



# The Lake Michigan Ozone Study (LMOS) 2017

Brad Pierce  
NOAA/NESDIS@CIMSS

Kohler-Andrae State Park, Sheboygan WI

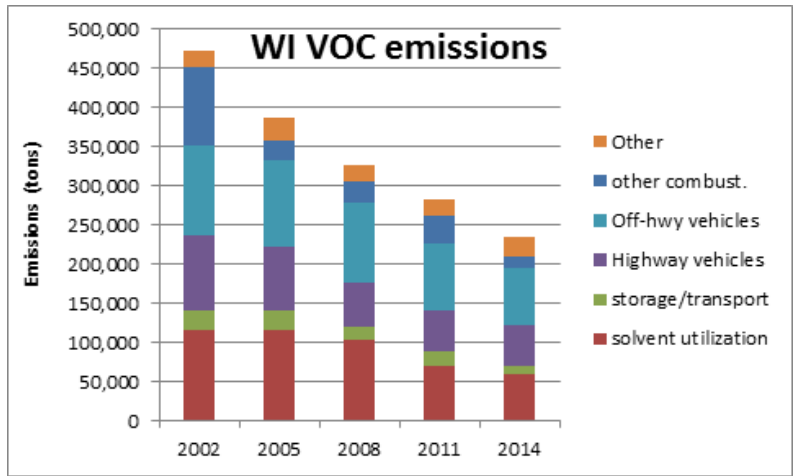
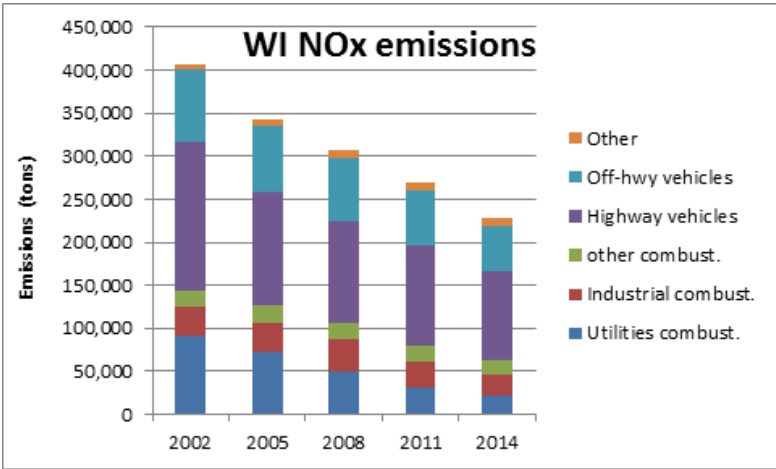


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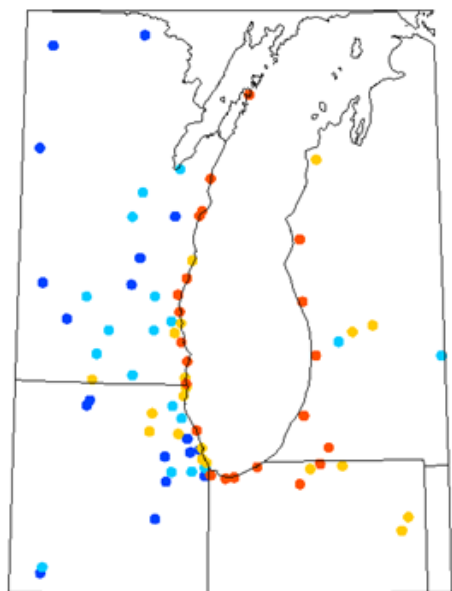
*Despite dramatic reductions in ozone precursor emissions, many areas bordering Lake Michigan continue to violate federal air quality standards. This problem has persisted for decades and is one of the most challenging air quality issues in the eastern U.S.*

# Wisconsin emissions are declining and ozone is improving

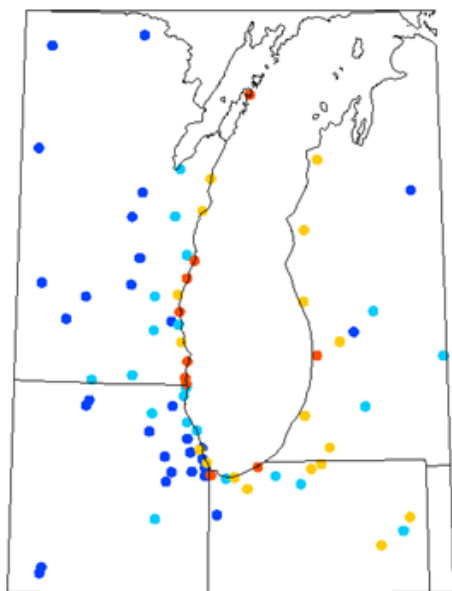


NO<sub>x</sub>= NO+NO<sub>2</sub> (nitrogen oxides) VOC=Volatile Organic Compounds, both are ozone precursors

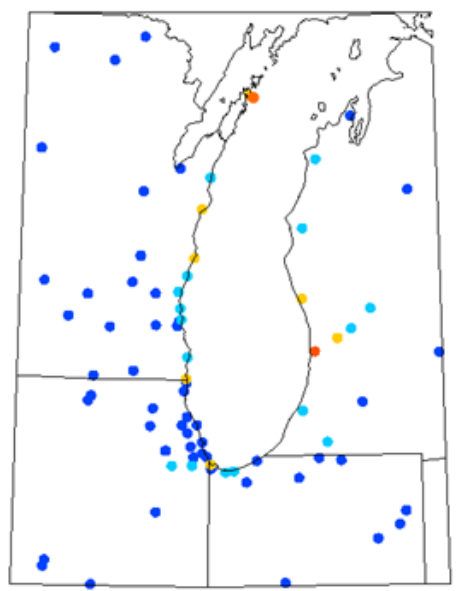
Ozone Design Values, 1995\_1997



Ozone Design Values, 2000\_2002



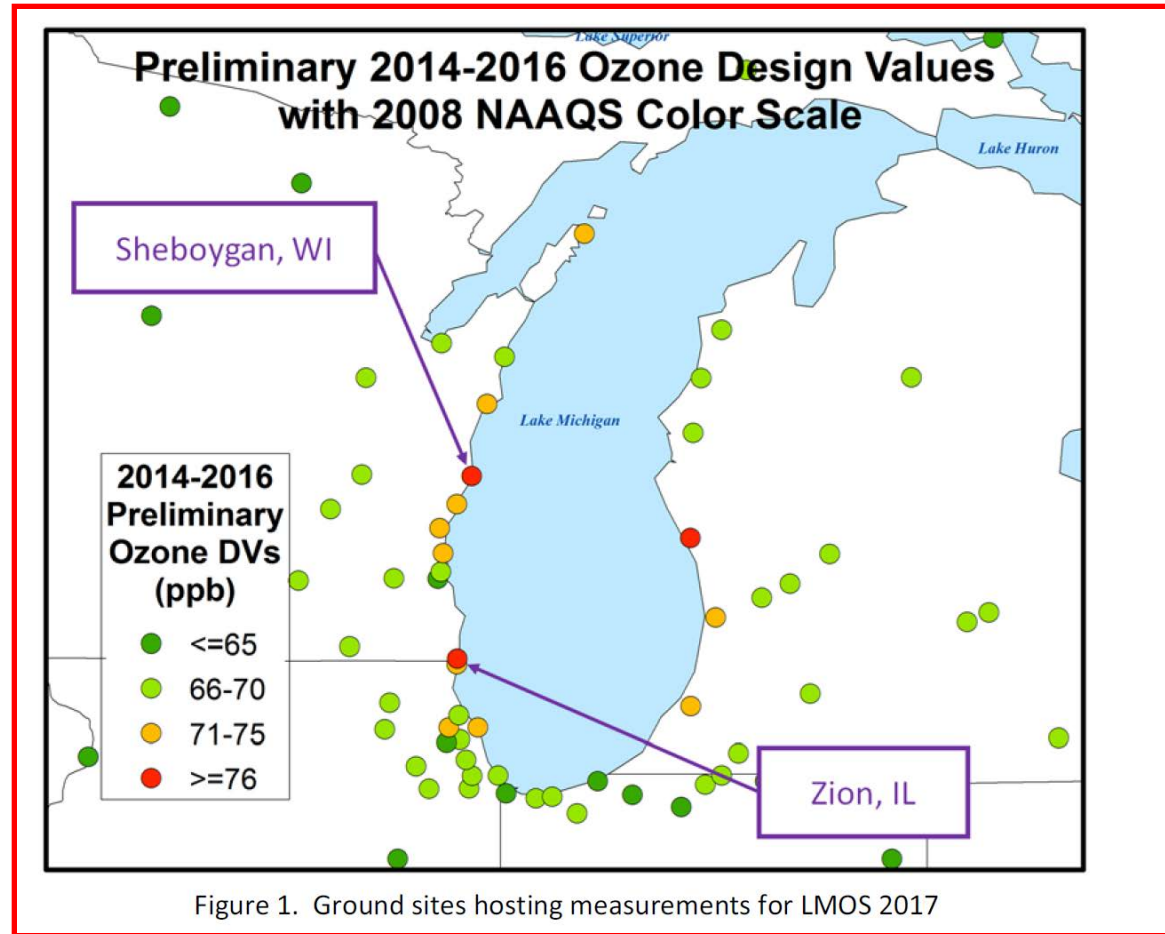
Ozone Design Values, 2005\_2007



DV, in ppb  
 90+ (Red)  
 85-89 (Orange)  
 80-84 (Yellow)  
 < 80 (Cyan/Blue)

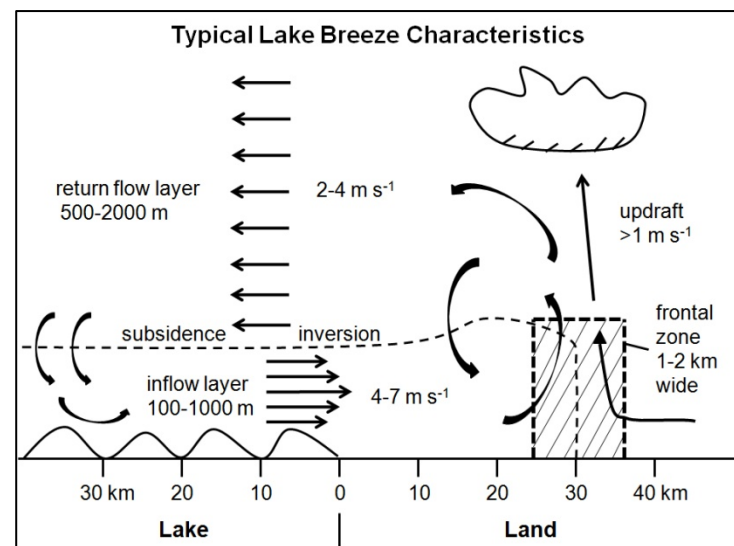
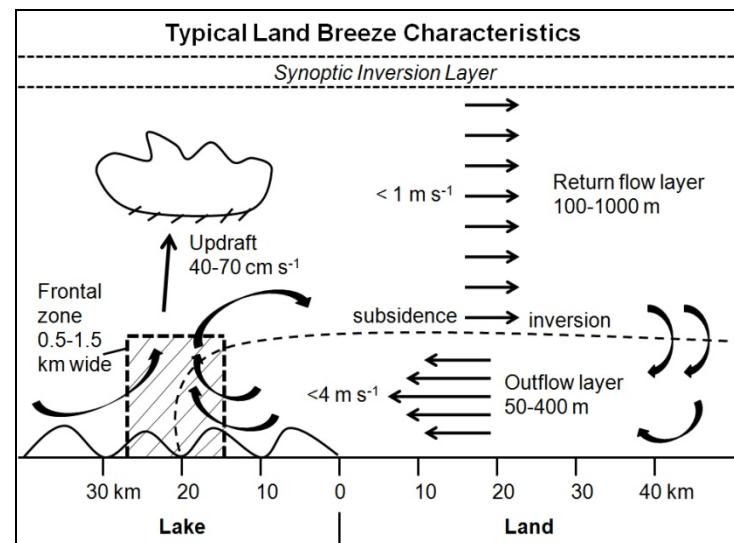
# But there are still coastal sites which are still above the new ozone standard (70ppbv)

- Anticipated new non-attainment areas with new, lower ozone standard and persistent exceedances of the old (2008) ozone standard.
- Impact of high ozone on public health in high density urban areas (Chicago, Milwaukee, Detroit, Windsor). Also, these areas serve as large emissions sources.



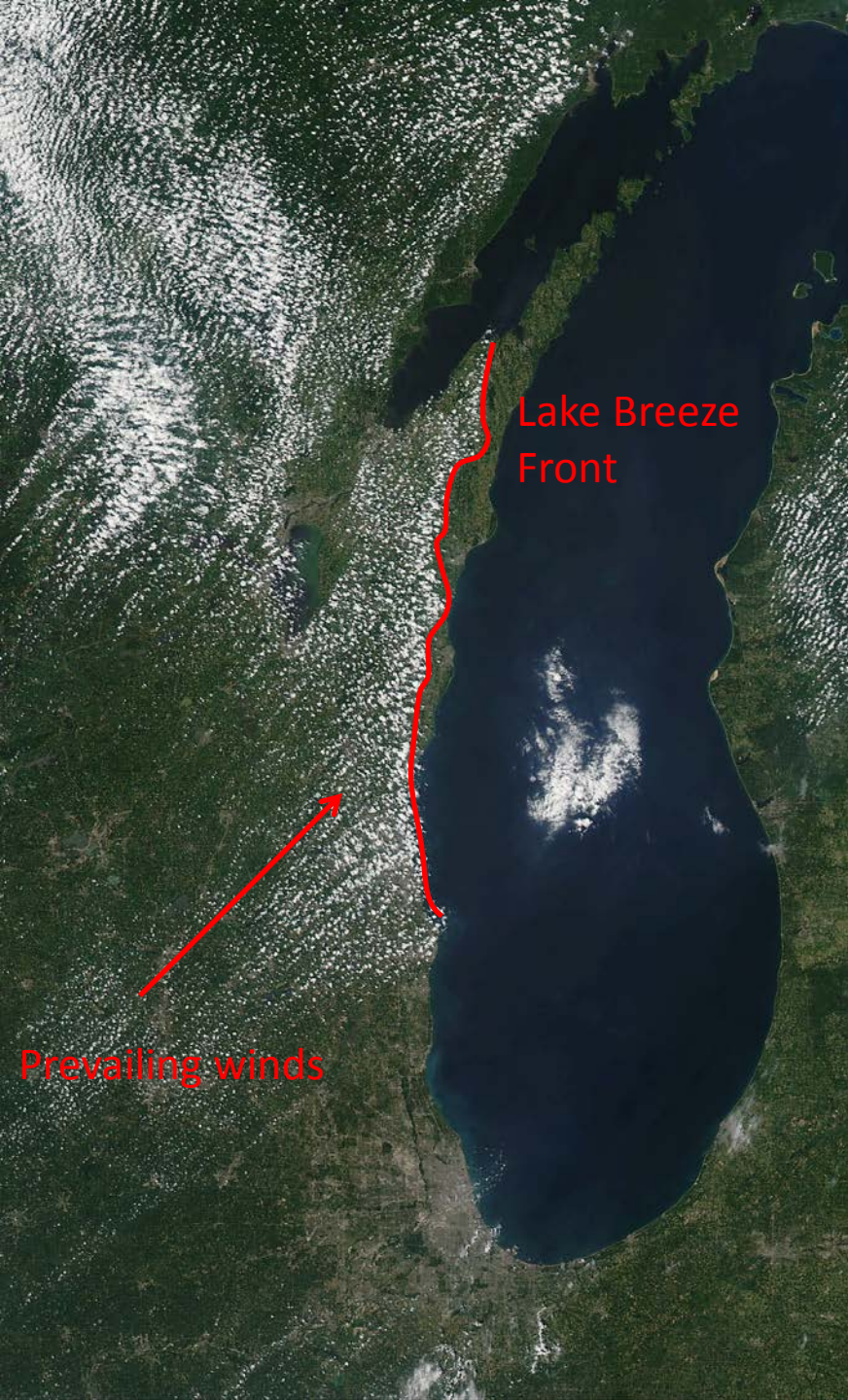
# Lake Michigan and Ozone Formation

- *Land breeze* blows ozone precursor compounds from rush hour over lake.
- The boundary layer height is low due to cold water chilling the air above.
- The pollutants are concentrated near the surface where ozone forms.
- An afternoon *lake breeze* transports the ozone back onto land.





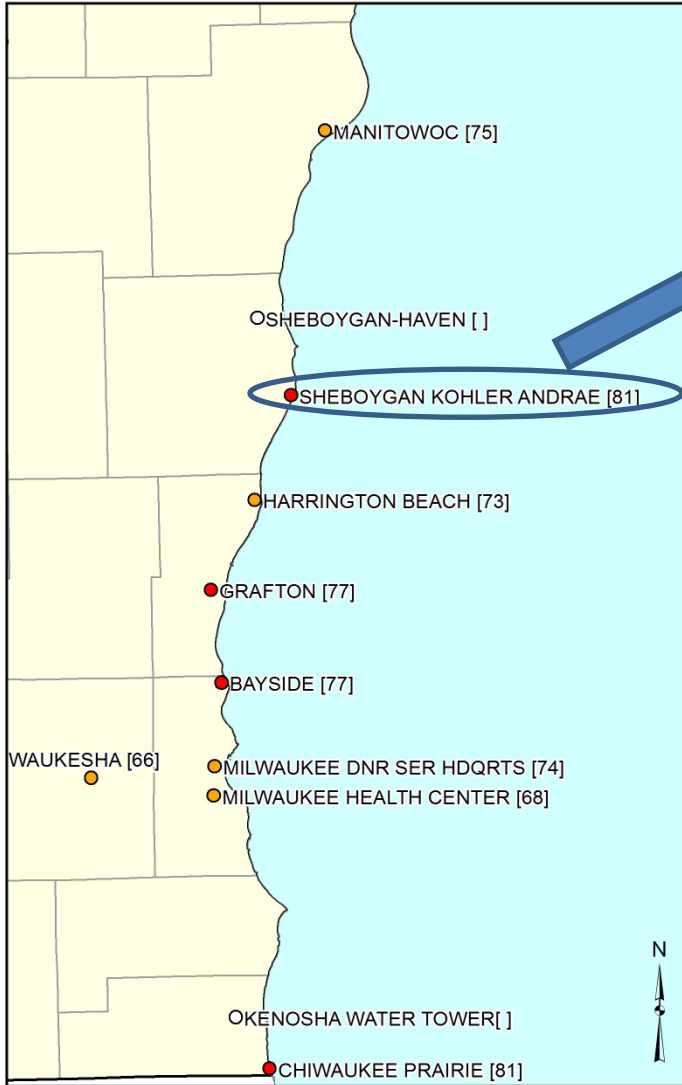
**MODIS Image July 17, 2011**



Satellite image of Lake Michigan showing Lake Breeze Front

**From Mike Majewski, WDNR**

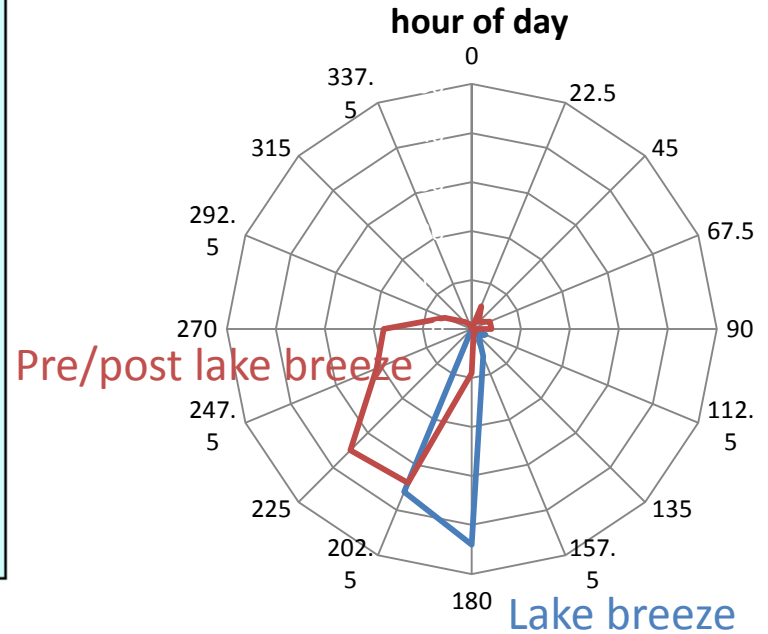
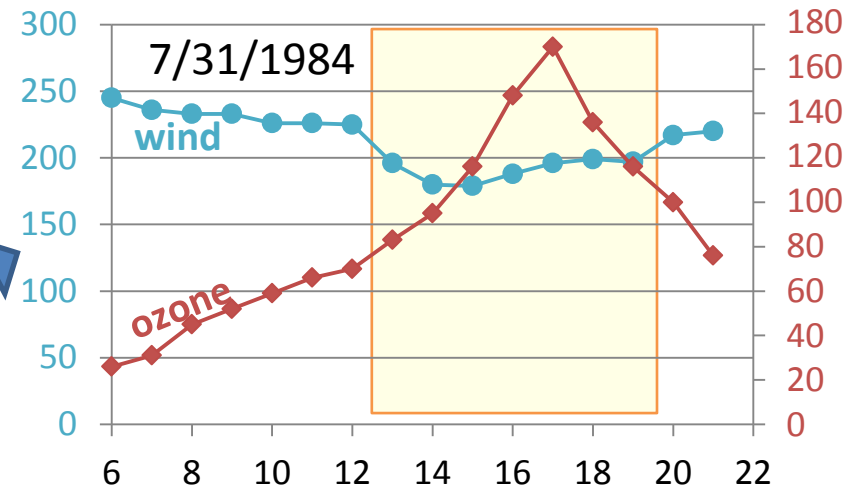
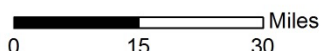
# Effects of the lake breeze on ozone concentrations



## 8-Hour Ozone DVs in ppb

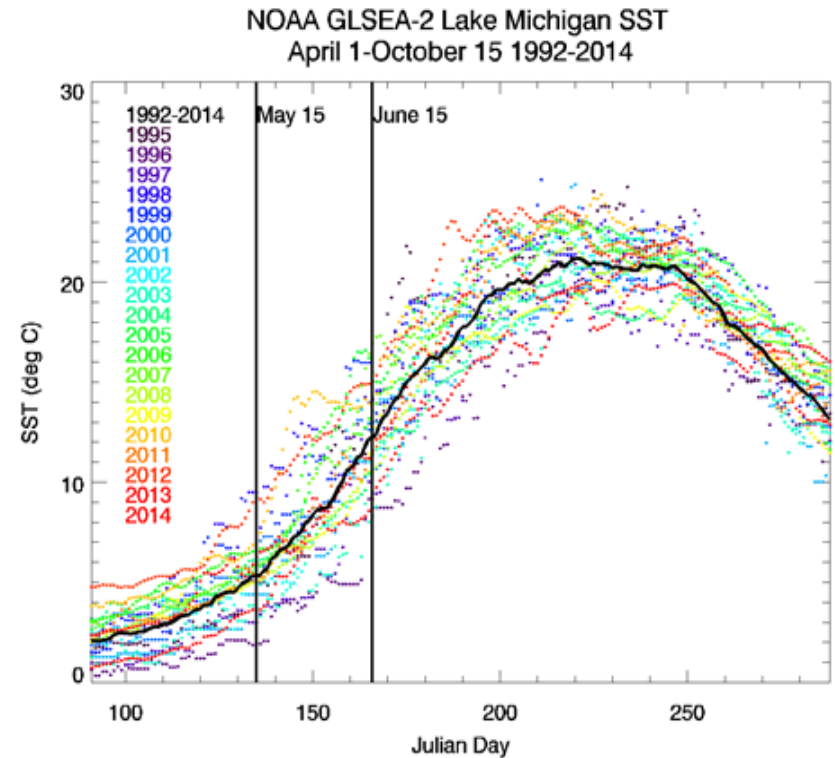
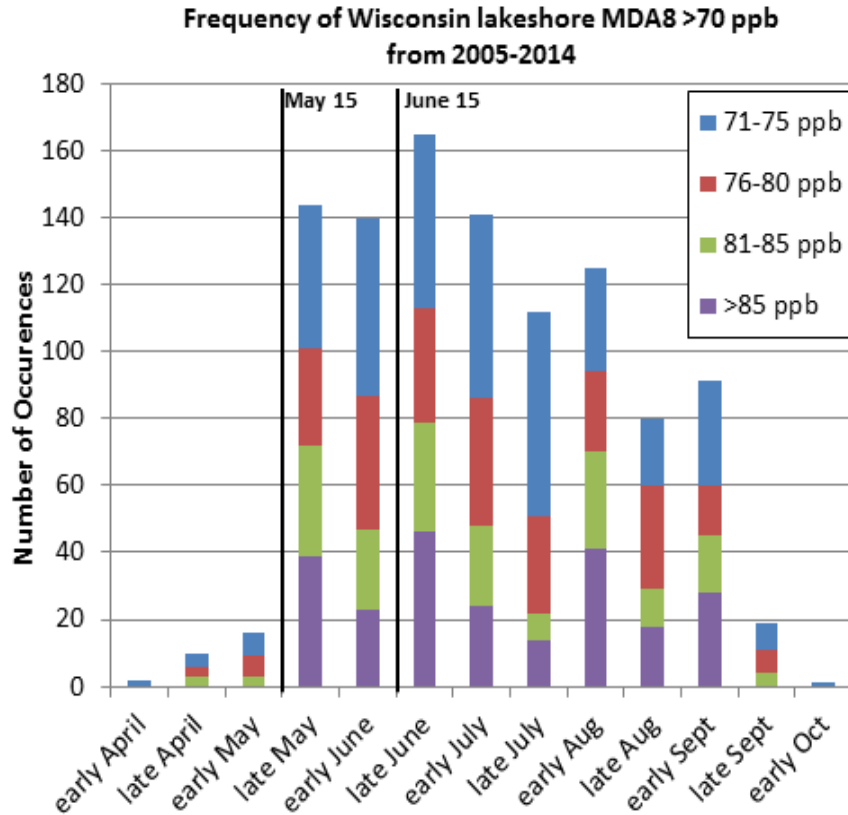
- Data Incomplete
- ≤ 65
- 66 - 75
- 76 - 84
- ≥ 85

**Ozone Standards**  
1997 NAAQS: 84 ppb  
2008 NAAQS: 75 ppb



# Lake Michigan Ozone Study (LMOS) 2017

## Campaign Study Period May 22- June 22, 2017



Primary science objectives focusing on characterizing the recirculation, aging, and mixing of the Chicago and Milwaukee urban plumes as they move over Lake Michigan and their impact on surface ozone.



# LMOS Measurement Suite

SSEC SPARC Trailer  
(HALO Wind Lidar, AERI T/Q profiles, HSRL aerosol extinction, CIMEL aerosol optical depth),

EPA Pandora (Column NO<sub>2</sub>, HCHO), insitu (O<sub>3</sub>, NO<sub>x</sub>, HCHO)

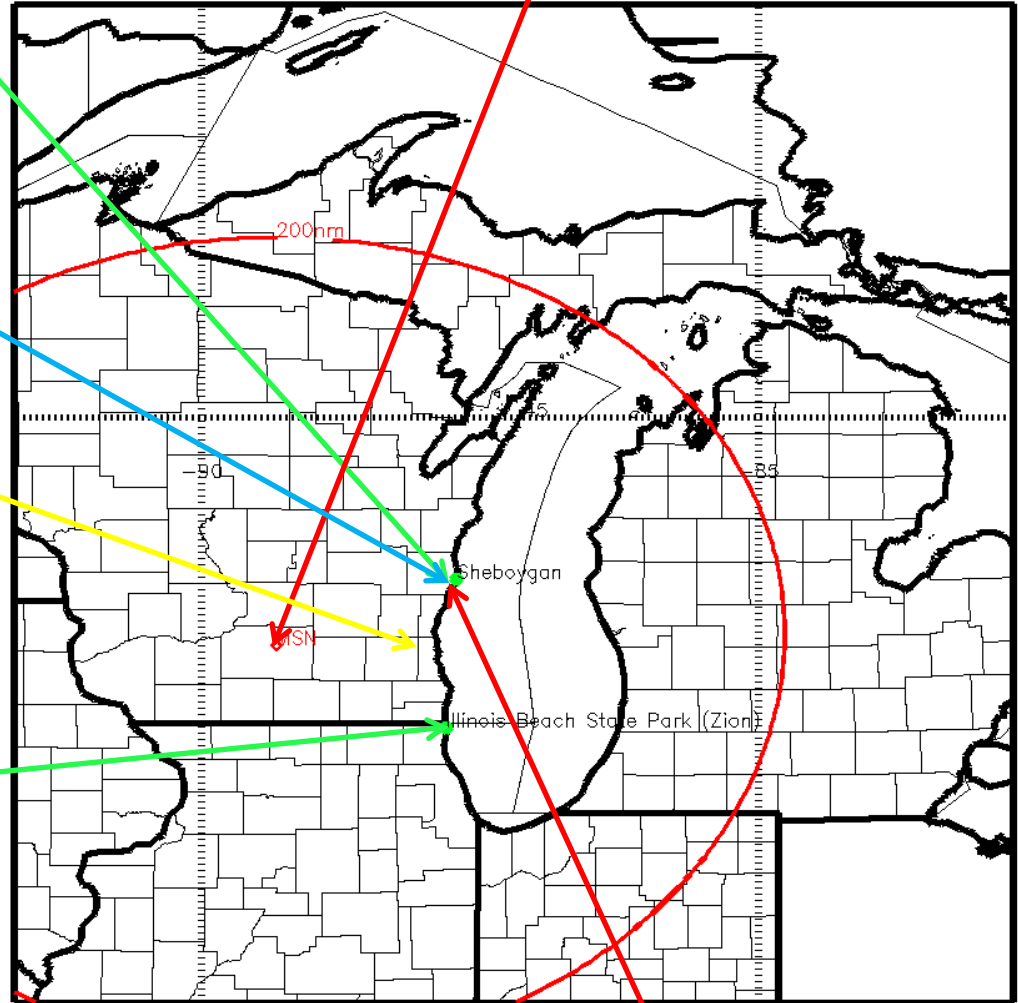
NOAA Ship (EPA Pandora, ceilometer, insitu O<sub>3</sub>, (tethered Kite and shipboard),

EPA Geospatial Measurement of Air Pollution (GMAP) mobile van (O<sub>3</sub>)

UNI Microwave Radiometer T/Q profiles, SoDAR winds, Pandora (Column NO<sub>2</sub>, O<sub>3</sub>)

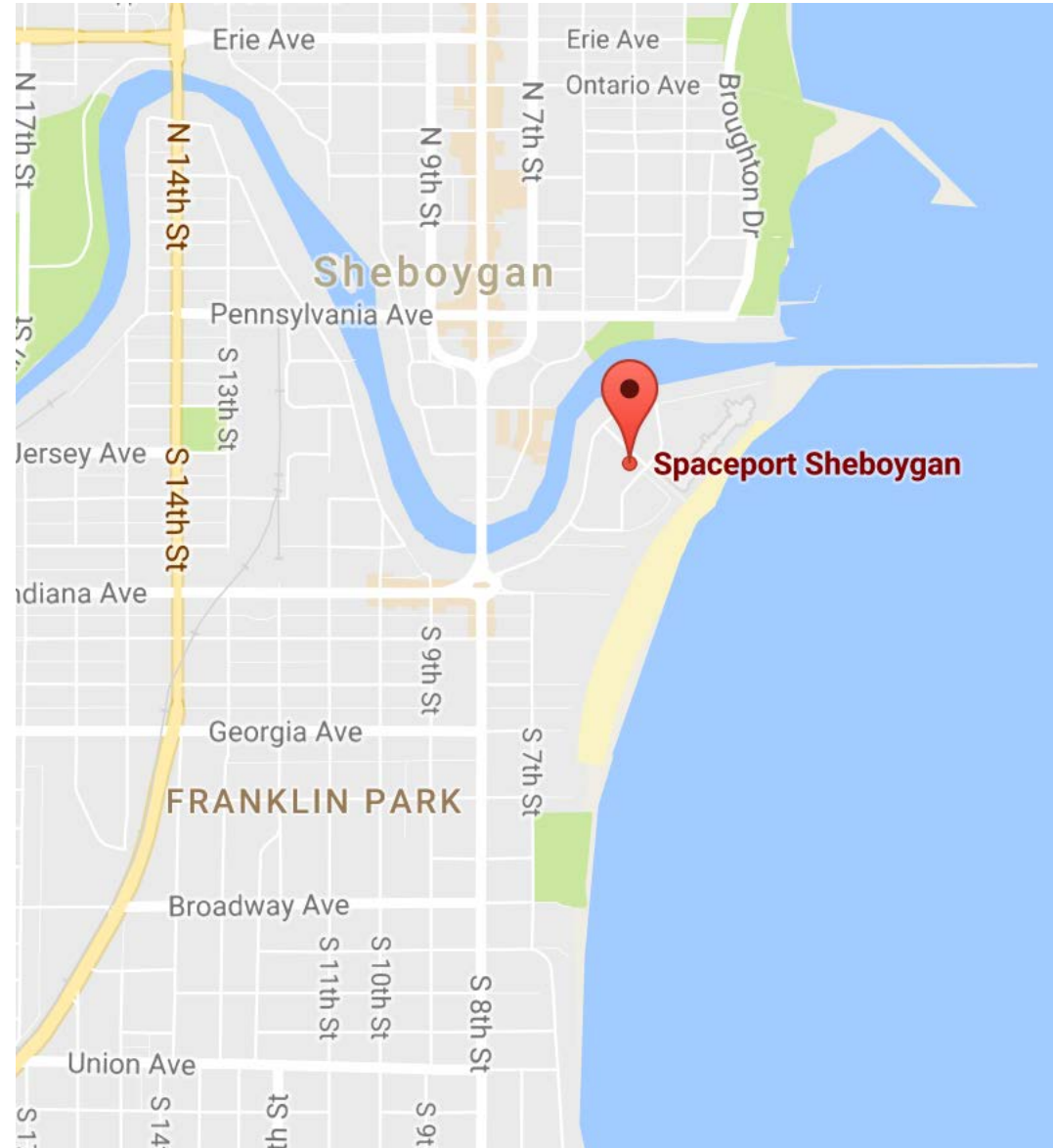
Insitu super site (UW-Madison/UofM NO<sub>y</sub>/VOC U-Iowa Aerosol)

NASA airborne column NO<sub>2</sub>, HCHO, O<sub>3</sub>, and aerosols (GEOTASO Airborne UV-VIS Spectrometer, AirHARP Polarimeter)



Scientific Aviation insitu O<sub>3</sub>, NO, NO<sub>2</sub>

# Sheboygan Ground Site: Spaceport Sheboygan



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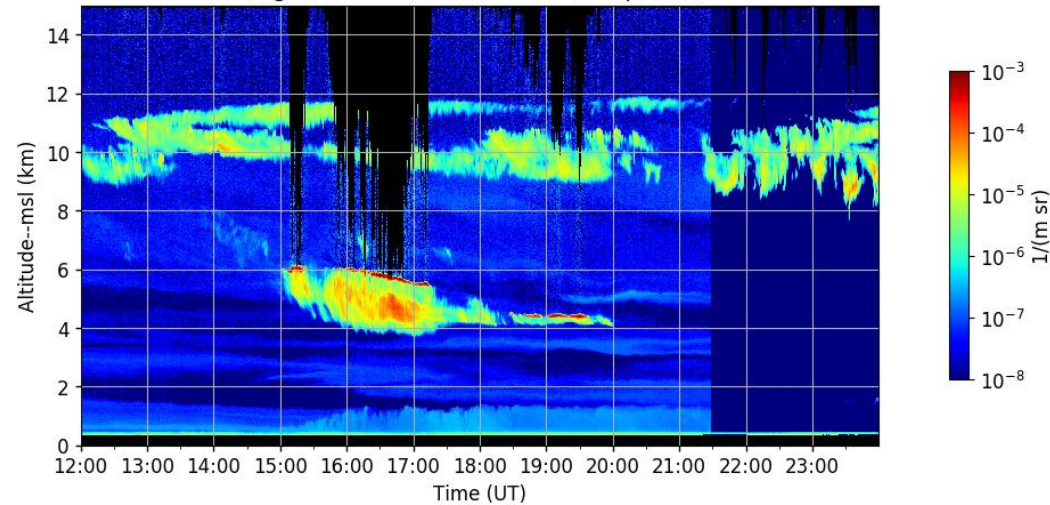
## UW-Madison SPARC Trailer

- **Boundary Layer Meteorology/Surface Meteorology** Tim Wagner, Univ. of Wisconsin. SPARC: the SSEC Portable Atmospheric Research Center. funded by NOAA
  - *Profiles:* Atmospheric Emitted Radiance Interferometer (AERI), HSRL Lidar, Doppler lidar wind profiler.
  - *In situ meteorology:* Vaisala T, RH, pressure, wind speed, wind direction, precipitation.
- **O3 Profiles** by Tethered Kite (ozone and meteorology), in conjunction with Dept. of Atmospheric Science, Univ. Wisconsin.



CL-51 positioned next to Space Science and Engineering Center, University of

bagohsrl 532 backscatter 01-Apr-2017





# Sheboygan Research Site: Spaceport Sheboygan EPA Research Trailer

## U.S. EPA Federal Reference Methods for Trace Gases along with Formaldehyde (O<sub>3</sub> precursor):

### ➤ NO<sub>x</sub>/NO<sub>y</sub> methods:

- Teledyne T500U Cavity attenuated phase shift spectroscopy (CAPS)
- Teledyne 200EUP Photolytic converter – O<sub>3</sub> chemiluminescence

### ➤ O<sub>3</sub> method:

- 2B Technologies M211 Scrubberless UV

### ➤ HCHO

- Aerodyne QCL

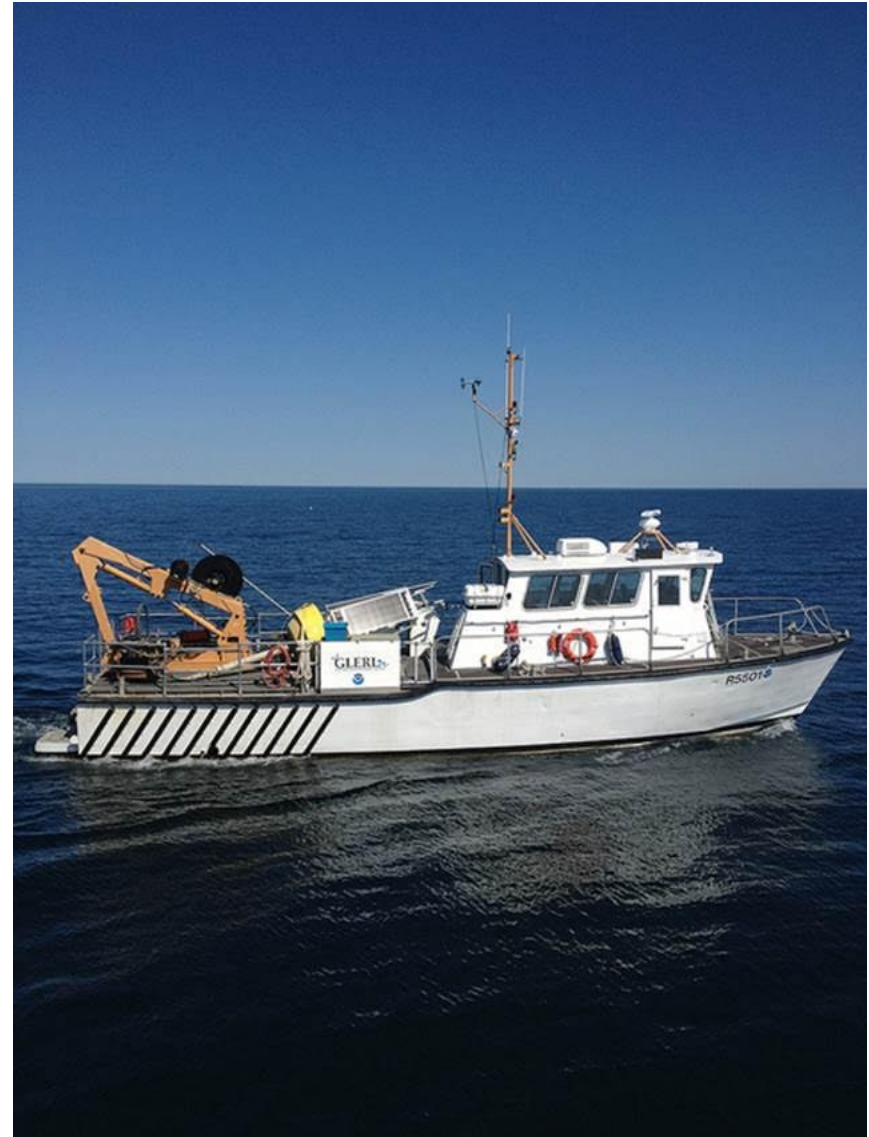


# Ship measurements: NOAA -GLERL Lake Michigan Field Station Research Vessel R5503



**The NOAA Great Lakes Environmental Research Laboratory (GLERL) will be providing the RV R5503 during June 2-22**

- EPA Pandora, ceilometer, insitu O3 measurements using tethered Kite and shipboard
- Based out of Sheboygan, WI during deployment





# Mobile Van Measurements: EPA Region Geospatial Measurement of Air Pollution (GMAP)

## Coastal/inland ozone gradients

GMAP has an integrated Differential Ultra Violet Absorption Spectroscopy (DUVAS) that can provide high frequency (1 second) measurements while moving or parked.



# Airborne Measurements: NASA GeoTASO, Scientific Aviation insitu O<sub>3</sub> and NO<sub>x</sub>

NASA Beechcraft UC-12 instrument 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<sub>2</sub>, HCHO, and aerosols.

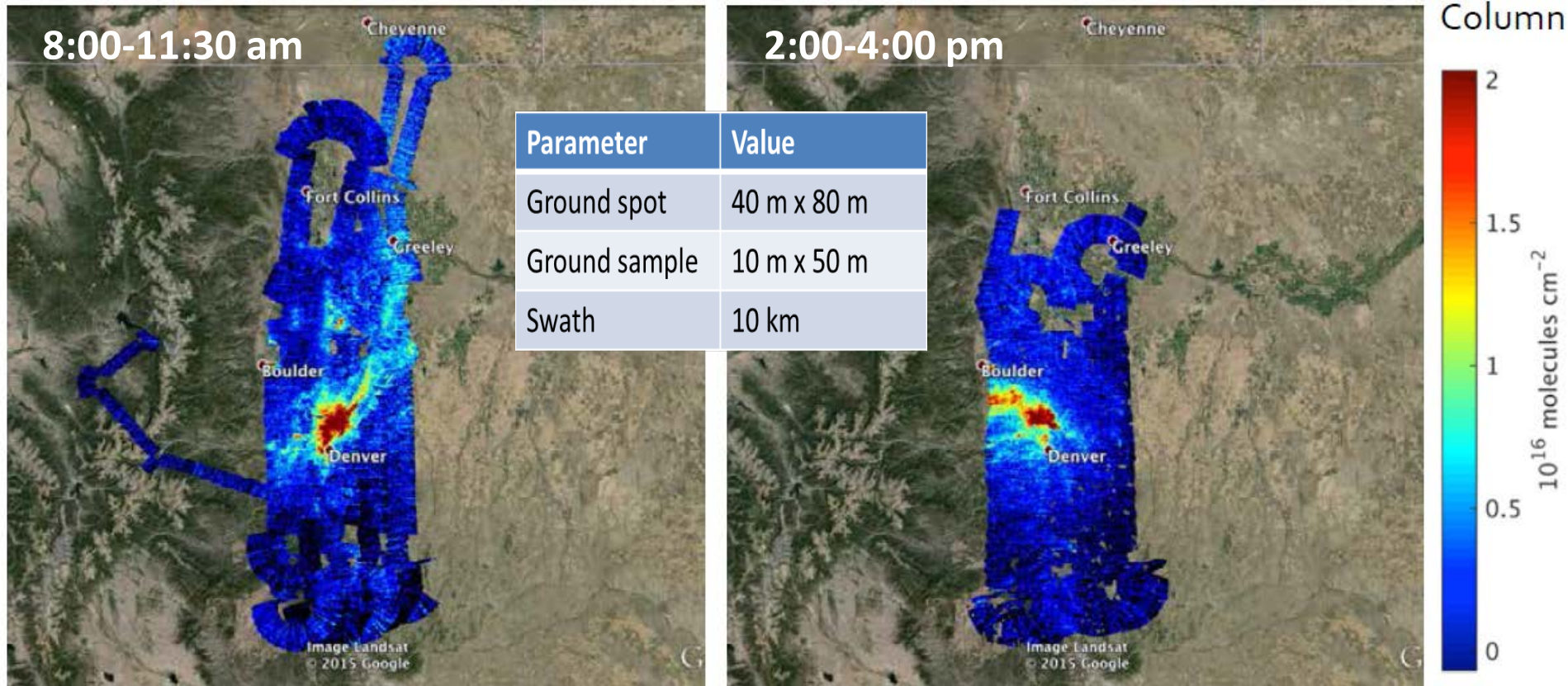


Scientific Aviation Mooney airplane equipped with meteorological, O<sub>3</sub> and NO<sub>x</sub> measurements. Spirals over key ground sites and measurements within the boundary layer over land and water. *Funded by Electric Power Research Institute (EPRI)*

# NASA Airborne Remote Sensor Geostationary Trace Gas and Aerosol Sensor Optimization (GeoTASO)

- Airborne platform
- Column retrievals of NO<sub>2</sub>, HCHO, O<sub>3</sub>, SO<sub>2</sub>, CHOCHO

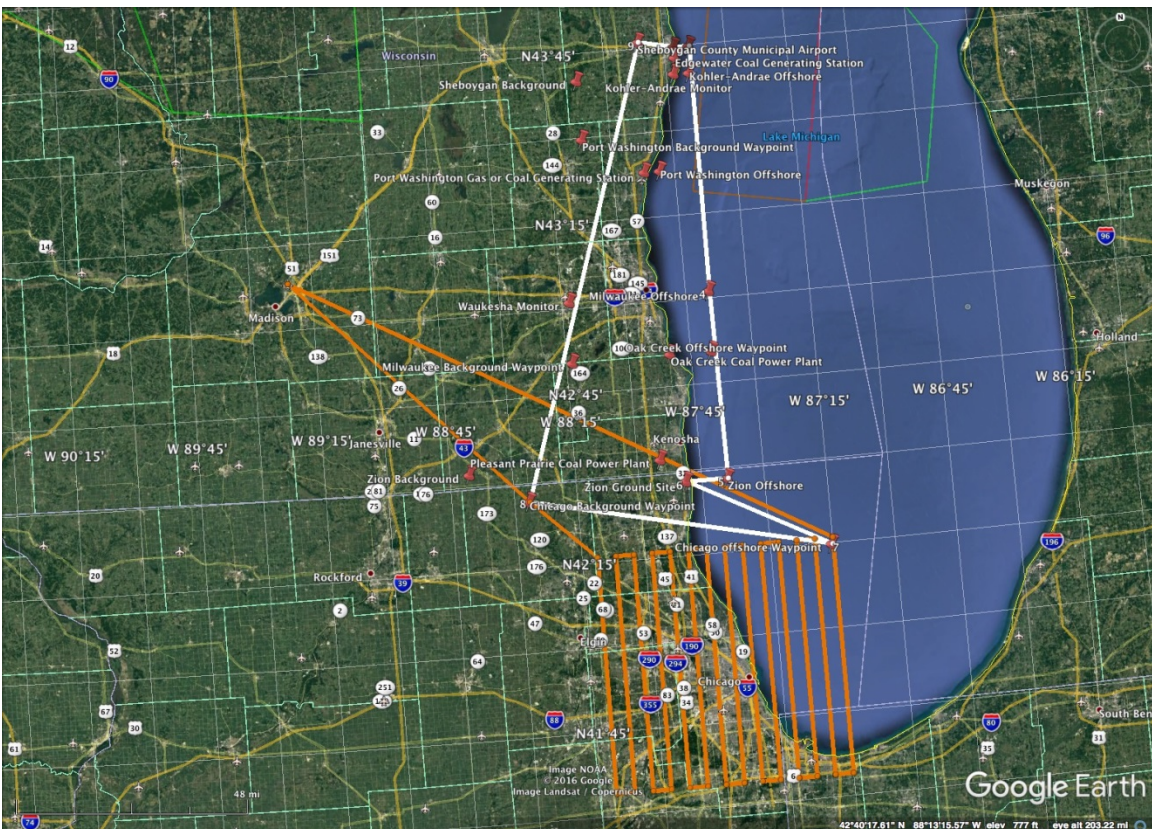
## NO<sub>2</sub> over Denver, 2 August 2014



From Caroline Nowlan (Harvard-Smithsonian Center for Astrophysics, Cambridge, MA)

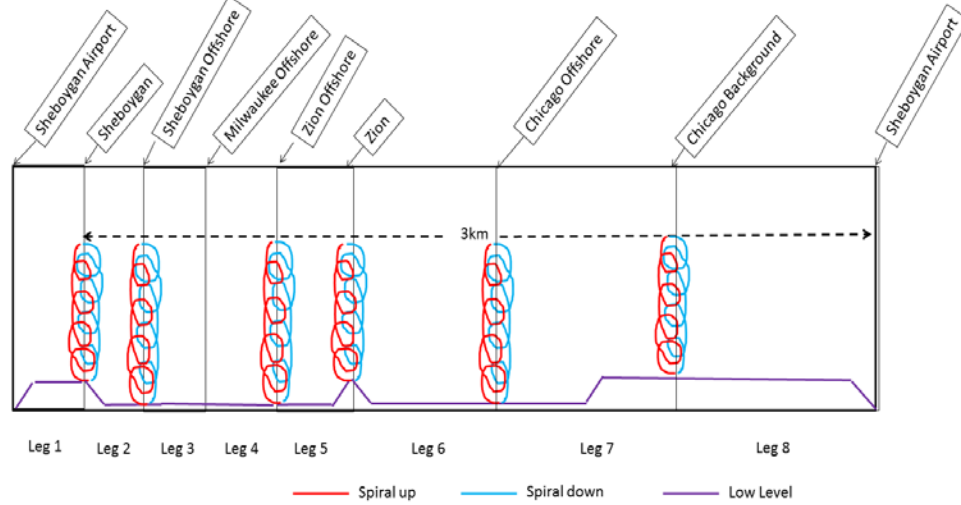


# Scientific Aviation (white)/GeoTASO (orange): Chicago Raster Flight Plan



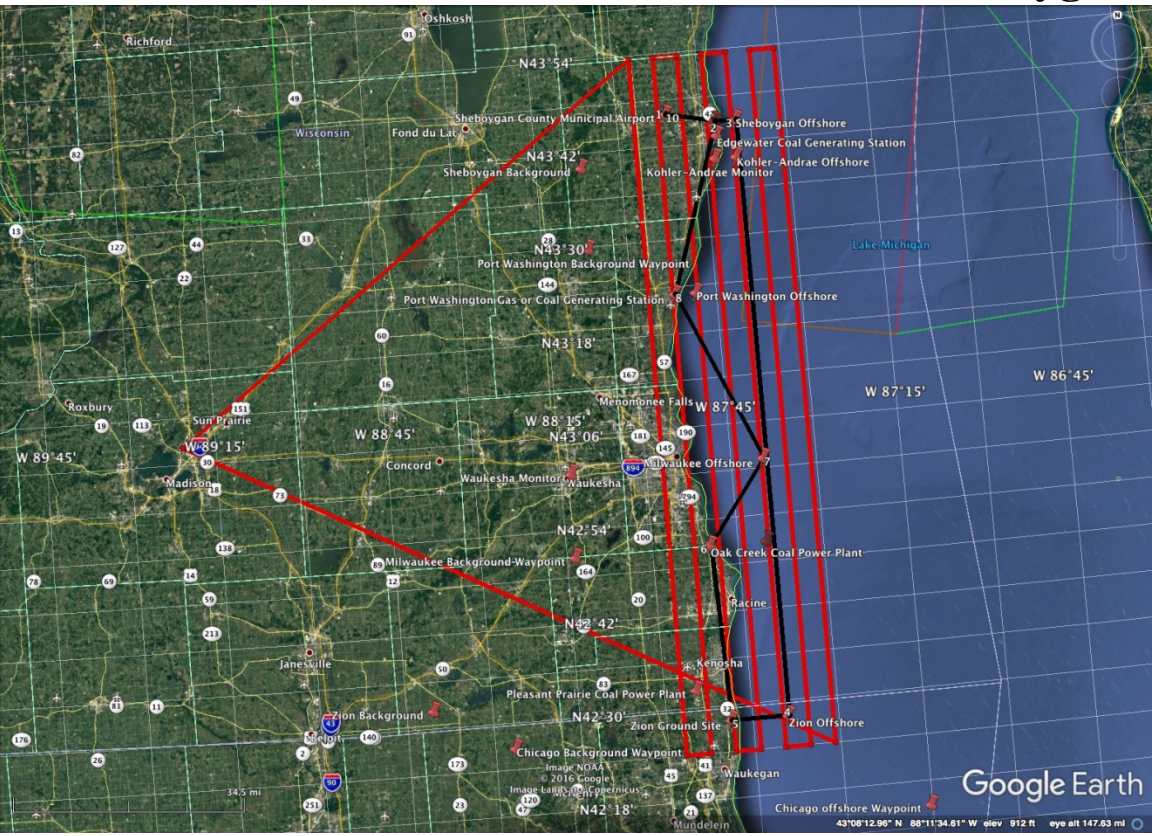
## Scientific Aviation Profiling

Chicago emissions with background and offshore profiling



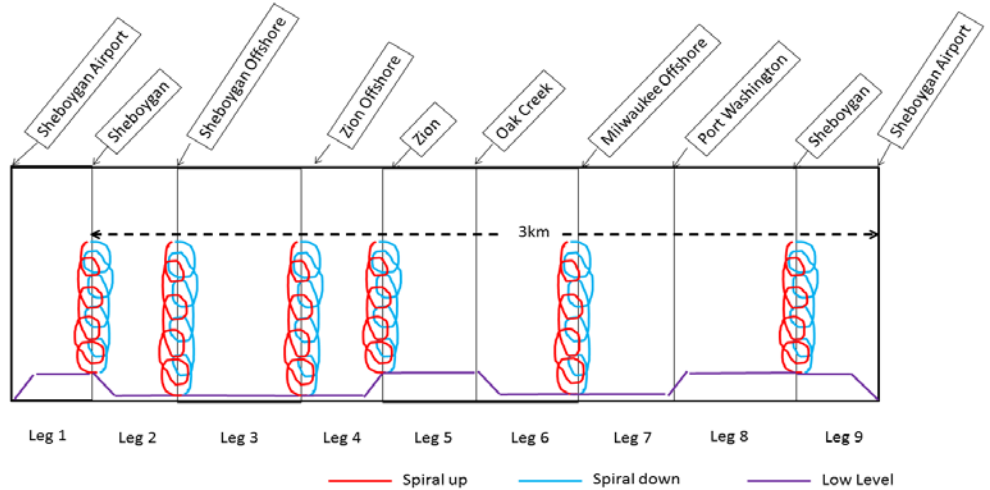
Leg 1 Leg 2 Leg 3 Leg 4 Leg 5 Leg 6 Leg 7 Leg 8  
 — Spiral up — Spiral down — Low Level

# Scientific Aviation (black)/GeoTASO (red): Sheboygan to Zion Raster Flight Plan



## Scientific Aviation Profiling

**Zion to Sheboygan coastal survey with onshore and offshore profiling**

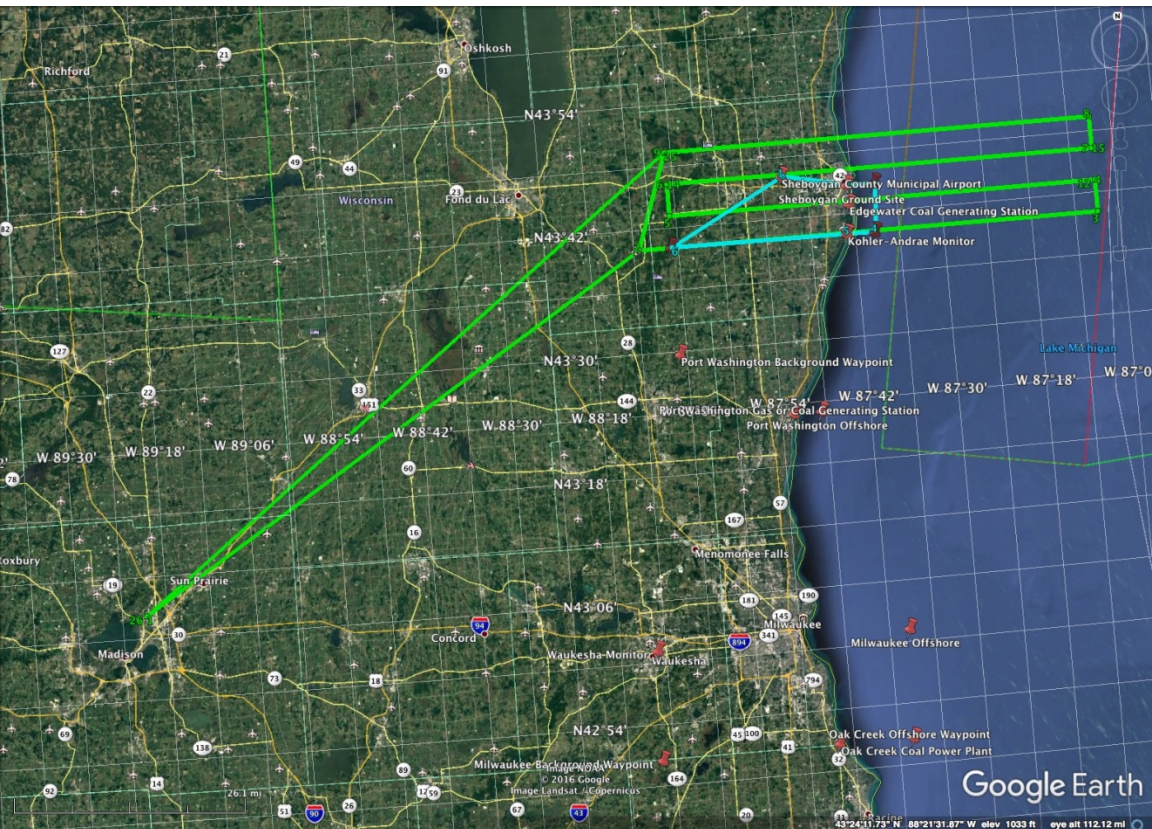


Leg 1    Leg 2    Leg 3    Leg 4    Leg 5    Leg 6    Leg 7    Leg 8    Leg 9

— Spiral up    — Spiral down    — Low Level

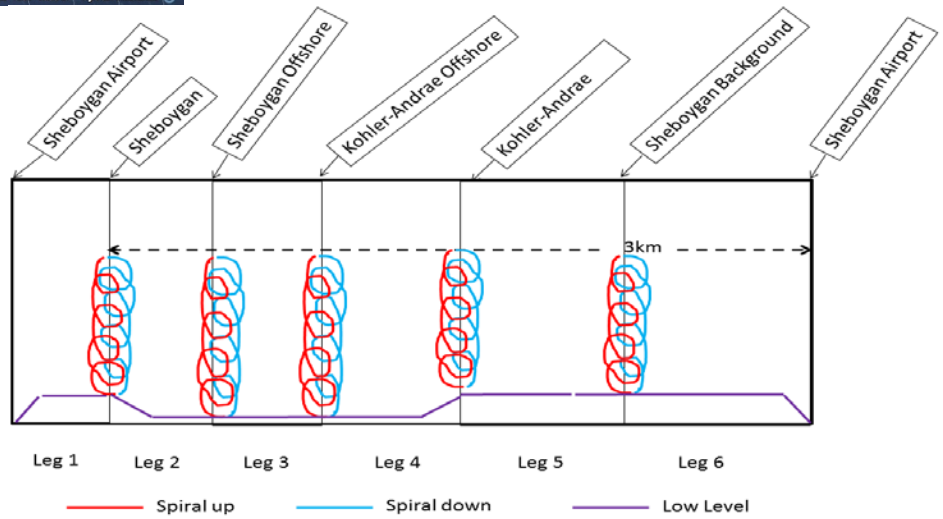


# Scientific Aviation (blue)/GeoTASO (green): Sheboygan Raster (Three circuits) Flight Plan



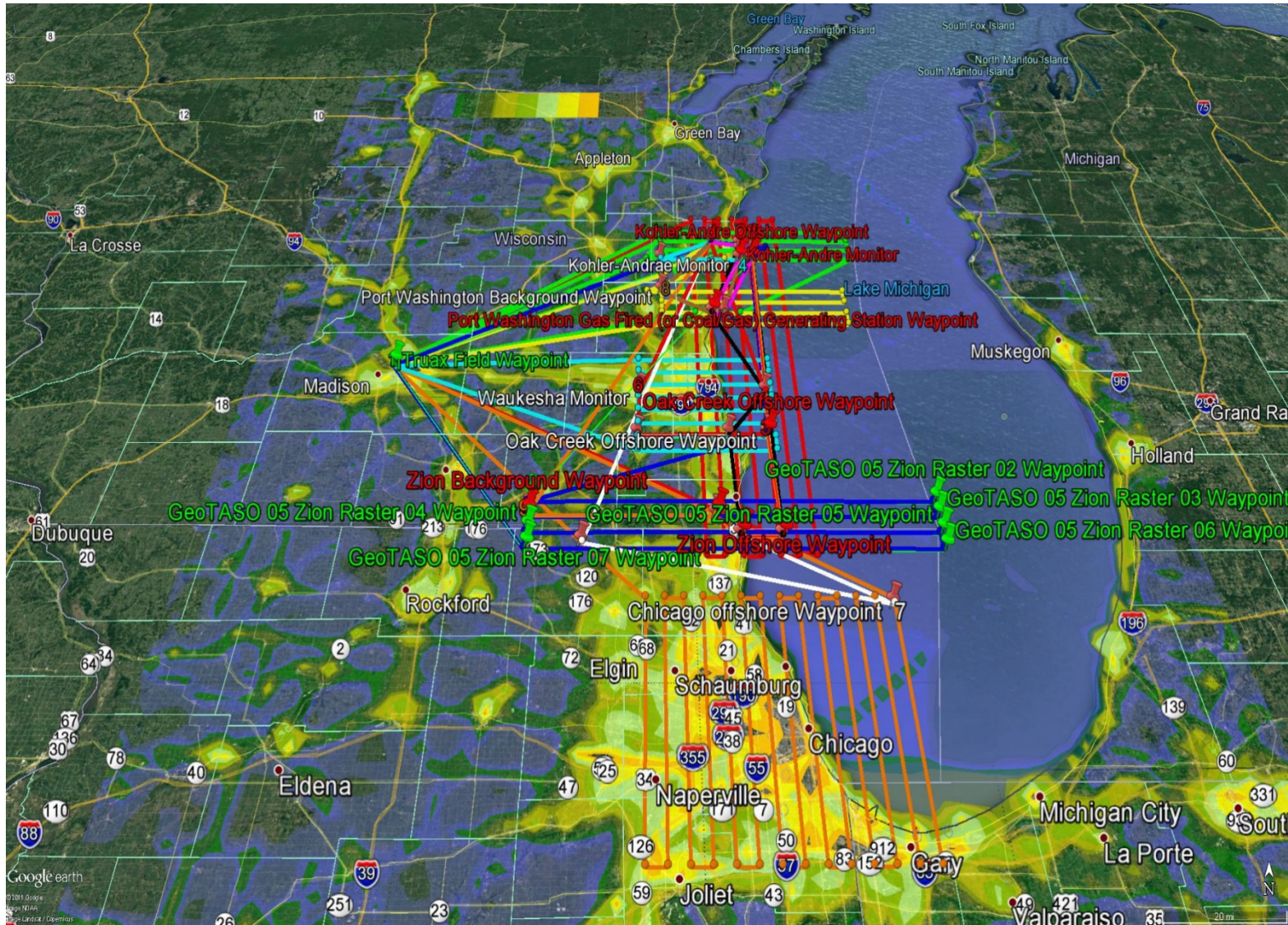
## Scientific Aviation Profiling

Sheboygan survey with background, onshore and offshore profiling





# All LMOS Flights with EPA National Emission Inventory 2011 NOx emissions





*Thanks to the Jane Brill and the Sheboygan  
County Chamber for help with LMOS  
Sheboygan site selection, accommodations, and  
logistics!*

*Questions?*

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