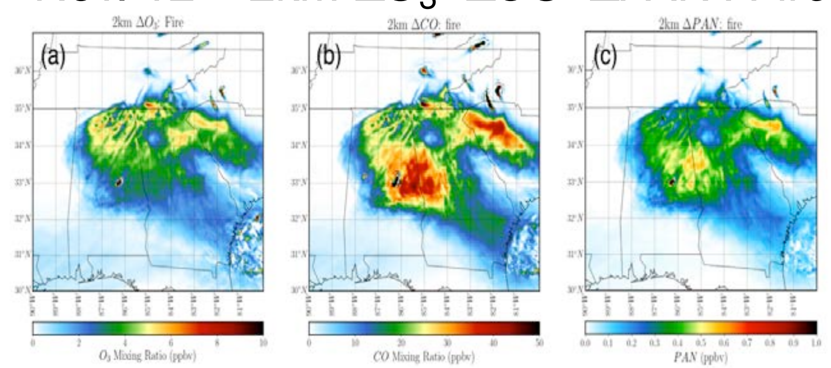
WRF-Chem
Nov. 12-14 Surface ΔO_3: Fire



WRF-Chem
Vertical ΔO_3: Fire



WRF-Chem
Nov. 12 2km ΔO_3 ΔCO ΔPAN : Fire



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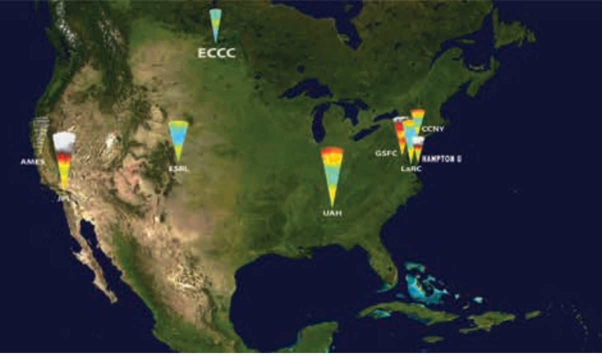
Tropospheric Ozone LIDAR Network



Conclusions

1. The spatio-temporal characteristics of prevalent atmospheric structures exhibit substantially higher resolution than space-borne sensors can physically measure.

2. Lidars can measure this spatio-temporal structure in a few places over limited times.

3. Space-borne sensors can measure these structures in lower resolution hourly across the North American continent.

4. The synergy of space-borne sensors with ground based (and aircraft) lidars and other sensors afford the best approach to measuring and diagnosing important air-quality structures and processes in a modeling framework.

TEMPO

TEMPO Institutions

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INECC
INSTITUTO NACIONAL DE ECOLOGÍA Y CAMBIO CLIMÁTICO

INSMET

NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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POR MI RAZA HABLARÁ EL ESPÍRITU

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SAINT LOUIS UNIVERSITY

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

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LET THERE BE LIGHT
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THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

HARVARD UNIVERSITY
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TOLNet Science Team

TEMPO Science Team

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6th Annual TOLNet Meeting
with
2nd Annual OWLETS
6-8 May 2019
College Park, MD USA

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