

Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas

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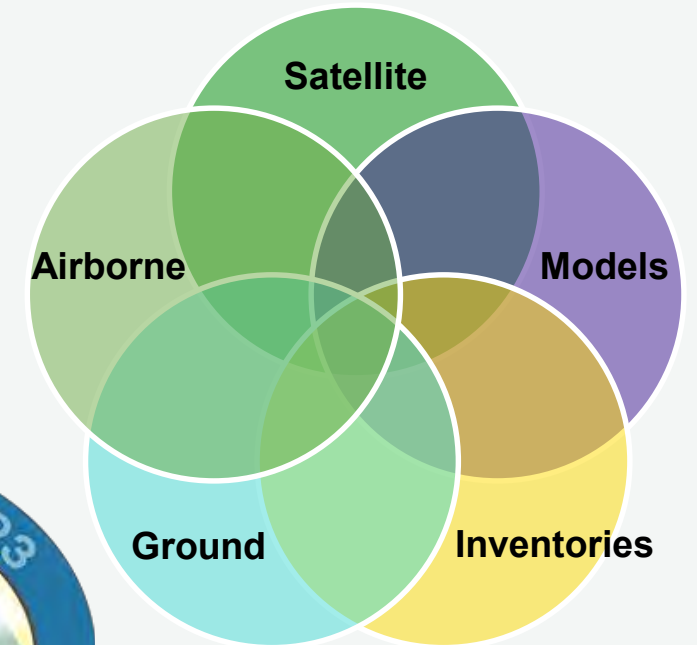
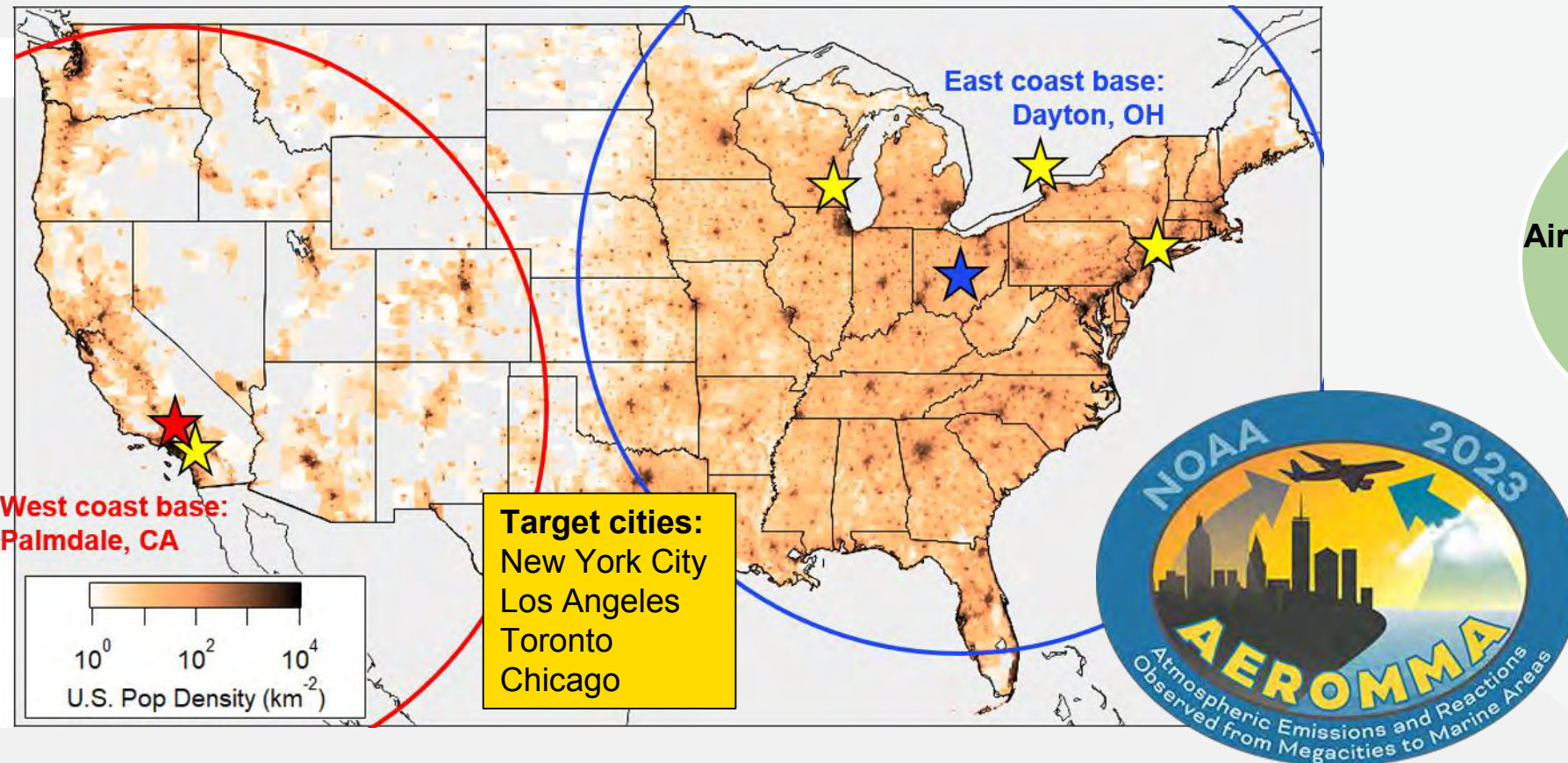
CIESRDS

Cooperative Institute for Earth Systems
Research and Data Science

In 2023, AEROMMA addressed emerging research needs in air quality and climate in North American cities.

AEROMMA investigates atmospheric composition and emissions in urban and marine environments and the urban-marine interface that alter tropospheric chemistry and composition.

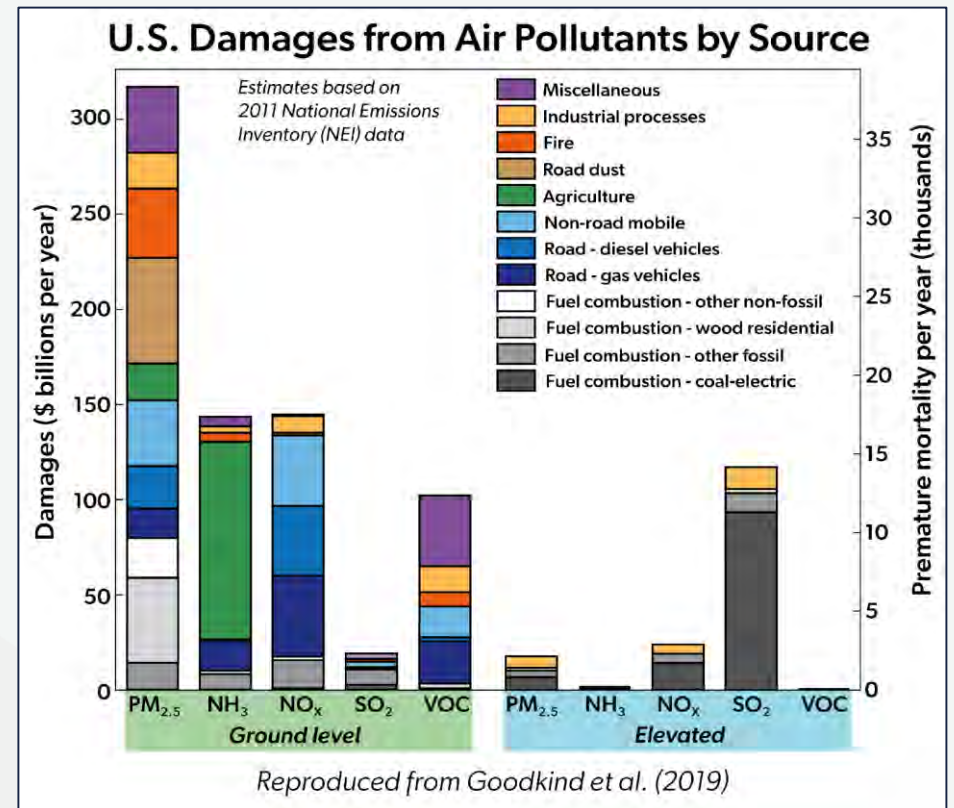
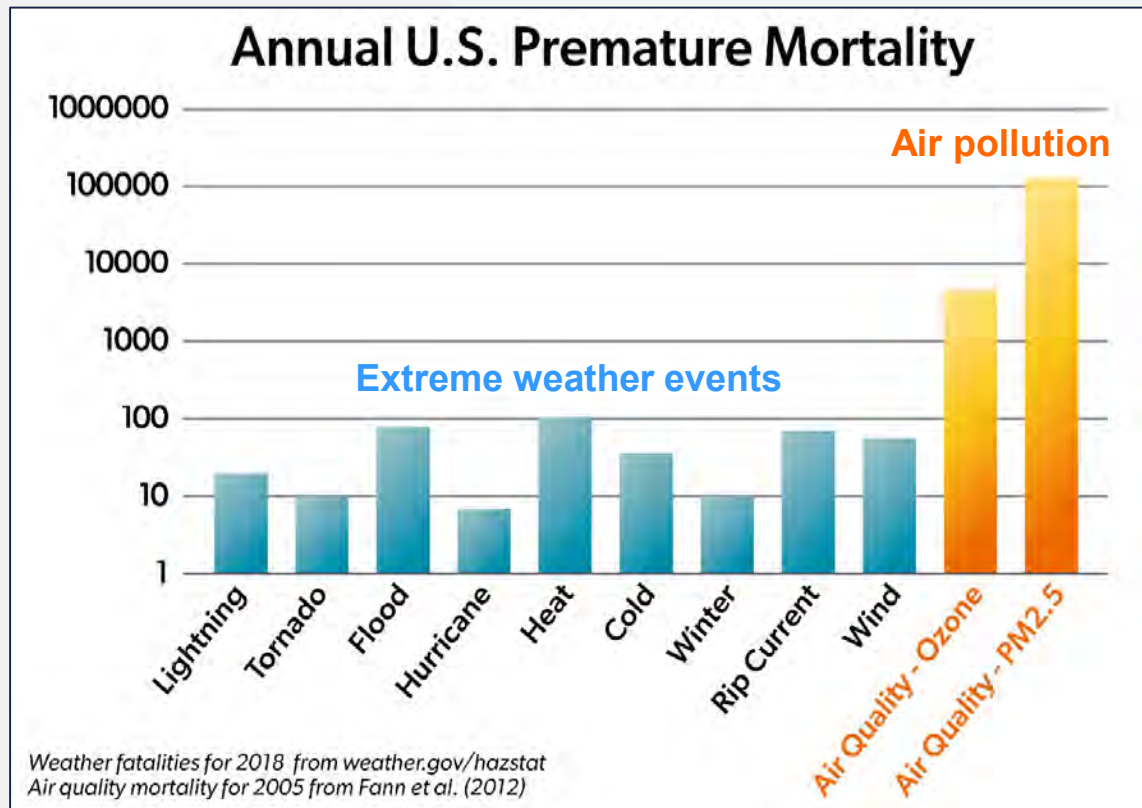
AEROMMA brings together air quality measurements from **street-level to space**.



AEROMMA is motivated by air quality impacts on public health.

Air pollution results in **100,000+ premature deaths** in the U.S. annually.

Ground-level air pollution results in **>\$800 Billion in damages** in the U.S. annually.



AEROMMA supports NOAA's mission by understanding/predicting changes in air quality and climate and sharing this knowledge and information with others.

AEROMMA is part of a larger campaign (AGES+).
 It represents the largest NOAA-led, air quality-focused study to date.

Collaborating institutions:

+22 academic institutions

+8 state & local partners

AGES+ SUMMER 2023

NASA TEMPO
 Geostationary satellite observations of air pollutants over the US

NASA STAQS
 Airborne measurements over New York City, Chicago, Toronto, and Los Angeles

NOAA AEROMMA
 Airborne measurements over New York City, Chicago, Toronto, Los Angeles, and Pacific Ocean

NOAA CUPiDS
 Airborne measurements around New York City

UMD/NOAA NEC-AQ-GHG
 Airborne and mobile measurements of the North East Corridor

Ground sites:
 New York City
 Toronto, Canada
 Atlanta, GA
 Chicago, IL
 La Jolla, CA

NOAA mobile lab

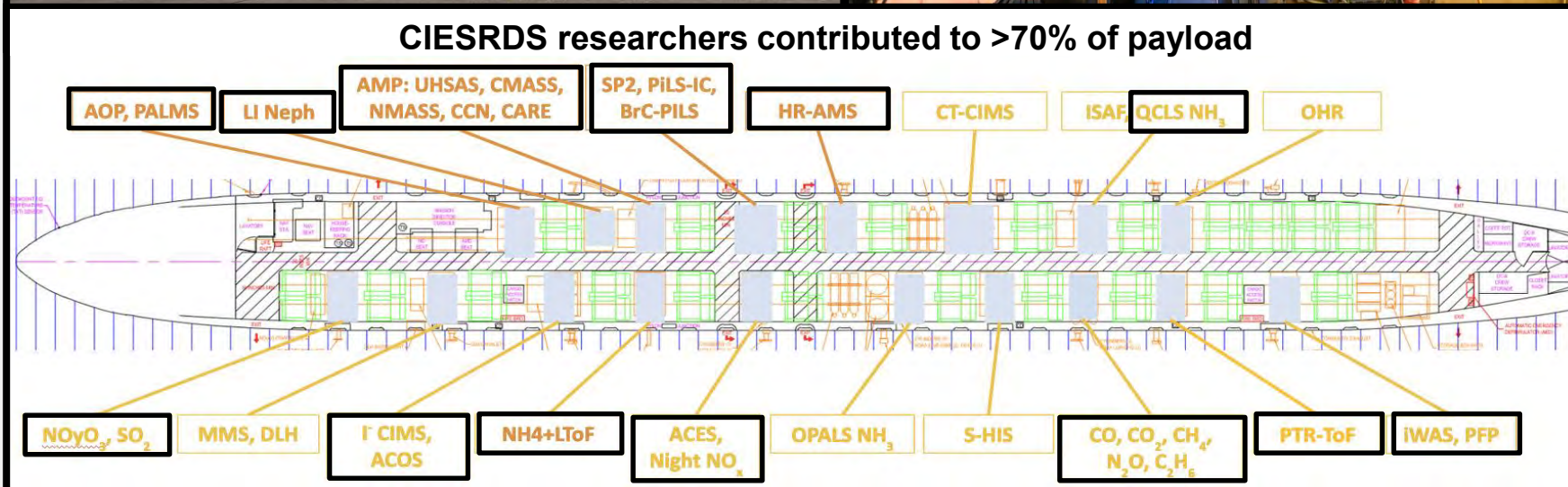
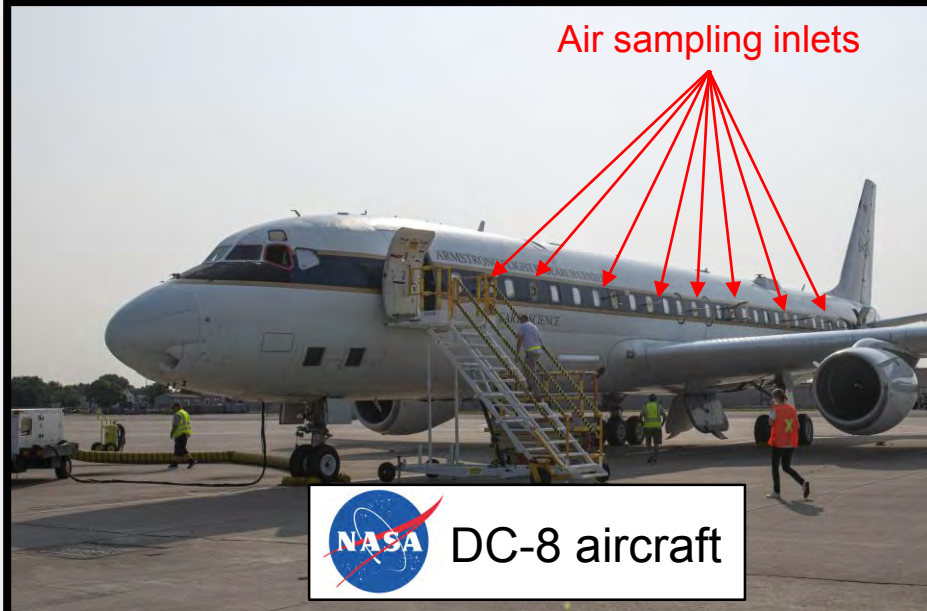
CIESRDS researchers led & contributed to:

LM-BREEZE

Air (In)quality in New York City

*NESDIS = NOAA's National Environmental Satellite, Data, and Information Service

AEROMMA included a comprehensive, state-of-the-art, airborne suite of gas and aerosol instrumentation.



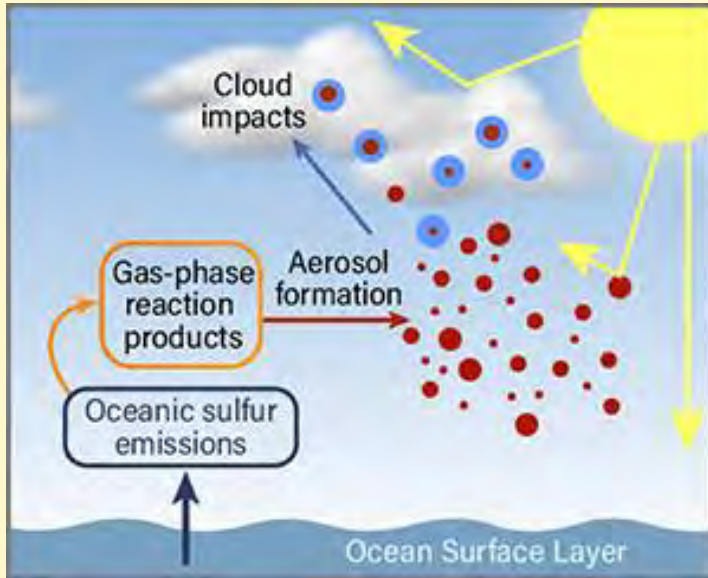
AEROMMA conducted 26 flights allowing statistical sampling of North American cities and marine areas.



Figure credit: Wyndom Chase

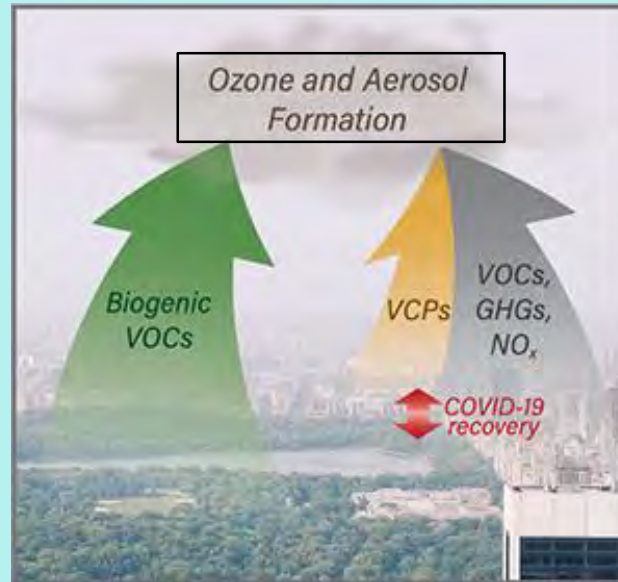
AEROMMA has four overarching goals driven by NOAA's mission and prior CIESRDS-NOAA research.

- 1 Provide new perspectives on emissions and chemistry for the marine sulfur cycle



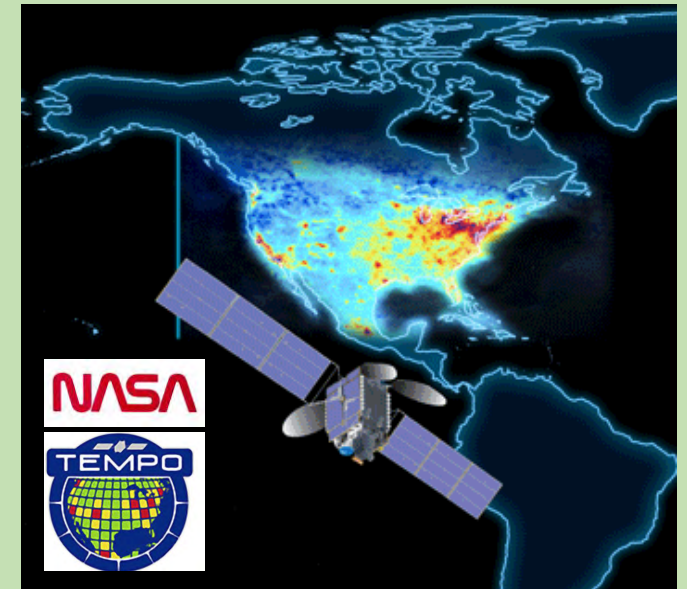
Motivated by CIESRDS-NOAA research that discovered new marine sulfur species.

- 2 Understand the role of urban emissions in ozone (O_3) and fine particle ($PM_{2.5}$) formation



Motivated by CIESRDS-NOAA research on changing emissions sources over time.

- 3 Validate new technology for space-based observations of atmospheric composition



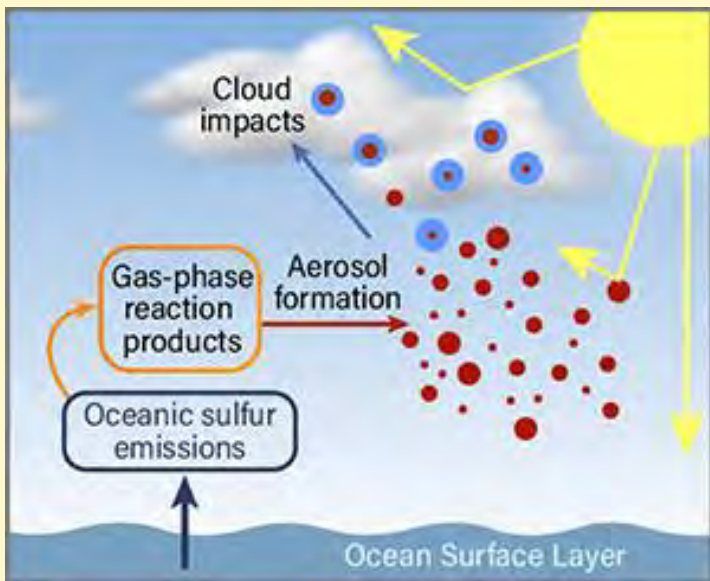
Motivated by CIESRDS-NOAA model data assimilation and TEMPO "first light".

- 4 Utilize findings to evaluate and improve emissions inventories, models, and forecasts.

AEROMMA has the most comprehensive airborne measurements of species in the marine sulfur cycle.

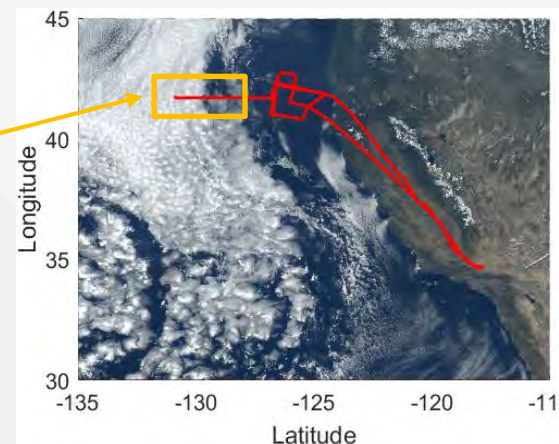
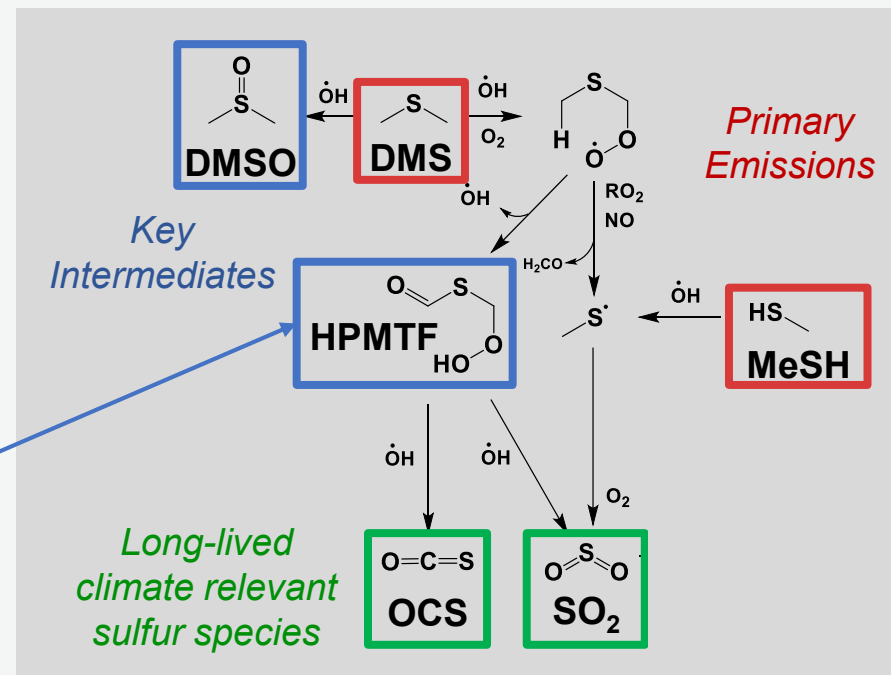
1

Provide new perspectives on emissions and chemistry for the marine sulfur cycle



Motivated by CIESRDS-NOAA research that discovered new marine sulfur species.

- **Dimethyl sulfide (DMS)** is a major source of natural sulfur emissions to Earth's atmosphere.
- Its subsequent oxidation to **long-lived species and sulfate aerosol** help regulate the natural climate system.
- CIESRDS scientists discovered **hydroperoxymethyl thioformate (HPMTF)**.
- AEROMMA had 4 marine flights that addressed uncertainties in this oxidation cycle.
- **HPMTF** is readily lost through cloud interactions leaving less sulfur species available to produce "cooling" sulfur aerosol.

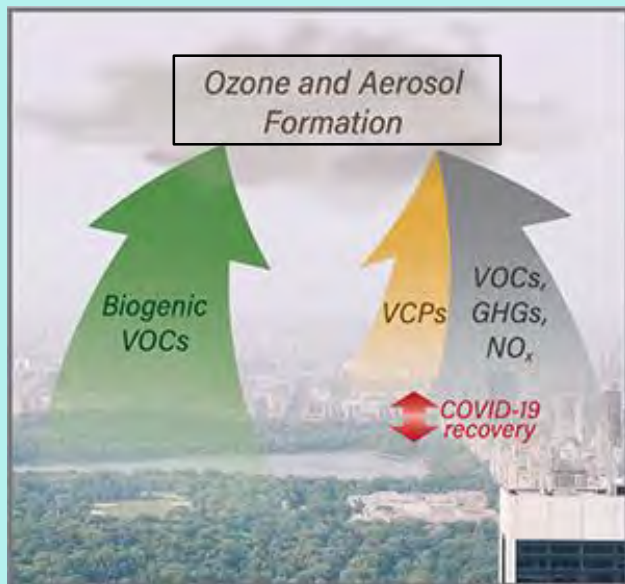


Jernigan et al., in prep.

AEROMMA characterized urban sources of VOCs, an important ingredient in ozone and PM formation.

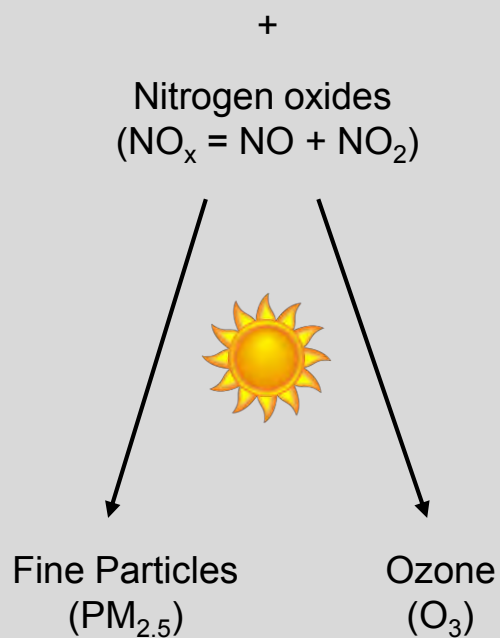
2

Understand the role of urban emissions in ozone (O₃) and fine particle (PM_{2.5}) formation



Motivated by CIESRDS-NOAA research on changing emissions sources over time.

Volatile Organic Compounds (VOCs)

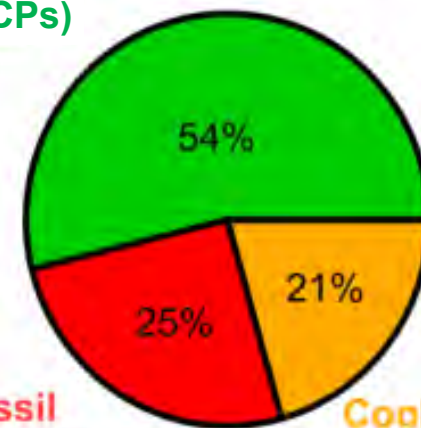


VCPs are a larger source of VOCs than fossil fuels.

Cooking emissions are an important source of VOCs.

Modern anthropogenic VOC distribution

Volatile Chemical Products (VCPs)



Fossil Fuels

Cooking

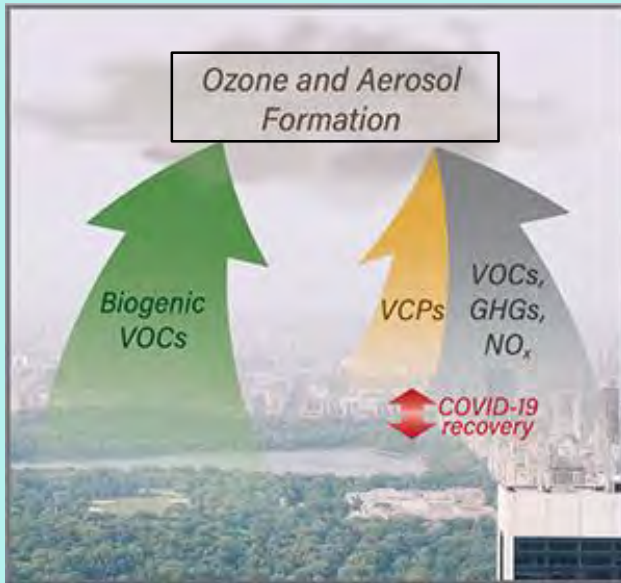


Coggon et al., ACP, 2024.
Stockwell et al., ACP, 2025.

AEROMMA characterized urban sources of VOCs, an important ingredient in ozone and PM formation.

2

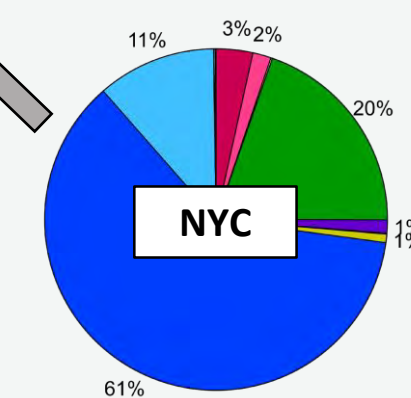
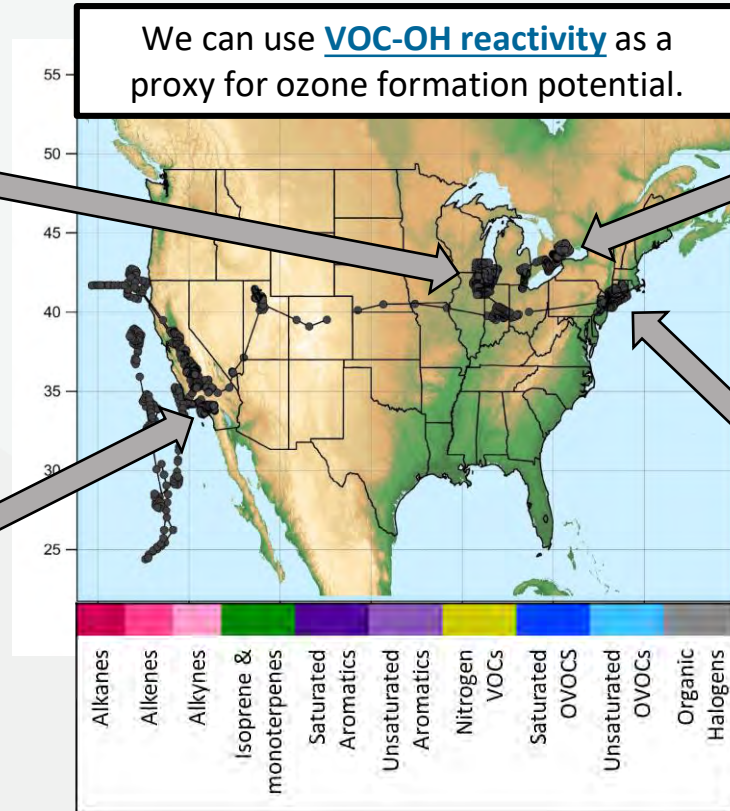
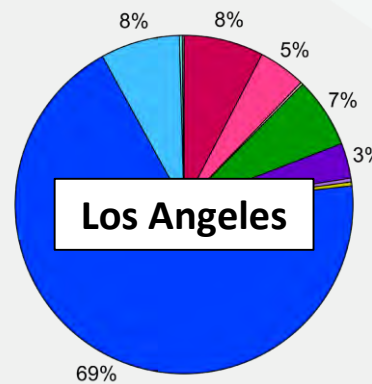
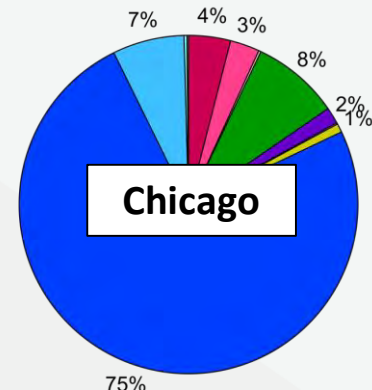
Understand the role of urban emissions in ozone (O₃) and fine particle (PM_{2.5}) formation



Motivated by CIESRDS-NOAA research on changing emissions sources over time.

Saturated Oxygenated VOCs, associated with VCPs (and cooking), contributed the most to OH-reactivity.

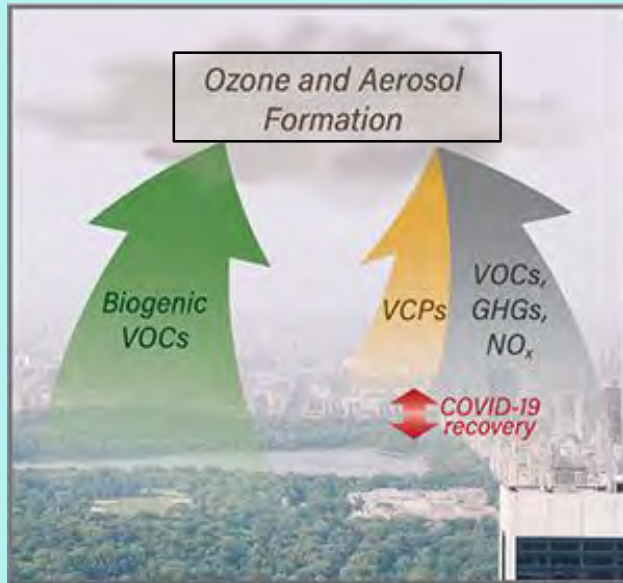
Isoprene & monoterpenes, associated with biogenics and VCPs, contributed more to OH-reactivity in NYC than LA.



AEROMMA provided an understanding of pollutant formation pathways and future tendencies.

2

Understand the role of urban emissions in ozone (O₃) and fine particle (PM_{2.5}) formation



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Volatile Organic Compounds (VOCs)

+

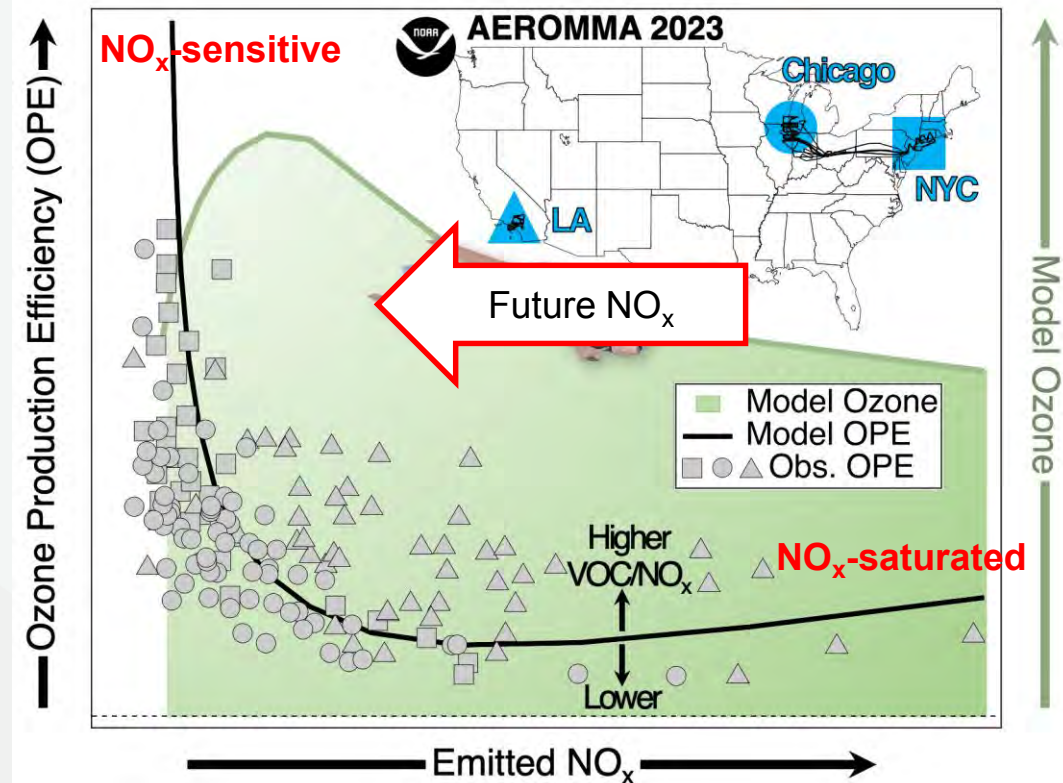
Nitrogen oxides (NO_x = NO + NO₂)



Fine Particles (PM_{2.5})

Ozone (O₃)

Future NO_x reductions will lead to NO_x-sensitive conditions, which will lead to **total reduced ozone**, even though **ozone production will be more efficient**.

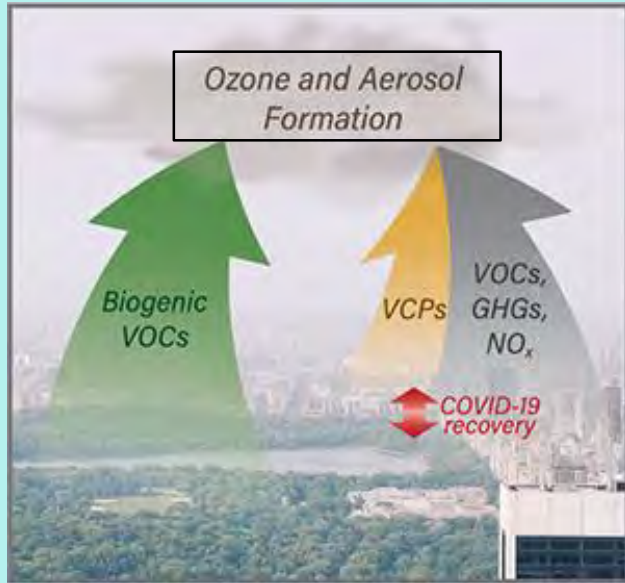


Chace et al., ES&T, 2025.

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Understand the role of urban emissions in ozone (O₃) and fine particle (PM_{2.5}) formation



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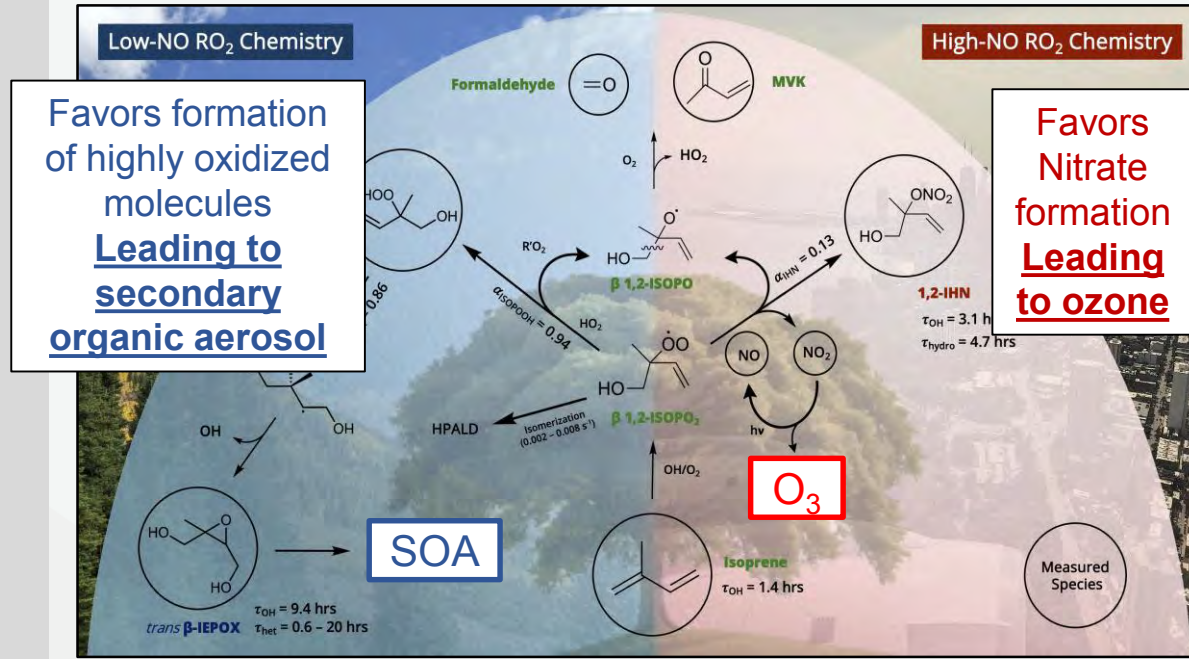
Nitrogen oxides (NO_x = NO + NO₂)



Fine Particles (PM_{2.5})

Ozone (O₃)

In a lower NO_x future, formation of **highly oxidized molecules** will potentially lead to formation of **more secondary organic aerosols**.



Favors formation of highly oxidized molecules **Leading to secondary organic aerosol**

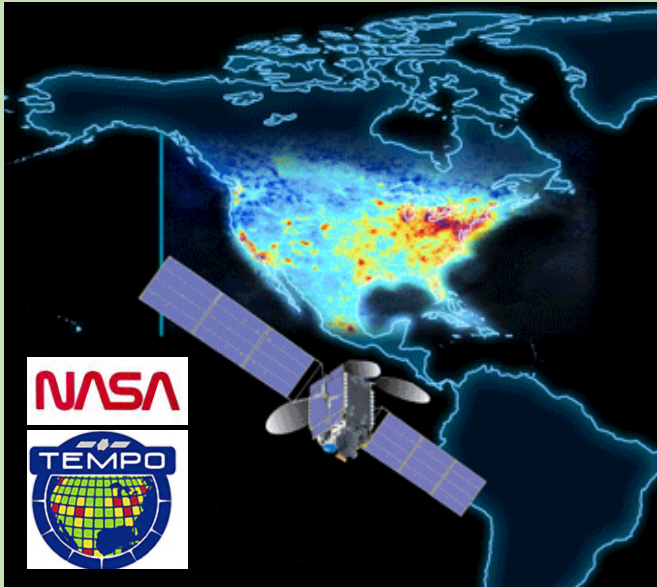
Favors Nitrate formation **Leading to ozone**

Robinson et al., Science Advances, accepted.

AEROMMA *in-situ* observations helped evaluate new high-resolution satellite data products.

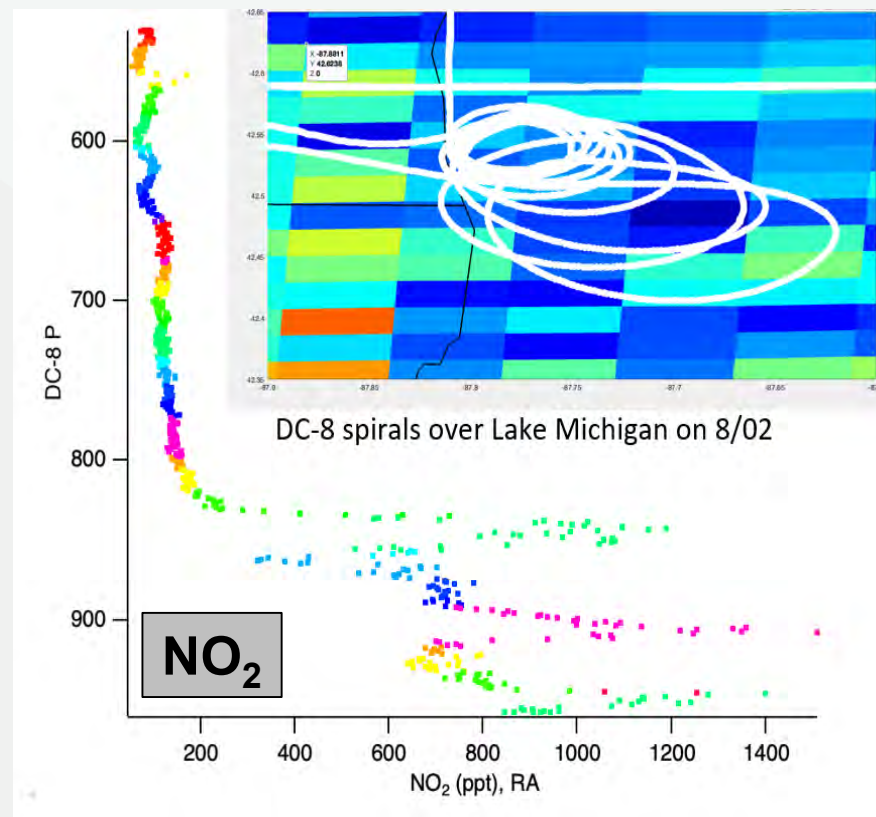
3

Validate new technology for space-based observations of atmospheric composition



Motivated by CIESRDS-NOAA model data assimilation and TEMPO “first light”.

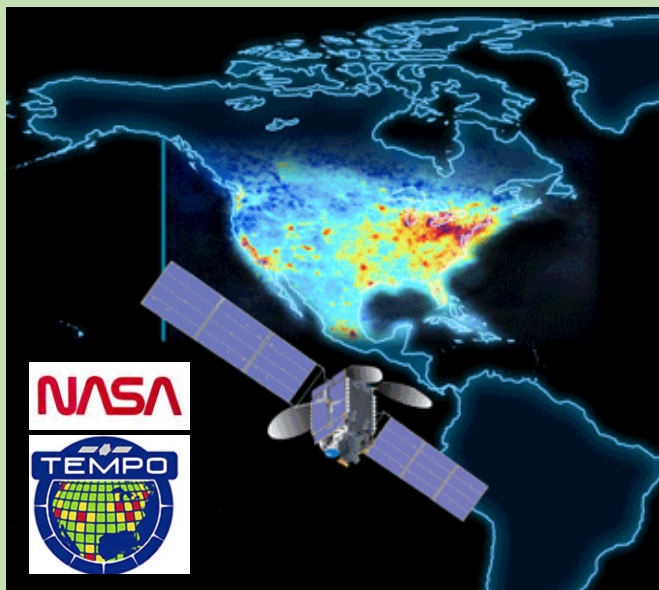
- **NASA’s TEMPO (Tropospheric Emissions: Monitoring Pollution)** is the first ever space-based instrument to monitor air pollutants across North America during daytime at **high spatial (2 x 5 km) and temporal (hourly) resolution**.
- AEROMMA flights were purposefully synchronized with TEMPO overpasses and provided “first light” measurement validation.



AEROMMA *in-situ* observations helped evaluate new high-resolution satellite data products.

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Validate new technology for space-based observations of atmospheric composition



Motivated by CIESRDS-NOAA model data assimilation and TEMPO "first light".

TEMPO satellite retrievals show strong agreement with AEROMMA *in-situ* airborne observations.

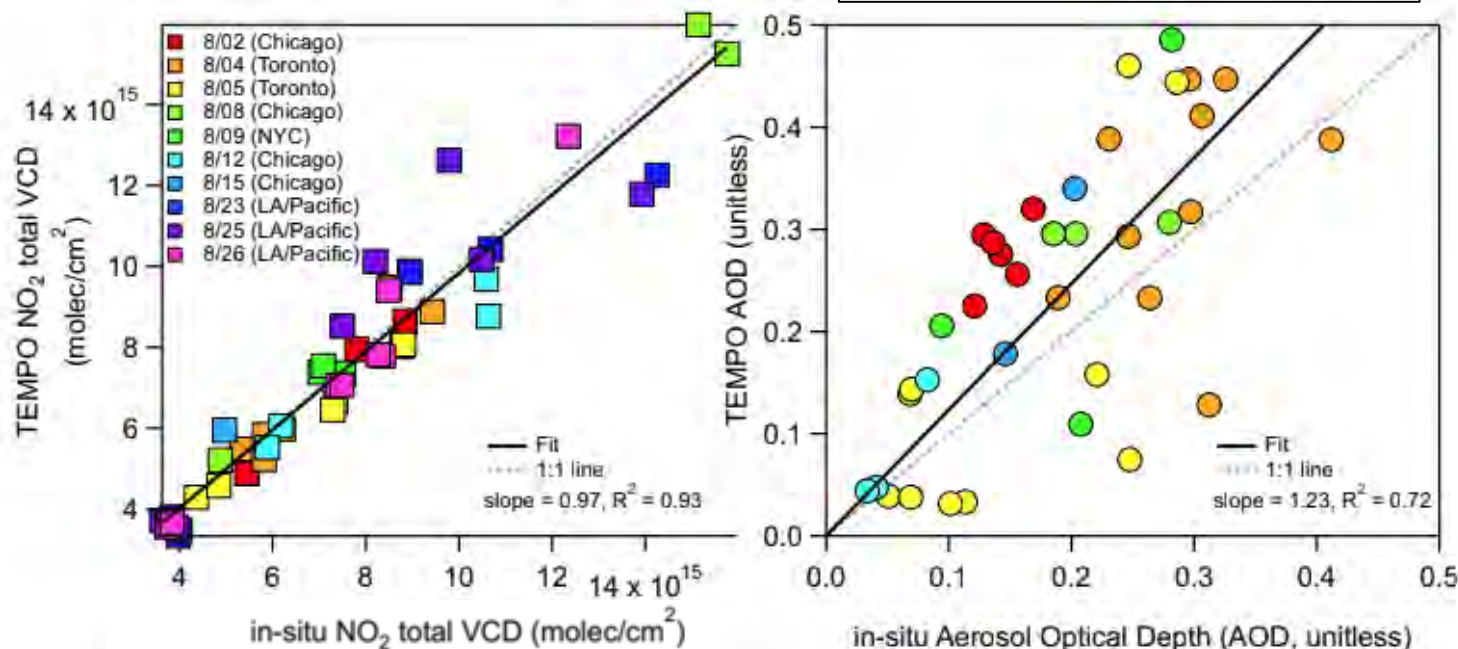
NO₂

an ingredient in O₃ formation
Waxman et al., in prep.

Aerosol optical depth

a measure of sunlight extinction and planetary "cooling"
Huynh et al., in prep.

TEMPO



AEROMMA

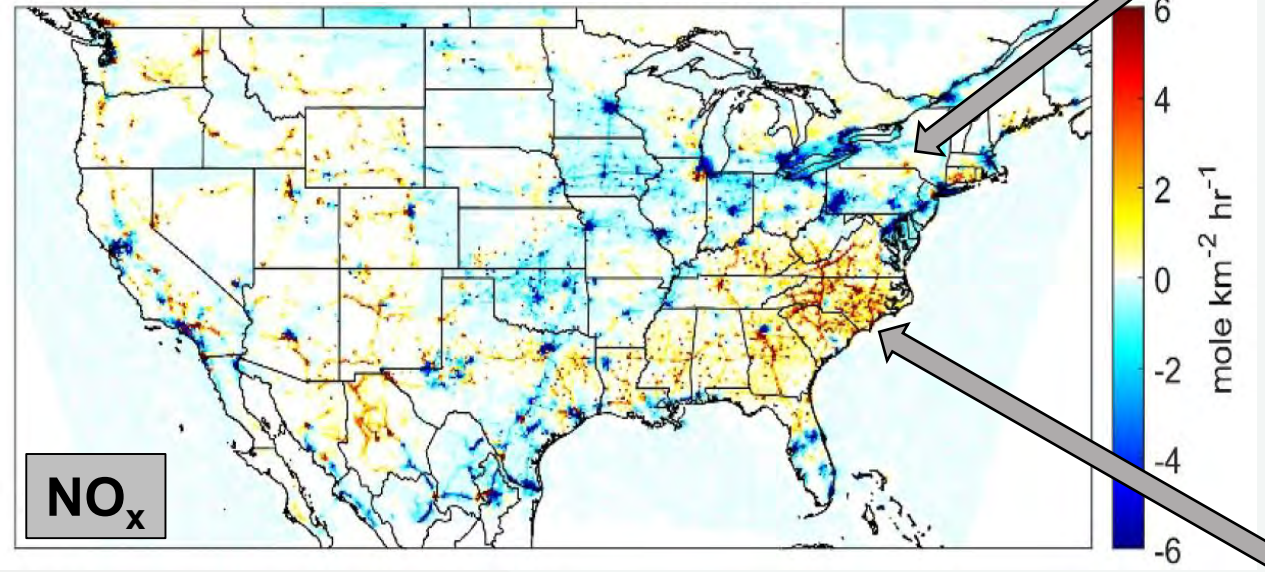
Assimilating AEROMMA-validated TEMPO data into emissions inventories improves models, forecasts, and R2O.

4

Evaluate and improve emissions inventories, models, and forecasts

- Air quality forecast models rely on input from bottom-up emissions inventories.
- Emissions inventories can be improved through data assimilation of high-resolution satellite observations.
- Assimilation of TEMPO data, validated by *in-situ* AEROMMA observations, improves model simulations.

TEMPO adjustments of a bottom-up inventory



Cool colors indicate where inventory emissions were adjusted down.

Warm colors indicate where inventory emissions were adjusted up.

Hsu et al., JGR, 2026

Research to operations (R2O):

AEROMMA and TEMPO data helped develop a new, high-resolution, “one-stop-shop” emissions inventory for air pollutants.

Lyu et al., JGR, 2025.



<https://csl.noaa.gov/groups/csl4/gra2pes/datasets/>

CIESRDS scientists are key to AEROMMA's success!



See more AEROMMA science findings and data products at:
<https://csl.noaa.gov/projects/aeromma/>



Members of the AEROMMA Science Team at Wright Patterson Air Force Base in Dayton, OH.

Credit: Mónica Vázquez González

59+ CIESRDS researchers contributed to AEROMMA

Adam Ahern	Christopher Jernigan	Victoria Treadaway
Ken Aikin	Jan Kazil	Siyuan Wang
Sarah Albertin	Meng Li	Eleanor Waxman
Wayne Angevine	Ming Lyu	William Weston
Sunil Baidar	Congmeng Lyu	Caroline Womack
Kelvin Bates	Nate Malarich	Lu Xu
Brian Carroll	Richard Marchbanks	Quindan Zhu
Wyndom Chace	Brandi McCarty	Michael Zucker
Kai-Lan Chang	Rich McLaughlin	Kristen Zuraski
Owen Cooper	Georgia Michailoudi	<i>...and more</i>
Zachary Decker	Arthur Mizzi	
Samantha DeLone	Gordon Novak	
Tony Fodel	Jeff Peischl	
Colby Francoeur	Alison Piasecki	
Harrold Gamarro	Ilana Pollack	
Audrey Gaudel	Cathy Rasco	
Colin Gurganus	Quazi Rasool	
Colin Harkins	Michael Robinson	
Xen Hasnat	Nell Schafer	
Jian He	Morgan Selby	
Max Holloway	Christoph Senff	
Nate Howard	Chelsea Stockwell	
Howard Hsu	Ed Strobach	
Han Huynh	Sam Taylor	
Nazrul Islam	Richard Tisinai	

plus 4 summer interns/visiting scholars

Thank you!

Questions?

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17 Peer-reviewed publications
(many more in prep/review)
100+ Conference presentations
20+ Press releases
4 Datasets published



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