Open letter to parties interested in the

2017 Lake Michigan Ozone Study

March 21, 2017

1. Introduction

In an April 2016 white paper [*Pierce et al.*, 2016], a field campaign addressing ozone and its precursors over Lake Michigan was proposed. A combination of satellite remote sensing, aircraft remote sensing, and ground-based *in situ* monitoring will be conducted during the period May 22, 2017 to June 22, 2017. This combination of measurements will provide critical observations for answering several important research questions, and for evaluating a new generation of high resolution meteorology, chemical transport, and coupled air quality models attempting to better simulate ozone episodes in the region.

As of March, 2017, LMOS 2017 has achieved and surpassed the critical mass of instrumentation and observing platforms necessary to make it a success. Some important components are still pending final approval, but the experiment is positioned for success with the existing confirmed participation. The steering committee extends its thanks to the enthusiastic response from many individuals and groups in the atmospheric chemistry, atmospheric science, and air quality management communities.

The purpose of this letter is to update interested parties on the aspects of the LMOS 2017 study that are confirmed, and to list the measurement, modeling and funding needs that are pending or that remain. Table 1 lists study components and groups that are tentatively responsible for those components. In cases where participation is not yet confirmed, the reasons vary. In some cases, participation is contingent on funding. In others it is contingent on availability of instruments and personnel. And in others, principle investigators are considering the scientific opportunity of participation.

For those with questions about the Lake Michigan Ozone Study, please contact the members of the Scientific Steering Committee listed below.

Brad Pierce – brad.pierce@noaa.gov
Jassim (Jay) Al-Saadi – j.a.al-saadi@nasa.gov
Tim Bertram – timothy.bertram@wisc.edu
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2. Overview of Measurements

Two field sites will be hosting numerous atmospheric composition and structure measurement systems for LMOS 2017. These are shown in Figure 1 and include

- Zion, Illinois
- Sheboygan, Wisconsin (located at Spaceport Sheboygan)

In addition to these fixed sites, mobile platforms include

- **GeoTASO**: The Geostationary Trace gas and Aerosol Sensor Optimization (GeoTASO) instrument (column NO_2 and formaldehyde, HCHO), on the NASA Langley Research Center Beechcraft UC-12 aircraft flying out of Madison, Wisconsin.[i]
- **GMAP**: EPA region 5 Geospatial Measurement of Air Pollution (GMAP) mobile sampling system. GMAP makes in situ measurements of a wide range of trace gases of relevance to LMOS 2017 via differential UV absorption spectroscopy (UV-DUVAS, Duvas Technologies, DV 3000) and of CH_4 and H_2S (Picarro) from a telescoping mast. To be deployed at Zion, and then used in mobile mode to map spatial gradients.
- ***In situ* aircraft**: Scientific Aviation, scientifically equipped Mooney airplanes with meteorological measurements, a 2B model 205 ozone analyzer, and an Eco Physics model CLD88 NO analyzer. Scientific Aviation will be flying out of Sheboygan, WI.
- **USEPA Lake Guardian ship:** Plans are under development for the Lake Guardian and/or the NOAA Storm research vessel to carry lightweight autonomous samplers for formaldehyde, NO_2 and ozone as well as a ceilometer (boundary layer height) and Pandora (column O_3, NO_2 and formaldehyde). (pending approval).

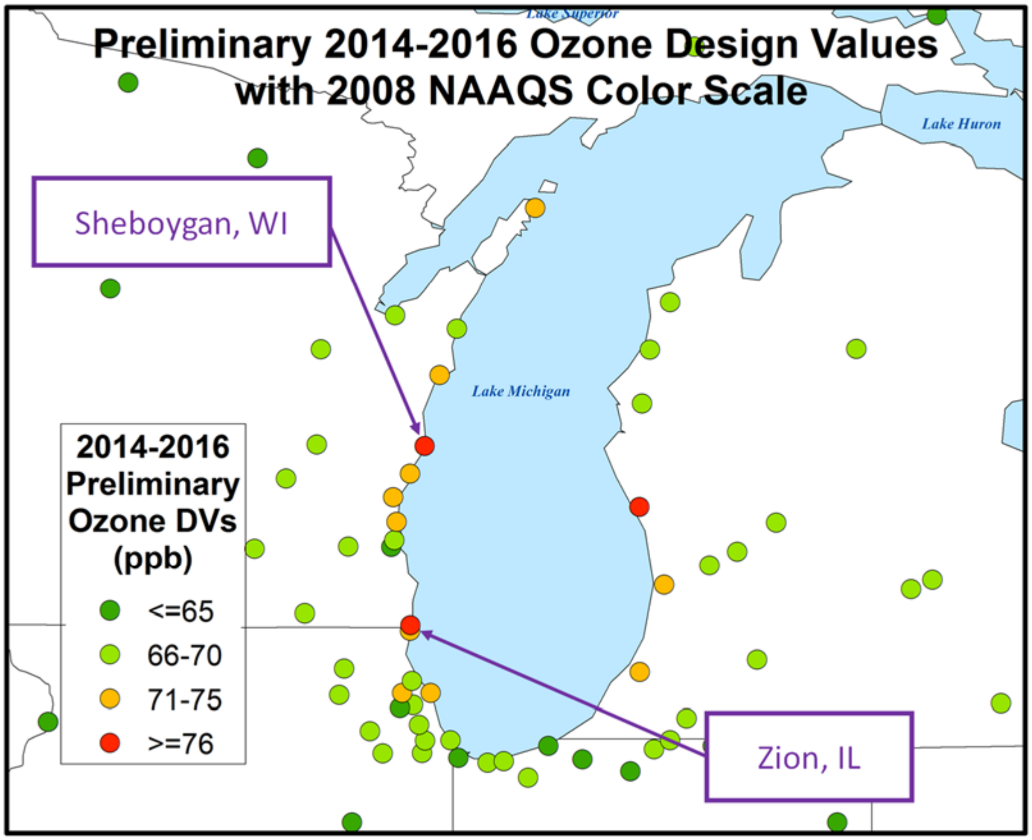

Figure 1. Ground sites hosting measurements for LMOS 2017

Section 3. Science Objectives

1. Determine the concentrations, speciation, and patterns of variability in VOCs, NO_y, and VOC oxidation products, and their relationships to coastal ozone episodes at the Zion, IL sampling site (NSF proposal) and over Lake Michigan and the surrounding airsheds (overall project)
    - *What are the predominant drivers of OH reactivity*?
    - *To what degree does accelerated chemistry in the shallow lake boundary layer contribute to coastal ozone enhancements?*
2. Quantify ozone production efficiency and the sensitivity of coastal ozone production to NO_x and VOC using multiple observation-based methods.
3. Determine the relative time-dependent influences of biogenic-rich and biogenic-poor regional air masses, urban plumes, localized emissions, and Great Lakes shipping emissions on $PM_{2.5}$ at the measurement site (NSF) and throughout the domain (whole project) using source apportionment methods and analysis of transport fields.
    - *What is the relative importance of urban, regional, and local precursors in coastal ozone production?*
    - *What is the relative contribution of inter- and intra-state NO_x and VOC emissions and emissions sources on ozone production rates along Lake Michigan?*
4. Evaluate chemical transport model skill for predicting critical aspects of coastal and lake meteorology, oxidant concentrations, VOC and NO_y speciation, the spatial and vertical distribution of O_3 precursors, and $PM_{2.5}$ sources. Apply the observationally-constrained model to quantify the spatial and temporal variation in NO_x and VOC sensitivity for coastal ozone production, and potential for future changes.
    - *How can configurations and lessons learned in the project "Improving Ozone Simulations in the Great Lakes Region" (EPRI, University of Georgia, and the University of Alabama—Huntsville) be applied to or tested with LMOS 2017.*
    - *What dynamical and chemical processes dominate model errors in predicting coastal ozone?*
    - *How can we improve model emission inventories?*
    - *How well do regional models capture ozone production chemistry as assessed through evaluation of critical measurement indicators (e.g., H_2O_2:HNO_3 ratio, HCHO:NO_x ratio, NO_y and VOC lifetime and partitioning).*
5. To what extent do lake breeze circulations effect ozone production?

6. How can remote sensing products (e.g., measurements of NO_2 and HCHO) be used to constrain ozone predictions?
7. GOES-R. Measurements collected during LMOS will be used to support GOES-R Advanced Baseline Imager (ABI) Baseline and Future Product validation during the GOES-R Post Launch Test (PLT).
8. Explaining in coastal vs. inland ozone concentration differences. Inland sites are 5-10 ppb lower than coastal sites and the determination of the quantitative reasons for this, and their representation in models, is important.

Section 4. Measurement List and Status

The table below lists measurements and modeling that are part of LMOS 2017. Figures in Section 5 show some of the sites and instrument systems. Green dots indicate confirmed participation. Yellow dots () indicate participation contingent on other factors such as other funding or instrument availability.

Table 1. Measurement / Status List for LMOS 2017

Study component	Notes & participation status (i.e., confirmed, pending funding, highly likely, etc.)
Aircraft 1 and aircraft 1 payload	
Description	NASA Langley Beechcraft UC-12 Jay Al-Saadi, NASA Langley Research Center
Aircraft deployment location	Madison, WI (MSN) Truax Field
Aircraft payload	(1) Geostationary Trace gas and Aerosol Sensor Optimization (GeoTASO). GeoTASO is a UV-Vis Spectrometer that is an airborne simulator for the future Tropospheric Emissions: Monitoring of Pollution (TEMPO) mission and is used to retrieve column NO_2, HCHO, and aerosols. (2) AirHarp, the airborne version of the Cubesat Hyper-Angular Rainbow Polarimeter (HARP), a wide-FOV imaging polarimeter capable of performing highly accurate retrievals of cloud and aerosol micro-physical properties. Four polarized wavelengths (0.44, 0.55, 0.67, and 0.87 µm) with up to 20 unique, along-track viewing angles that span a ±47° cross-track and ±55° along-track FOV. The hyper-angular capability allows for 60 individual viewing angles at 0.67µm, providing the sampling of cloud parameters at very high angular and spatial resolution.[ii]

Aircraft 2 and aircraft 2 payload	
Description and Status	Scientific Aviation Mooney Aircraft, confirmed
Aircraft deployment location	Sheboygan, WI
Aircraft payload	Meteorological measurements; 2B model 205 ozone analyzer (10 Hz); Eco Physics model CLD88 NO_x analyzer with photolytic converter (switches between NO and NO_x every 20 sec).
Forecast modeling / flight planning support	
4 km WRF-Chem + NOx sensitivity	University of Iowa, Charles Stanier & Greg Carmichael based on WRF configuration work by EPRI, University of Georgia, and the University of Alabama—Huntsville under the project: "Improving Ozone Simulations in the Great Lakes Region."
3 km WRF + Flexpart for point and area sources	NOAA NESDIS Air Quality Remote Sensing Group
12 km Ozone Forecast	NWS Operational National Air Quality Forecasting Capability (NAQFC), 12 km 48-hr forecast. CMAQ-NCEP
Interpretation of national weather, local conditions, lake breeze, air quality forecasts	Wisconsin Department of Natural Resources National Weather Service, Sullivan Office

Zion, IL ground-based chemistry and meteorological vertical profiling	
Location	Zion, Illinois – Location confirmed Illinois Beach State Park EPA Site ID 17-097-1007; 42.4676 N 87.81 W
Routine measurements	O_3 (operational); 10m meteorology
Available space and power	Collocated, air conditioned trailer; 10m sampling tower. Dedicated breaker box is operational providing 110V (200 A) for instrument use.
Needed maintenance or upgrades	General maintenance to verify operation of air conditioning unit and extend/repair the inlet tower will need to be conducted prior to deployment.
Ozone	Routinely monitored by Illinois EPA via UV absorption
CO	Commercial monitor, operated by Bertram Group. Provided by LADCO/State of Indiana.
NO_y	TBD,
NO_x/NO_2 (not true)	Commercial Chemiluminescence Monitor, operated by Bertram Group. On loan from LADCO/State of Indiana.
UV, Solar Rad	Operated by Bertram Group. On loan from LADCO/State of Indiana.
Meteorology	Meteorology tower operated through 2013 by IEPA. Will be repaired or replaced before campaign.
Photolysis Rates (JNO_2, JO_3)	Spectral radiance measurement by calibrated filter radiometer (i.e. Metcon). Steering committee is seeking an instrument loan for this.
SO_2	Commercial monitor, UV Absorption.
Ceilometer / Boundary Layer Height	CL-51 Ceilometer. Jim Szykman, EPA NERL.
Column NO_2, O_3, Formaldehyde	Pandora Ground-based Solar Spectrometer. Jim Szykman, EPA NERL.

Boundary Layer Meteorology (High temporal resolution observations of water vapor, temperature, and wind profiles)	Alan Czarnetzki. Alan.Czarnetzki@uni.edu University of Northern Iowa Radiometrics MP-3094A microwave profiler (temperature, water vapor). Atmospheric Systems miniSoDAR (wind speed and direction from 15 to 250 m AGL).
CO, CH_4, CO_2	Cavity Ringdown Spectroscopy.
Speciated Non-Methane (C2-C12) Hydrocarbons	Continuous automated GC-MS. On loan from EPA, operated by the Bertram Group.
Select VOC and oVOC (alcohols, aldehydes)	PTR-QiTOF. Alkenes, aromatics, aldehydes, terpenoids, ketones, nitriles, organic acids, isoprene + oxidation products, etc. Millet Group, Univ. of Minnesota.
Nitric acid, select alkyl nitrates and organic acids, $ClNO_2$, N_2O_5	CIMS (I^-), Bertram Group, University of Wisconsin.
Hydrogen peroxide and organic peroxides	CIMS (O_2^-), Bertram Group, University of Wisconsin.
Speciated aerosol chemistry (filter-based inorganic ions, OC/EC, organic molecular markers)	Filter-based aerosol IC, GC-MS, Stone group, University of Iowa.
Speciated aerosol metals	Filter-based aerosol IC, GC-MS, Stone group, Univ. of Iowa.
Aerosol size distribution	SMPS, Stanier group, University of Iowa.
Low-cost PM2.5 sensor	Pair of AirBeam PM2.5 sensors, for evaluation, Stanier group, University of Iowa. Tom Peters group continuous/integrating low-cost portable sampler
Radon-222	Deployment of low-power continuous Rn-222 monitor, under discussion with R. William Field, University of Iowa College of Public Health. Radon will be a tracer of airmass history in terms of lake (minimal radon) vs. land.

Sheboygan, WI ground-based ozone and formaldehyde and meteorological vertical profiling	
Location	Sheboygan Wisconsin – location confirmed Meteorology: 43.746 N 87.81 W 5 miles north of EPA Site ID 551170006; 43.679 N, 87.716 W
Routine measurements	O_3 (operational/confirmed) at EPA Site 551170006
Boundary Layer Meteorology Surface Meteorology	Tim Wagner, Univ. of Wisconsin. SPARC: the SSEC Portable Atmospheric Research Center. *Profiles:* Atmospheric Emitted Radiance Interferometer (AERI), HSRL Lidar, Doppler lidar wind profiler (SPARC). Ceilometer (EPA), MPL Lidar (EPA). *In situ meteorology:* Vaisala T, RH, pressure, wind speed, wind direction, precipitation. (SPARC)
Ceilometer / Boundary Layer Height	Jim Szykman, EPA NERL.
NO_2, O_3, Formaldehyde	All instruments from EPA Office of Research and Development Team.[iii] Pandora Ground-based Solar Spectrometer. Jim Szykman, EPA NERL. 2B Technology M211 O3 (10-sec) NO/NO2/NOx/NOy Cavity Attenuated Phase Shift Spectroscopy (CAPS) O3 Chemiluminescence with Mo converter (Teledyne T200U) O3 Chemiluminescence with photolytic converter (Teledyne T200EUP) HCHO Quantum Cascade Laser, Aerodyne, 1765 cm^{-1}
O_3 Profiles by Tethered Balloon	Kite-based vertical sounding system, with measurement of pressure, temperature, winds, and ozone. Ozone measurement by 2B Technologies 205 or POM. In conjunction with Dept. of Atmospheric Science, Univ. Wisconsin.
Other Mobile Platforms	
RV Lake Guardian (USEPA Great Lakes Monitoring Program) or NOAA RV Storm – see Figures S14 (May 19 – June 3 is window of opportunity on these vessels)	Discussions underway to carry lightweight autonomous samplers for formaldehyde, NO_2 and ozone as well as a ceilometer (boundary layer height) and Pandora (column O_3, NO_2 and formaldehyde). Available instrumentation list: • O3: 2B Technologies 205 or POM
GMAP / EPA region 5 Geospatial Measurement of Air Pollution (GMAP) mobile sampling system.	GMAP makes in situ measurements of a wide range of trace gases of relevance to LMOS 2017 via differential UV absorption spectroscopy (UV-DUVAS, Duvas Technologies, DV 3000) and of CH_4 and H_2S (Picarro) from a telescoping mast. To be deployed at Zion, & then used in mobile mode to map spatial gradients. Marta Fuoco, fuoco.marta@epa.gov

Table 2. Supplemental measurements and increased data acquisition frequency at long-term measurement sites. See Figure S13 and Figure 2. *Some additional coastal ozone sites may need to be identified and included in this list for increased data frequency.*

Site	AQS-ID	Routine Measurements	Special Measurements	Routine Met data?	Data Acquisition Frequency Increase?
Manitowoc	55-071-0007	NO_x, Ozone, NO_y, Wind s/d, Temp		Yes	
Sheboygan Haven	55-117-0009	Ozone		No	Yes
Spaceport Sheboygan	NA	None	Pandora Ceiliometer + many additional measurements (see section 4)	No	NA
Kohler Andrae	55-117-0006	Ozone		No	Yes
Harrington Beach	55-089-0009	Ozone, $PM_{2.5}$		Yes	Yes
Grafton	55-089-0008	Ozone	Pandora Ceiliometer	No	Yes
Waukesha	55-133-0027	Ozone, $PM_{2.5}$, PM_{10}		Yes	
Milw. DNR SER	55-079-0026	Ozone, NO_x, NO_y, SO_2, $PM_{2.5}$, PM_{10}, Hg, Wind s/d, Temp, PM coarse, VOCs, speciated $PM_{2.5}$	Pandora Ceiliometer	Yes	Yes
Milw. Health Ctr	55-079-0010	Ozone, $PM_{2.5}$, Hg, Wind s/d, Temp, VOCs, PM_{10}, toxic metals		Yes	
Racine	55-101-0020	Ozone		No	
Kenosha	55-059-0025	Ozone		No	
Chiwaukee Prairie	55-059-0019	Ozone		No	Yes
Zion	17-097-1007	Ozone	Pandora Ceiliometer + many additional measurements (see section 4)	Not until March 2017	Yes
Northbrook	17-031-4201	Ozone, CO, NO_x, NO_y, SO_2, $PM_{2.5}$, VOCs, Wind s/d, Temp		Yes	
Com Ed maint. bldg	17-031-0076	Ozone, speciated $PM_{2.5}$, NO_x, SO_2,Wind s/d, Temp		Yes	
Hammond CAAP	18-089-2008	Ozone		Yes	
Gary-IITRI	18-089-0022	Ozone, NO_2		Yes	

Pandora and Ceilometer Locations

Ceilometer deployments are of the Vaisala CL-51 with BL view software. This measures attenuated aerosol backscatter at 910 nm. Maximum resolution is 2s, but averaging to 16-36s to improve signal-to-noise ratio. Early deployment locations indicated by *.[1]

- Sheboygan Spaceport*
- Grafton*
- Zion
- Milwaukee SER*
- Ship-borne

Pandora

- Sheboygan Spaceport*
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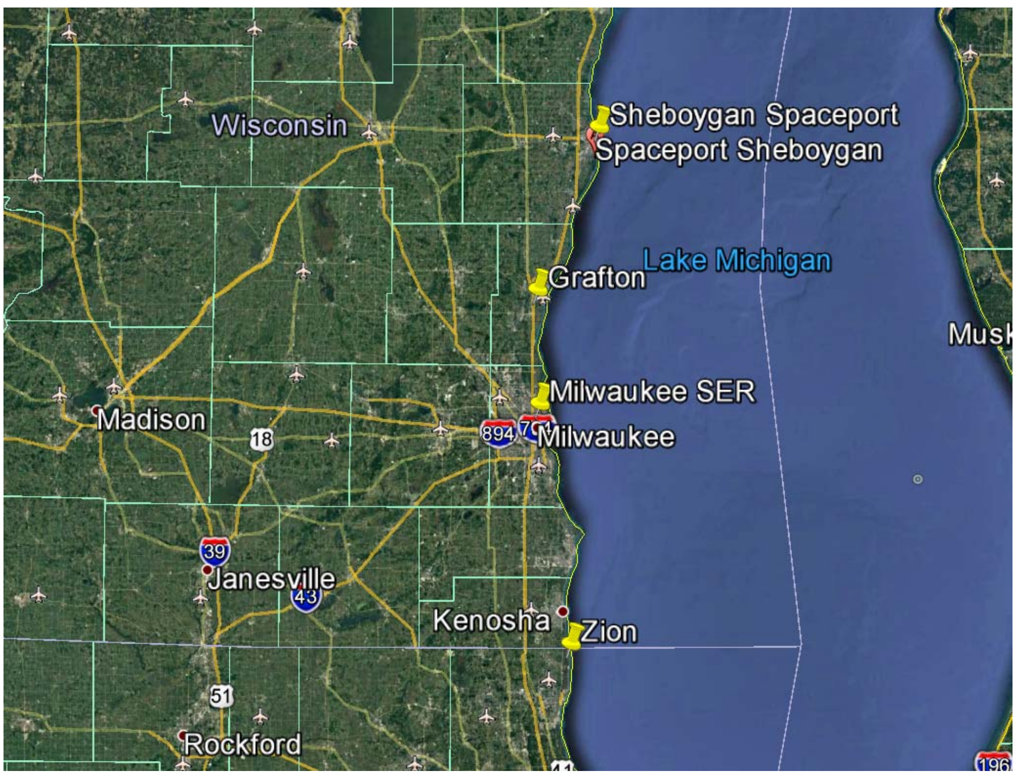

Figure 2. Proposed Pandora / Ceilometer locations

[1] Ceilometer locations still under discussion. Having inland/coastal paired ceilometers may achieve science objectives better than isolated ceilometers spaced up and down the Wisconsin coast.

Section 5. ABI Baseline and Future Product Validation during GOES-R Post Launch Testing

Measurements collected during LMOS will be used to support GOES-R Advanced Baseline Imager (ABI) Baseline (Table 1) and Future Product (Table 2) validation during the GOES-R Post Launch Test (PLT) (Launch+180 days). The Space Science and Engineering Center (SSEC) Portable Atmospheric Research Center (SPARC) trailer includes an Atmospheric Emitted Radiance Interferometer (AERI), a High Spectral Resolution Lidar (HSRL), and a Halo Photonics pulsed doppler LIDAR for high temporal and vertical resolution temperature, water vapor, aerosol/cloud backscatter/extinction, and wind profile retrievals. During LMOS 2017, the SPARC trailer will be deployed at Sheboygan, WI and will conduct high frequency high vertical resolution profile measurements of clouds, aerosols, water vapor, temperature, and winds associated with synoptic and lake breeze circulations along the Central Wisconsin portion of the Lake Michigan coast. In addition, we will deploy a 35 channel microwave radiometer (Radiometrics Corp. MP-3094A Microwave Profiler) and SoDAR wind profiler (Atmospheric Systems Corp. miniSoDAR) at Zion, IL to provide high frequency, moderate resolution profile measurements of water vapor, temperature, and winds associated with lake breeze circulations along the Southern Wisconsin portion of the Lake Michigan coast.

Table 3: Enhanced GOES-R Baseline Product Validation Measurements

GOES-R Baseline Product	**Enhanced Validation Measurements**
Aerosol Detection (Including Smoke and Dust) Aerosol Optical Depth (AOD)	High Spectral Resolution LIDAR (HSRL) CIMEL sunphotometer
Clear Sky Masks Cloud Optical Depth Cloud Top Height	GeoTASO (clear sky mask only) High Spectral Resolution LIDAR (HSRL)
Derived Motion Winds	Halo Doppler LIDAR SoDAR
Derived Stability Indices Total Precipitable Water Legacy Vertical Moisture Profile Legacy Vertical Temperature Profile	Atmospheric Emitted Radiance Interferometer (AERI) Radiometrics MP-3000A profiling microwave radiometer

Table 4: Enhanced GOES-R Future Product Validation Measurements

GOES-R Future Product	**Enhanced Validation Measurements**
Aerosol Particle Size	CIMEL Sunphotometer
Cloud Layers/Heights	High Spectral Resolution LIDAR (HSRL)
Ozone Total	Pandora spectrometer
SO2 Detection	GeoTASO
Visibility	High Spectral Resolution LIDAR (HSRL) CIMEL sunphotometer Atmospheric Emitted Radiance Interferometer (AERI) Radiometrics MP-3000A profiling microwave radiometer

GOES-R ABI Aerosol, Cloud, Sounding, and Air Motion Vector product validation will benefit by participating in LMOS 2017 due to collection of high frequency high resolution profile measurements of clouds, aerosols, water vapor, temperature, and wind variations associated with lake breeze circulations along the Lake Michigan coast. In addition to the GOES-R ABI product validation, NASA and EPA will deploy ground based and airborne high spectral resolution ultra-violet and visible spectrometer measurements during LMOS 2017 which will provide opportunities to develop blended products using GOES-R and measurements from the future Tropospheric Emissions: Monitoring of Pollution (TEMPO) geostationary air quality mission scheduled for launch by NASA in 2021.

Supplemental Figures and Tables

Figure S1. Location of the Zion sampling location within the green area (Illinois Beach State Park and the North Dunes Nature Preserve). The location of Wisconsin's Chiwaukee Prairie monitor is shown for reference.

Figure S2. Aerial image of the Zion sampling location (red box) relative to the coast.

Figure S3. Photographs of the operational O_3 trailer (left) used by Illinois EPA, and the vacant trailer (right) for LMOS 2017 *in situ* sampling.

Figure S4. RV Lake Guardian. 180 feet; 850 ton displacement. Source: http://oceanexplorer.noaa.gov/technology/vessels/lakeguardian/lakeguardian.html

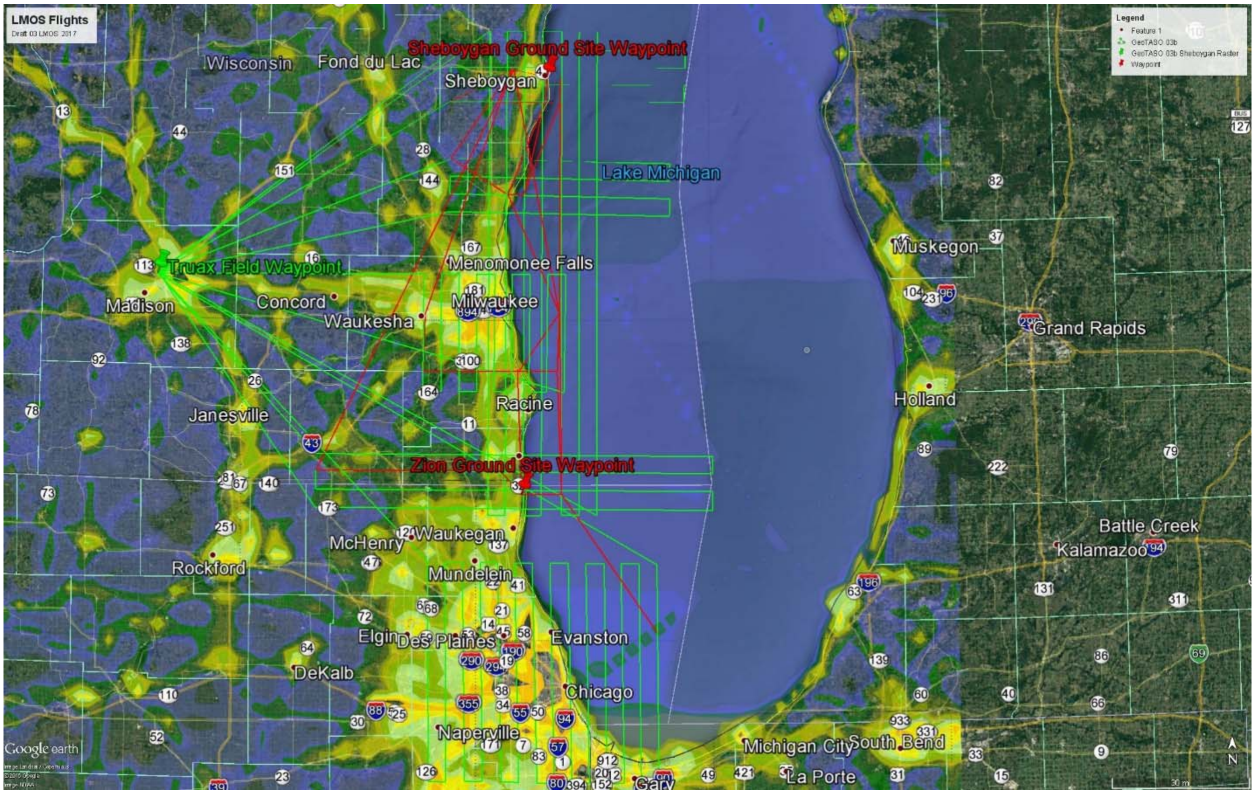

Figure S5. All proposed flight tracks as of iteration 3 (3/9/2017) for GeoTASO / AirHARP (Green) and Scientific Aviation (Red). For detailed / most up-to-date flight plans contact Brad Pierce. Flight plans are overlaid over 2011 NEI 4 km NO. Source: Brad Pierce

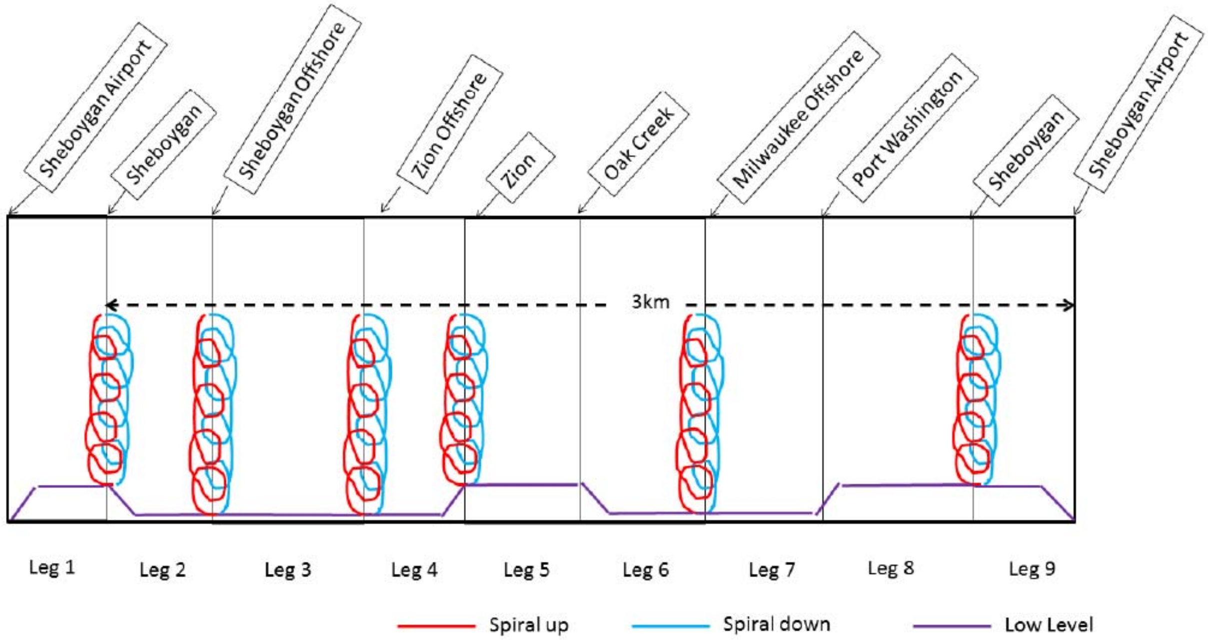

Figure S6. Sample of vertical profiles for Scientific Aviation.

Google map image below showing the location of the Spaceport museum. Satellite image to show the parking location of the SPARC trailer.

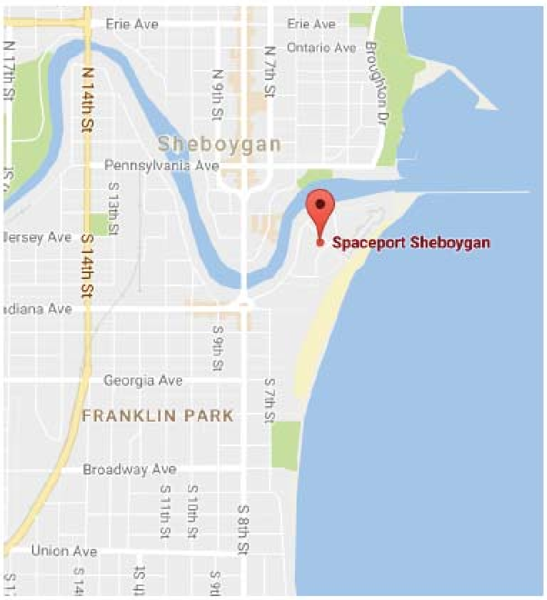

Figure S7. Spaceport Sheboygan Site

Figure S8. Streetview image of the Spaceport Museum from the East.

Figure S9. Exterior photos of EPA GMAP

Figure S10. EPA Research Trailer during Utah deployment. Source EPA ORD Valin/Whitehill/Szykman/Long/Williams.

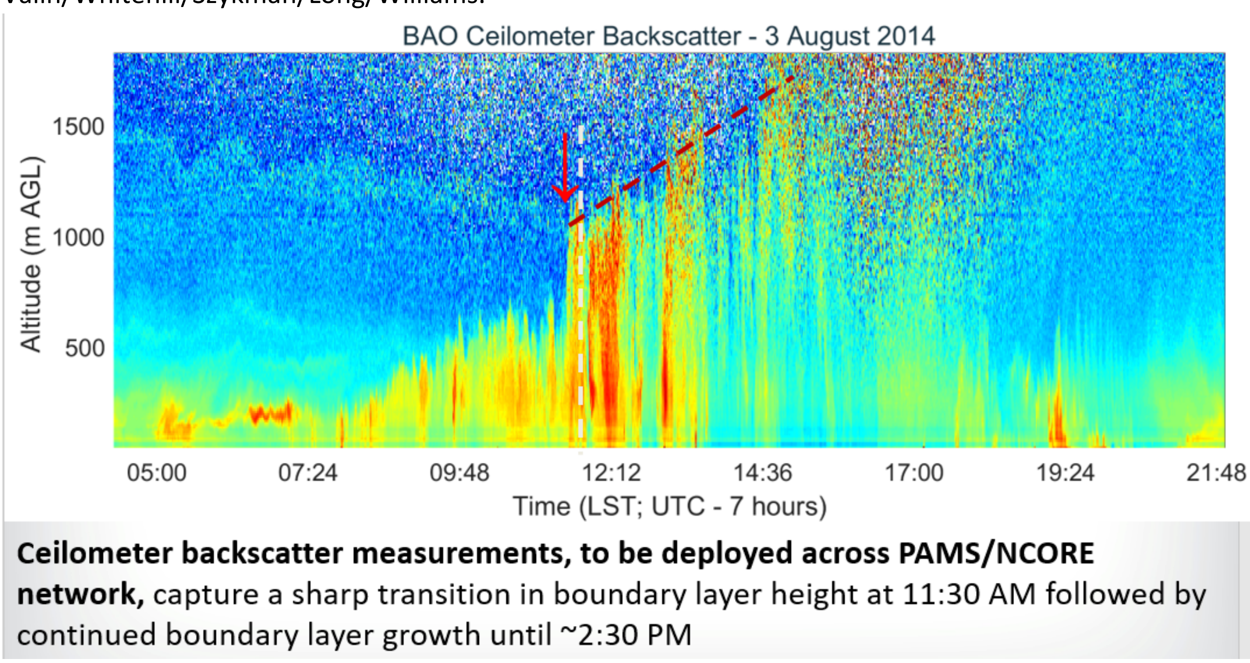

Figure S11. Sample backscatter data from CL51 Cielometer. Source EPA ORD Valin/Whitehill/Szykman/Long/Williams.

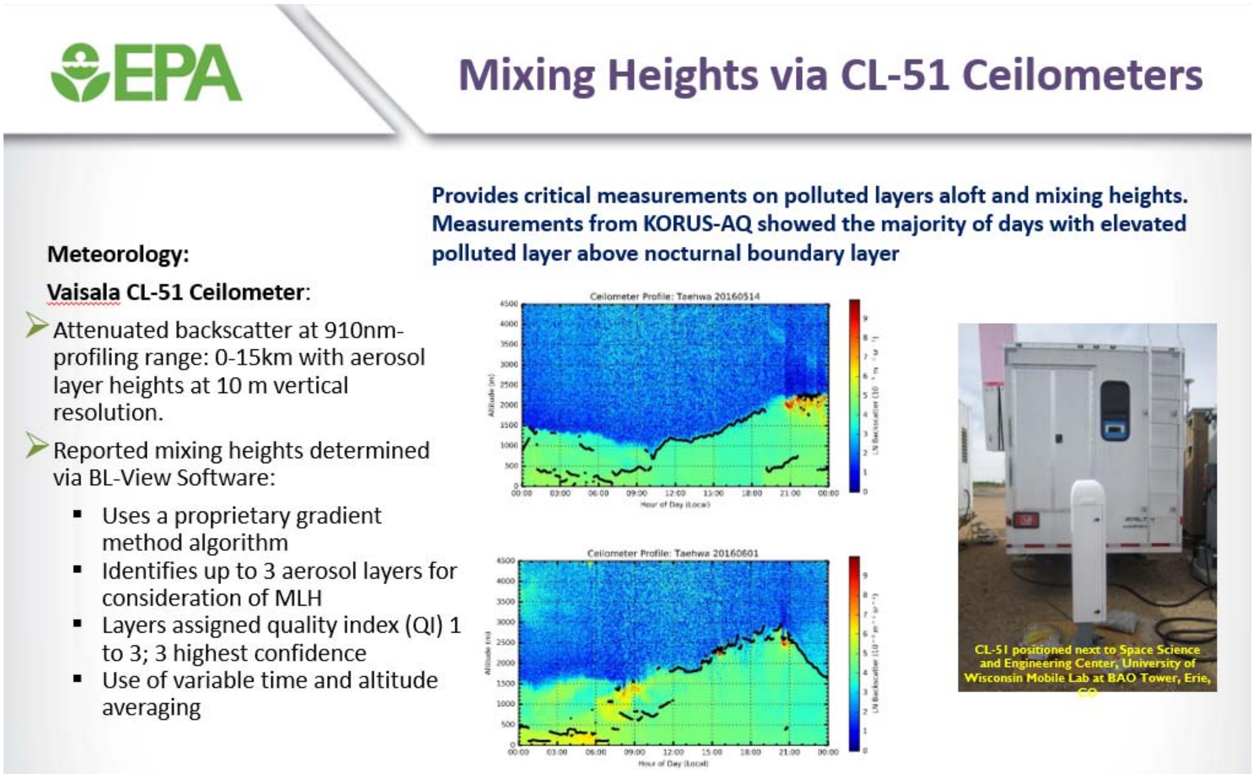

Figure S12. Information on CL51 Cielometer and retrieval of mixed layer height with BL view software. Source EPA ORD Valin/Whitehill/Szykman/Long/Williams.

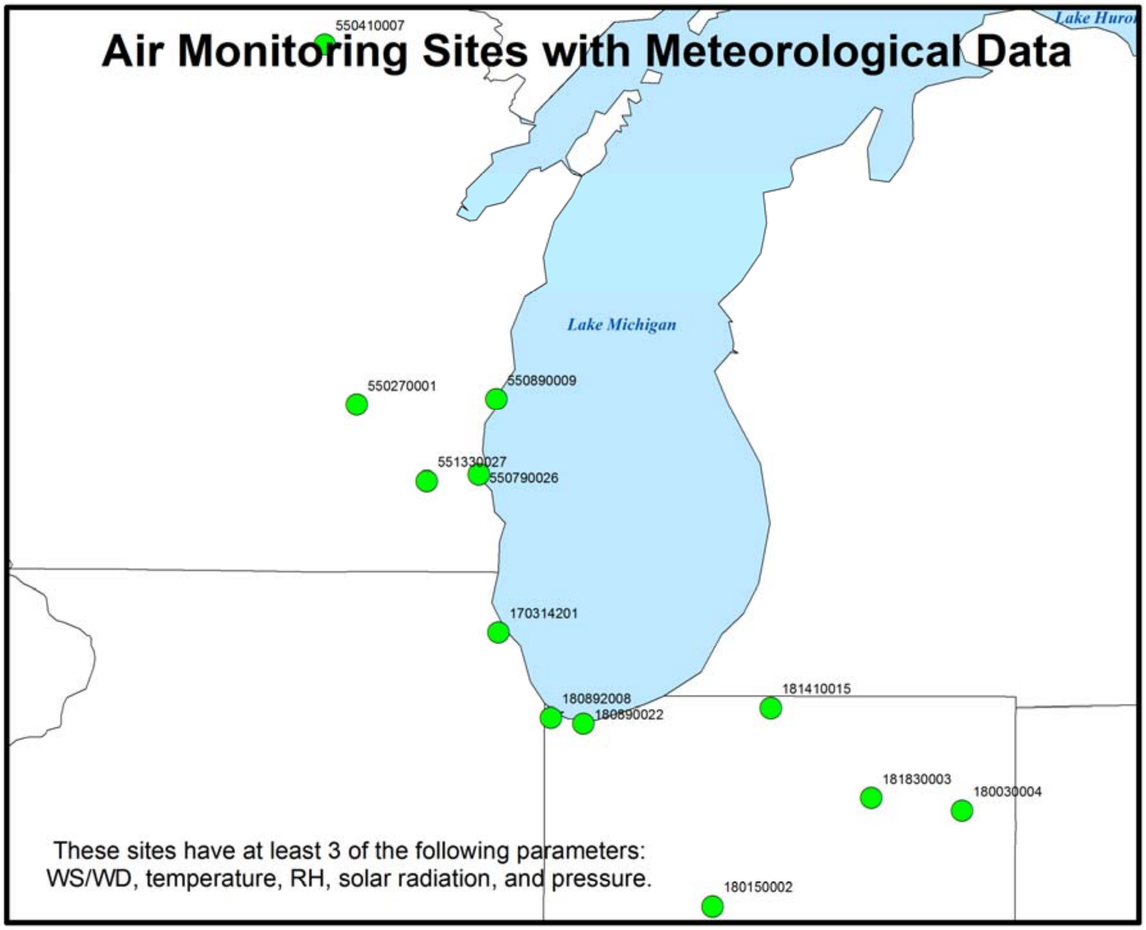

Figure S13. Air monitoring sites with meteorological data.

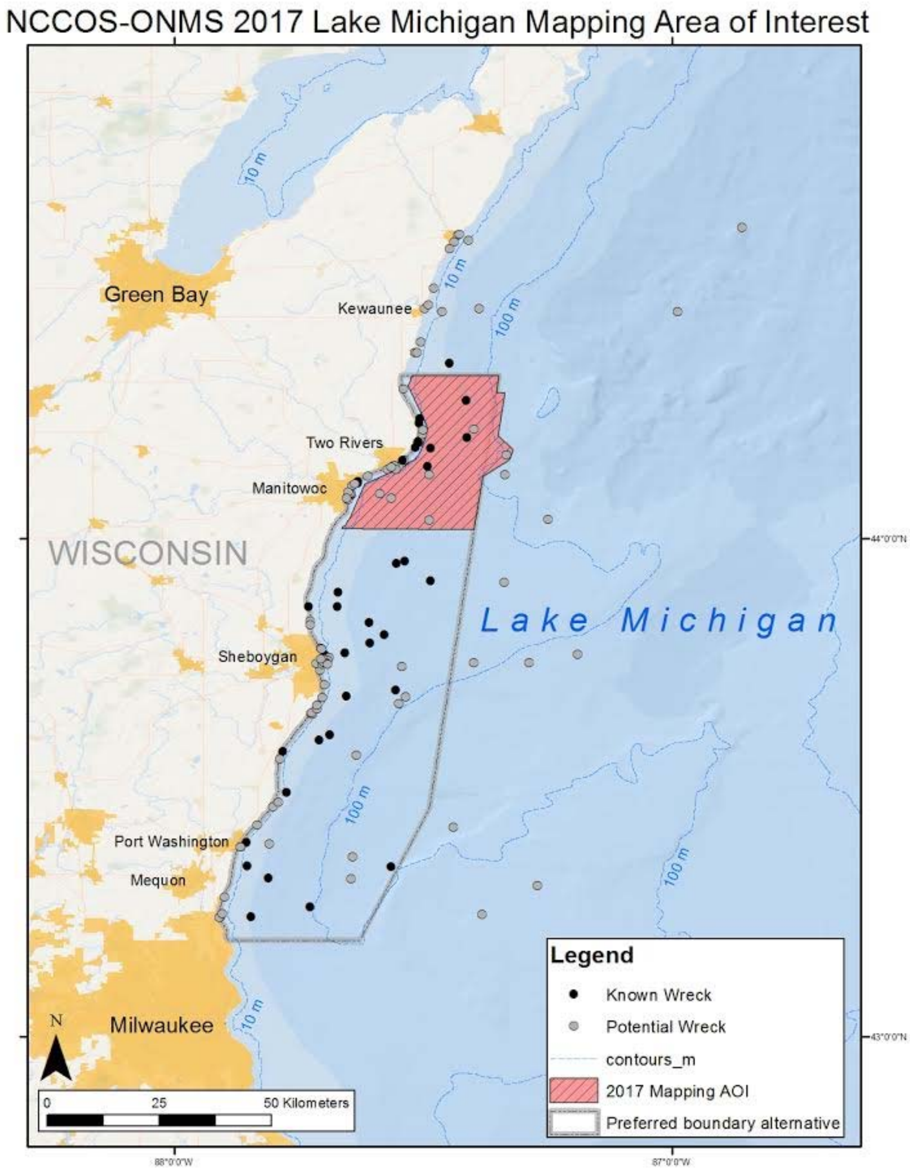

Figure S14. NOAA R/V Storm mapping location, May 19 – June.

The white paper is available at:
http://ladco.org/reports/ozone/post08/Great_Lakes_Ozone_Study_White_Paper_Draft_v6.pdf

Pierce, B., R. Kaleel, A. Dickens, T. H. Bertram, C. Stanier, and D. M. Kenski (2016), *White Paper: Lake Michigan Ozone Study 2017 (LMOS 2017)*.

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[i] The NASA GEOstationary Coastal and Air Pollution Events (GEO-CAPE) Program has committed the Geostationary Trace gas and Aerosol Sensor Optimization (GeoTASO) instrument for the period May 22 – June 22, 2017. GeoTASO is a UV-Vis Spectrometer that retrieves column concentrations of nitrogen dioxide (NO2), formaldehyde (HCHO), and aerosol optical depth – enabling high resolution spatial mapping of these pollutants. Flight hours have been secured for GeoTASO's participation on NASA Langley Research Center Beechcraft UC-12 aircraft.

[ii] AirHARP science PI for LMOS 2017 is J. Vanderlei Martins, University of Maryland Baltimore County (UMBC).

[iii] EMMD/SSAB: Jim Szykman – Remote sensing; David William – Remote sensing and air toxics; Lukas Valin – Remote sensing. EMMD/AQB -- Russell Long – Criteria gases; Andrew Whitehill – Criteria gases and air toxics.