A Cross Disciplinary, Multi-Tool Approach to Support Regional and Global Air Quality Assessment and Forecasting

R. Bradley Pierce
NOAA/NESDIS@CIMSS

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"Think globally, act locally"

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Outline:

1) **Background**
   - Pollution health & ecosystem effects
   - Regional trends
2) **Regional Air Quality**
   - 2017 Lake Michigan Ozone Study – "The Wisconsin Idea"
3) **Global Air Quality**
   - Global Trends
   - Aura Chemical Reanalysis
4) **Vision:** SSEC – Opportunities and Challenges

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Ozone Pollution health & ecosystem effects

- Tropospheric ozone (O3) is formed by photochemical reactions involving sunlight and precursor pollutants, including volatile organic compounds (VOCs), nitrogen oxides (NOX), and carbon monoxide (CO).

- In the troposphere, O3 acts as a powerful oxidizing agent, which can harm living organisms and materials.

    - Short-term exposure to elevated O3 concentrations leads to respiratory and cardiovascular effects and increased mortality

    - Long-term exposure to elevated O3 concentrations leads to reduced vegetation growth, productivity, and yield and quality of agricultural crops

U.S. EPA. Integrated Science Assessment (ISA) of Ozone and Related Photochemical Oxidants (Final Report, Feb 2013). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-10/076F, 2013.

Ozone Pollution health & ecosystem effects

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  - **Short-term exposure to elevated O3 concentrations leads to respiratory and cardiovascular effects and total mortality**
  - **Long-term exposure to elevated O3 concentrations leads to reduced vegetation growth, productivity, and yield and quality of agricultural crops**

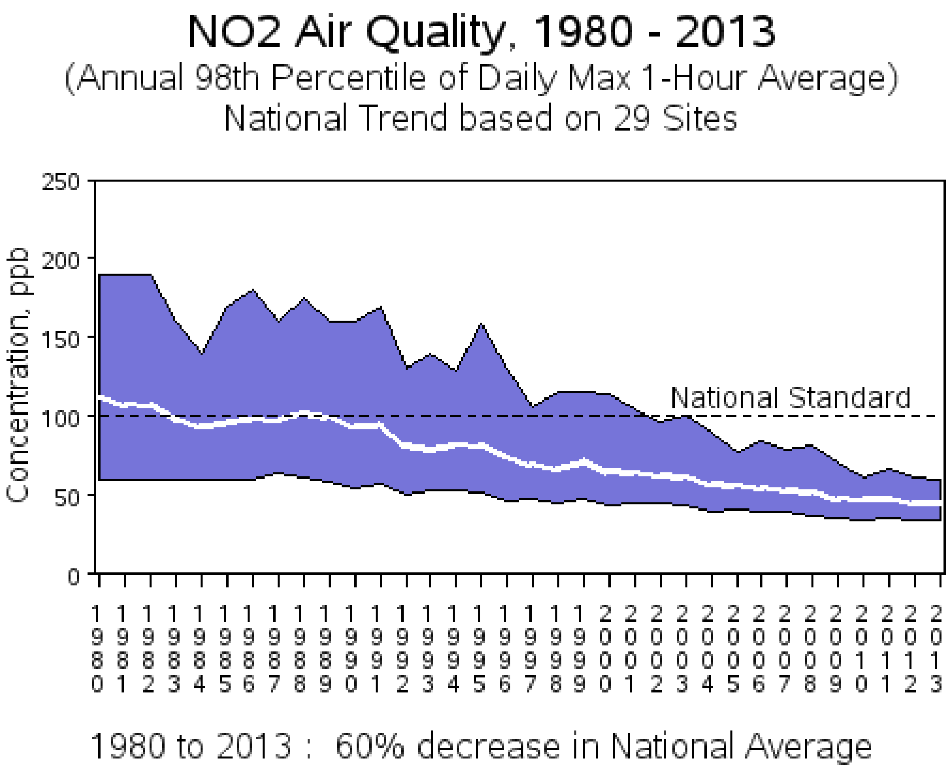
Tropospheric Formaldehyde (HCHO, a VOC), Nitrogen Dioxide (NO2, part of NOx), CO and O3 columns can all be observed from Satellites

U.S. EPA. Integrated Science Assessment (ISA) of Ozone and Related Photochemical Oxidants (Final Report, Feb 2013). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-10/076F, 2013.

Background: National Trends in Nitrogen Dioxide (NO2) Levels

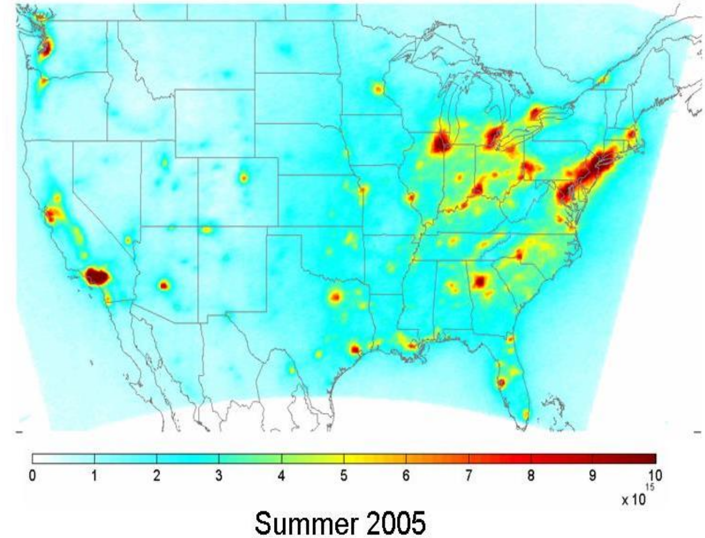
Overall, surface and column NO2 amounts are declining over the US due to regulations from the Clean Air Act

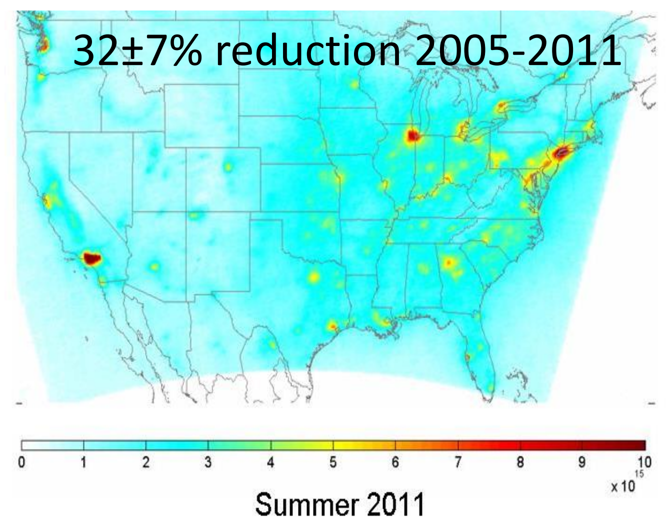
EPA NO2 trends from ground monitoring



http://www.epa.gov/airtrends/nitrogen.html

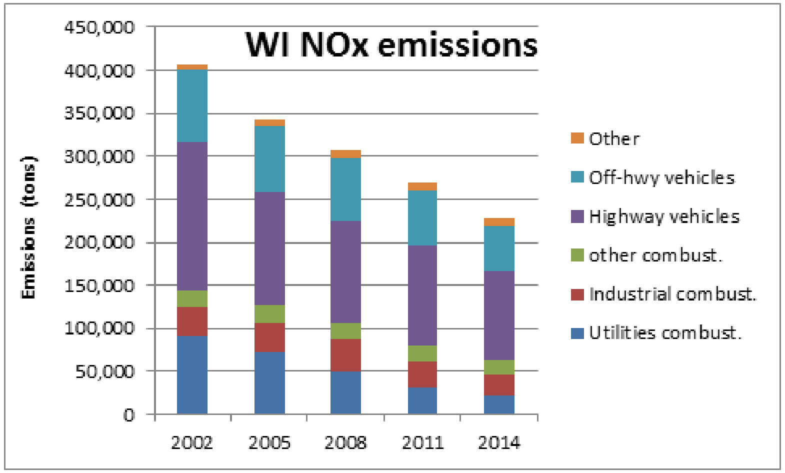
OMI Berkeley High-Resolution (BEHR) NO2 Column Retrievals

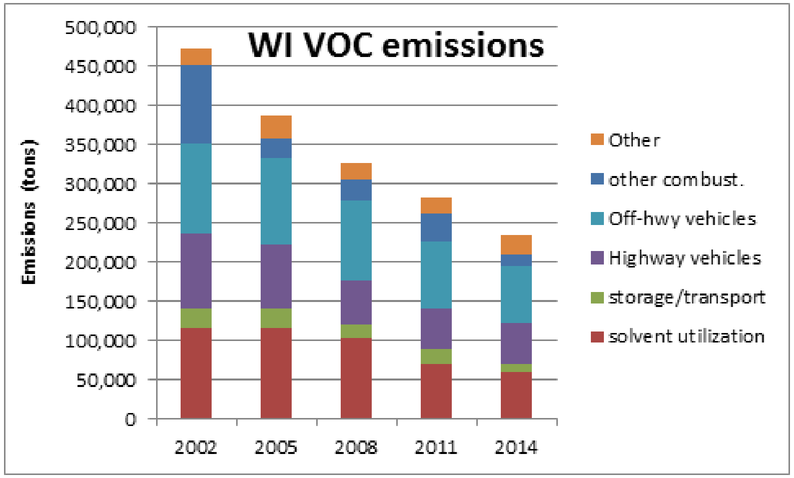




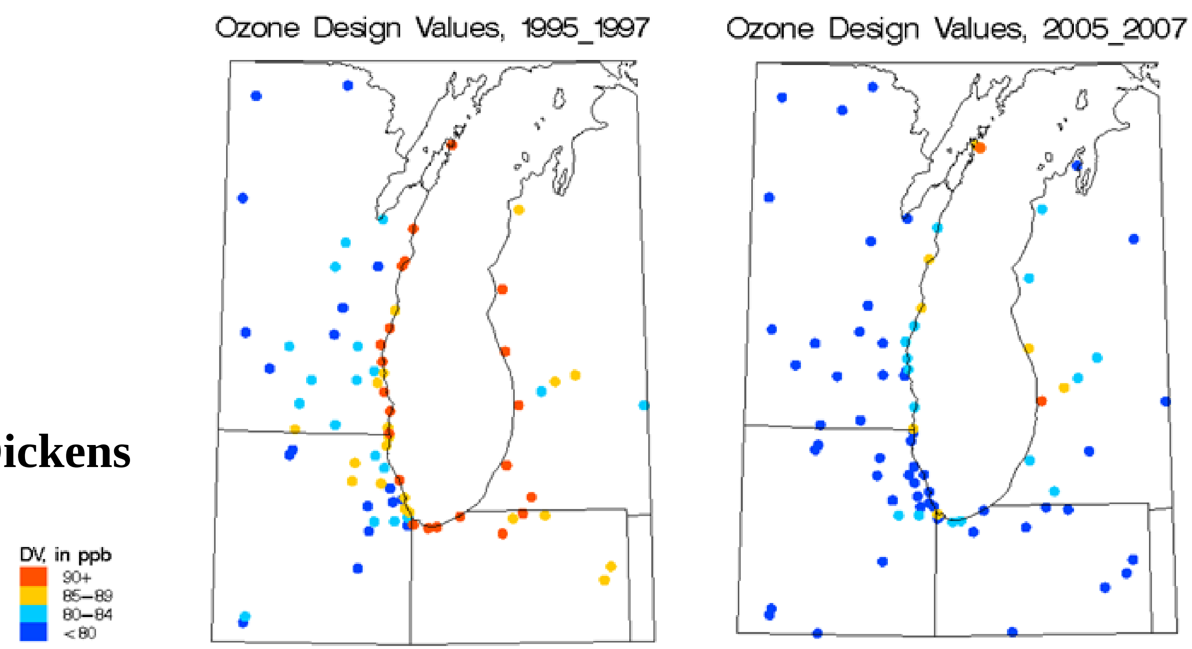
Russell et al., ACP 12, 12197-12209, doi:10.5194/acp-12-12197-2012, 2012.

Wisconsin emissions are declining and ozone is improving





NOx= NO+NO2 (nitrogen oxides) VOC=Volatile Organic Compounds, both are ozone precursors



Provided by Angie Dickens (WDNR) and Donna Kenski (LADCO)

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.

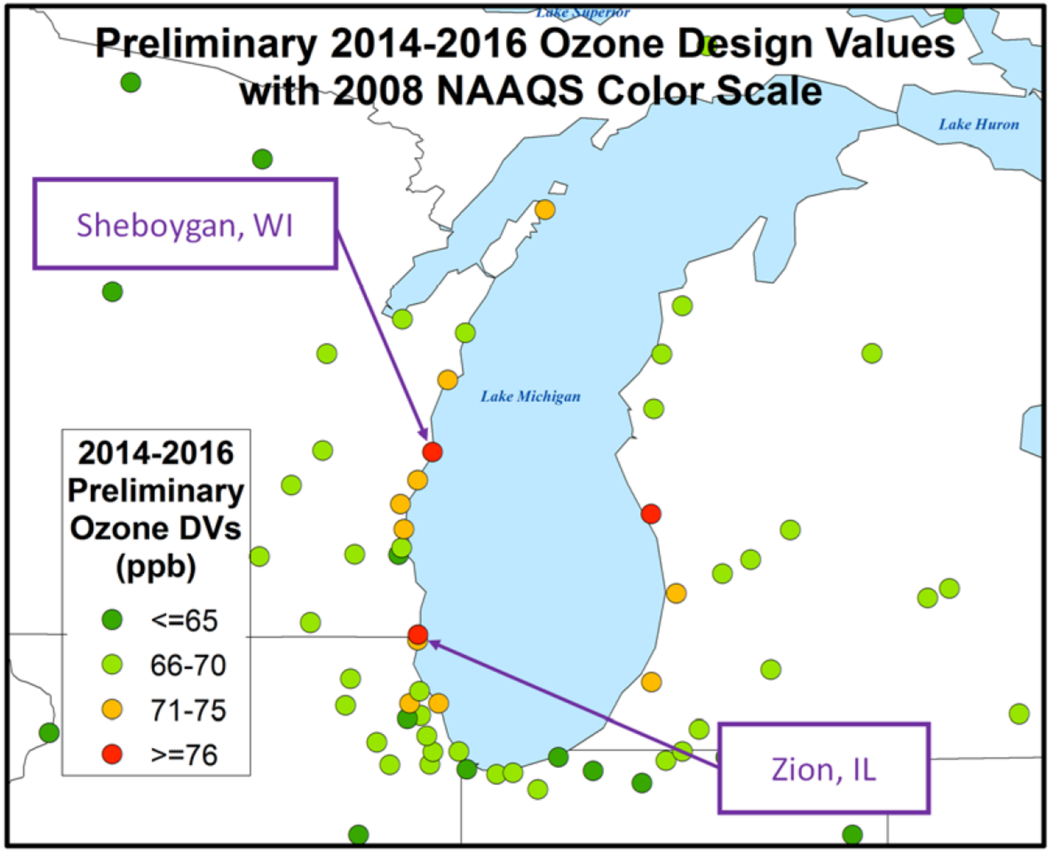


Figure 1. Ground sites hosting measurements for LMOS 2017

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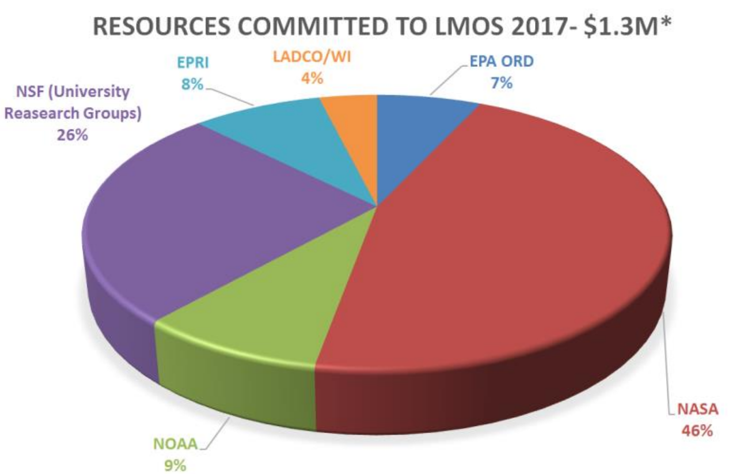
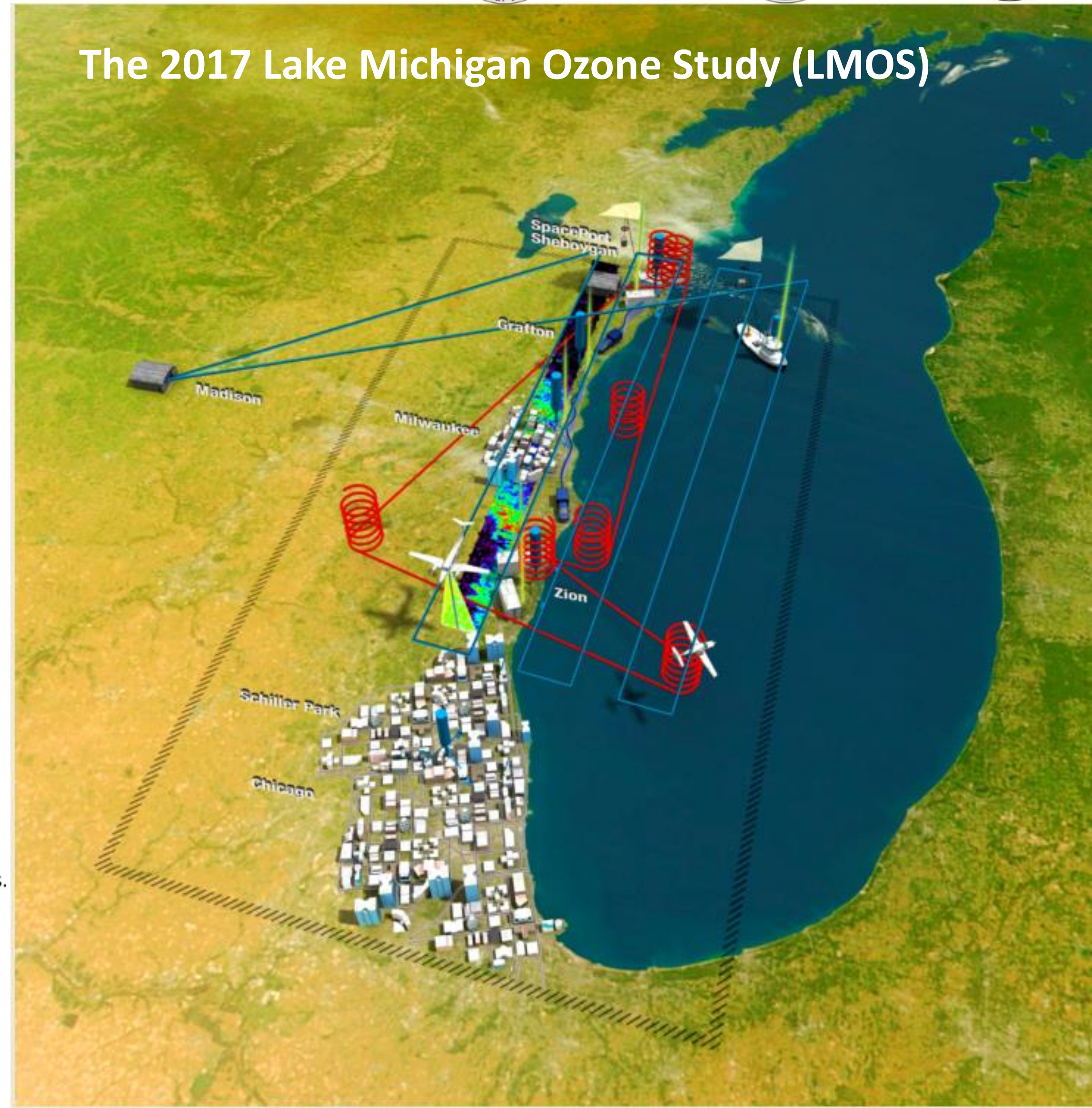
During May and June 2017, federal and state agencies, universities, and other partners measured air quality over Lake Michigan.



*Does not include FTE or travel cost from participating Federal Agencies.



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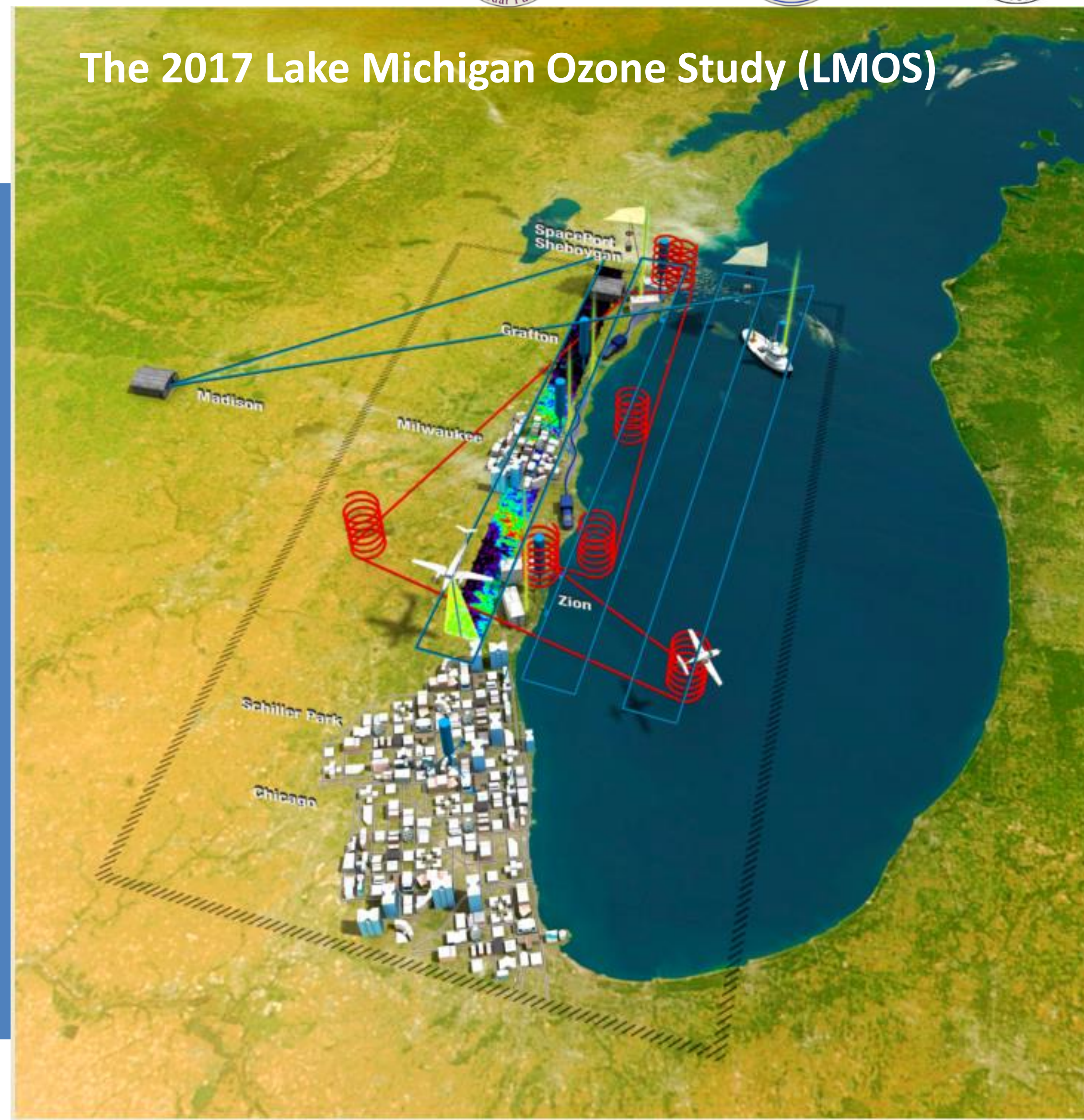
EPRI ELECTRIC POWER RESEARCH INSTITUTE

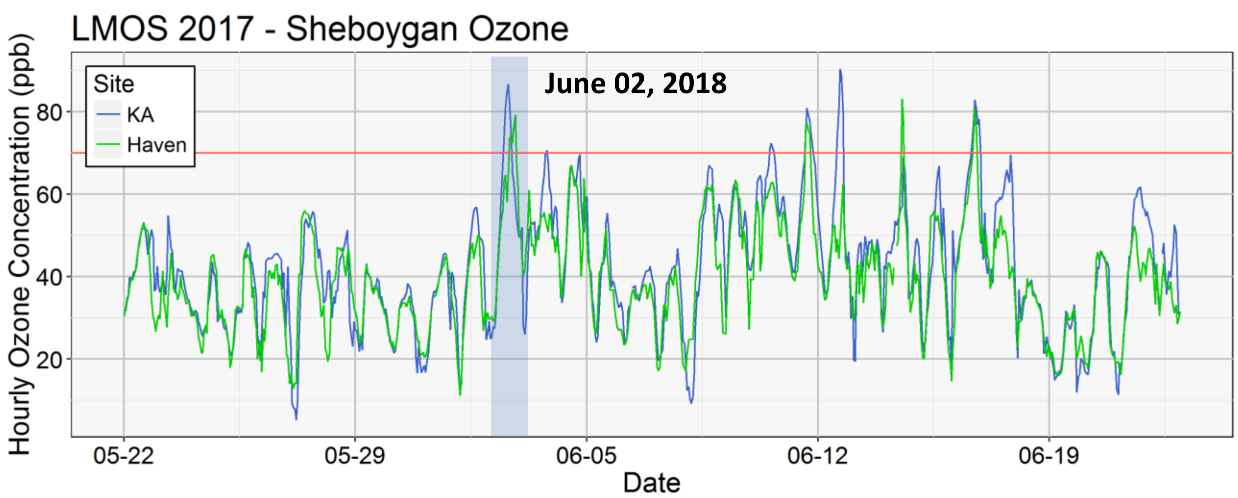
Lake Michigan Air Directors Consortium

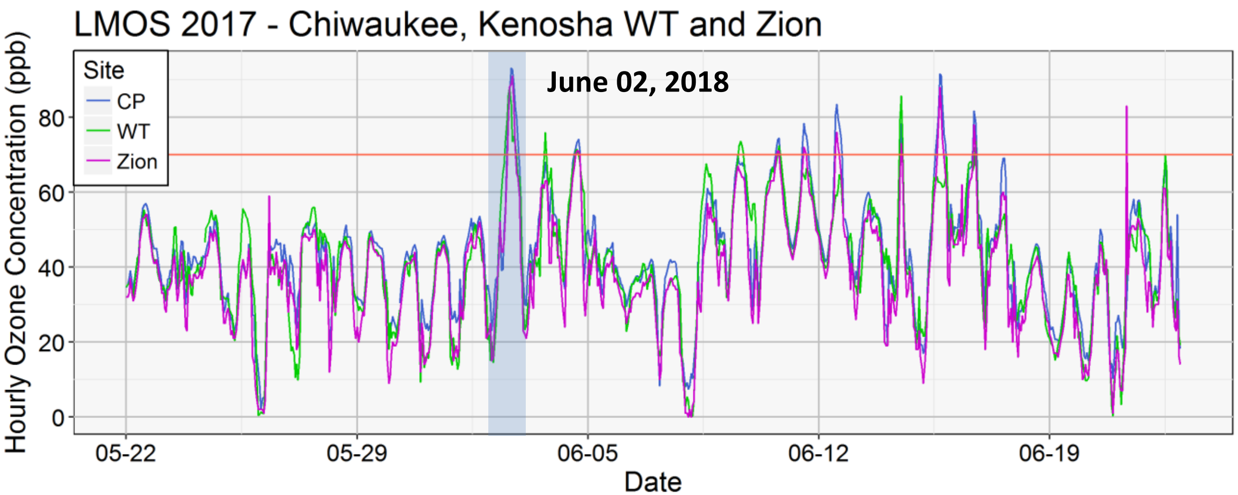


Objectives:

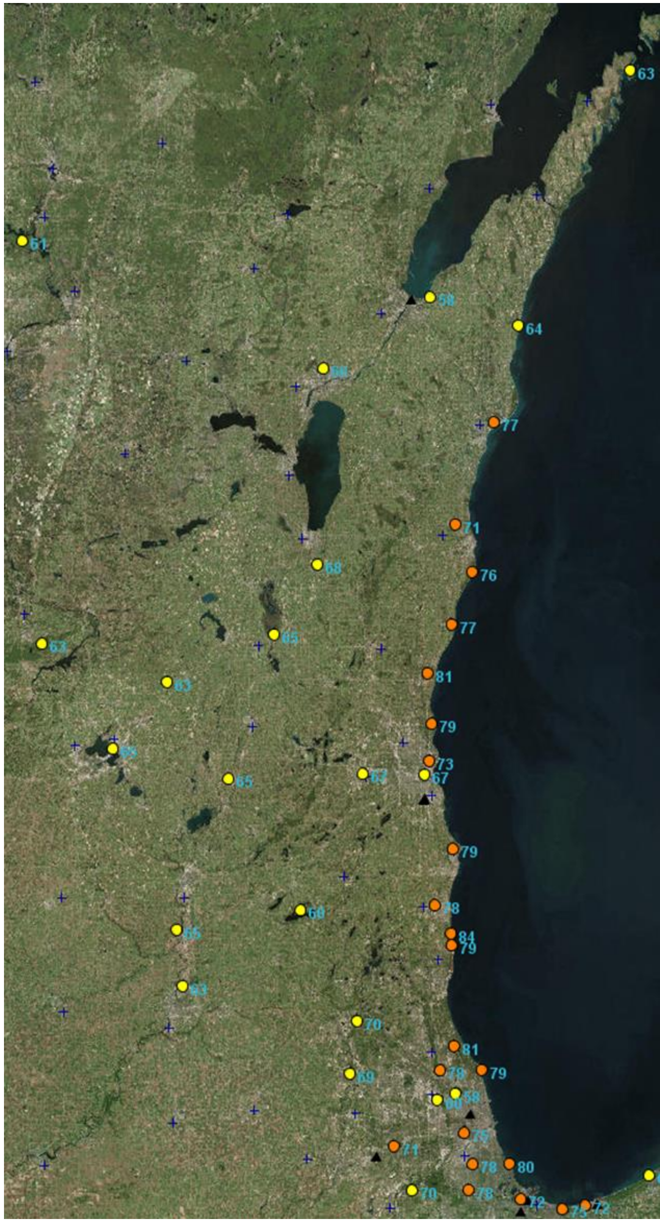
- Improved ozone forecasts for the region, which states and EPA use to meet state and federal Clean Air Act requirements.
- Better understanding of the lakeshore gradient in ozone concentrations, which could influence how EPA addresses future regional ozone issues.
- Improved knowledge of how emissions influence ozone formation in the region.

Lakeshore ozone during LMOS 2017





June 02, 2017 MDA8

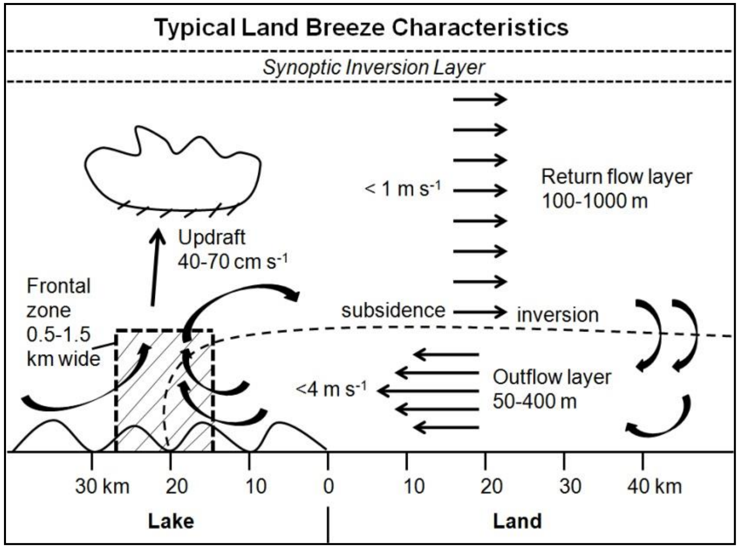


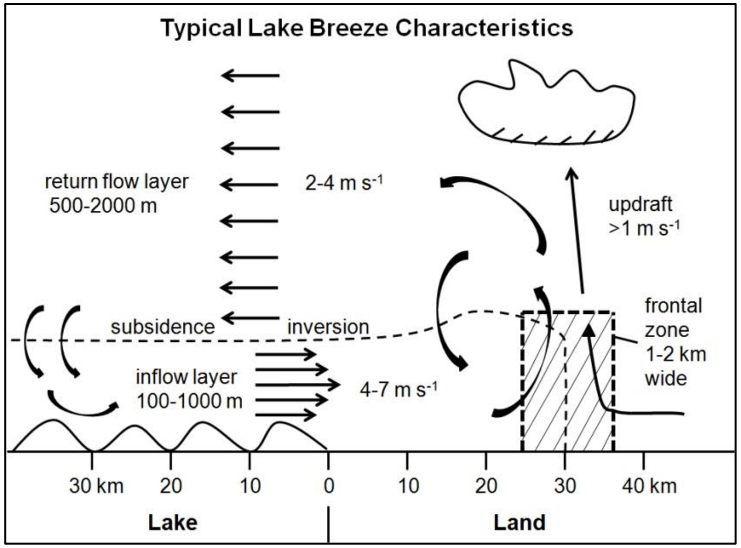
MDA8=Maximum Daily 8 hour Average

Provided by Angie Dickens (WDNR)

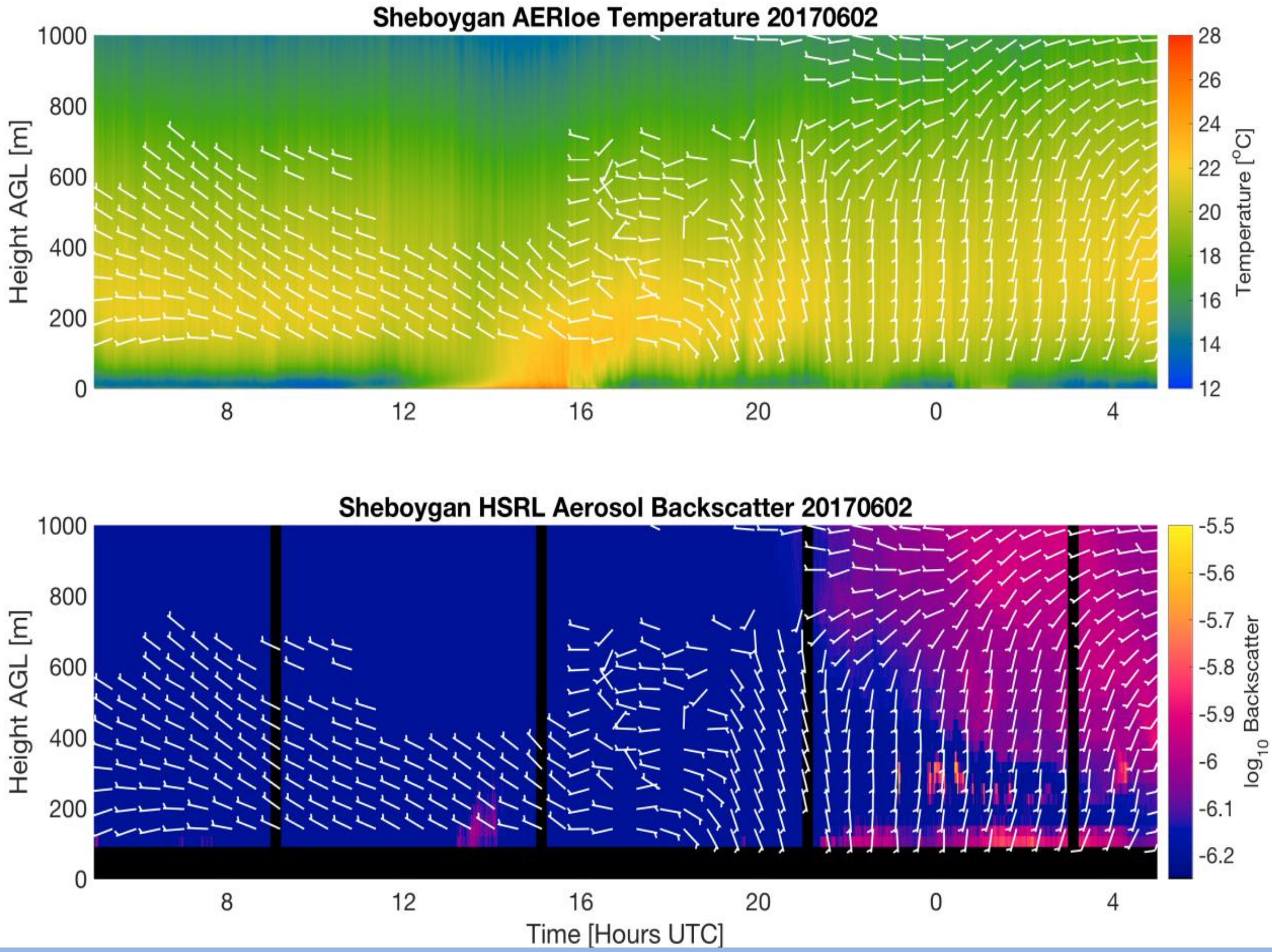
Lake Michigan and Ozone Formation

- ***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.





LMOS 2017 SSEC SPARC Remote Sensing Measurements: June 02, 2017



Temp and watervapor measurements from Atmospheric Emitted Radiance Interferometer (AERI), aerosol backscatter measurements from the High Spectral Resolution LIDAR (HSRL), and Doppler Lidar wind measurements.

Provided by Tim Wagner (UW-Madison SSEC)

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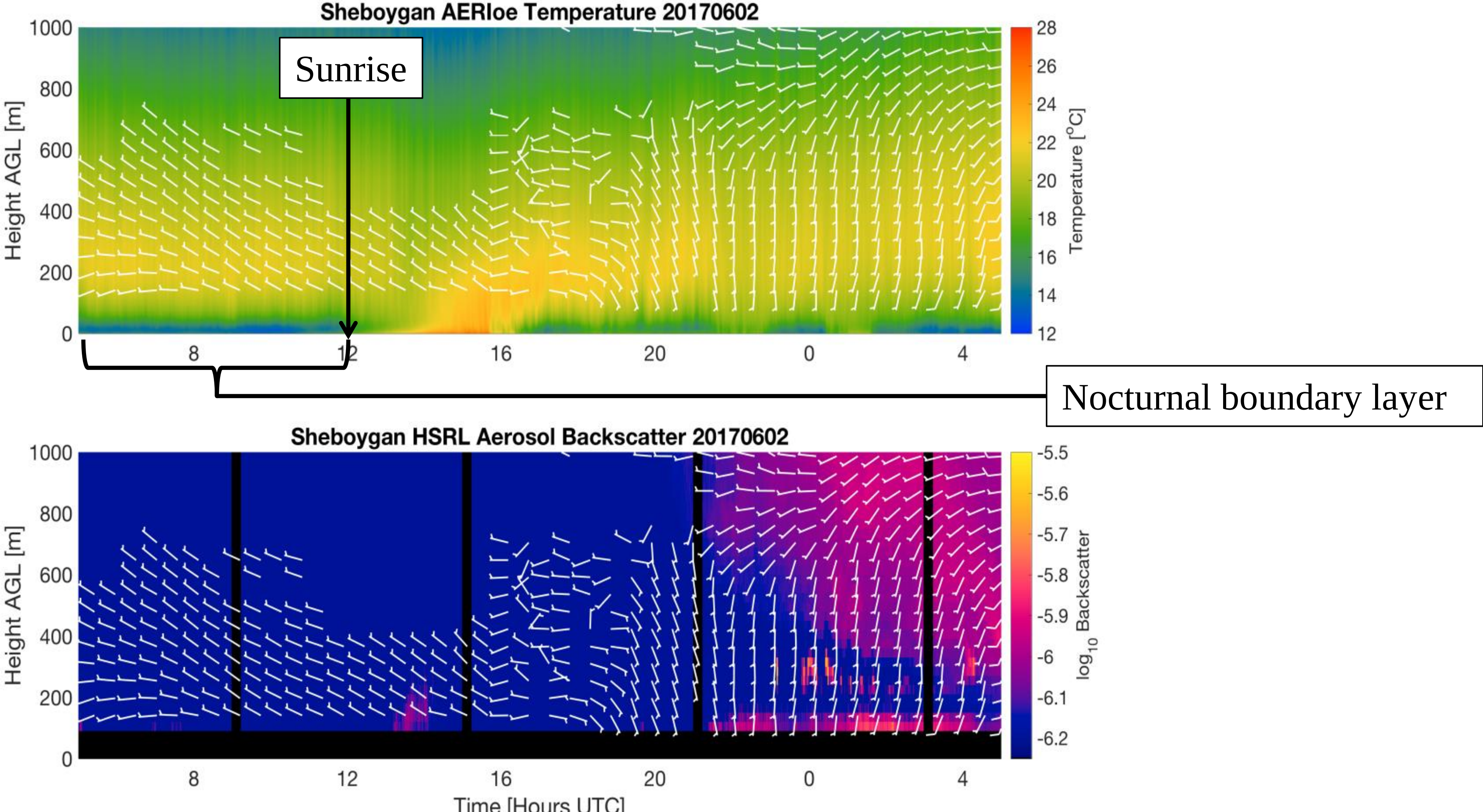

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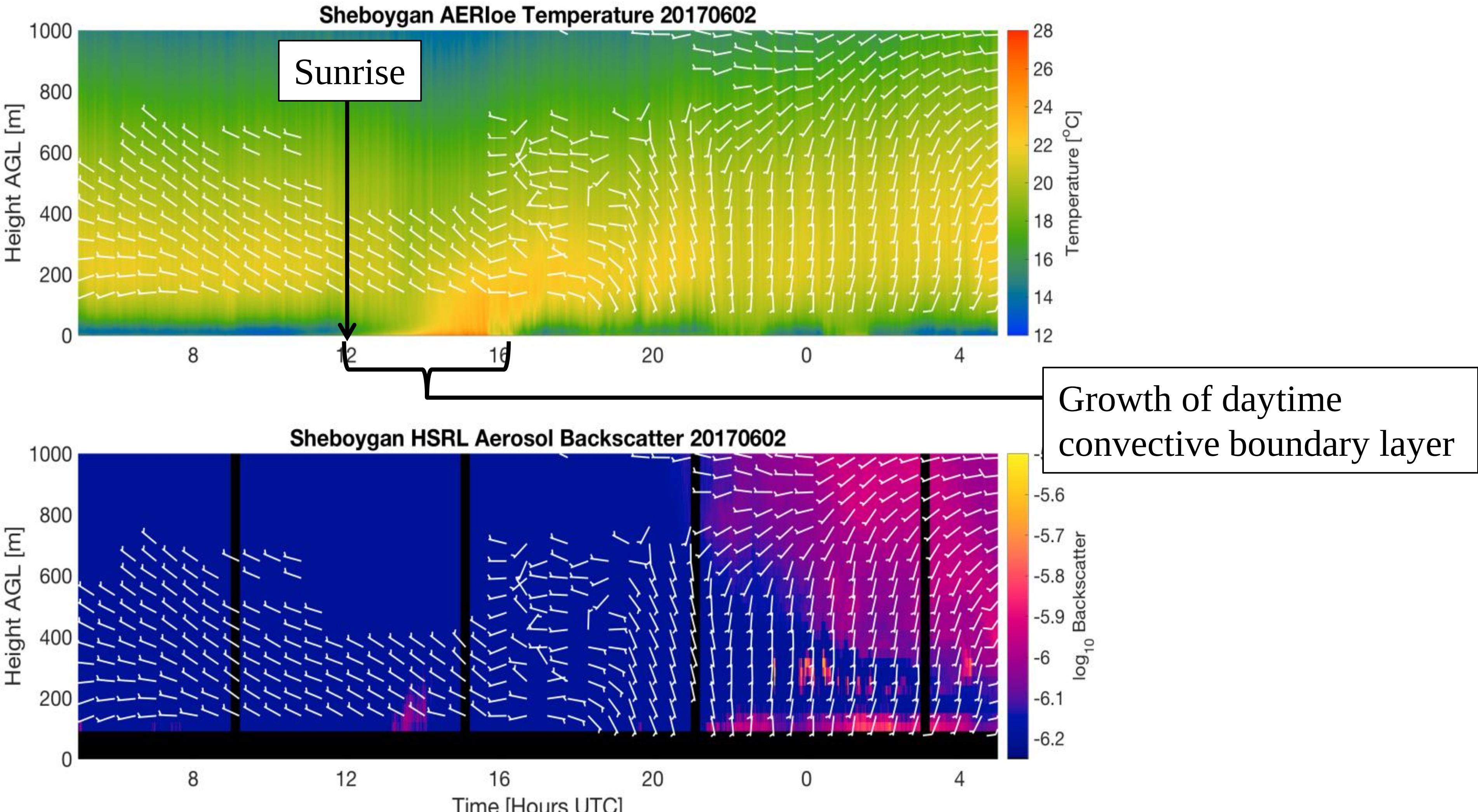

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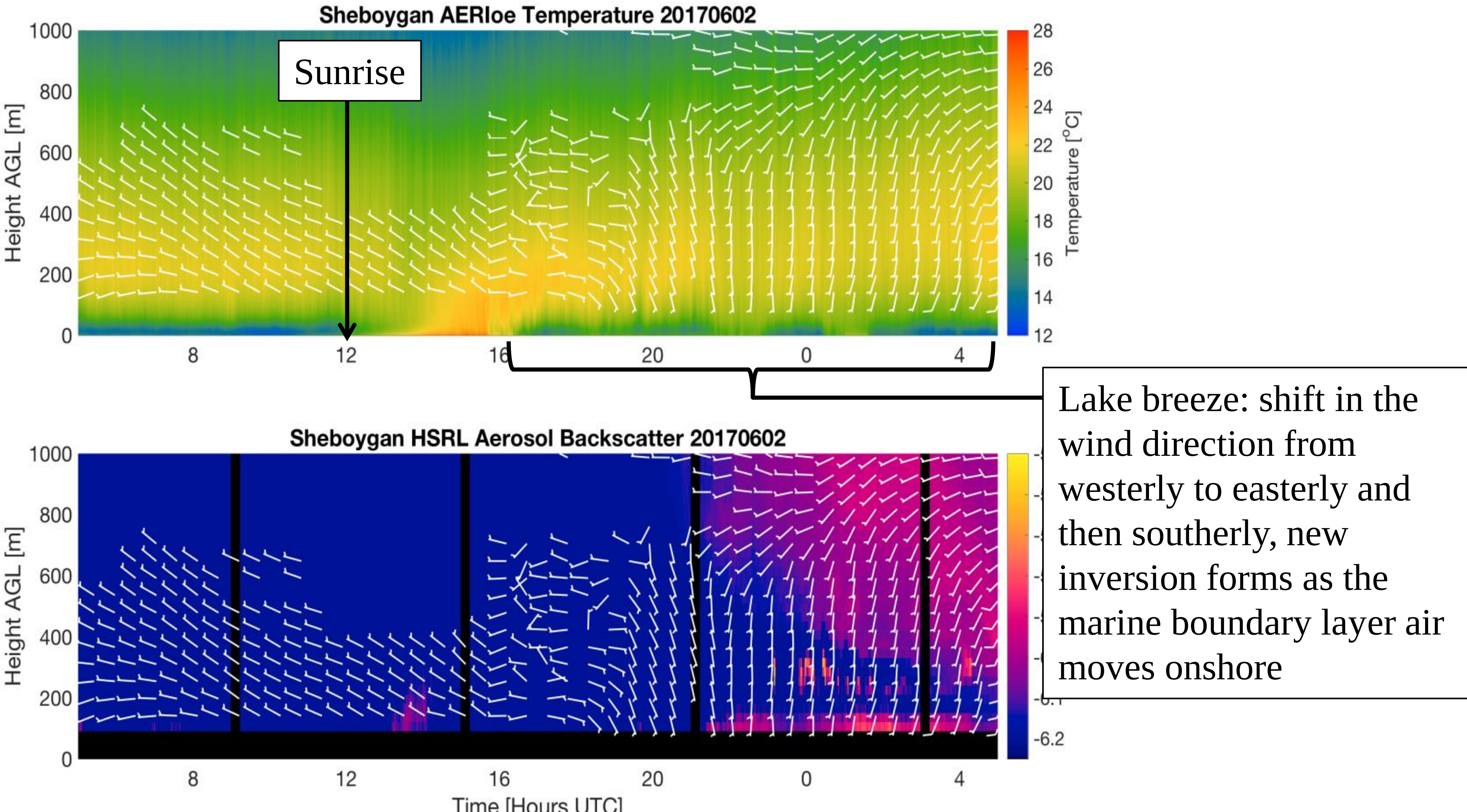

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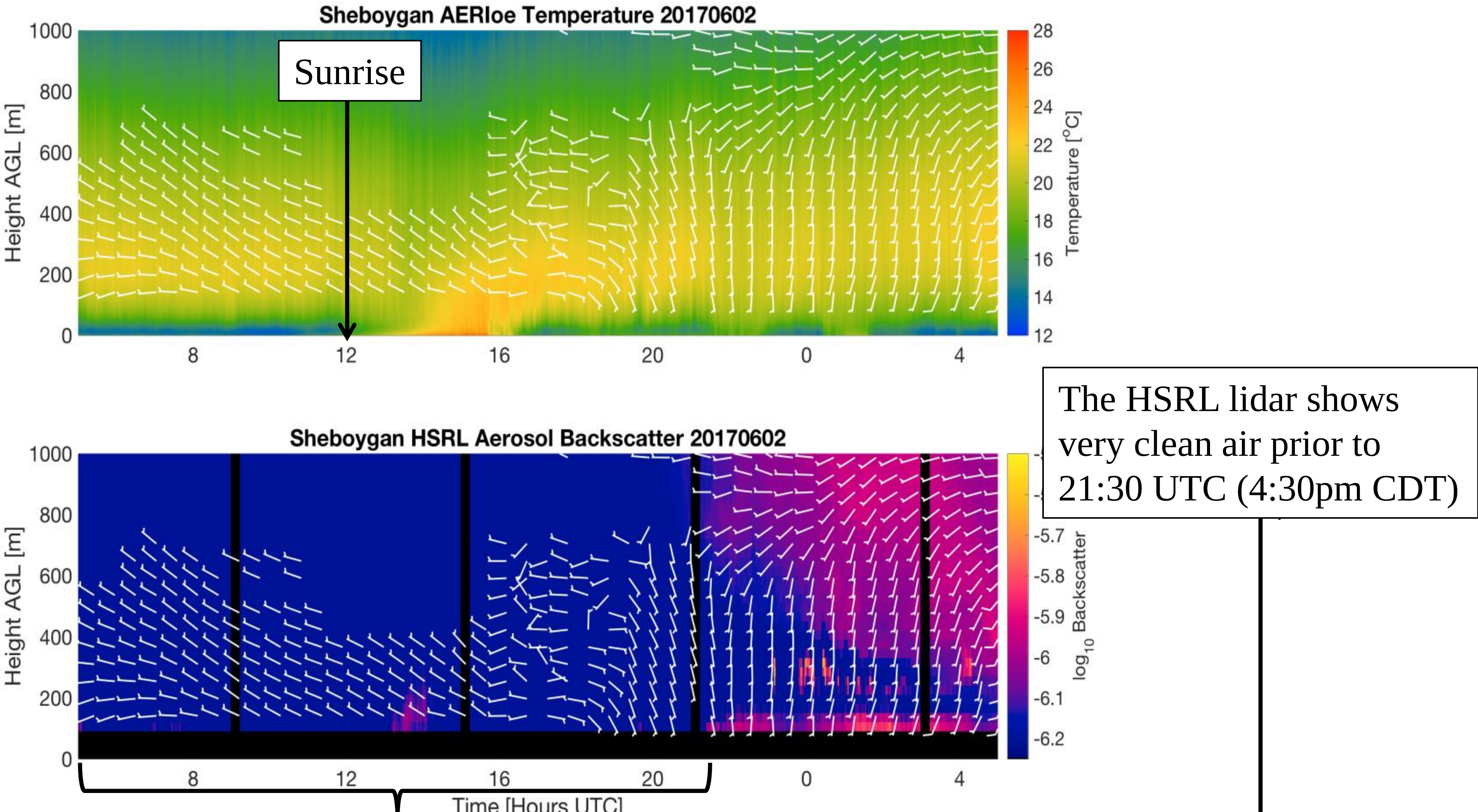

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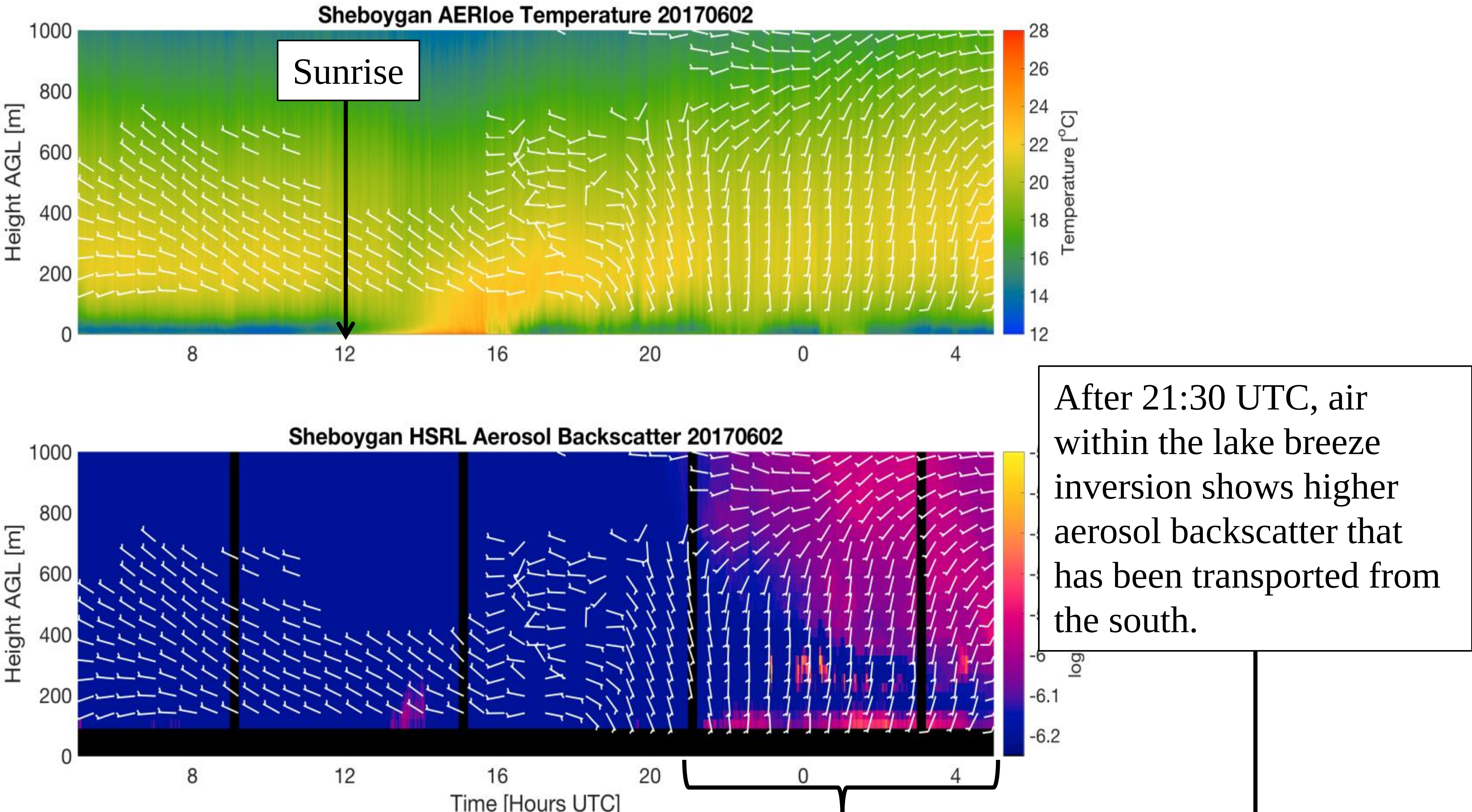

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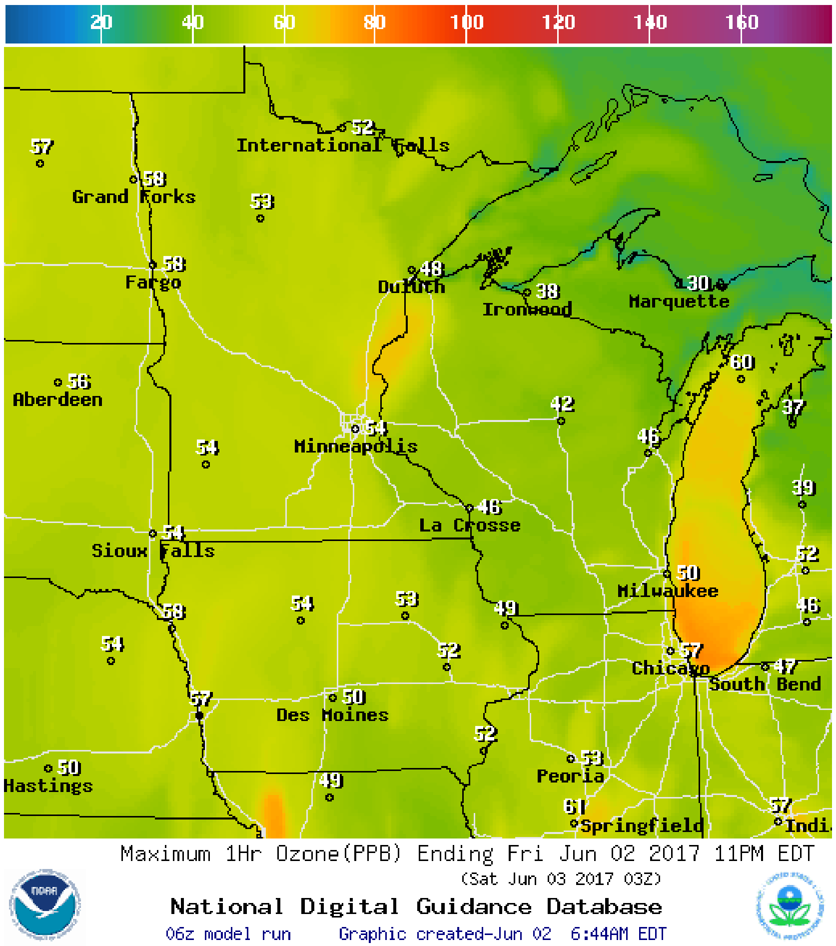
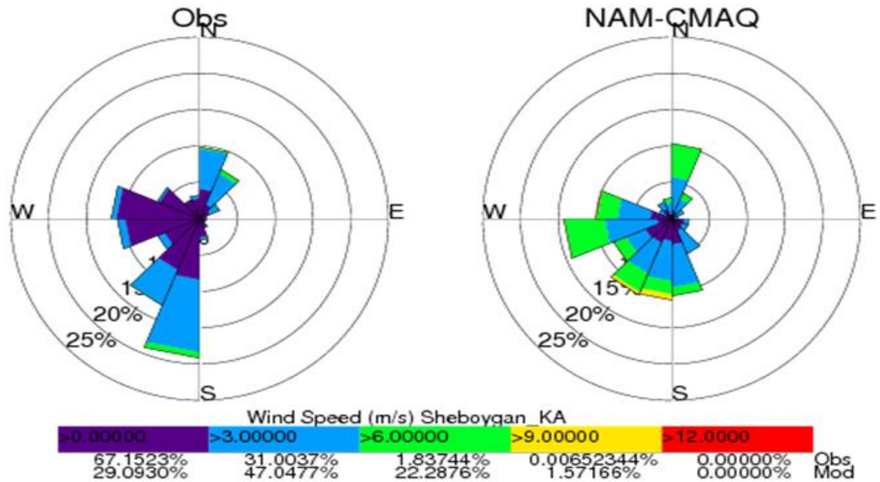
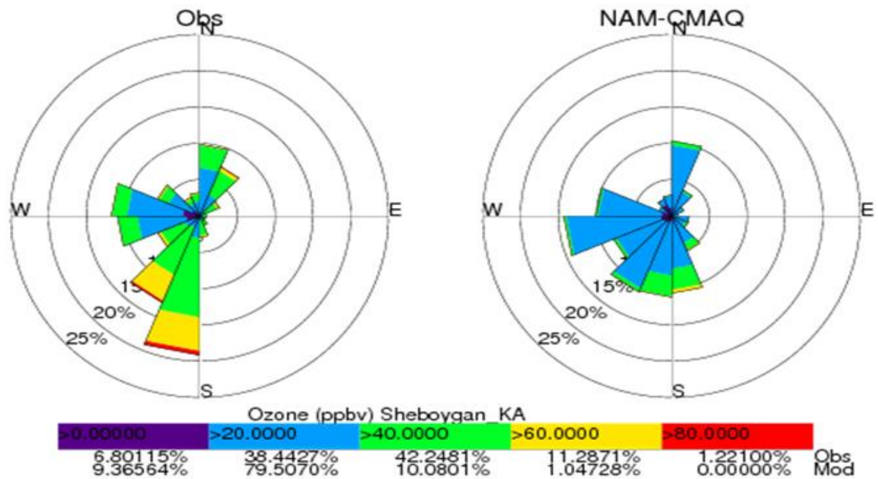
National Weather Service NAM-CMAQ ozone forecasts during LMOS 2017 (http://airquality.weather.gov/)





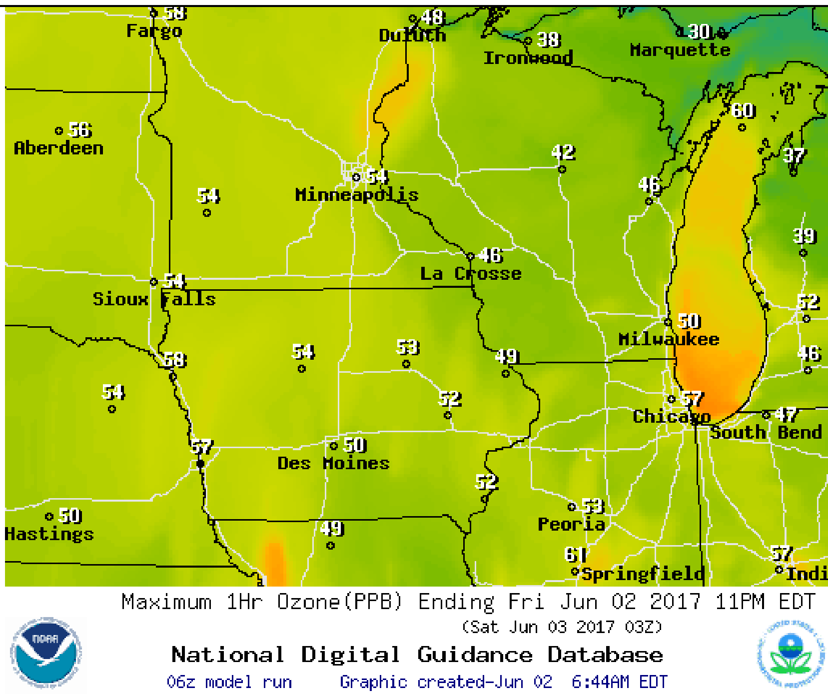
May 22 through June 22, 2017

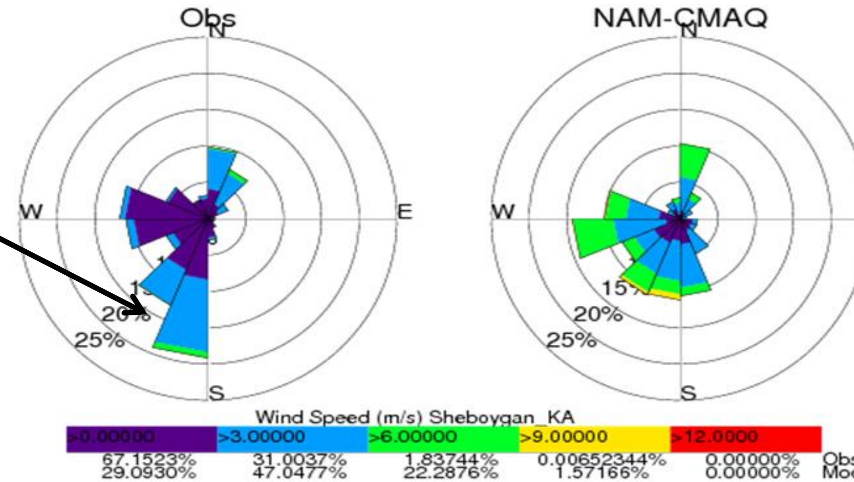


The North American Model (NAM) meteorology drives the Environmental Protection Agency's (EPA) Community Multiscale Air Quality Model (CMAQ)

National Weather Service NAM-CMAQ ozone forecasts during LMOS 2017 (http://airquality.weather.gov/)

NAM-CMAQ underestimates the frequency of the prevailing southerly winds and overestimates the frequency of westerly winds and wind speeds at Sheboygan, KA.





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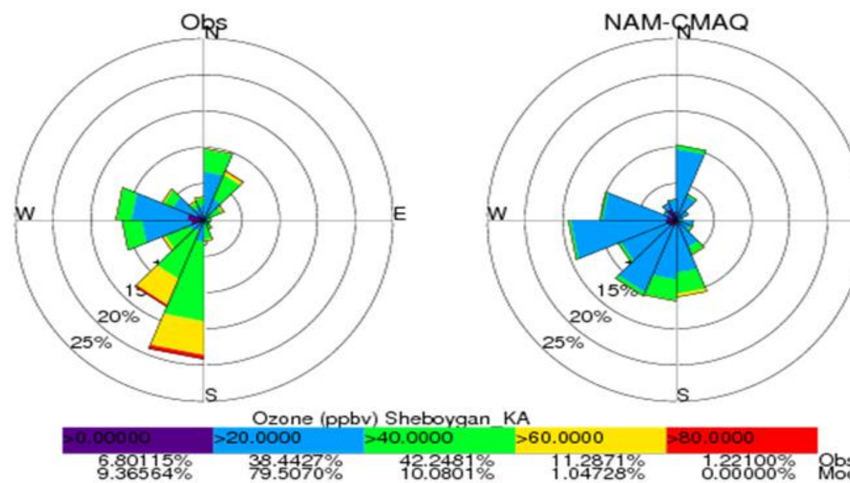

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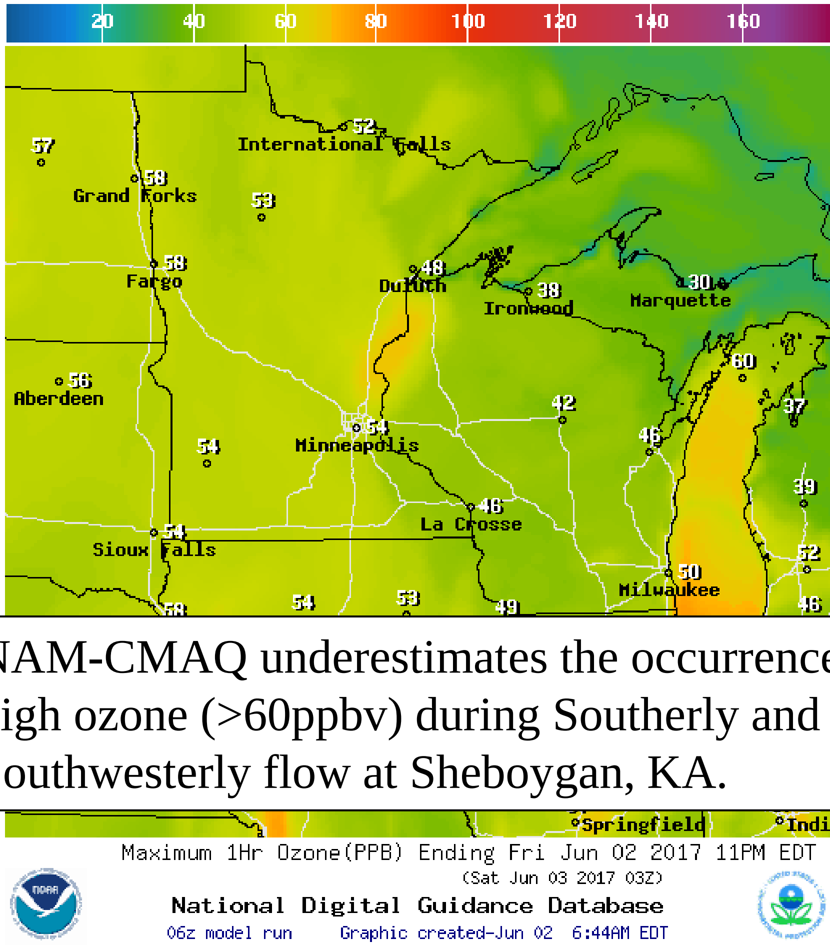

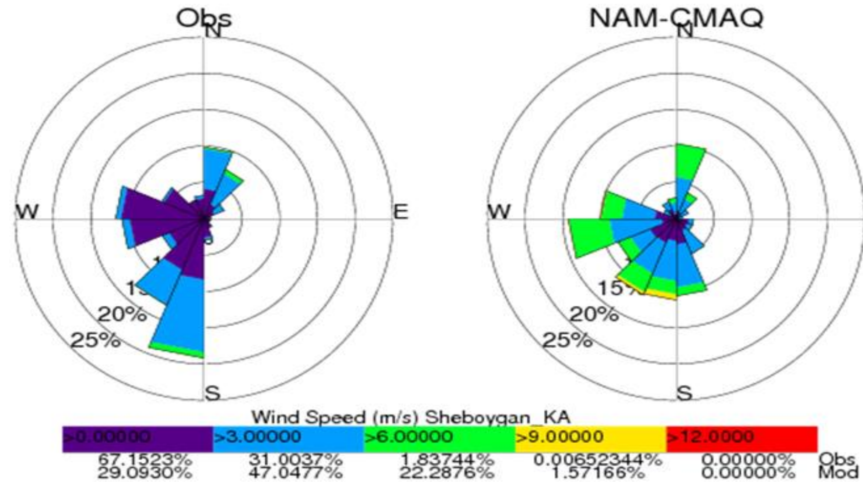

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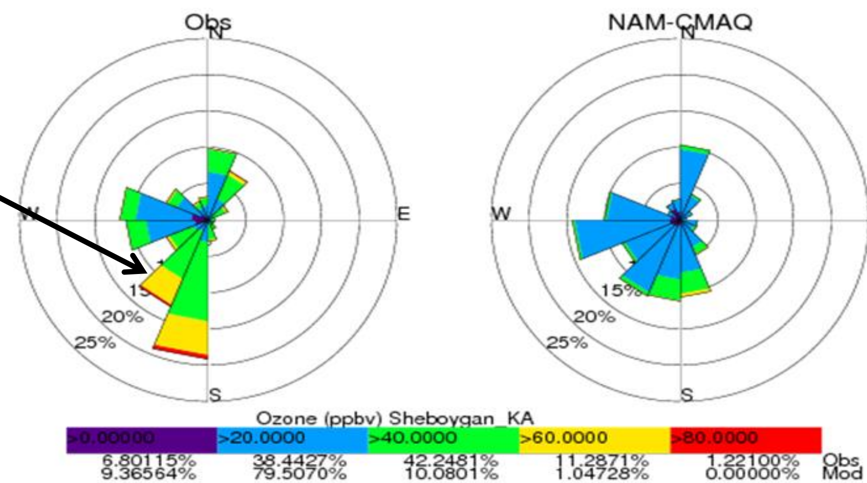
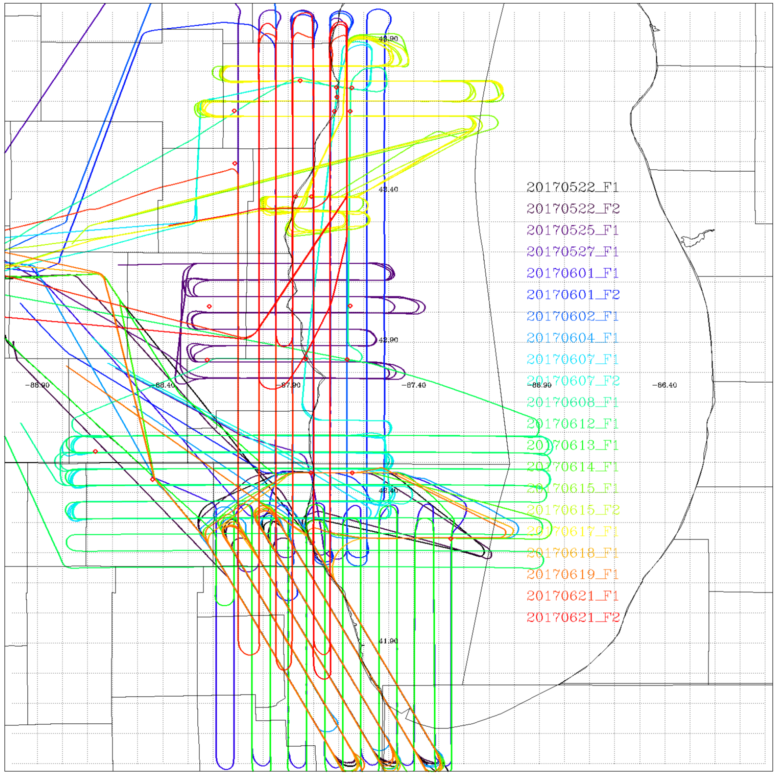


NAM-CMAQ underestimates the occurrence of high ozone (>60ppbv) during Southerly and Southwesterly flow at Sheboygan, KA.

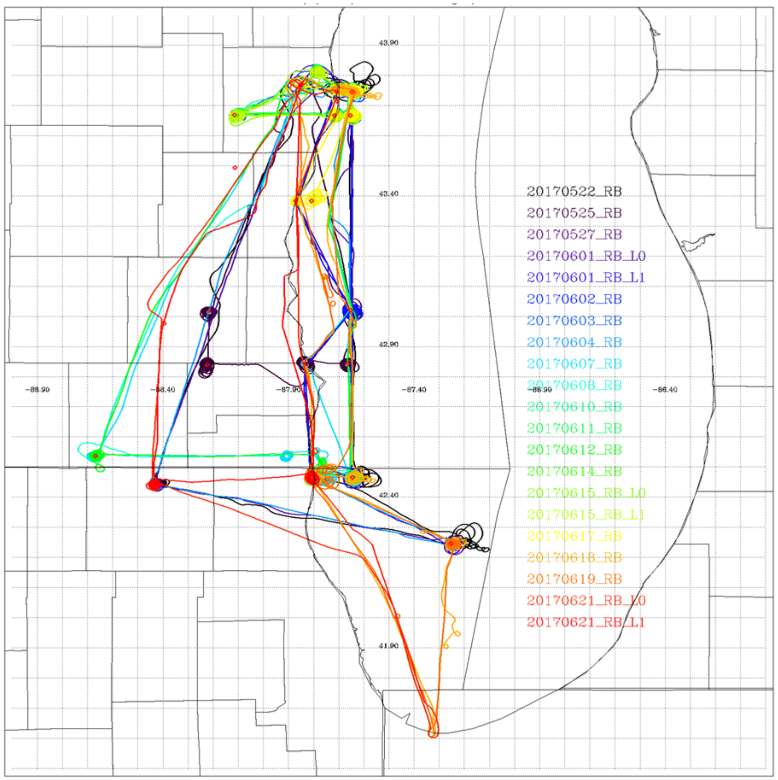
The North American Model (NAM) meteorology drives the Environmental Protection Agency's (EPA) Community Multiscale Air Quality Model (CMAQ)

LMOS 2017 Aircraft Measurements

NASA GeoTASO remote sensing Flights



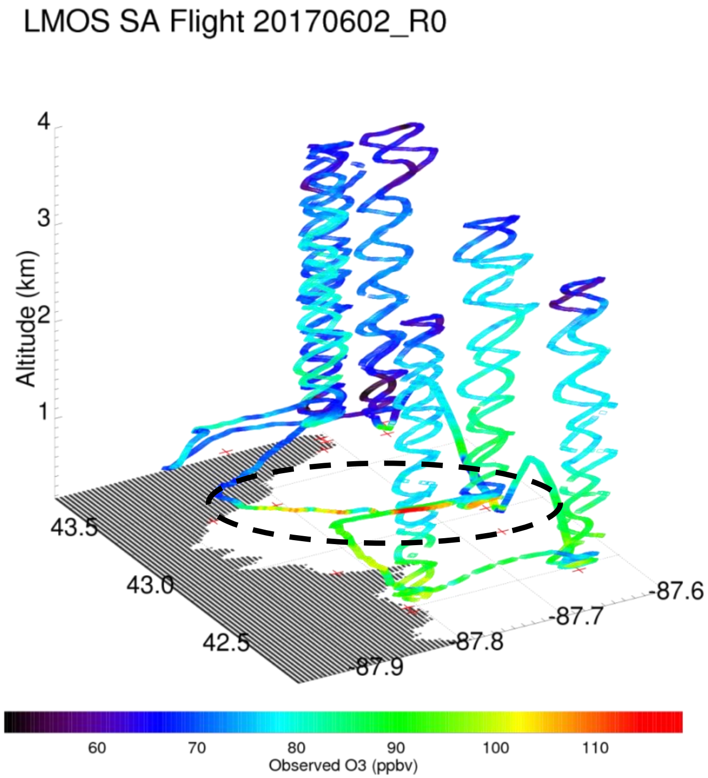
Scientific Aviation insitu sampling Flights

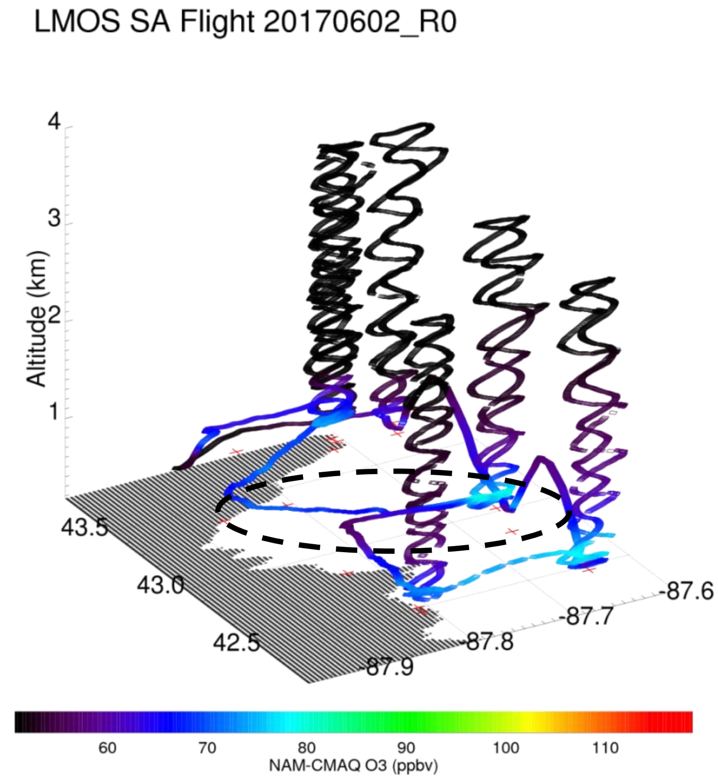


GeoTASO (Geostationary Trace gas and Aerosol Sensor Optimization) is an airborne hyperspectral mapping instrument that is being used as an airborne testbed for future high-resolution trace-gas observations from geostationary sensors such as TEMPO

The Electric Power Research Institute (EPRI) provided funding for Scientific Aviation Flights during LMOS

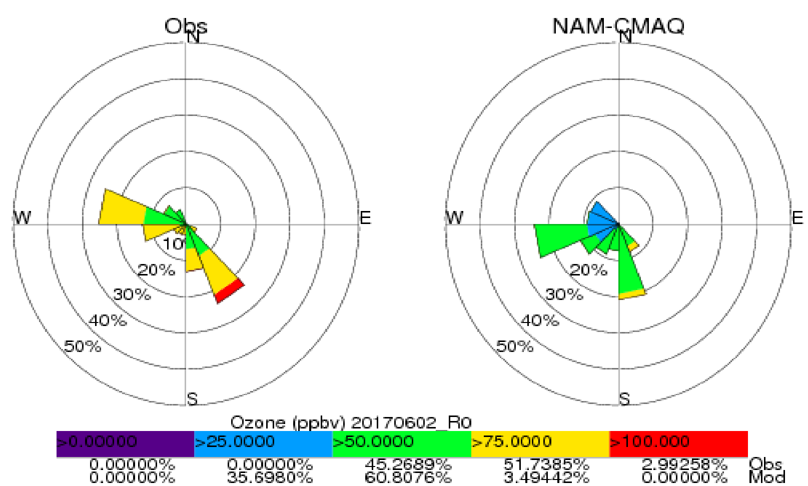
Coastal Ozone Exceedance Day





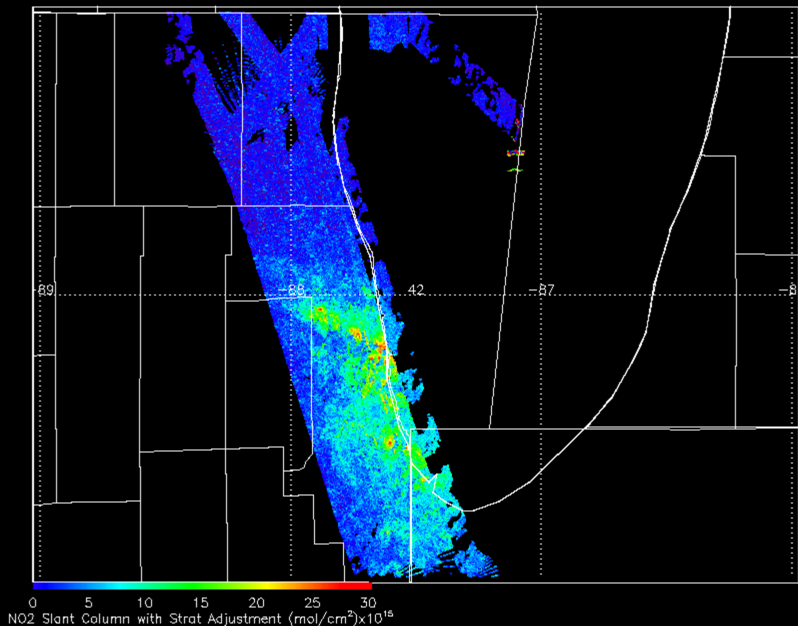
Max Observed O3 > 110ppbv

Max NAM-CMAQ O3 < 80ppbv

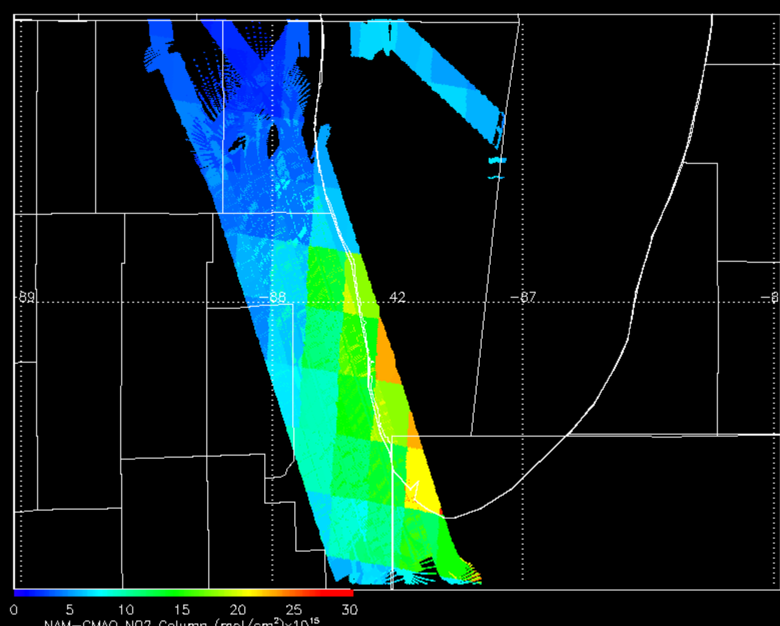


LMOS Chicago Emissions Mapping (weekday morning rush hour)

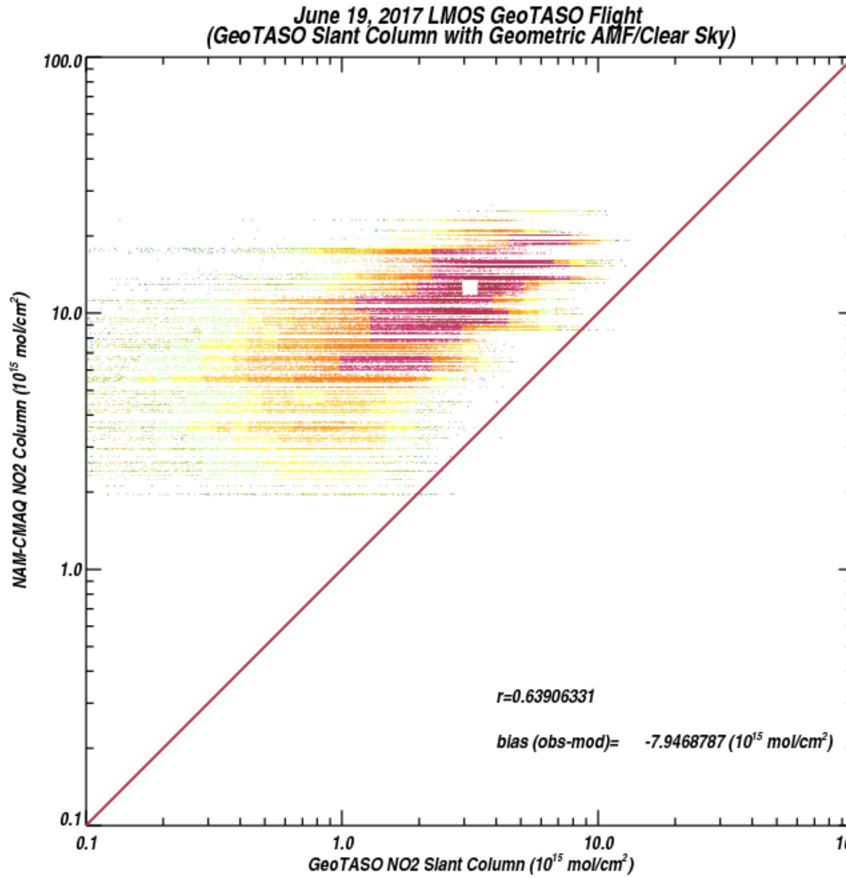
GeoTASO NO2 Slant Column June 19, 2017



NAM-CMAQ NO2 Column June 19, 2017



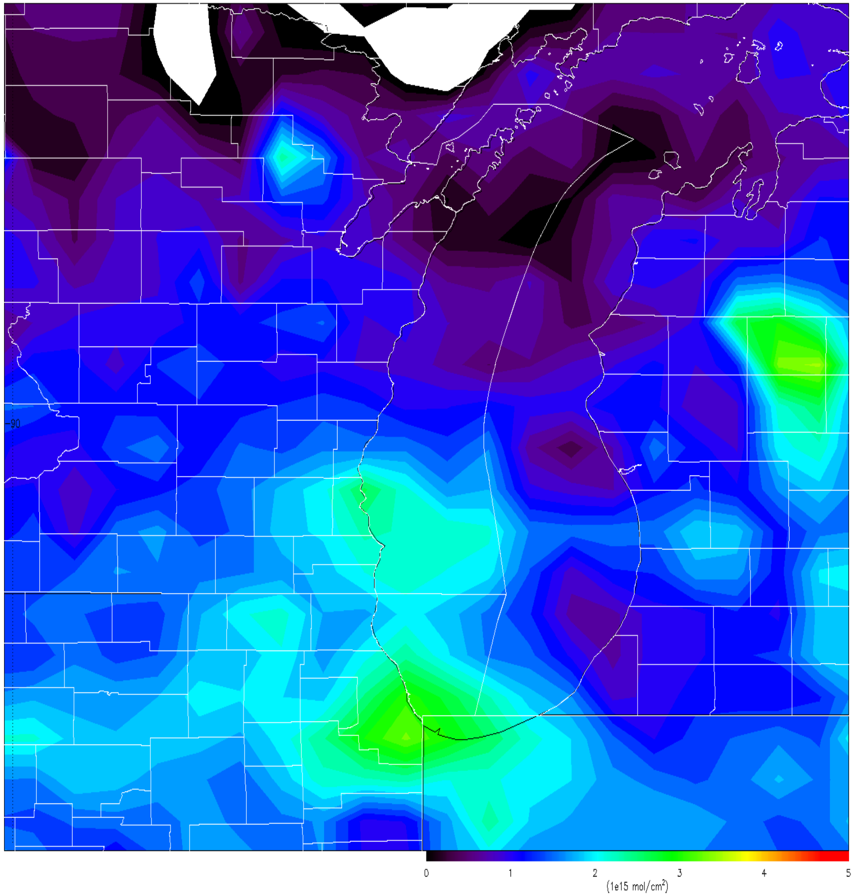
NAM-CMAQ significantly overestimates observed NO2 column



Aura Ozone Monitoring Instrument (OMI) Tropospheric NO2 column Data Assimilation

With Monica Harkey (UW-Madison SAGE), Allen Lenzen (UW-Madison SSEC)

OMI Tropospheric NO2 column during LMOS 2017



$$\frac{\Delta E}{E} = \beta \times \frac{\Delta \Omega}{\Omega}.$$

NOx emissions adjustments (ΔE) are constrained using OMI tropospheric NO2 column analysis increments (ΔΩ)

β accounts for the sensitivity of the NO2 column to changes in NOx emissions following Lamsal et al 2011.

Lamsal, L. N., et al. (2011), Application of satellite observations for timely updates to global anthropogenic NOx emission inventories, Geophys. Res. Lett., 38, L05810, doi:10.1029/2010GL046476.

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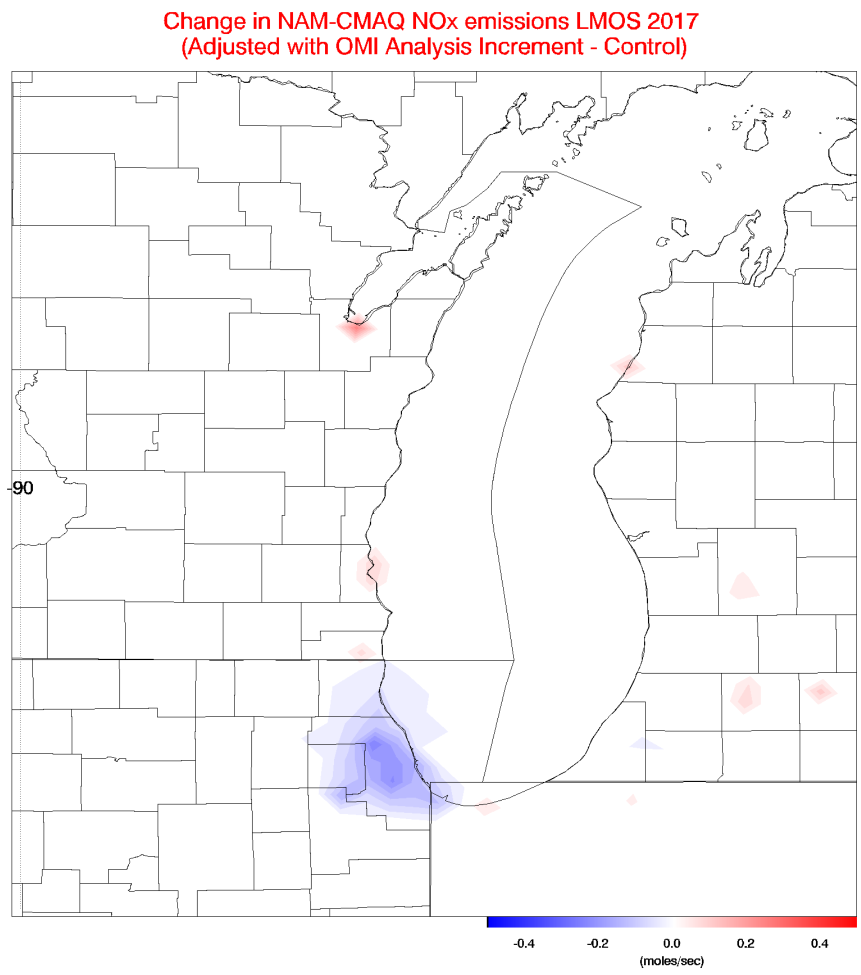
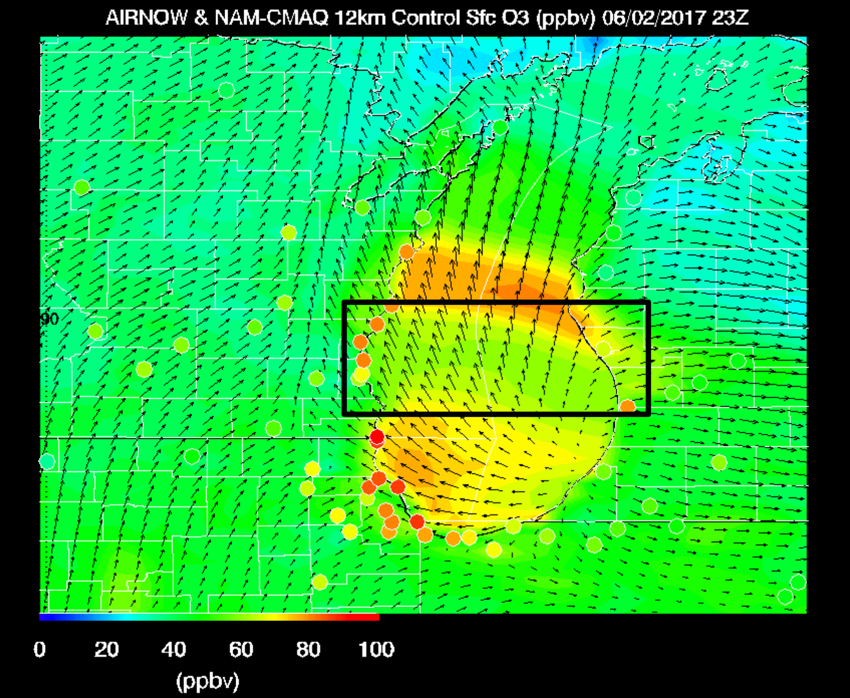
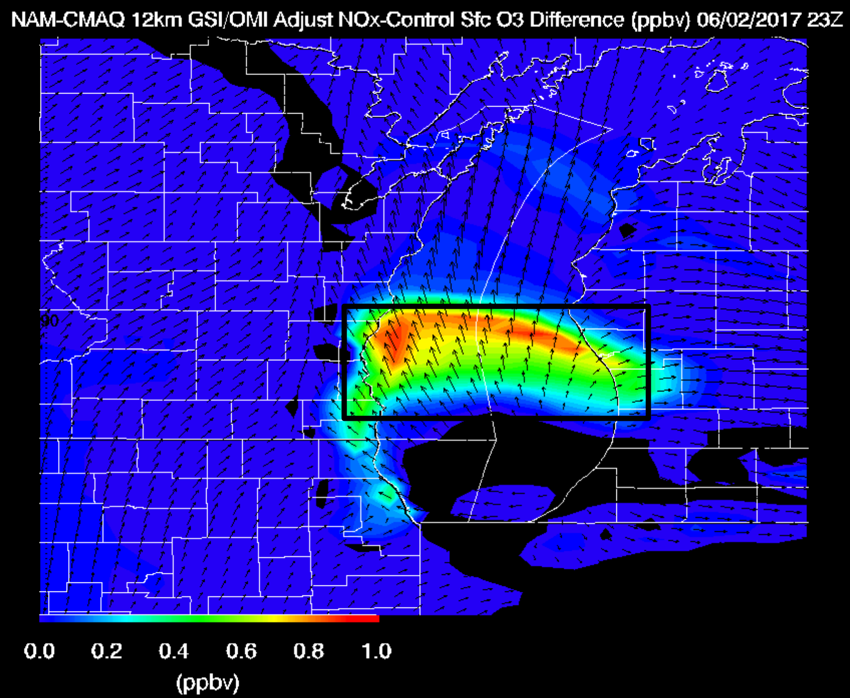


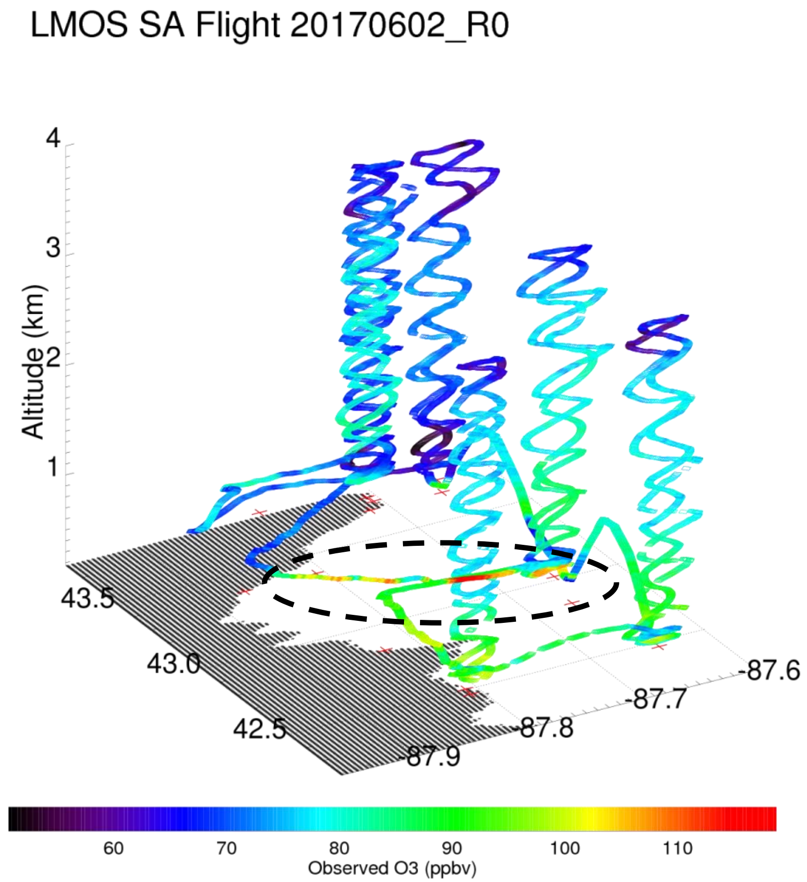
$$\frac{\Delta E}{E} = \beta \times \frac{\Delta \Omega}{\Omega}.$$

Assimilation of OMI NO2 results in small (~4%) reductions in NOx emissions over Chicago

Lamsal, L. N., et al. (2011), Application of satellite observations for timely updates to global anthropogenic NOx emission inventories, Geophys. Res. Lett., 38, L05810, doi:10.1029/2010GL046476.



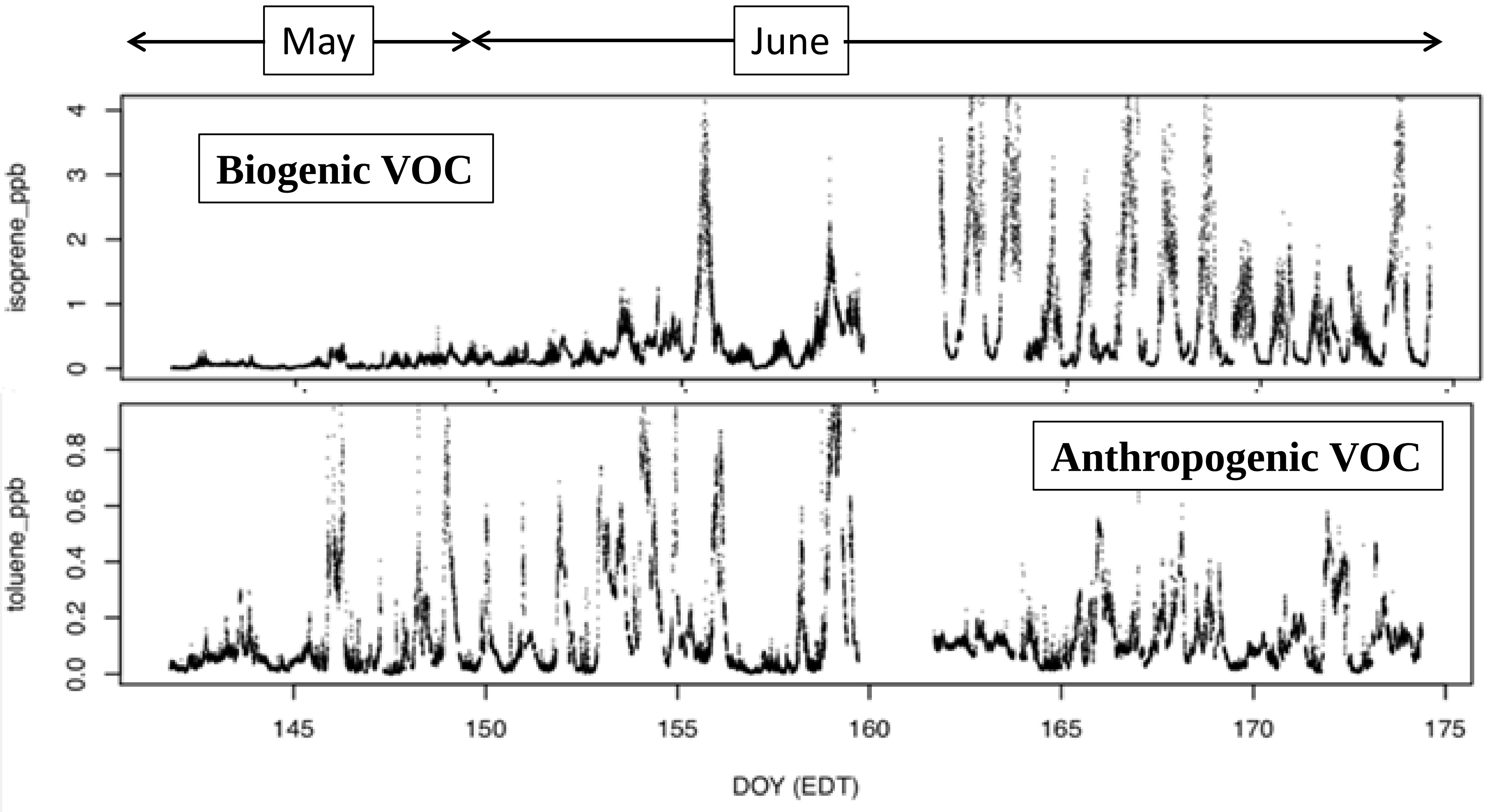




Max Observed O3 > 110ppbv

Reductions in NOx emissions on high ozone day leads to slight (~1ppbv) increases in surface ozone

In-situ measurements of volatile organic compounds at Zion by high-resolution proton-transfer time-of-flight mass spectrometry



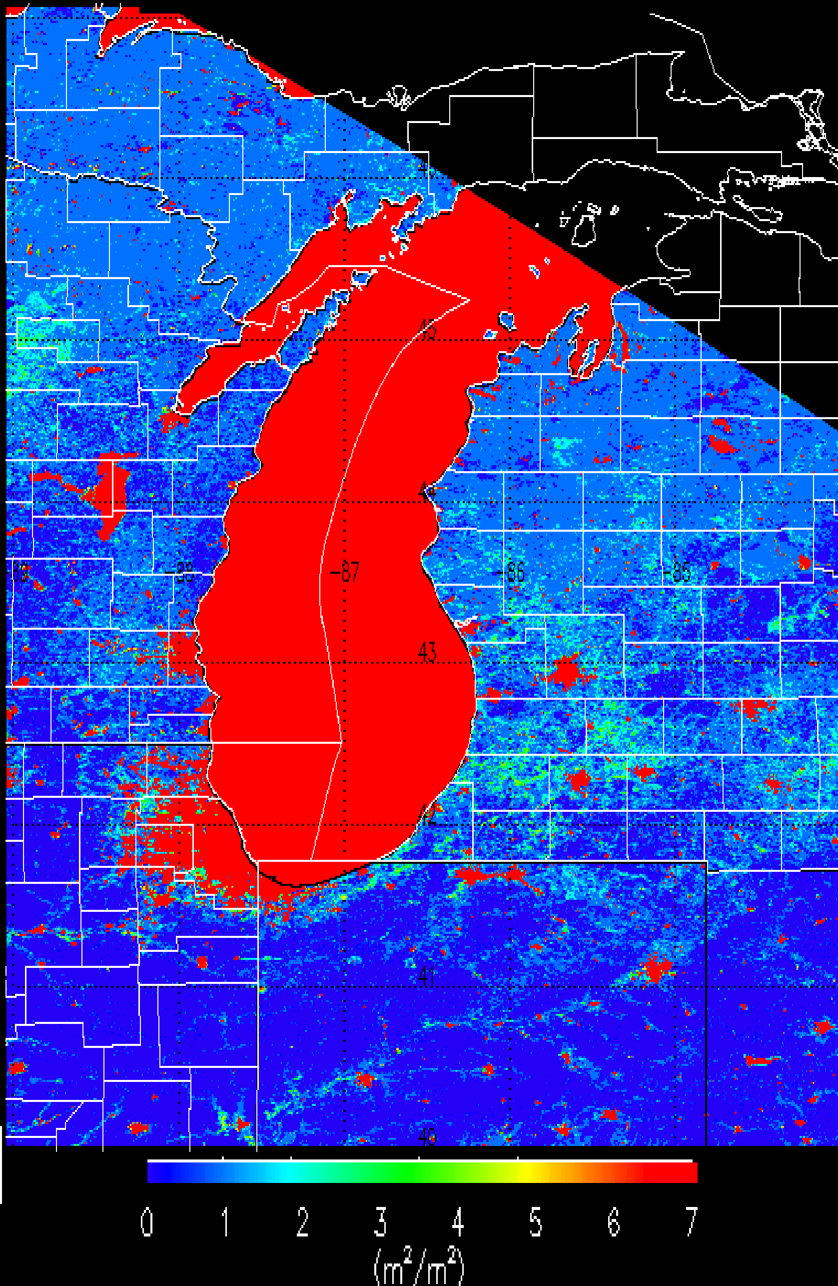
Zion VOC measurements show significantly higher biogenic contributions during the second half of LMOS 2017 – spring leaf out has a strong influence on biogenic VOC emissions

Provided by Dylan Millet (University of Minnesota)

Satellite True Color Image
VIIRS May 07, 2017

Low Leaf Area Index (LAI) prior to leaf out

Satellite Land Surface Retrieval
MODIS 8-day average LAI



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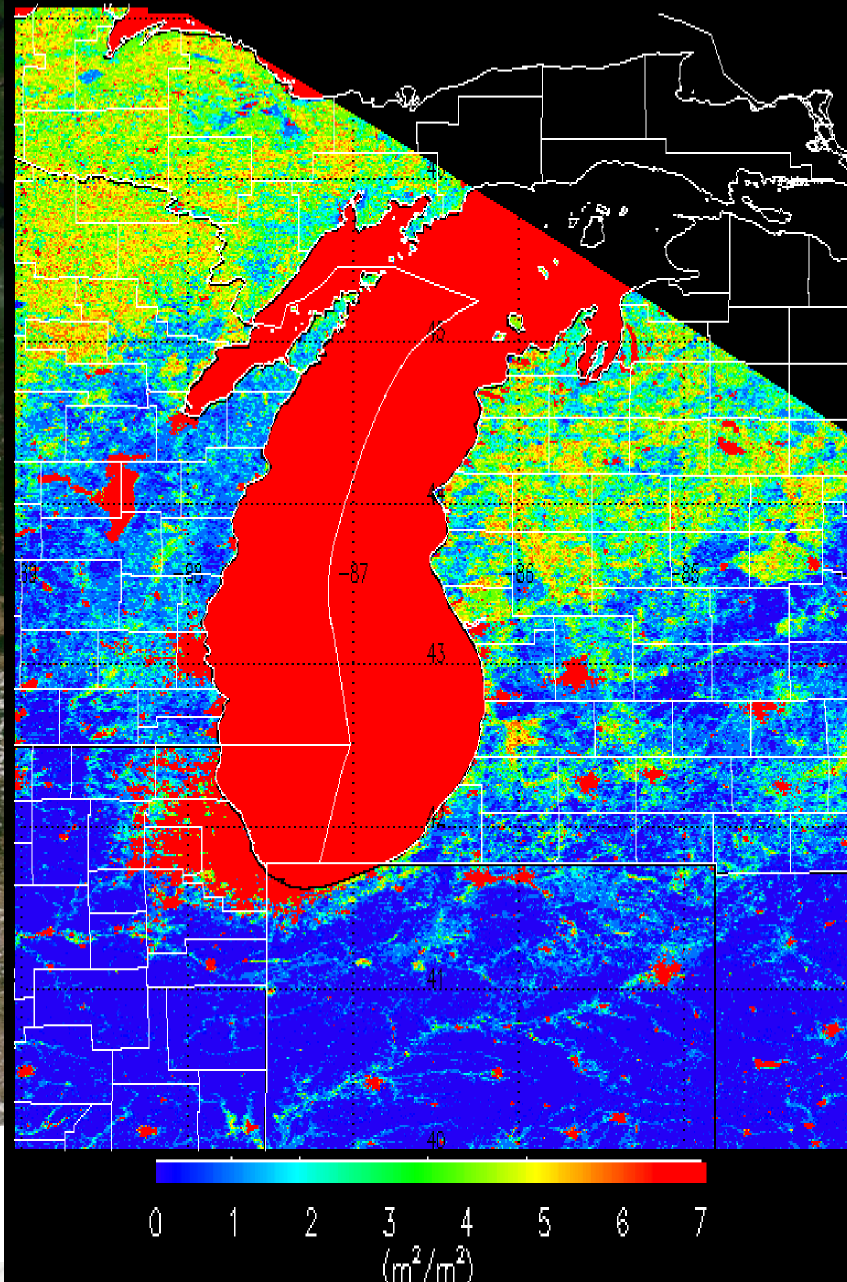
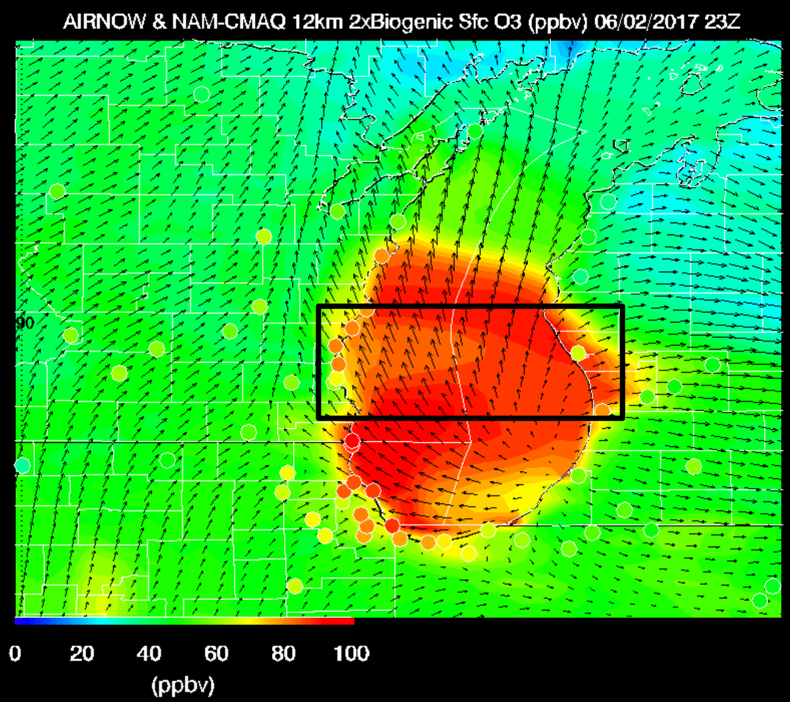
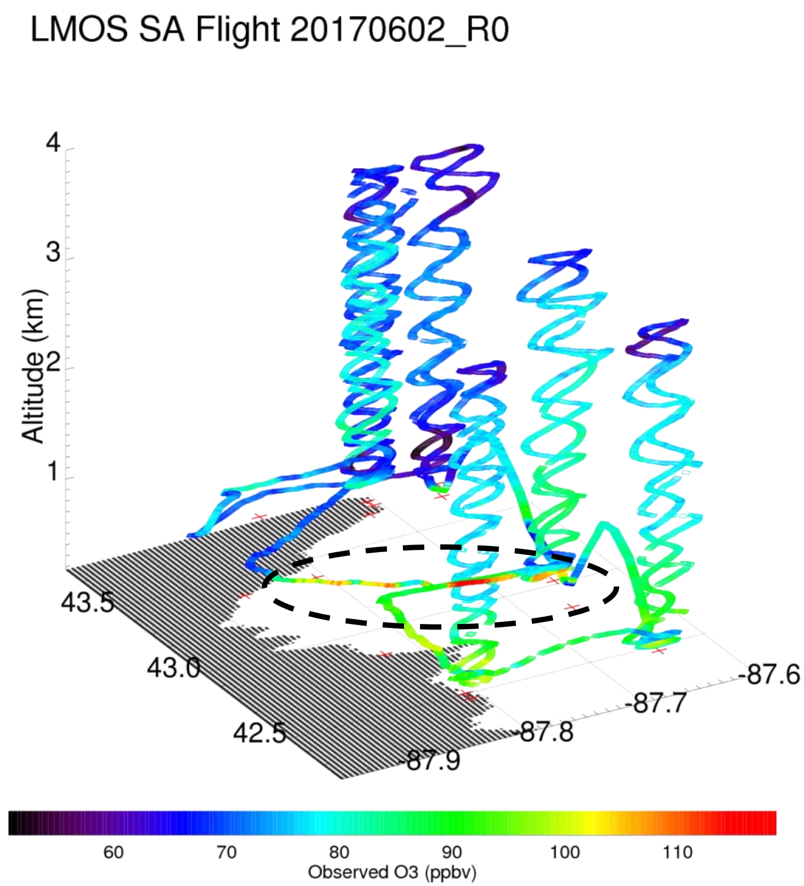
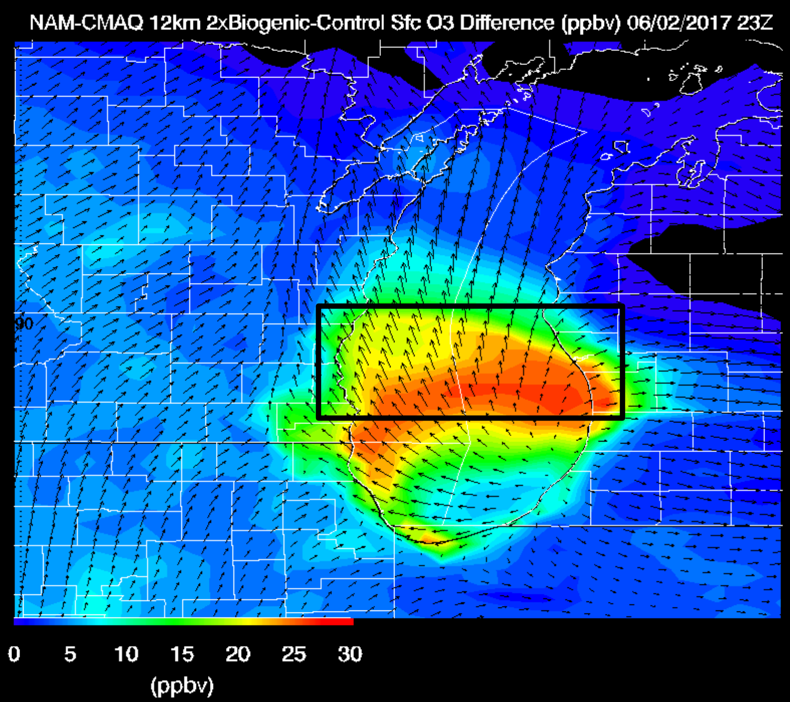


Increased Leaf Area Index (LAI) during leaf out





Max Observed O3 > 110ppbv



Doubling Biogenic VOC emissions within NAM-CMAQ leads to large (25-30 ppbv) increases in surface ozone

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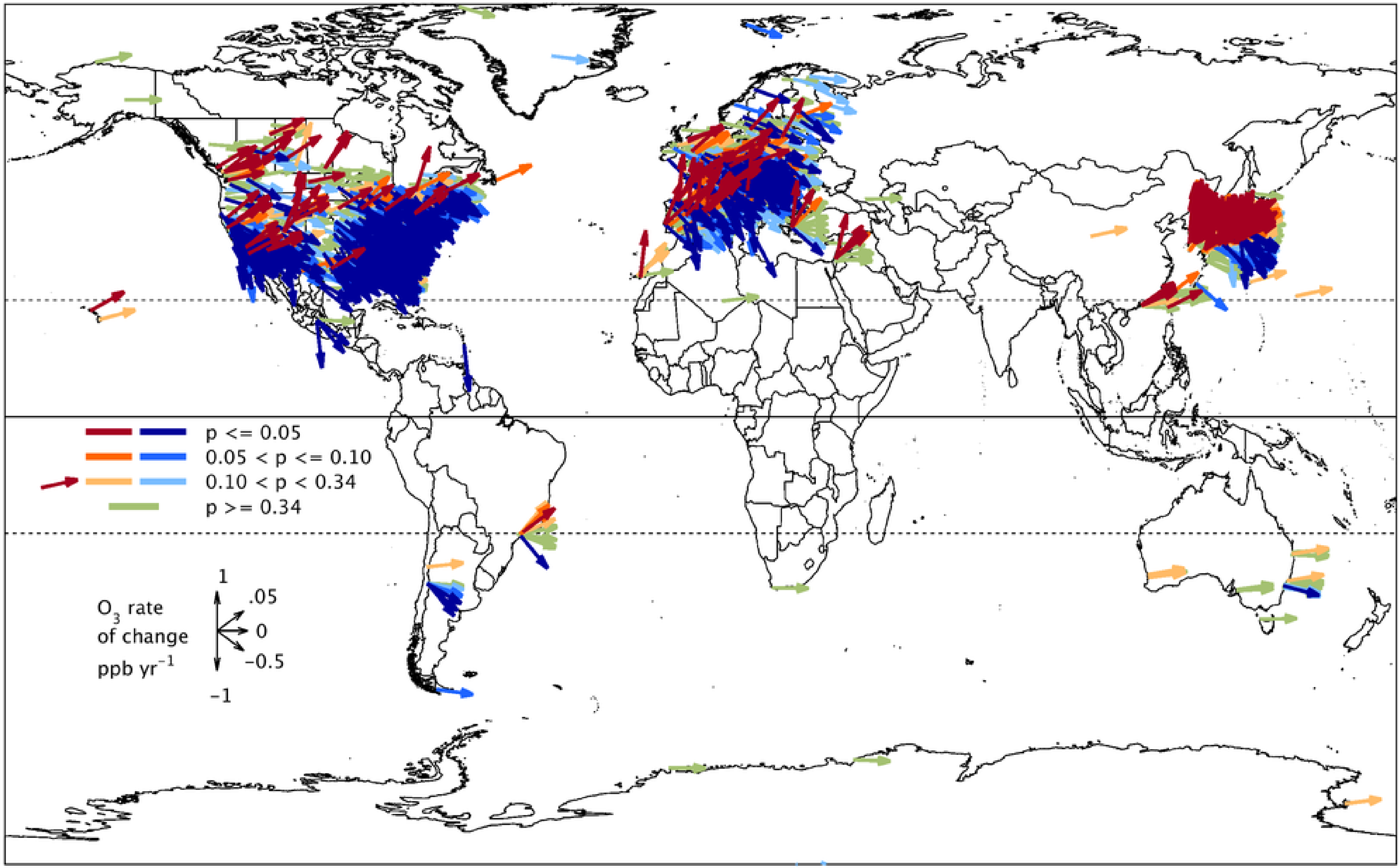
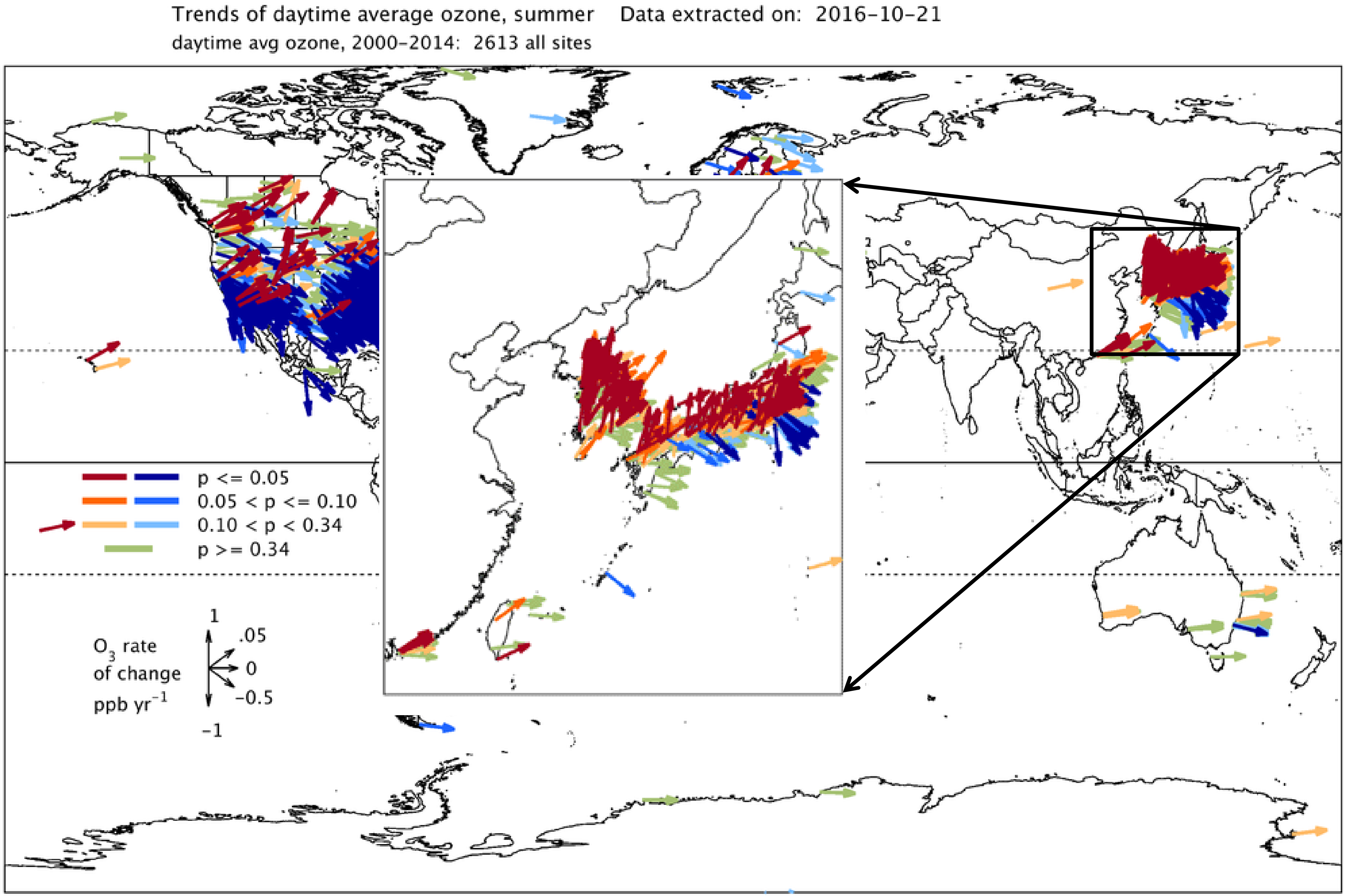
4) **Vision:** SSEC – Opportunities and Challenges

Trends of daytime average ozone, summer   Data extracted on: 2016-10-21
daytime avg ozone, 2000-2014: 2613 all sites

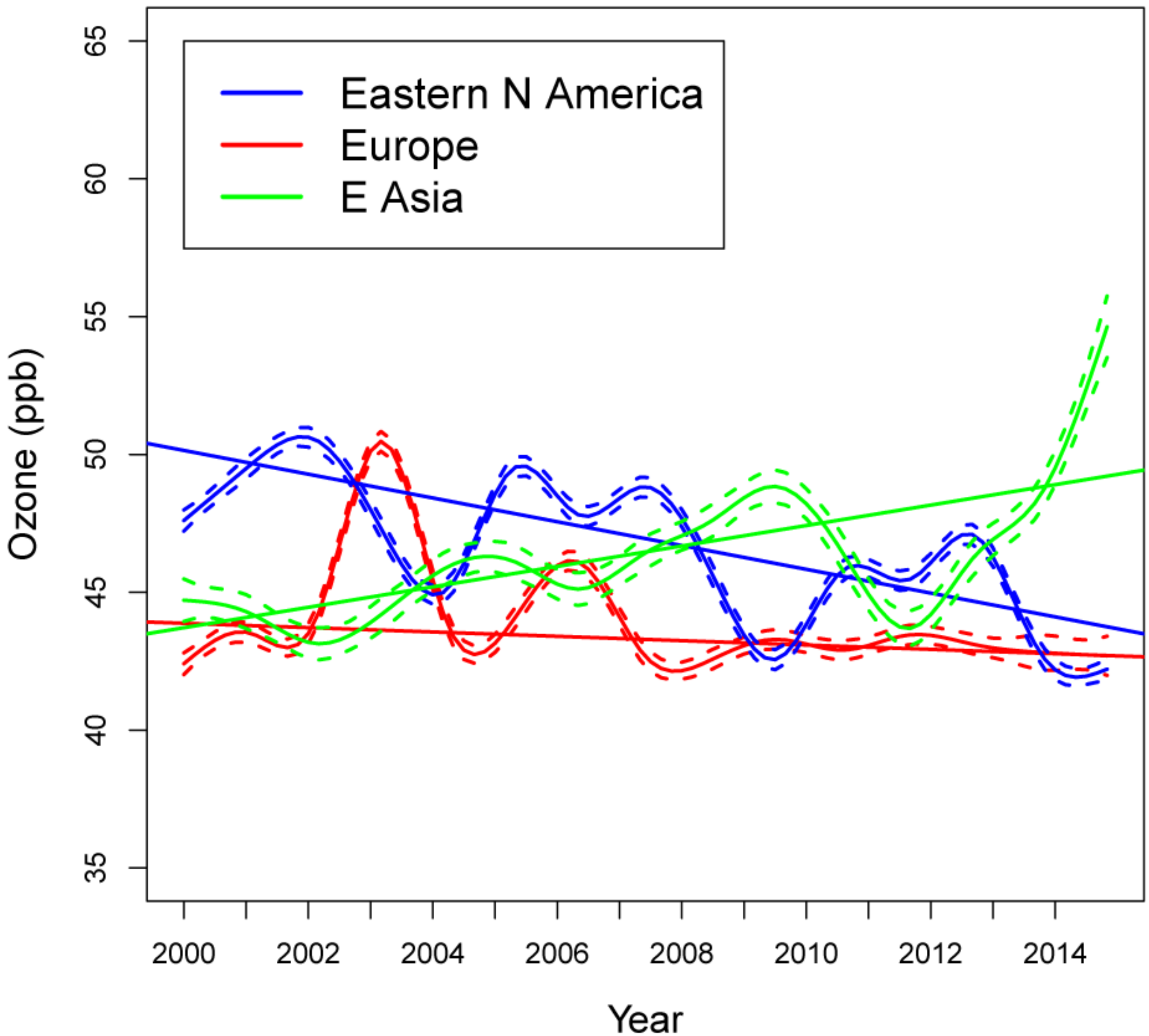


Chang, K-L, et al 2017 Regional trend analysis of surface ozone observations from monitoring networks in eastern North America, Europe and East Asia. Elem Sci Anth, 5: 50,https://doi.org/10.1525/elementa.243



Chang, K-L, et al 2017 Regional trend analysis of surface ozone observations from monitoring networks in eastern North America, Europe and East Asia. Elem Sci Anth, 5: 50,https://doi.org/10.1525/elementa.243

Maximum Daily 8 hour Average (MDA8) Ozone Trends



Chang, K-L, et al 2017 Regional trend analysis of surface ozone observations from monitoring networks in eastern North America, Europe and East Asia. Elem Sci Anth, 5: 50,https://doi.org/10.1525/elementa.243

RAQMS Aura Chemical Reanalysis

Project Summary

- **Utilize the Real-time Air Quality Modeling System (RAQMS) to conduct a multi-year global chemical and aerosol reanalysis using NASA Aura and A-Train measurements.**

- **Follows the path lead by the European Center for Medium Range Weather Forecasting (ECMWF) for development of operational air quality forecasting.**

- **Provides a comprehensive chemical and aerosol analyses for assessing global air quality and for providing lateral boundary conditions for regional air quality management activities.**

Assimilated Satellite Data

- **Terra/Aqua MODIS Aerosol Optical Depth and Fire Detection**
- **Aqua AIRS Carbon Monoxide Retrieval**
- **Aura MLS and OMI ozone Retrievals**
- **Aura OMI Tropospheric NO2 Retrievals**

Funded by the NASA Health and Air Quality Applications Program

RAQMS Description

1. **Online global chemical and aerosol assimilation/ forecasting system**

2. **UW-Madison hybrid $\theta-\eta$ coordinate model (UW-Hybrid) dynamical core**

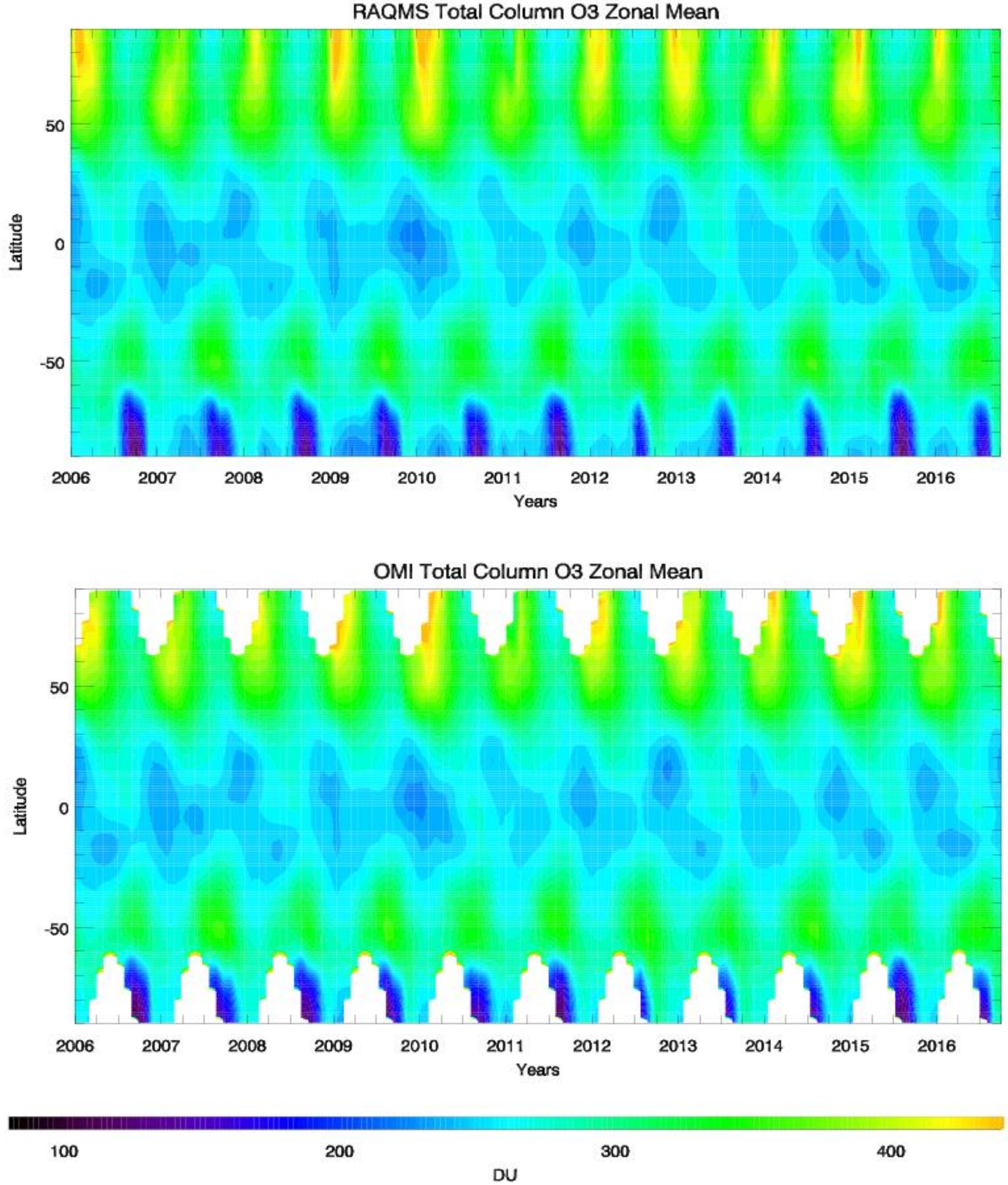
3. **Unified stratosphere/troposphere chemical prediction scheme (LaRC-Combo) developed at NASA LaRC**

4. **Aerosol prediction scheme (GOCART) developed by Mian Chin (NASA GSFC).**

http://raqms-ops.ssec.wisc.edu/index.php

RAQMS was developed by NASA Langley Research Center and the UW- Madison SSEC and has provided real-time global air quality forecasts since January, 2010

Analyzed vs OMI Total Column O3



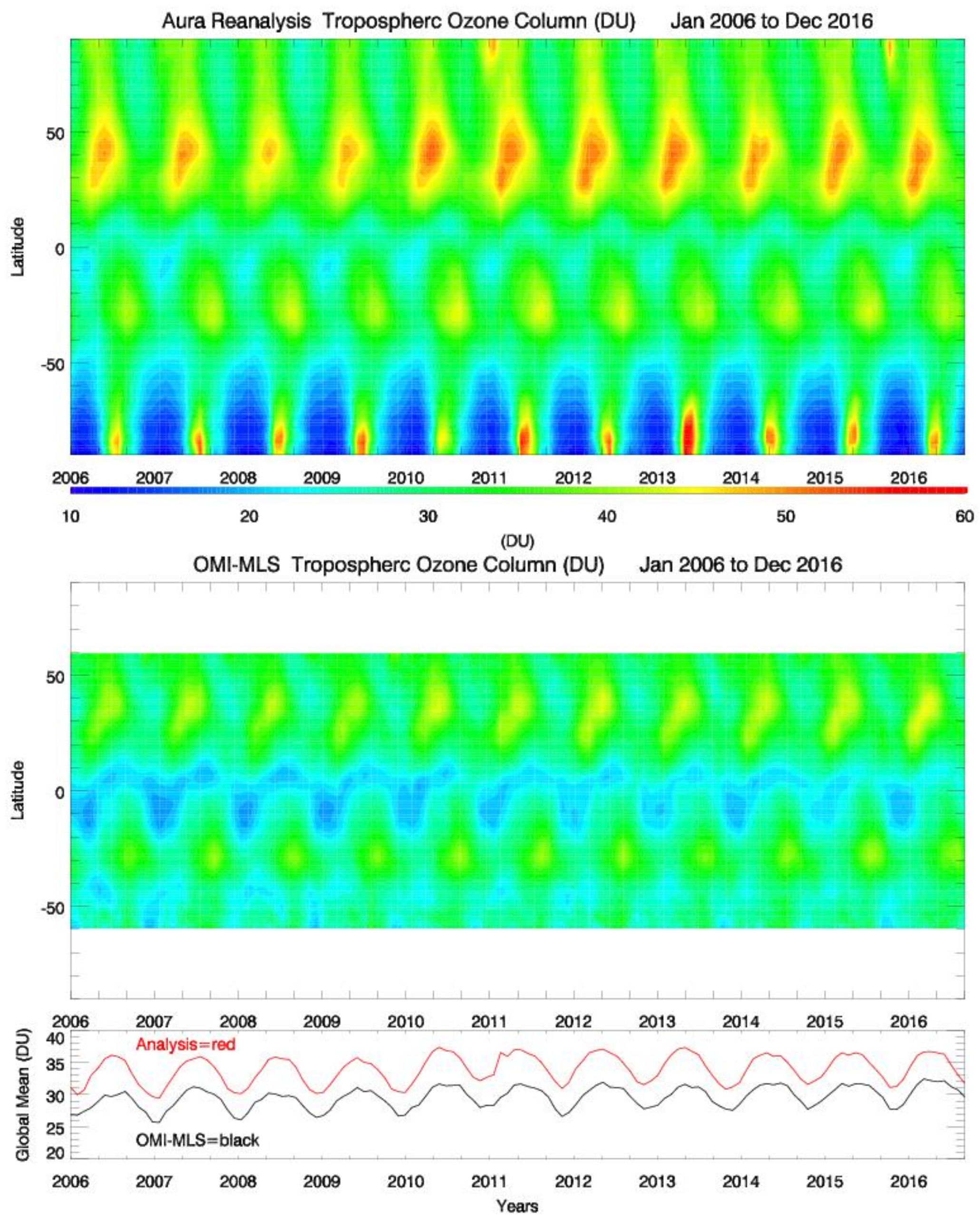
Aura Reanalysis captures inter-annual variability of Total Column O3 including: tropical quasi-biennial oscillation (QBO, Camp et al, 2003), Antarctic ozone hole, and unprecedented Arctic ozone loss in 2011 (Manney et al, 2011)

Provided by Margaret Bruckner (UW-Madison AOS)

Camp, C. D., M. S. Roulston, and Y. L. Yung, Temporal and spatial patterns of the interannual variability of total ozone in the tropics, J. Geophys. Res., 108(D20), 4643, doi:10.1029/2001JD001504, 2003.

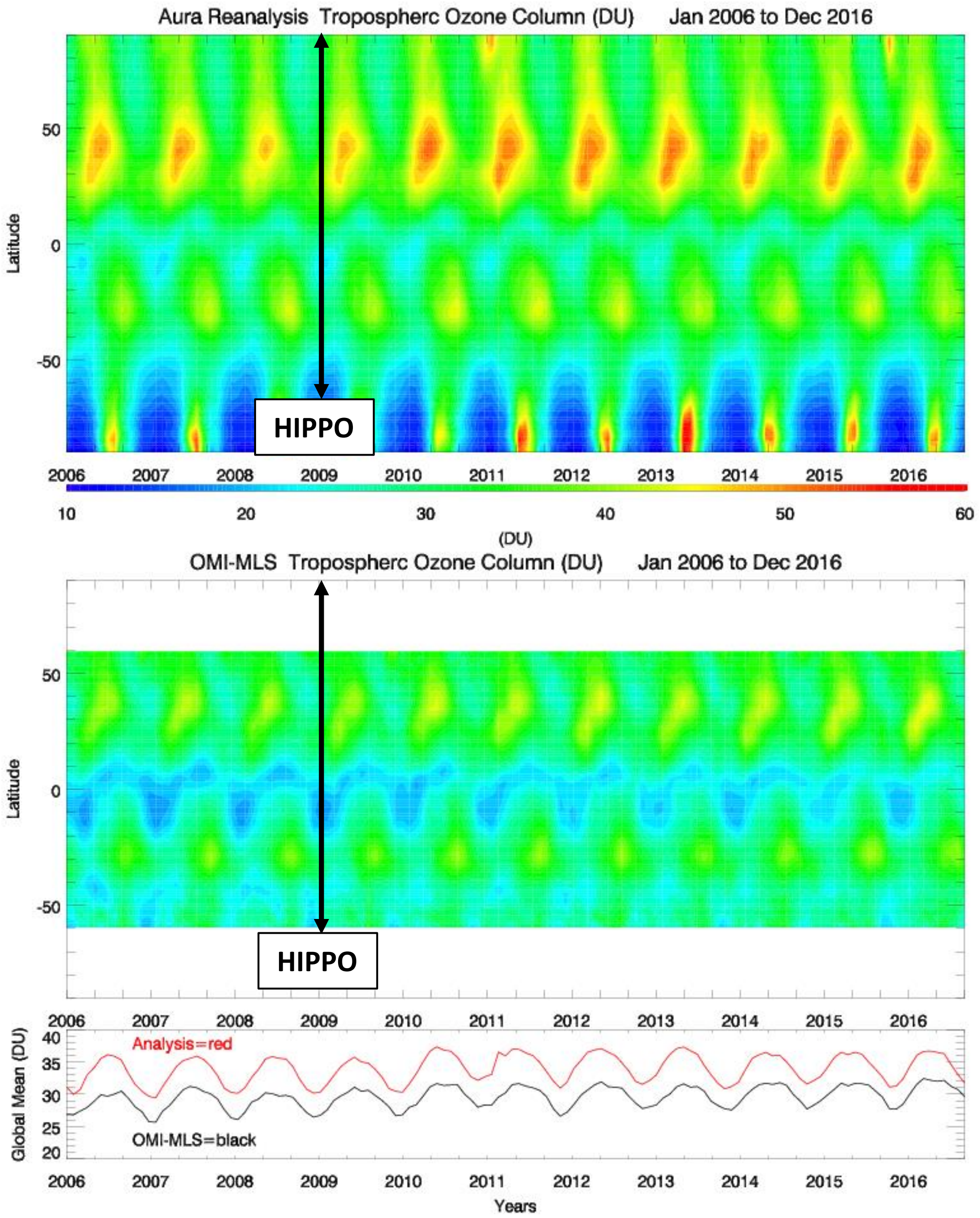
Manney, G. L., Santee, M. L., Rex, M., Livesey, N. J., Pitts, M. C., Veefkind, P., et al. (2011). Unprecedented Arctic ozone loss in. *Nature, 478*(7370), 469–475.

Analyzed Tropospheric Ozone Column (TOC) vs OMI-MLS Tropospheric Ozone Residuals (TOR)



Aura Reanalysis captures seasonal variation but shows a systematic high bias relative to the OMI-MLS TOR

Ziemke, et al. (2006), Tropospheric ozone determined from Aura OMI and MLS: Evaluation of measurements and comparison with the Global Modeling Initiative's Chemical Transport Model, J. Geophys. Res., 111, D19303, doi:10.1029/2006JD007089.

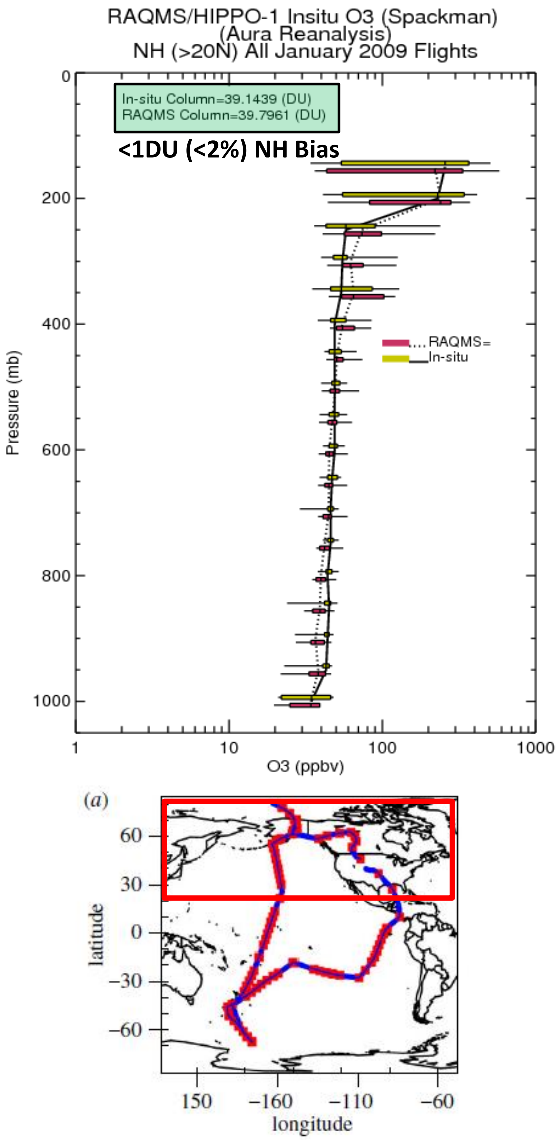


Airborne measurements from NSF HIPPO-I field campaign are used to verify Aura Reanalysis TOC over the Pacific Ocean during January 2009

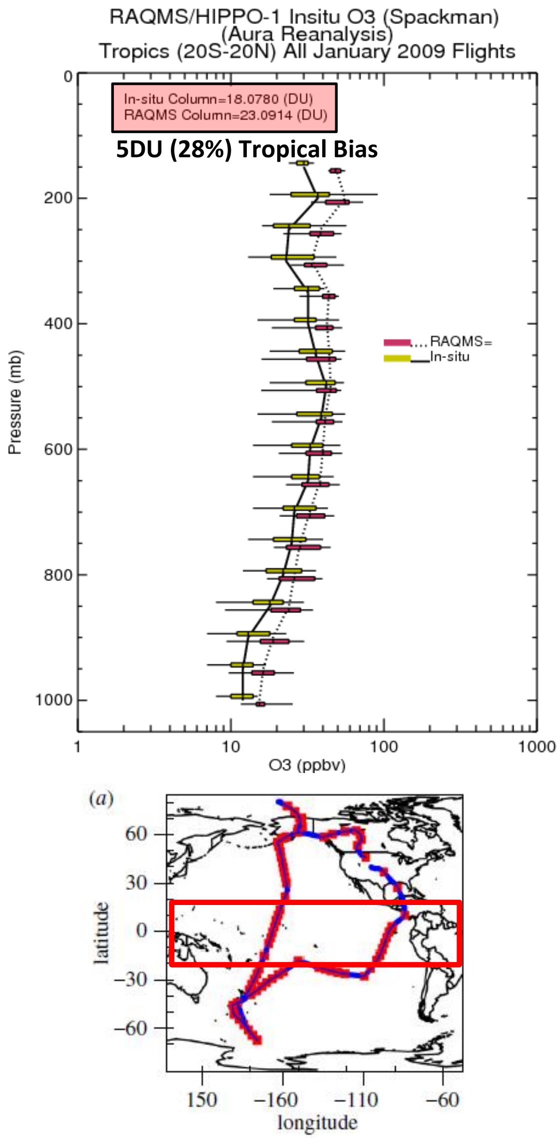
Wofsy S. et al., 2011,HIAPER Pole-to-Pole Observations (HIPPO): fine-grained, global-scale measurements of climatically important atmospheric gases and aerosols, Phil. Trans. R. Soc. A (2011) 369, 2073–2086 doi:10.1098/rsta.2010.0313

HIPPO-1 January 2009 O3 Verification

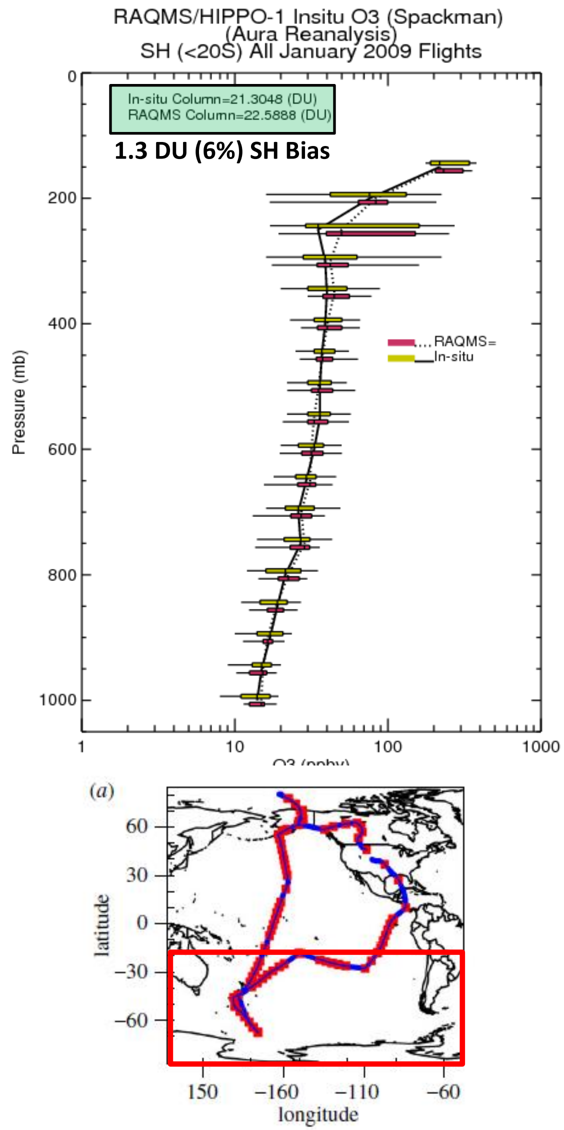
Northern Hemisphere



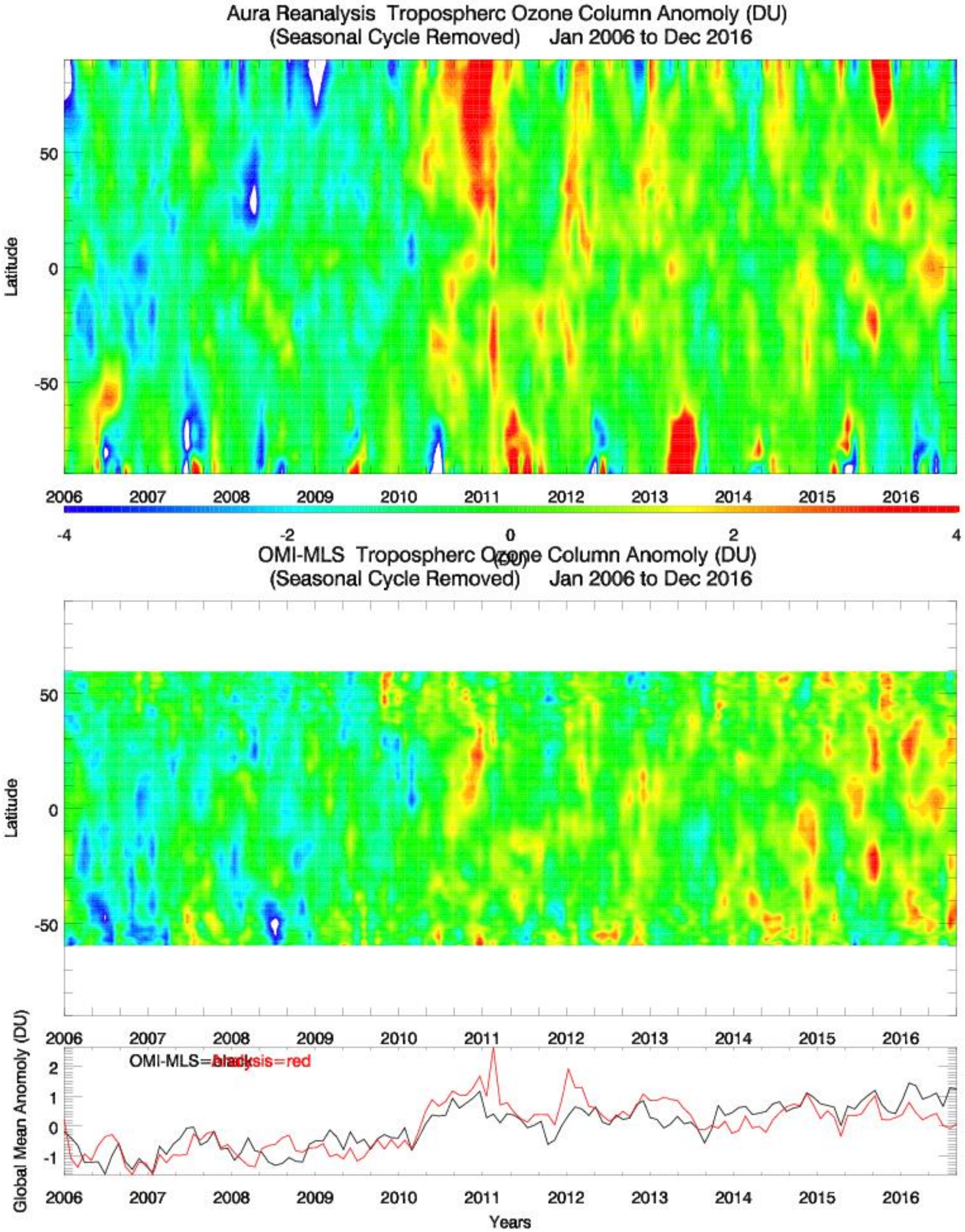
Tropics



Southern Hemisphere

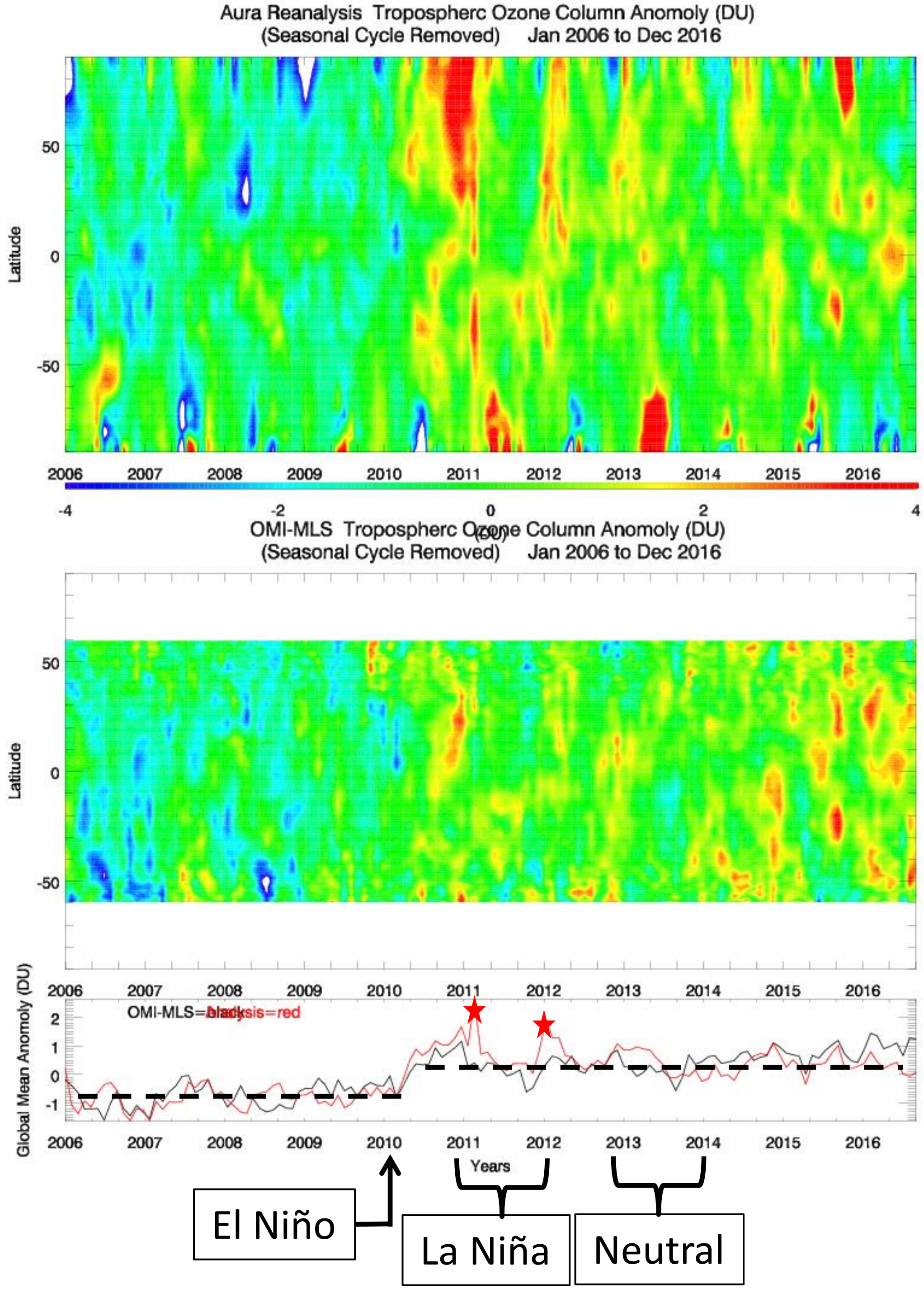


Tropical Pacific region (20N-20S) dominates the high bias in tropospheric ozone column

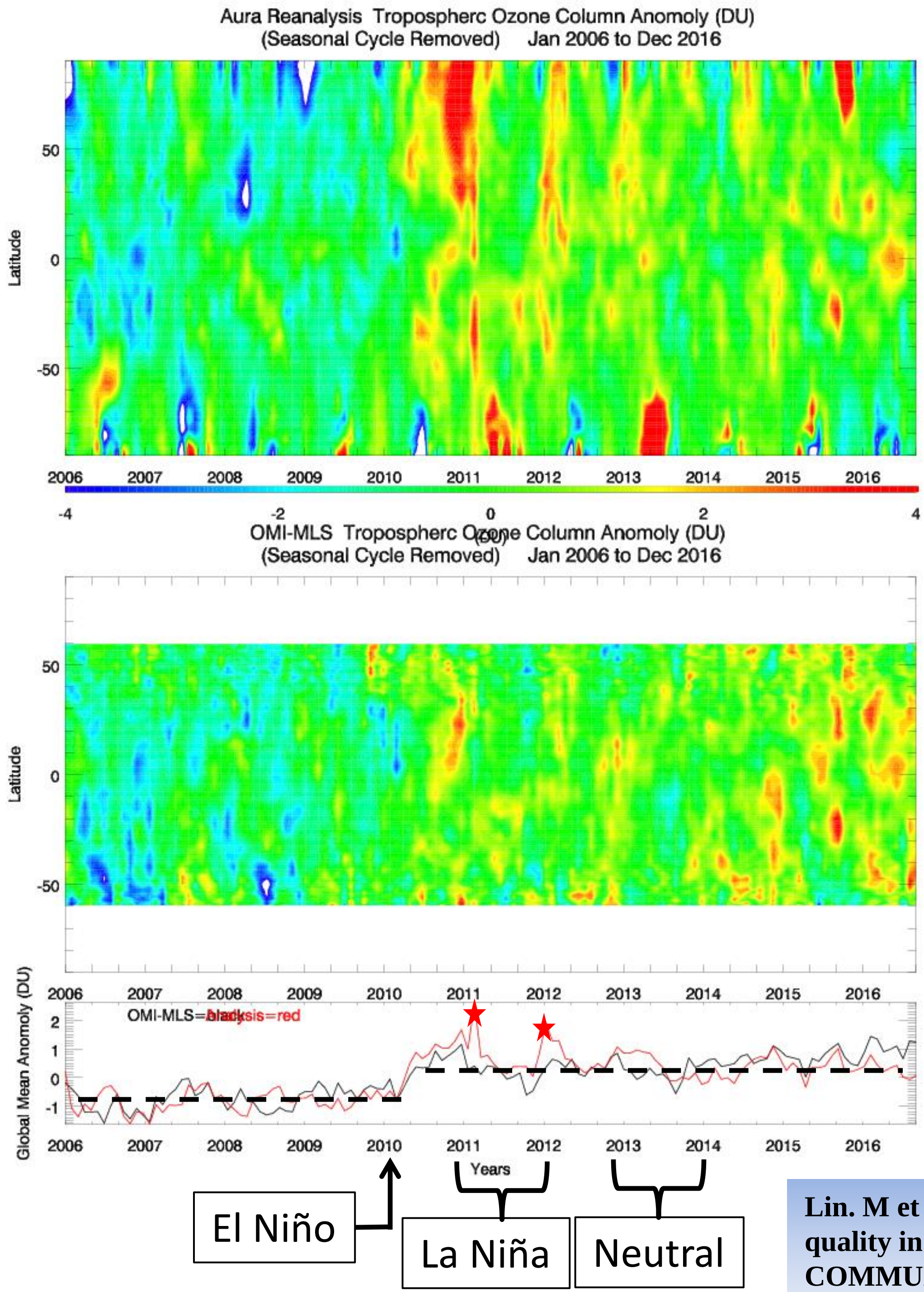


Analyzed Tropospheric Ozone Column (TOC) Anomoly – Annual Cycle Removed vs OMI-MLS Tropospheric Ozone Residuals (TOR) Anomoly – Annual Cycle Removed

Correlation=0.668



Analyzed Tropospheric Ozone Column (TOC) Anomoly – Annual Cycle Removed vs OMI-MLS Tropospheric Ozone Residuals (TOR) Anomoly – Annual Cycle Removed

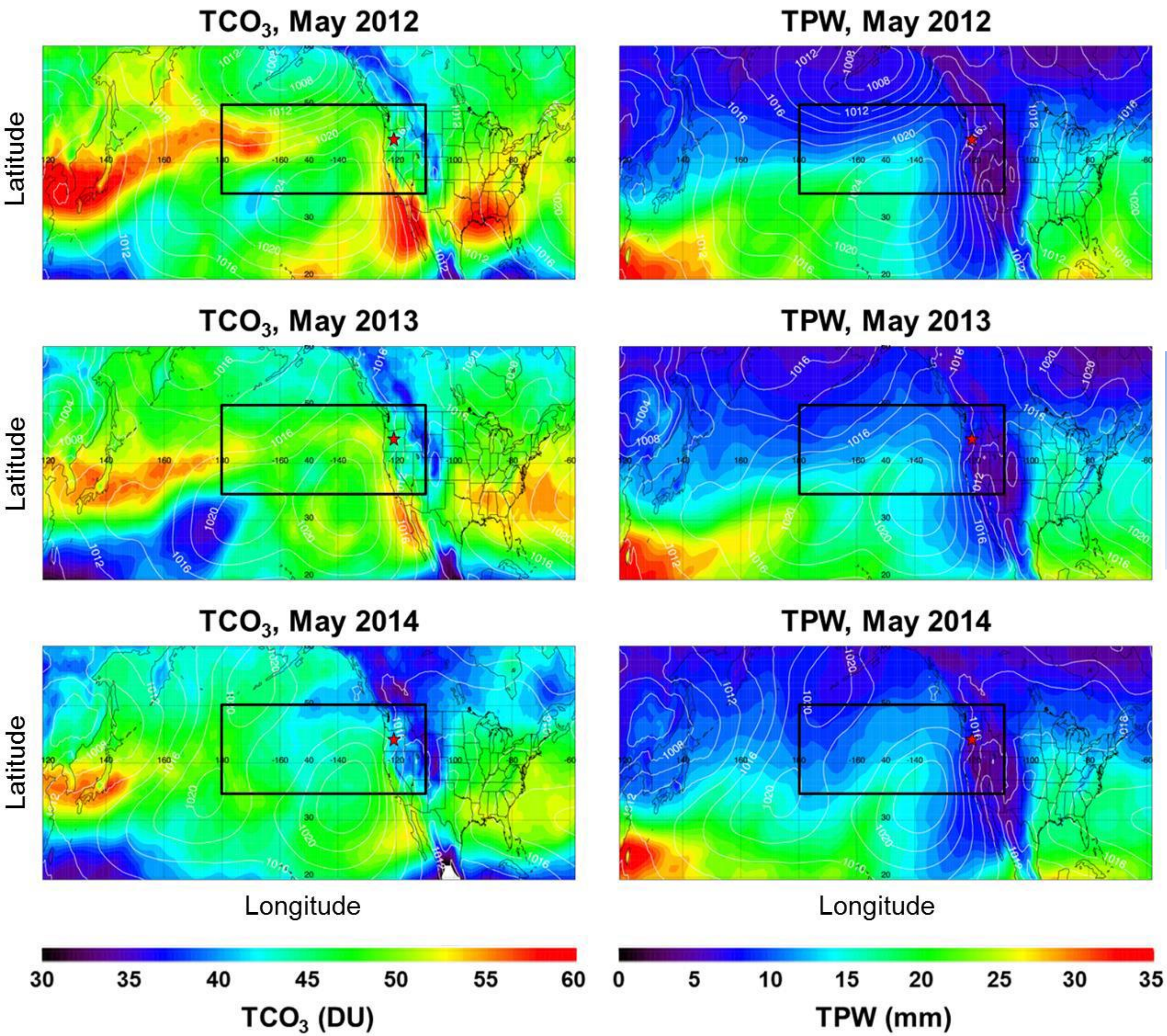


Analyzed Tropospheric Ozone Column (TOC) Anomoly – Annual Cycle Removed vs OMI-MLS Tropospheric Ozone Residuals (TOR) Anomoly – Annual Cycle Removed

More frequent late spring stratospheric intrusions occur following strong La Niña Winters (Lin et al, 2015)

Lin. M et al, 2015, Climate variability modulates western US ozone air quality in spring via deep stratospheric intrusions, NATURE COMMUNICATIONS DOI: 10.1038/ncomms8105

RAQMS Total Column Ozone (TCO) and Total Precipitable Water (TPW) May 2012-2014

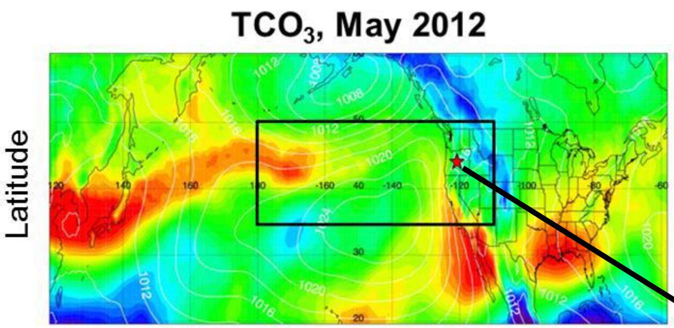


Higher TCO and lower TPW during May 2012

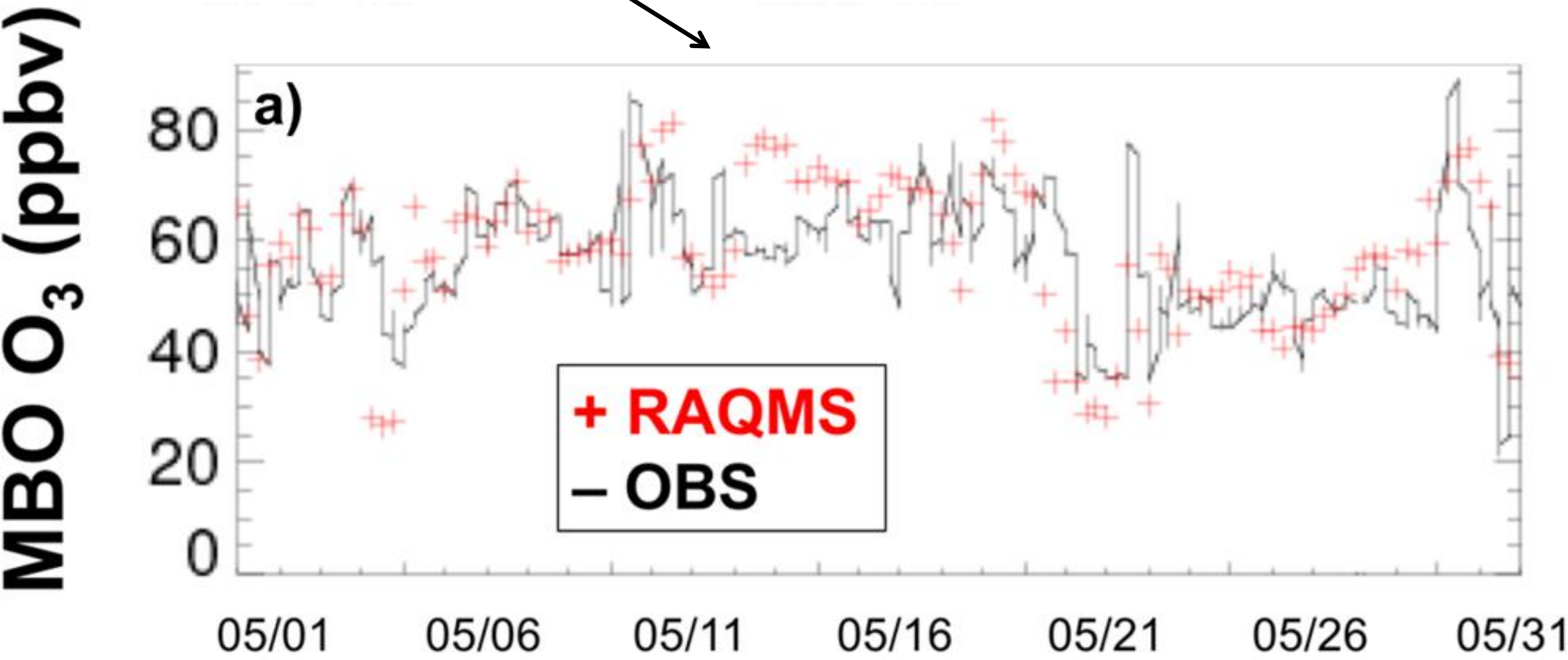
Signatures of Stratospheric intrusions (high ozone and low water vapor)

Baylon, P. M., et al, 2016, Interannual Variability in Baseline Ozone and Its Relationship to Surface Ozone in the Western U.S., Environ. Sci. Technol. 2016, 50, 2994−3001, DOI: 10.1021/acs.est.6b00219

Comparison with Surface Ozone at Mount Bachelor Observatory (MBO), May 2012



"Enhanced UT/LS events in Spring 2012 shifted the MDA8 O3 distribution to higher values, and as a result increased the number of exceedance days across some sites in the western U.S."

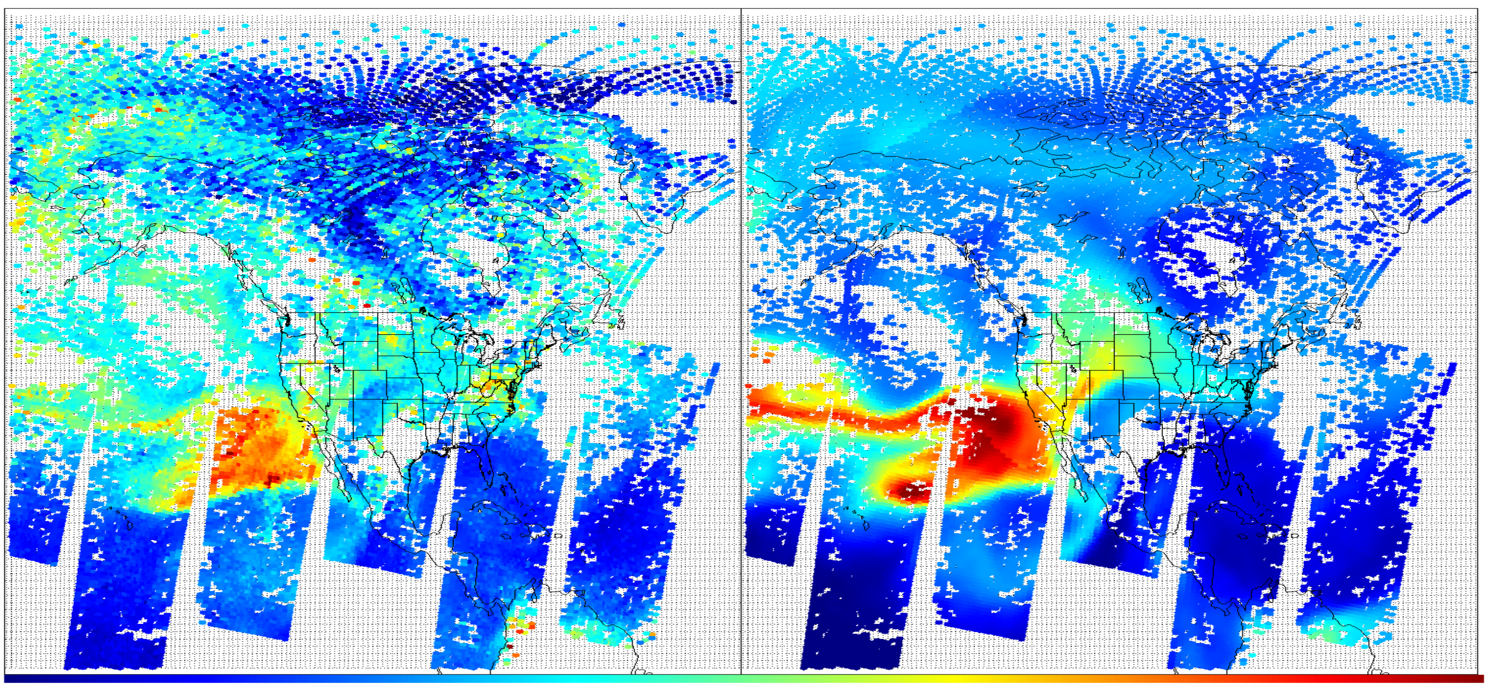


Baylon, P. M., et al, 2016, Interannual Variability in Baseline Ozone and Its Relationship to Surface Ozone in the Western U.S., Environ. Sci. Technol. 2016, 50, 2994−3001, DOI: 10.1021/acs.est.6b00219

Future directions:

1) Currently preparing report for Lake Michigan Air Directors Consortium (LADCO) summarizing LMOS 2017 preliminary findings and recommendations for State Implementation Plan modeling
2) Supported by the NOAA Research Transition Acceleration Program (RTAP) to implement a reduced version of RAQMS chemistry into the Next Generation Global Prediction System (NGGPS)
3) Plan to extend the RAQMS Aura Reanalysis beyond 2016 using trace gas and aerosol retrievals from Suomi National Polar-orbiting Partnership (S-NPP) and NOAA-20

S-NPP CrIS Full Spectral Resolution CO **RAQMS CO**



Mid-tropospheric (200-700mb) Cross-track Infrared Sounder (CrIS) CO and RAQMS (ppbv) on March 21, 2015

Outline:

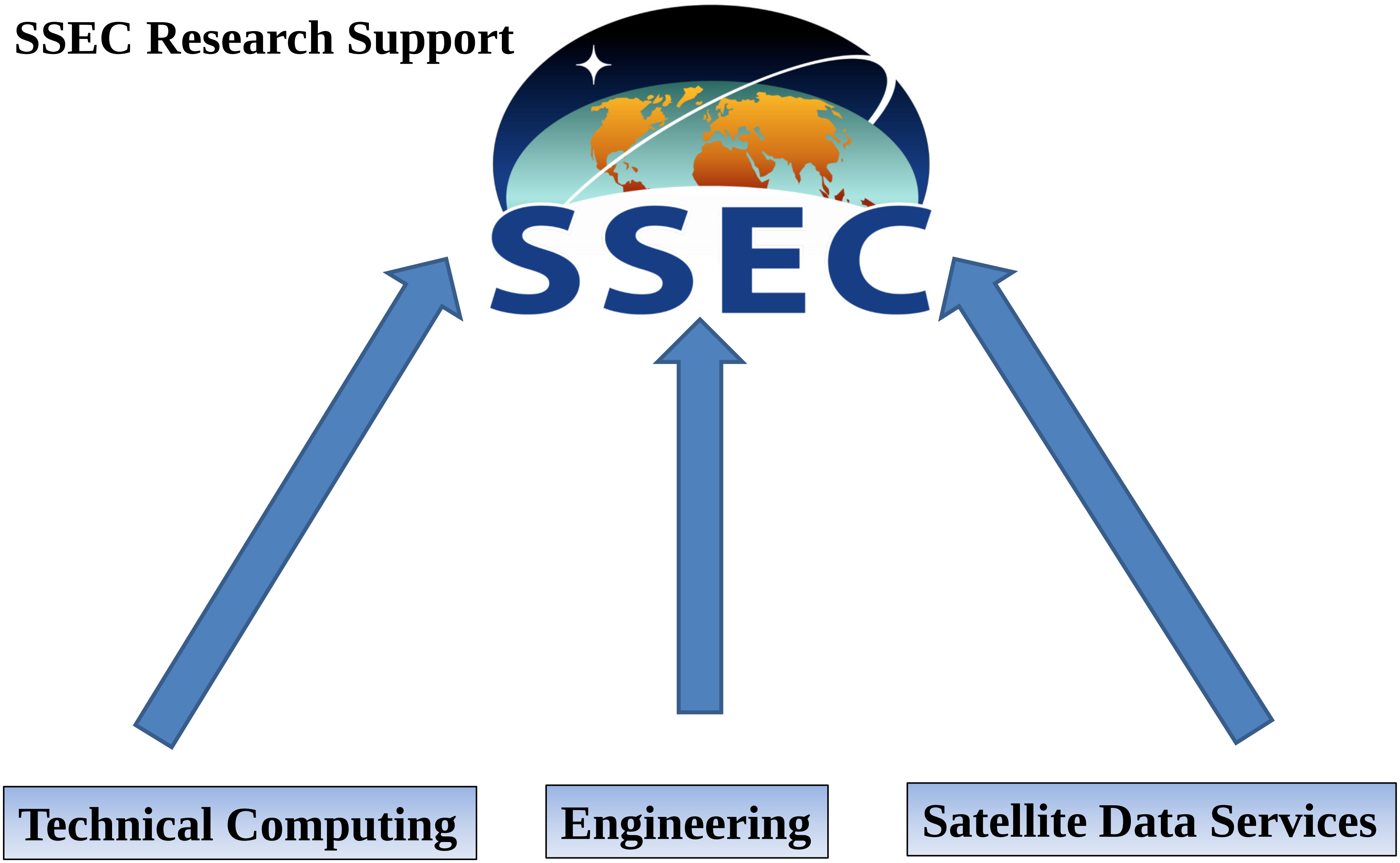
1) **Background**
   - Pollution health & ecosystem effects
   - Regional trends
2) **Regional Air Quality**
   - 2017 Lake Michigan Ozone Study – "The Wisconsin Idea"
3) **Global Air Quality**
   - Global Trends
   - Aura Chemical Reanalysis
4) **Vision:** SSEC – Opportunities and Challenges

Why I'm applying for the SSEC Director position

I have a strong commitment to the continued success of SSEC as an international leader in development and utilization of space based Earth observations

- **SSEC has played a critical role in my ability to accomplish my research goals throughout my career**
- **I feel a sense of responsibility to contribute to the continued success in a leadership role**

SSEC Research Support



Three cornerstones of SSEC research: advancing satellite instrument observing capabilities, acquiring and validating the associated measurements, and deriving useful products and information.

SSEC Large Programs

Atmosphere Science Investigator-led Processing Systems (SIPS)

Ice Drilling Design and Operations (IDDO)

Cooperative Institute for Meteorological Satellite Studies (CIMSS)

SSEC Science Team Participation

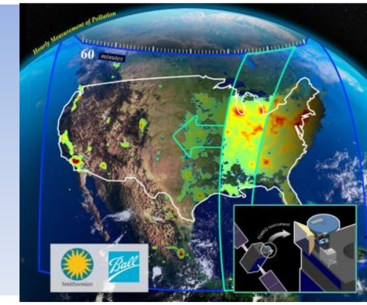
S-NPP
AIRS
MODIS
Applied Sciences
GPM
CloudSat
OCO-2

FRAPPE
PECAN
TORERO

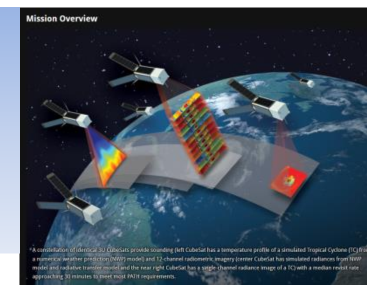
Hazardous Wx Testbed
Proving Ground
GOES-R AWG
JPSS
RTAP

Opportunities: SSEC NASA Earth Venture participation

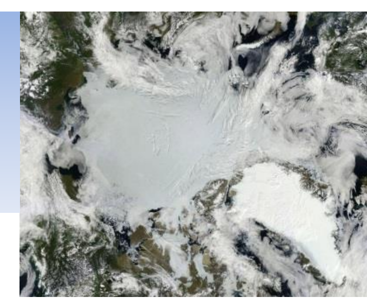
The Tropospheric Emissions: Monitoring of Pollution (TEMPO) measure air pollution of North America hourly and at high spatial resolution. TEMPO observations are from the geostationary vantage point, flying on a geostationary commercial communications host spacecraft. (PI: Kelly Chance, Smithsonian Astrophysical Observatory) (Brad Pierce, Co-I, Air Quality forecasting and data assimilation)



The Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) mission will measure environmental and inner-core conditions for tropical cyclones (TCs) at an unprecedented combination of horizontal and temporal resolution (PI, William Blackwell, MIT Lincoln Laboratory) (Chris Velden, Co-I, SSEC responsible for ground system)



The Polar Radiant Energy in the Far Infrared Experiment (PREFIRE) will fly a pair of small CubeSat satellites to probe a little-studied portion of the radiant energy emitted by Earth for clues about Arctic warming, sea ice loss, and ice-sheet melting. (PI: Tristan L'Ecuyer of the University of Wisconsin, Madison)



These Earth Venture missions were in response to the 2007 Decadal Survey

Challenges: Supporting SSEC engineering infrastructure to support SSEC and campus research.

Challenges: Increasing the number of PI level staff and external UW collaborations at SSEC.

Challenges: Supporting SSEC engineering infrastructure to support SSEC and campus research.

Strengthen SSEC's collaboration with the UW-Madison Physical Sciences Lab (PSL) to provide more sustained funding for SSEC engineering staff.

Challenges: Increasing the number of PI level staff and external UW collaborations at SSEC.

Challenges: Supporting SSEC engineering infrastructure to support SSEC and campus research.

Strengthen SSEC's collaboration with the UW-Madison Physical Sciences Lab (PSL) to provide more sustained funding for SSEC engineering staff.

Pursue NASA and/or NOAA Incubation funding to support the development of expanded capabilities for the S-HIS, including short wave infrared channels for retrieving methane, carbon monoxide, and carbon dioxide

Challenges: Increasing the number of PI level staff and external UW collaborations at SSEC.

Challenges: Supporting SSEC engineering infrastructure to support SSEC and campus research.

Strengthen SSEC's collaboration with the UW-Madison Physical Sciences Lab (PSL) to provide more sustained funding for SSEC engineering staff.

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Challenges: Increasing the number of PI level staff and external UW collaborations at SSEC.

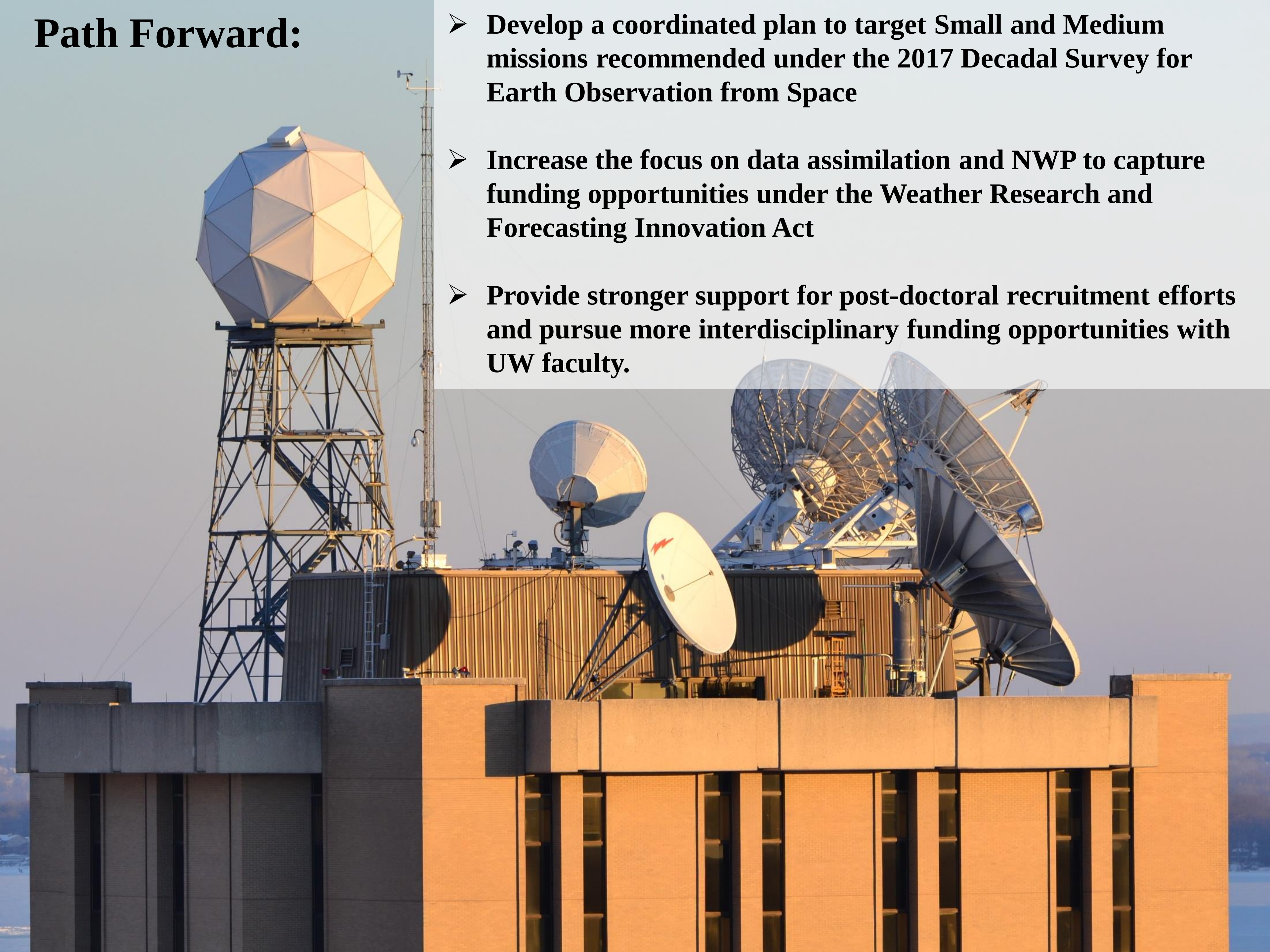
Continue collaboration with Astronomy and Physics Departments, and strengthen collaboration with other departments through programs such as UW2020, Data Science Initiative (Institute for Foundations of Data Science)

Path Forward:

- Develop a coordinated plan to target Small and Medium missions recommended under the 2017 Decadal Survey for Earth Observation from Space

- Increase the focus on data assimilation and NWP to capture funding opportunities under the Weather Research and Forecasting Innovation Act

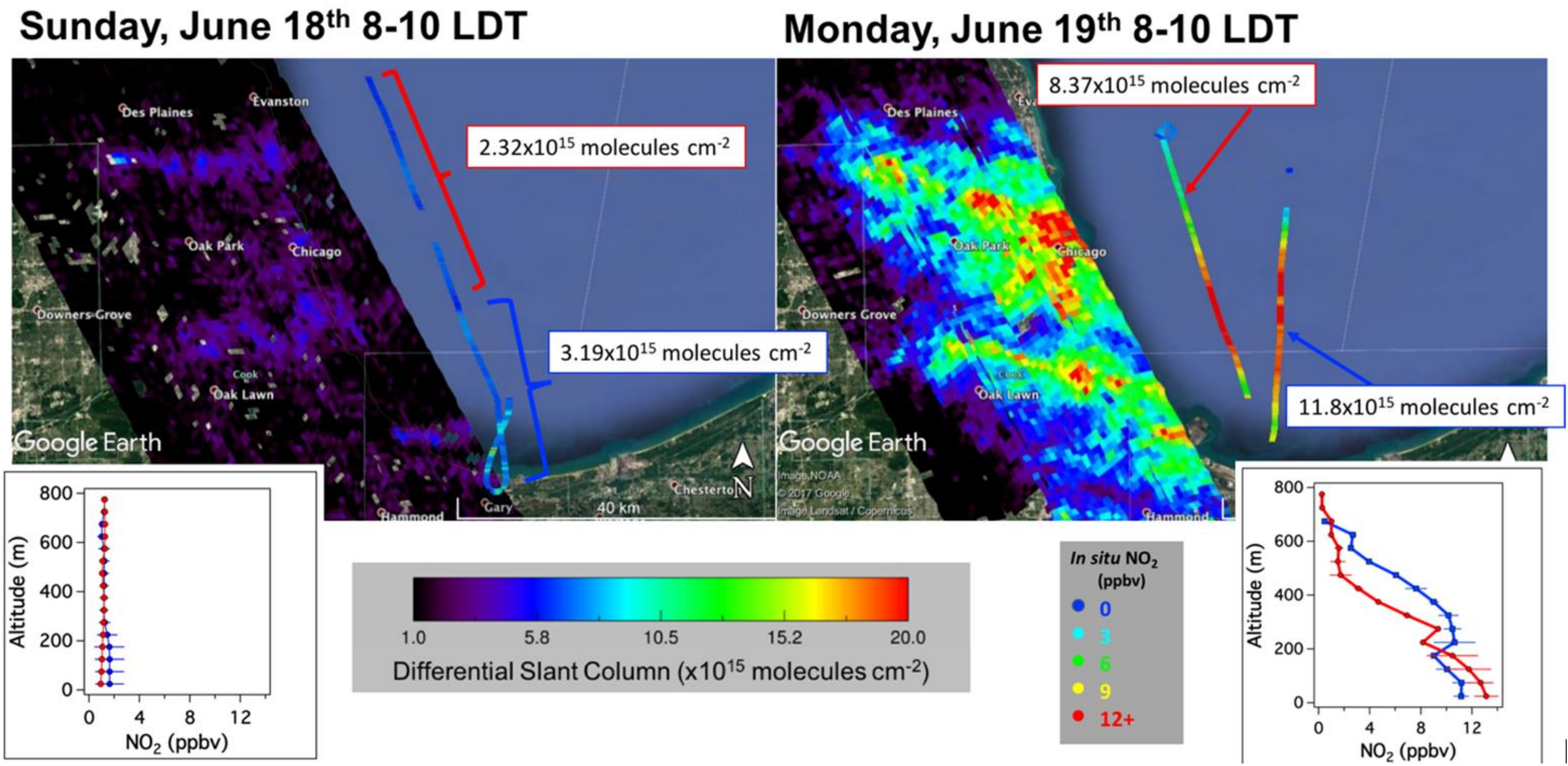
- Provide stronger support for post-doctoral recruitment efforts and pursue more interdisciplinary funding opportunities with UW faculty.



Questions?

Extra Slides

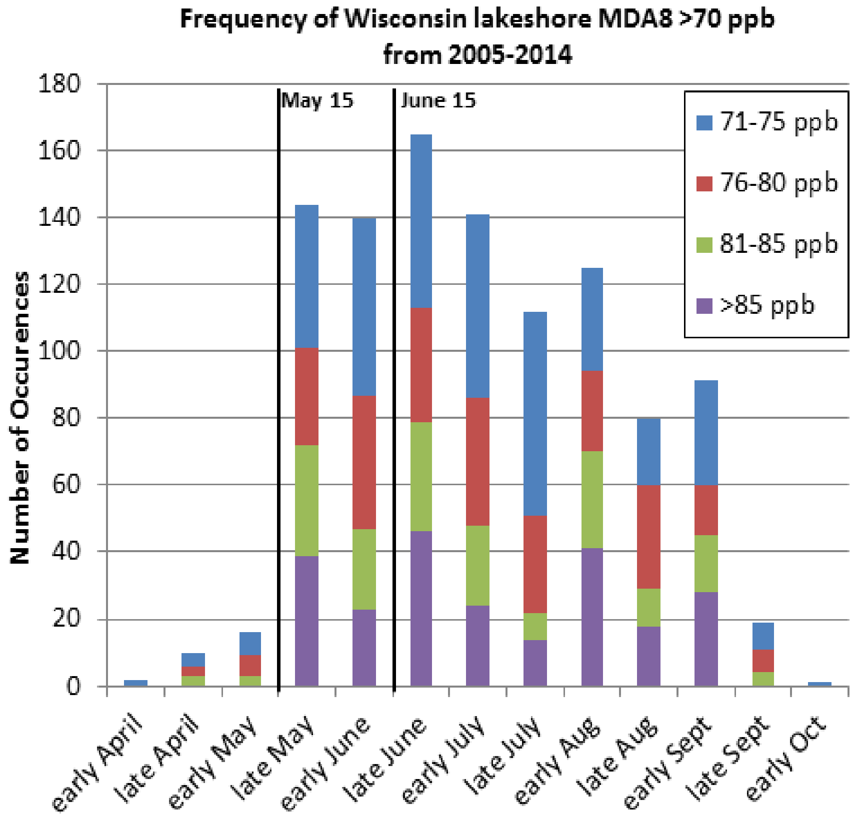
Chicago Emission Mapping Weekend/Weekday

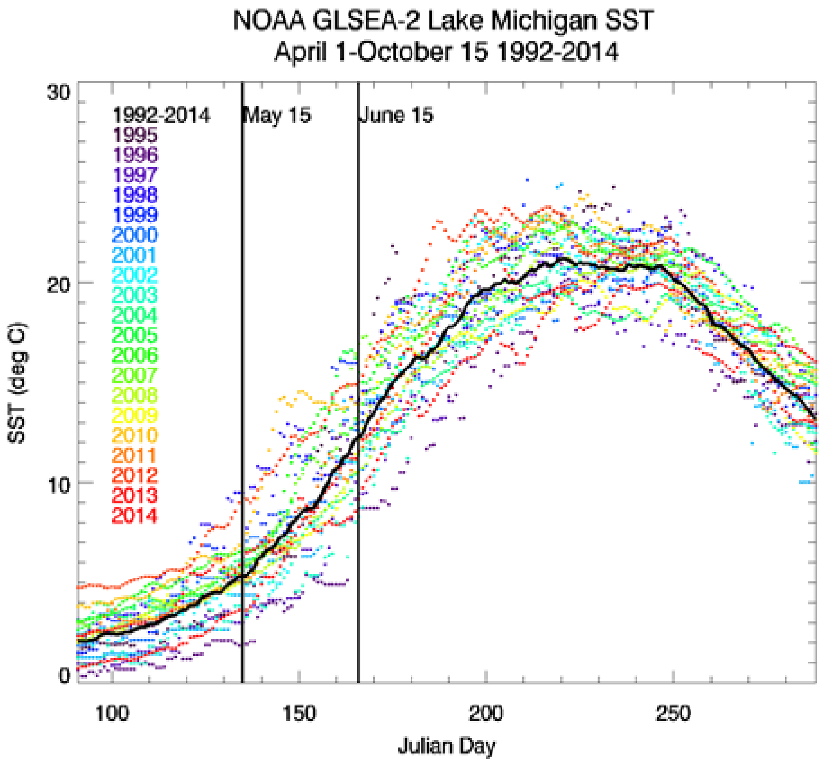


GeoTASO (Geostationary Trace gas and Aerosol Sensor Optimization) is an airborne hyperspectral mapping instrument built by Ball Aerospace (Leitch et al., 2014) and is being used as an airborne testbed for future high-resolution trace-gas observations from geostationary sensors such as TEMPO (Analysis by Laura Judd, NASA/LaRC)

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.

Lake Michigan Ozone Study White Paper: http://www.ladco.org/

Atmos. Chem. Phys., 17, 15151–15165, 2017
https://doi.org/10.5194/acp-17-15151-2017

Atmospheric Chemistry and Physics

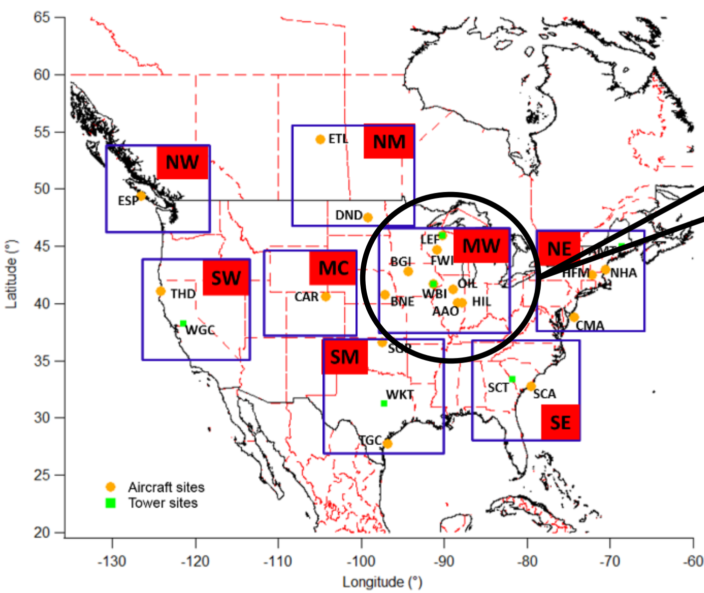
Gradients of column CO_2 across North America from the NOAA Global Greenhouse Gas Reference Network

Xin Lan[1,2], Pieter Tans[1], Colm Sweeney[1,2], Arlyn Andrews[1], Andrew Jacobson[1,2], Molly Crotwell[1,2], Edward Dlugokencky[1], Jonathan Kofler[1,2], Patricia Lang[1], Kirk Thoning[1], and Sonja Wolter[1,2]

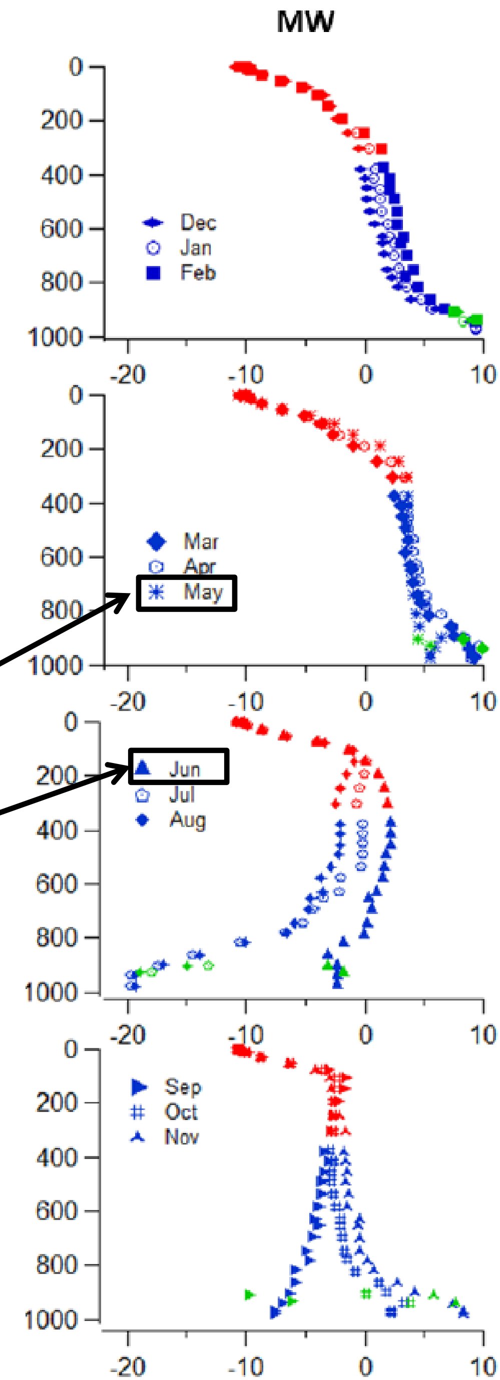
[1]National Oceanic and Atmospheric Administration, Earth System Research Laboratory, Boulder, CO, USA
[2]University of Colorado, Cooperative Institute for Research in Environmental Sciences, Boulder, CO, USA

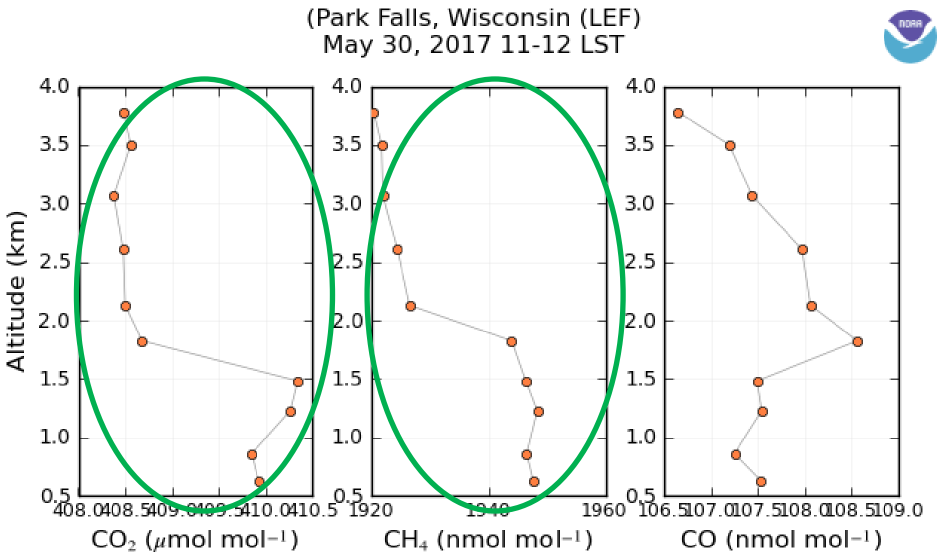
"In wintertime, monotonic decrease of CO2 with altitude can be observed from all regions, in which high PBL CO2 is mainly driven by surface emissions and reduced vertical mixing (Denning et al., 1999; Stephens et al., 2007)"

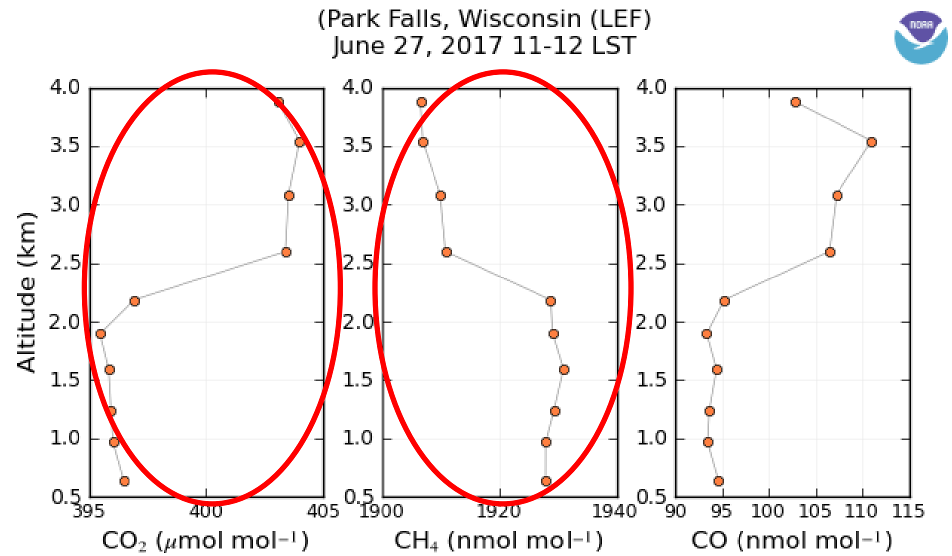
" Surface CO2 decreases dramatically in the growing season in those regions influenced by high plant activity, such as the NM and MW regions."



LMOS during May-June transition to summer-time drawdown





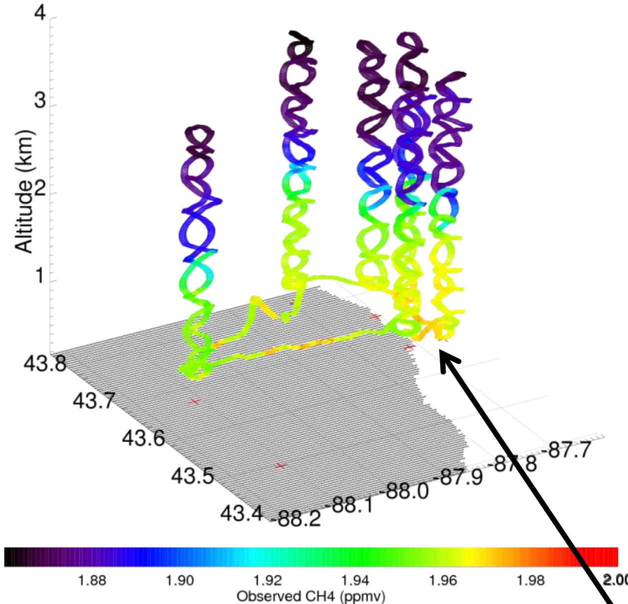


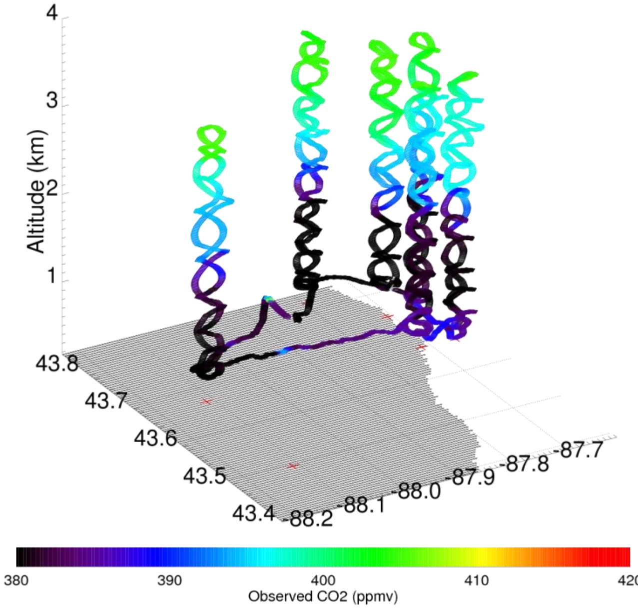
NOAA/ESRL Park Falls Tall Tower Aircraft measurements during LMOS

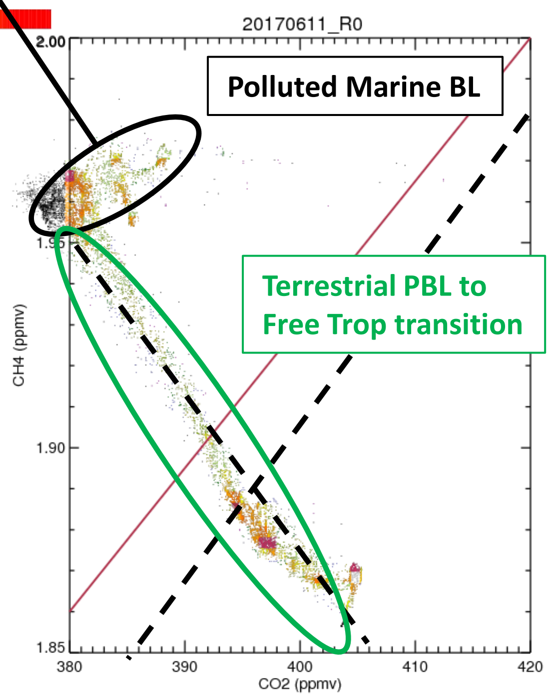
- **High CH4 within PBL and low CH4 aloft**
- **High CO2 within PBL on May 30, 2017 (CO2/CH4 positively correlated)**
- **CO2 draw down within PBL on June 27, 2017 (CO2/CH4 anti-correlated)**

LMOS occurred during leaf out and transition to summer-time CO2 drawdown – also strong influence on biogenic VOC emissions

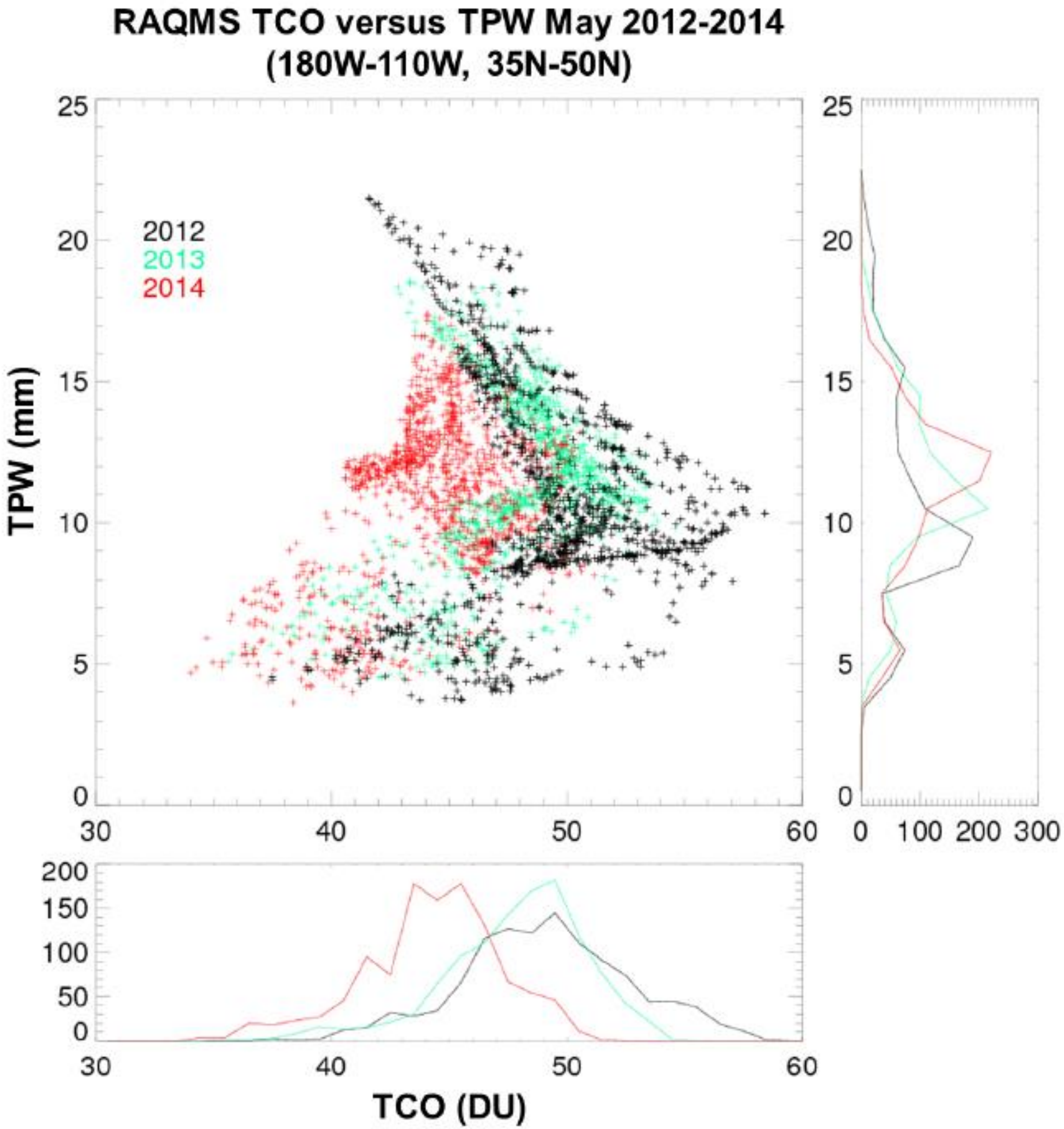
Coastal Ozone Exceedance Day







- CO2 and CH4 anti-correlated except for offshore of Sheboygan KA (region of higher CO2 below 1km)

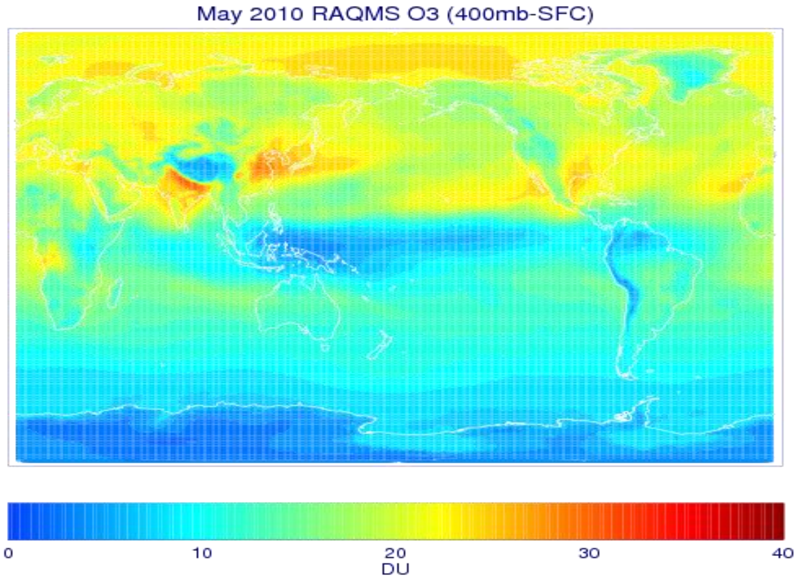


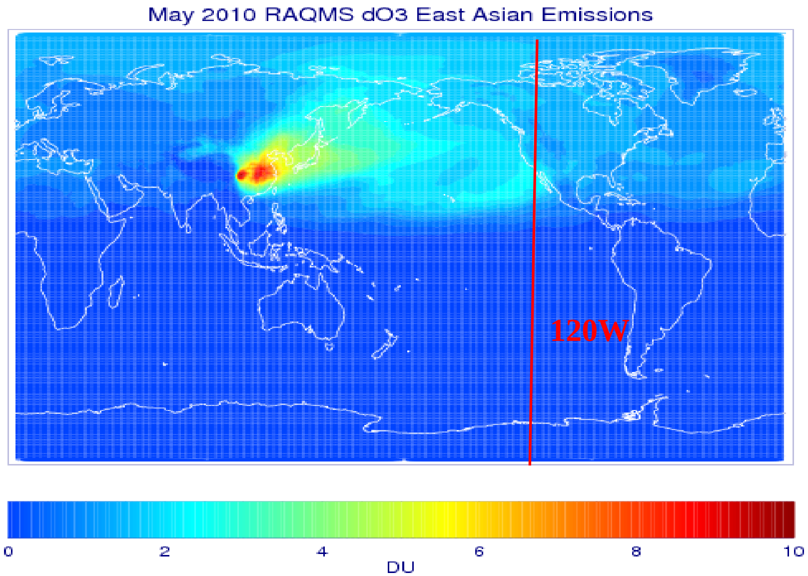
Signatures of Stratospheric intrusions include: high ozone and low water vapor

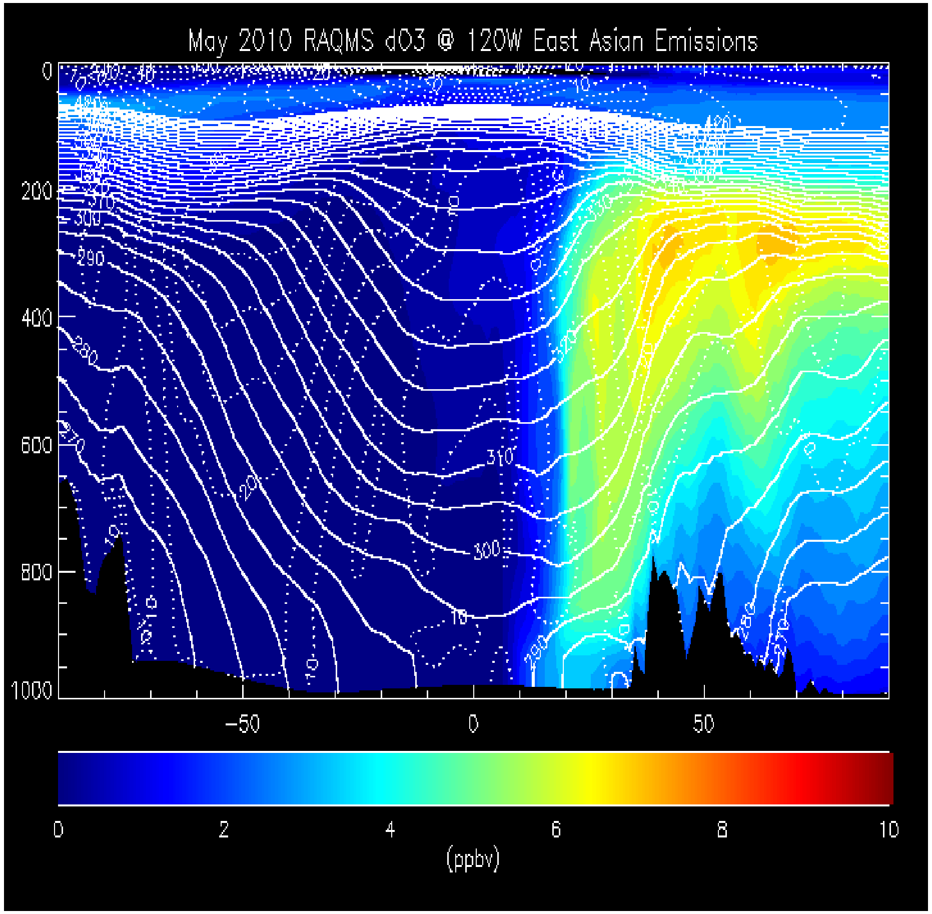
- **May 2012 (black) shows highest TCO and lowest TPW**
- **May 2014 (red) shows lowest TCO and highest TPW**

Baylon, P. M., et al, 2016, Interannual Variability in Baseline Ozone and Its Relationship to Surface Ozone in the Western U.S., Environ. Sci. Technol. 2016, 50, 2994−3001, DOI: 10.1021/acs.est.6b00219

Impacts of East Asian Emissions – May 2010







Impact of East Asian ozone production extends into North America with potential US Air Quality impacts

Huang, M et al, 2017 Impact of intercontinental pollution transport on North American ozone air pollution: an HTAP phase 2 multi-model study, Atmos. Chem. Phys., 17, 5721–5750, 2017, doi:10.5194/acp-17-5721-2017

Summary of measurements made during the LMOS 2017 field campaign

Location	Measurement*	Research Institution*
Ground Sites		
Spaceport Sheboygan	Remote sensing of meteorology (SPARC Trailer)	UW-Madison -SSEC
	In situ measurements of pollutants	U.S. EPA ORD
Zion, IL	Remote sensing of meteorology (Sodar/MW Radiometer)	Univ. Northern Iowa
	Detailed in situ chemical measurements	Univ. Iowa, UW-Madison, Univ. Minnesota
	Routine measurements of ozone	Illinois EPA
Various†	Remote sensing of pollutants and boundary layer height	U.S. EPA ORD
Sheboygan transect	In situ measurements of ozone at four locations	U.S. EPA ORD
Airborne Platforms		
Lakeshore region	Airborne remote sensing of NO_2 (GeoTASO)	NASA
	Airborne remote sensing of clouds (AirHARP)	Univ. Maryland, Baltimore County
	Airborne in situ profiling of pollutants and meteorology	Scientific Aviation (and NOAA?)
Shipboard Platform		
Lake Michigan	In situ measurements of pollutants	U.S. EPA ORD
	Remote sensing of pollutants and boundary later height	U.S. EPA ORD
Mobile Platforms		
Northeast IL and Southeast WI	In situ measurements of pollutants (GMAP)	U.S. EPA Region 5
Grafton to Sheboygan	In situ measurements of ozone and meteorology	UW-Eau Claire

GeoTASO = Geostationary Trace gas and Aerosol Sensor Optimization instrument
AirHARP = Airborne Hyper Angular Rainbow Polarimeter
GMAP = Geospatial Mapping of Pollutants
† These measurements were made at Spaceport Sheboygan, Zion, two Wisconsin DNR monitoring locations (Grafton and Milwaukee SER) and one Illinois EPA monitoring location (Schiller Park).