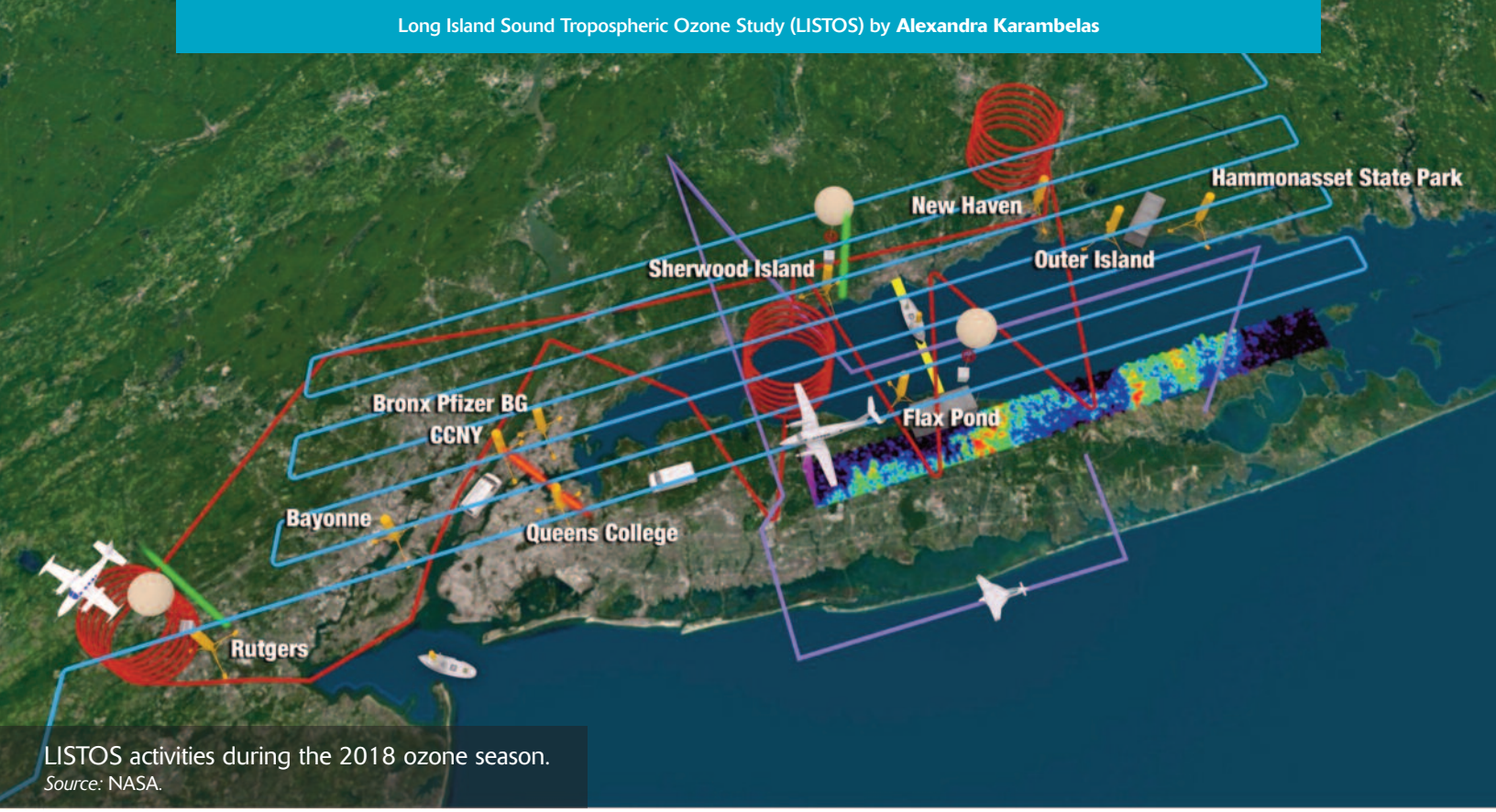

LISTOS activities during the 2018 ozone season.
Source: NASA.

LISTOS:

Toward a Better Understanding of New York City's Ozone Pollution Problem

An overview of the Long Island Sound Tropospheric Ozone Study.

Since 1990, ground-level tropospheric ozone (O_3) pollution has declined across the United States, largely as a result of clean air regulations developed under the 1990 U.S. Clean Air Act Amendments.[1] This trend, however, has flattened in recent years for the New York City (NYC) metropolitan area where persistently high episodic O_3 continues to be measured downwind along coastal Long Island Sound (see Figure 1). The continued presence of high surface O_3 in this area affects the health of tens of millions of people living across this densely populated region.

In recognition of this public health concern, several state and federal agencies, along with university research groups, launched a large coordinated measurement campaign in the summer of 2018 to better understand the complex chemistry and pollution transport in the region. Contributing members to this multifaceted campaign, known as the Long Island Sound Tropospheric Ozone Study (LISTOS; see Table 1), obtained measurements from land observation sites, research aircraft, marine vessels, and space-based observations. Focus was given to Long Island Sound, where a land–sea breeze feature often leads to high O_3 concentrations along the Connecticut shoreline.

This article presents a high-level description of the LISTOS activities since data collection began in 2018. The peak activity was the summer of 2018, but analysis continues on the collected data sets. Efforts include assessing the impacts of key reactive carbon compounds known as volatile organic compounds (VOCs), tracking spatial gradients of air pollutants on Long Island via an on-road mobile lab, "ground truthing" emission estimates of nitrogen oxides (NO_X) based on aircraft and satellite measurements, and probing the vertical structure of the atmosphere for transported O_3 and aerosol layers (including long-range transport in wildfire plumes from western North America).

Other similar field campaigns such as the Ozone Water–Land Environmental Transition Study (OWLETS)[2] 1 and 2 over Chesapeake Bay, and the Lake Michigan Ozone Study (LMOS)[3] have examined how the land–water breezes influences O_3 transport and concentrations. [*Editor's Note*: See articles on OWLETS and LMOS published elsewhere in this issue.] LISTOS researchers were able to leverage insights from these previous campaigns to optimize their data collection efforts over Long Island Sound. For example, guidance was sought from state air quality forecasters with local knowledge of the region to inform the launching of field activities on days predicted to be favorable for meeting research objectives.

Understanding Ozone Formation in the Long Island Sound

Warm temperatures and direct sunlight are critical for tropospheric O_3 formation from the photochemistry of NO_X and VOCs in the atmosphere. For O_3, problems, the major NO_X sources are from the burning of fossil fuels by mobile sources and at power plants on the local and regional scale. Important VOC sources include chemical solvents in urban areas and vegetation on a regional scale. In the LISTOS region, air pollution that reaches Long Island Sound can be confined within a stable and shallow marine layer, enhancing its chemical evolution as it travels downwind. A complicating factor is that the sensitivity of O_3 formation to NO_X and VOCs is non-linear. In NO_X-limited regimes, decreasing NO_X emissions leads to a decrease in O_3 formation. In VOC-limited regimes, decreasing NO_X may actually increase O_3 near strong NO_X emission sources before O_3 starts decreasing farther downwind (i.e., changing to NO_X-limited conditions).

The photochemical O_3 production regime for dense urban core regions

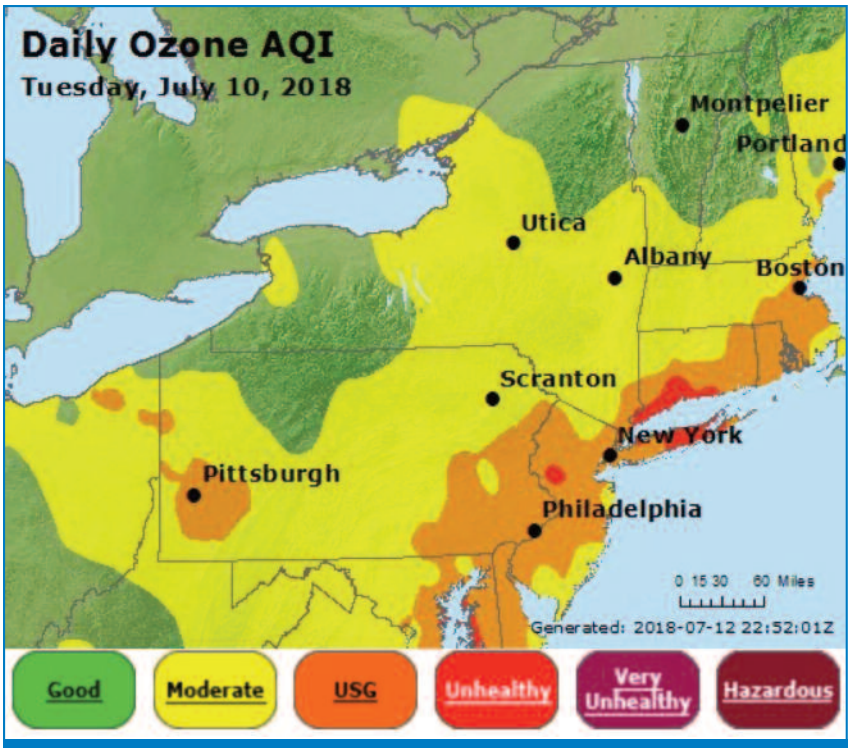

Figure 1. EPA AirNow graphic of the July 10, 2018, daily O_3 air quality index (AQI) interpolated from surface monitoring sites. Elevated O_3 is seen downwind of New York City along the Long Island Sound shoreline.
Source: U.S. Environmental Protection Agency (EPA) AirNow (https://www.airnow.gov/).

Table 1. List of contributing researchers to the LISTOS campaign.

Atmospheric Sciences Research Center, University at Albany, State University of New York James Schwab, Janie Schwab, Everette Joseph, Jie Zhang
Columbia University Róisín Commane, Arlene Fiore
Connecticut Department of Energy and Environmental Protection Michael Geigert, Pete Babich, Sam Sampieri
EPA Region 1 Robert Judge, Anne McWilliams
Maine Department of Environmental Protection Danielle Twomey, Martha Webster, Tom Downs
NASA Goddard John Sullivan, Scott Janz, Matthew Kowalewski, Peter Pantina, Sanxiong Xiong
NASA Langley Research Center Tim Berkoff, Guillaume Gronoff, Jay Al-Saadi, Laura Judd, Amin Nehrir, Travis Knepp
National Oceanic and Atmospheric Administration, Earth System Research Laboratories (1) and CIRES University of Colorado (2) Brian McDonald (1,2), Georgios Gkatzelis (1,2), Jessica Gilman (1), Matt Coggon (1,2), Carsten Warneke (1,2)
New Jersey Department of Environmental Protection Sharon Davis, Luis Lim
New York State Department of Environmental Conservation Dirk Felton, John Kent, Robert Gaza, Julia Stuart, Amanda Carpenter, Pete Furdyna, Jacqueline Perry, Erica Putman
Northeast States for Coordinated Air Use Management Paul Miller, Mahdi Ahmadi, George Allen
Stony Brook University John Mak
The City College of New York/NOAA EPP Center for Earth System Science and Remote Sensing Technology Fred Moshary, Maria Tzortziou, Barry Gross, Yonghua Wu, Mark Arend
University of Maryland Russell Dickerson, Xinrong Ren, Allison Ring, Tim Canty, Phillip Stratton, Sarah Benish
U.S. Environmental Protection Agency, Office of Research and Development Lukas Valin, James Szykman, David Williams, Andrew Whitehill, Jonathan Pleim
Yale University Drew Gentner, Jenna Ditto

like NYC can transition from VOC-limited to NO_X-limited with changes in emissions over time and in distance downwind from the strongest NO_X emission areas.[4] To mitigate potential near-source O_3 increases during a VOC-to-NO_X sensitivity transition, it is important to understand VOC speciation, emissions, concentrations, and O_3-forming potential to know whether additional VOC control strategies will be useful in combination with regional NO_X control strategies for reducing O_3 levels. LISTOS leveraged existing air quality monitors at key urban sites, as well as mobile air sampling methods and remote sensing techniques, to learn more about the O_3-forming potential of NO_X and VOCs in the region.

In addition to chemistry, atmospheric physics also plays a role in NYC's O_3 problem. A sea breeze along the Long Island Sound shoreline can play a major role in high coastal O_3 concentrations in the late afternoon, when the air over Long Island has been fueled by the photochemistry of O_3 precursors trapped in the shallow marine boundary layer transported from NYC and areas farther upwind. When the sea breeze begins blowing onshore, the highly polluted

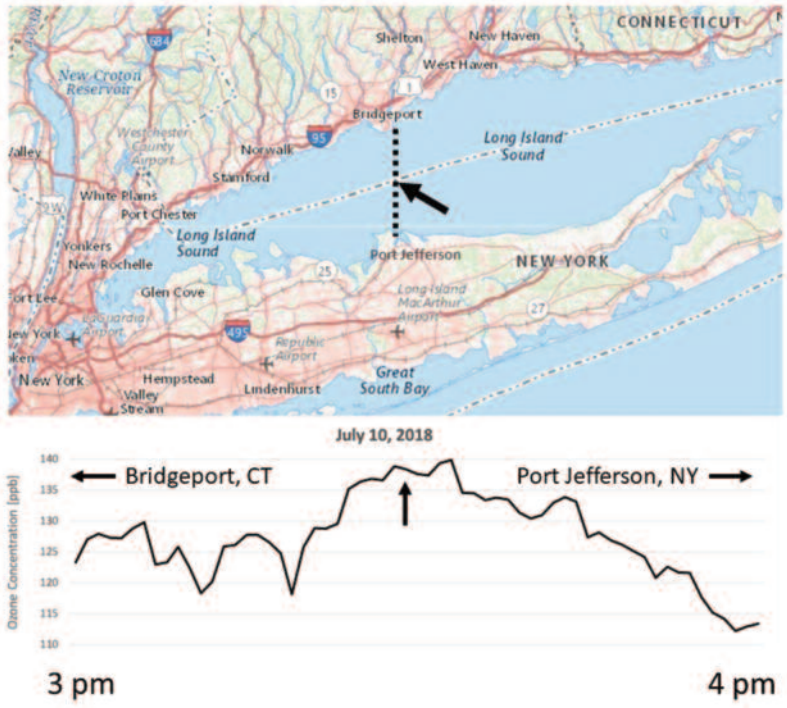

Figure 2. Route of the MV Park City Ferry operating between Bridgeport, CT, and Port Jefferson, NY, which measured O_3 during its crossings of Long Island Sound during summer 2018. The graph below plots measured O_3 between 3:00 pm and 4:00 pm local time on July 10. The highest O_3 concentrations are seen at the center of the Sound during this crossing, as indicated by the arrows.

Sources: Base map credit: U.S. Geological Survey (USGS; http://www.usgs.gov), O_3 measurements courtesy of M. Geigert, Connecticut Department of Energy and Environmental Protection.

marine layer is pushed into shoreline communities.

LISTOS Measurements

Searching for Precursor Transport and O_3 Formation in the Boundary Layer

An O_3 monitor on a car ferry captured the spatial and temporal evolution of O_3 during its trips between coastal Connecticut and Long Island's north shore several times a day (see Figure 2). An instrumented aircraft made boundary layer in situ measurements of O_3, NO_X, VOCs, black carbon, greenhouse gases, and important meteorological parameters used to derive boundary layer height. A second aircraft flew transects over Long Island Sound to capture high-resolution three-dimensional wind fields during O_3 pollution episodes in the region, which are important for capturing sea breeze dynamics. Balloons carrying ozonesondes (see Figure 3) measured vertical O_3 structure and meteorological parameters overlapping temporally with the research aircraft flights and satellite overpasses, in additional to nighttime launches for investigating potential O_3 transport in

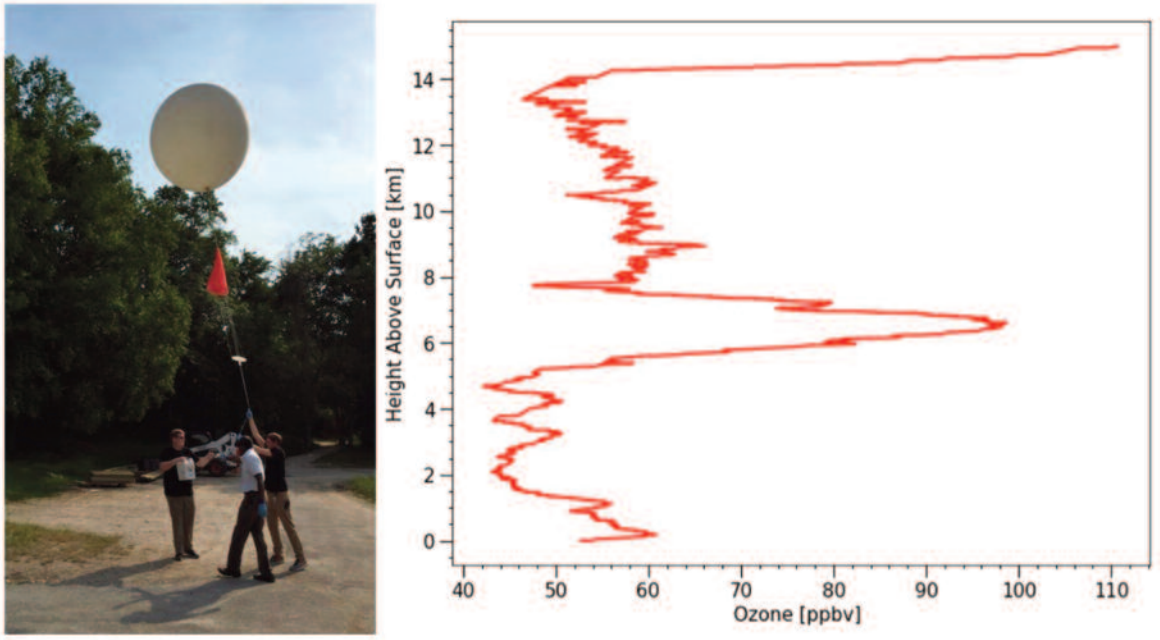

Figure 3. Photo of an ozonesonde launch (left) used to capture the vertical distribution of O_3 (right) and meteorological parameters during the LISTOS campaign.

Sources: Photo courtesy of J. Schwab, University at Albany.

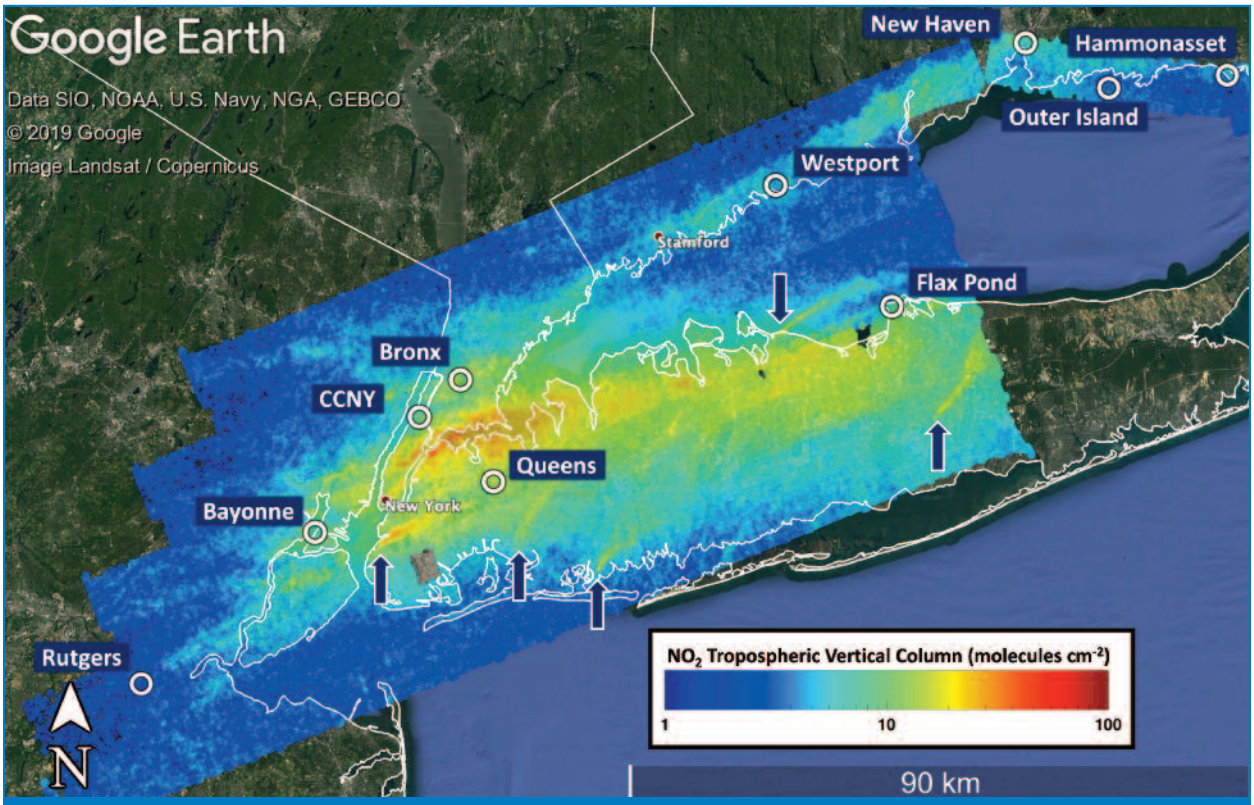

Figure 4. NASA aircraft measurements (GCAS) of tropospheric NO_2 columns on August 28, 2018, observed between 1:00 pm and 4:00 pm EDT. Circles indicate ground monitoring sites. Arrows point to sources of visible pollution plumes.
Sources: Courtesy of L. Judd and J. Al-Saadi, NASA.

nocturnal low-level jets along the Eastern Sea-board. Mobile lab observations on Long Island during high O_3 days showed steep gradients in O_3 concentrations over relatively short distances from shorelines.[5]

Remote Sensing for NO_X Emissions Inventory Evaluations

Emissions inventories provide air quality planners with knowledge of the current spatial and temporal variations of emissions contributing to local and regional air pollution episodes. Inventories, however, are challenging and time-consuming to compile, and lag current conditions by several years. During LISTOS, several complementary remote sensing measurements were performed from multiple perspectives to observe the heterogeneity in O_3 precursors and help in assessing emissions inventories. These observations helped identify rapid temporal changes and had the resolution to capture highly localized strong NO_X emission sources.

Early afternoon overpasses by two polar-orbiting satellites with the Ozone Monitoring Instrument (OMI)[6] and the newer TROPOspheric Monitoring Instrument (TROPOMI)[7] measure columns of nitrogen dioxide (NO_2, a component of NO_X) and other trace gases, globally, at spatial resolutions as fine as 3.5 × 5.5 km. This perspective was spatially and temporally downscaled during LISTOS with the use of a National Aeronautics and Space Administration (NASA) aircraft carrying either the Geostationary Trace gas and Aerosol Sensor Optimization (GeoTASO)[8] or GEOstationary Coastal and Air Pollution Events (GEO-CAPE) Airborne Simulator (GCAS)[9] airborne spectrometers. These instruments measure distributions of NO_2 across a localized area from the ground up to the aircraft's flight altitude of about 28,000 feet at sub-kilometer resolution capable of distinguishing isolated point sources (see Figure 4). Complementary to the other column measurements, a network of Pandora spectrometers measured vertical columns of NO_2 continuously throughout the day from their ground-based locations.[10] These instruments are co-located with existing air quality monitors that help link column measurements to ground-based air quality.

Observing Wildfire Plumes Transported Long Distances into the LISTOS Region

During the 2018 LISTOS campaign, aerosol and O_3 measurements from LIDAR remote sensing sites upwind, within, and downwind of NYC took advantage of a real-world experiment when smoke plumes entered the region after long-distance transport from large wildfires occurring in western Canada (see Figure 5, a and b). These LIDARs observed high-altitude layers of aerosols—including fine particulate matter, another criteria pollutant—along with O_3 that may

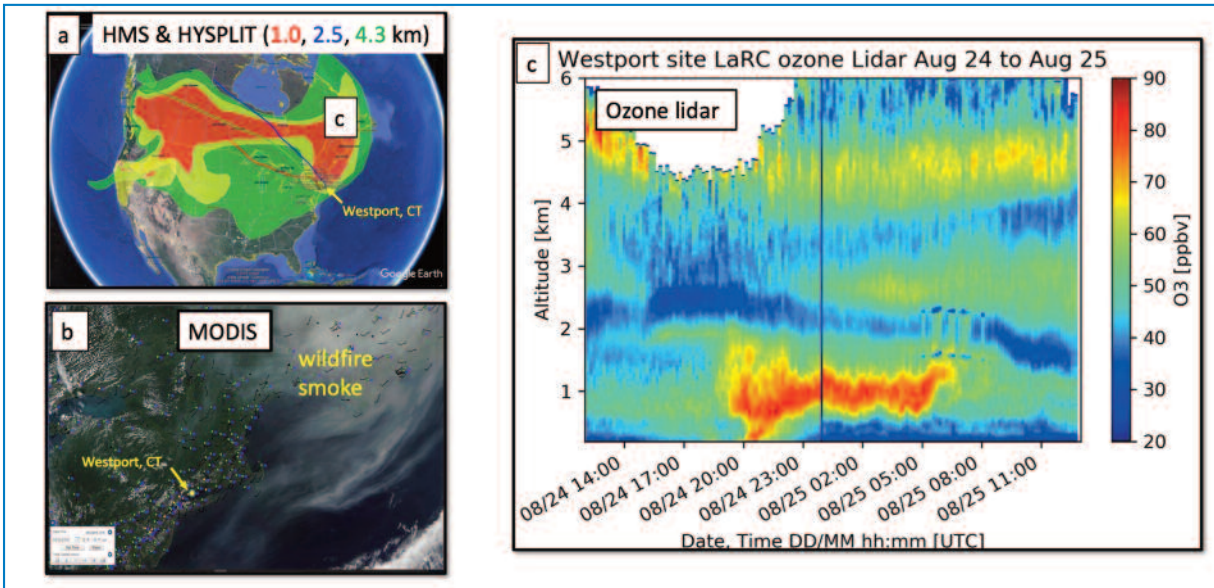

Figure 5. An August 24–25, 2018, wildfire transport event during LISTOS, showing (a) NOAA Hazard Mapping System (HMS) graphic of satellite observed smoke over the North America overlaid by HYSPLIT back-trajectories from Westport, CT; (b) True color image of afternoon smoke on August 24 (Aqua MODIS satellite instrument); and (c) August 24–25 O_3 curtain time series measured by the NASA Langley Research Center (LaRC) LIDAR (NASA TOLNet) located at Westport, CT, showing an O_3 layer aloft at about 3 km on August 25 and another at 4–5 km spanning both days.
Sources: Courtesy of T. Berkoff, NASA.

have been associated with the smoke plumes. The NASA High-Altitude LIDAR Observatory (HALO) co-located with GCAS provided an airborne perspective by profiling aerosol loading, properties, and type, as well as mixed-layer depths, and could detect regional gradients in wildfire smoke loading on days influenced by wildfire plumes. An example of an O_3 LIDAR during a smoke transport event from August 24–25, 2018, is shown in Figure 5c, where O_3 concentrations aloft were not observed to mix down to the surface during this observation period. In light of the increasing trends in

the size and intensity of western wildfires, improved knowledge of how aloft smoke plumes may or may not affect surface layer air pollution levels far downwind will be important for air quality agencies to better understand.[11]

Ongoing Research

With the wealth of detailed observations from LISTOS, plans are in place to incorporate the measurements into air quality modeling to inform future air quality strategies and state implementation plans in the Northeast. Higher resolution modeling domains will help resolve coastline dynamics and begin to capture wind patterns unique to the LISTOS region. For example, a notable LISTOS observation was the presence of a low-level jet just off the coast of Connecticut during some high O_3 events. Using the observations to evaluate higher resolution simulations will help modelers determine if the conditions for this low-level jet can be captured by the model, and if so, how this changes model biases in model-estimated pollution transport downwind of NYC.

The data gathered from the LISTOS campaign are valuable from a policy perspective for assessing contributions to elevated O_3, whether from local chemistry or long-range transport, subject to influence from land–sea circulation, or some combination of these factors. High-density observations enable visualizing the relationship between emissions and meteorology during the evolution of air pollution events. Using these observations, we can capture rapid changes in local emissions and contributions from afar, apply this information to higher resolution modeling, and use the results to better inform air quality planning. Ultimately, the information will lead to more refined strategies that improve air quality and better protect public health by targeting the local emission sources and upwind contributors that matter most. **em**

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Disclaimer: The views and opinions expressed in this article are those of the author and do not represent the official views of the participating agencies.

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