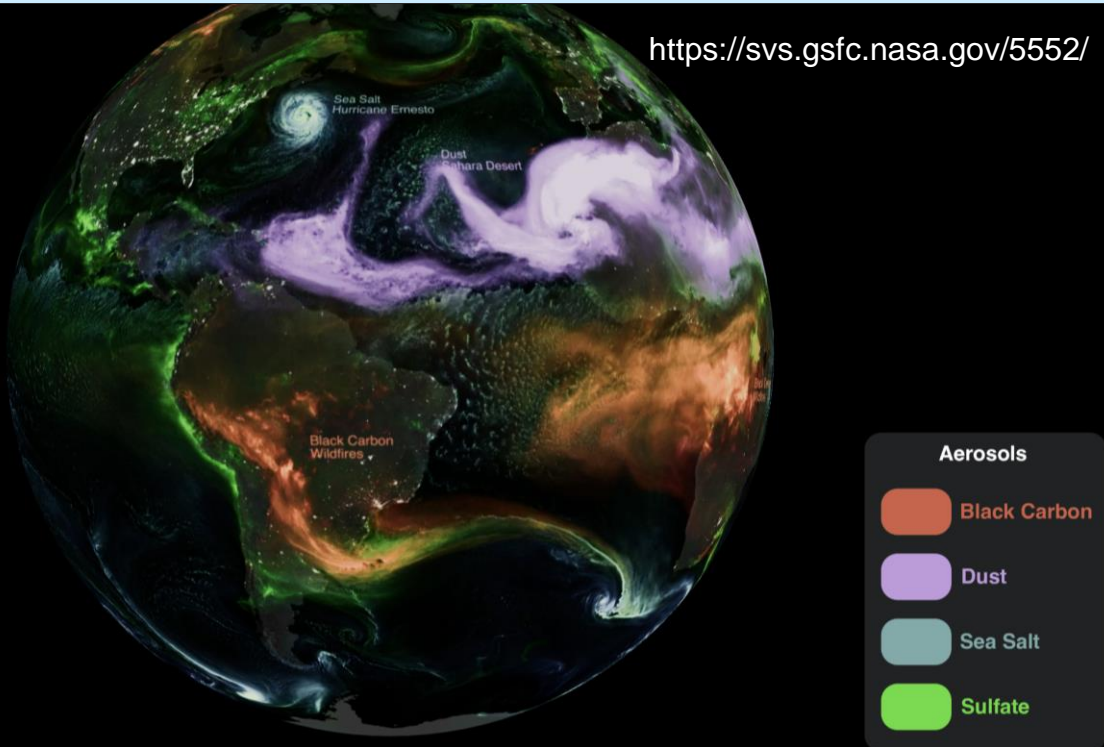


# Air Quality – Health – Climate Connections



Roadmap for today:

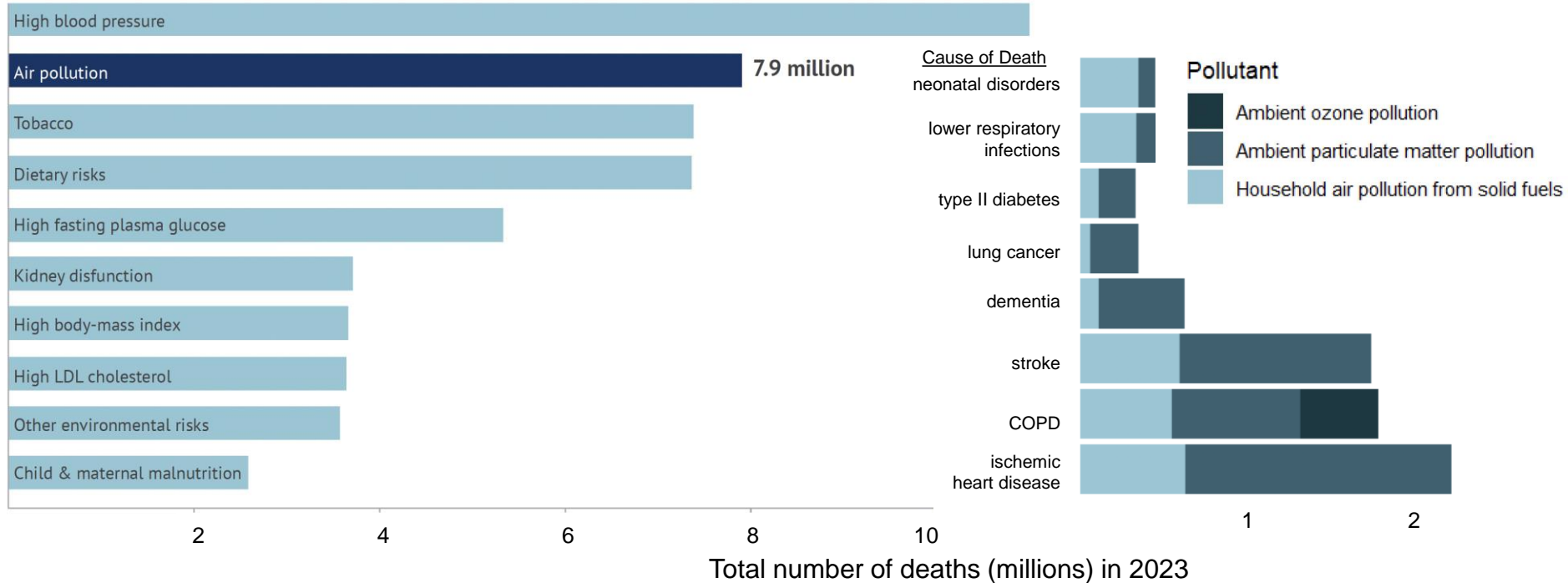
1. Satellite data in global health
2. Local-to-global impacts of air pollution
3. Compound extremes

Arlene M. Fiore  
amfiore @ mit.edu | teampacc.mit.edu



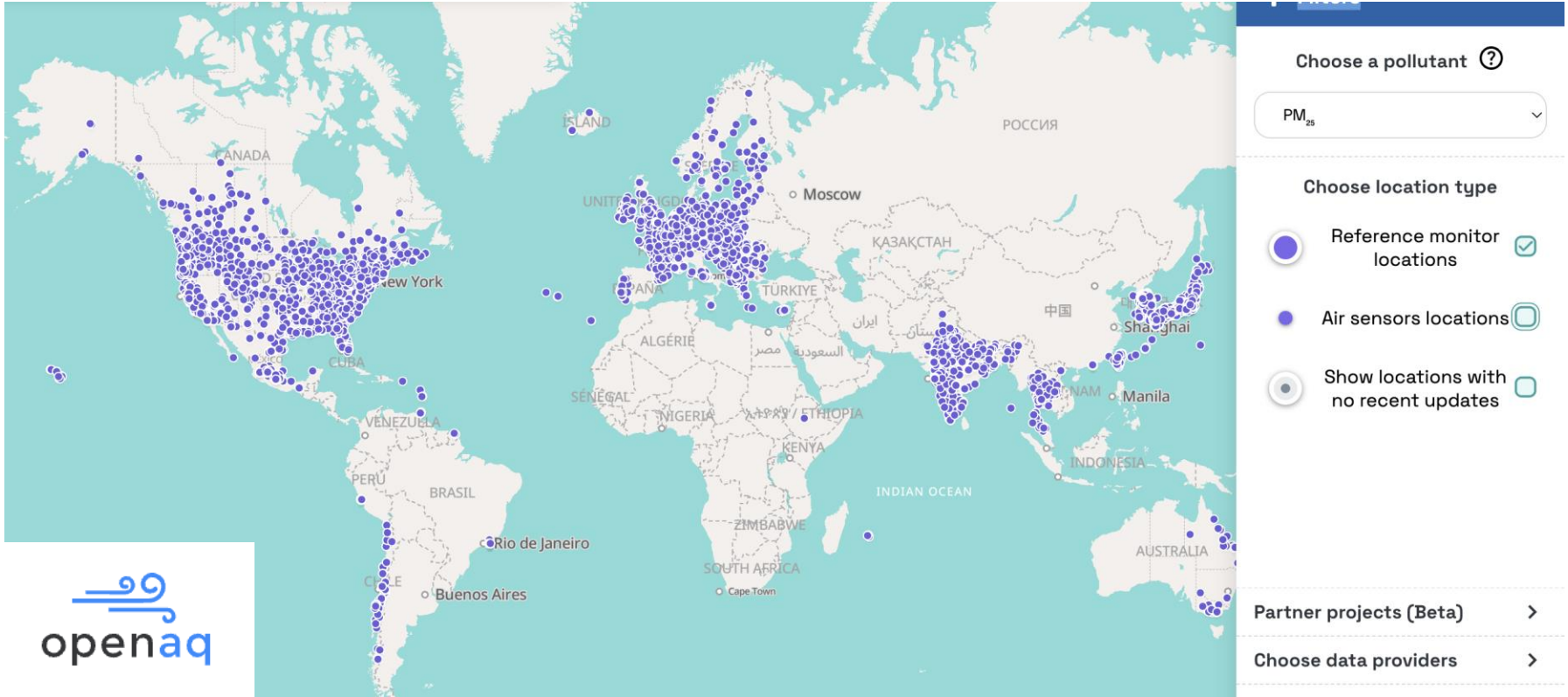
Global Change Forum 48  
MIT, Cambridge, MA  
March 26, 2026

# Air pollution consistently ranks among the top leading risk factors for global premature mortality



→ Ranks 2<sup>nd</sup> in the latest “State of Global Air/2025” (dominated by ambient (Health Effects Institute & Institute for Health Metrics and Evaluation’s Global Burden of Disease Project))

# Vast regions of the planet do not have a single publicly available high-quality measurement for particulate matter (or other air pollutants)



<https://explore.openaq.org/?parameter=pm25&sensors=false>

# Global exposure to fine particles (PM<sub>2.5</sub>) for health studies

derived by fusing multiple satellite Aerosol Optical Depth products, models and surface measurements

Annual mean surface PM<sub>2.5</sub> ( $\mu\text{g m}^{-3}$ ) for 2013

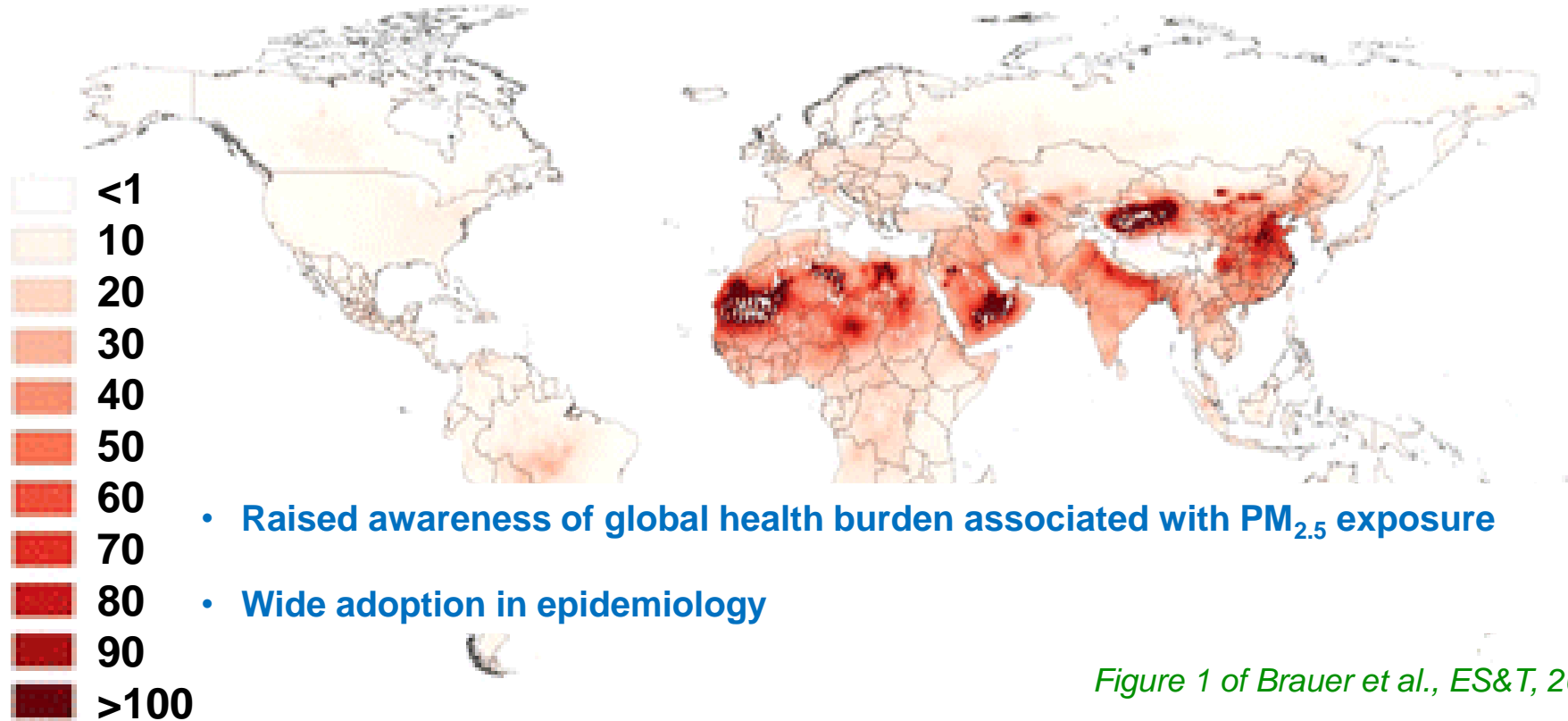
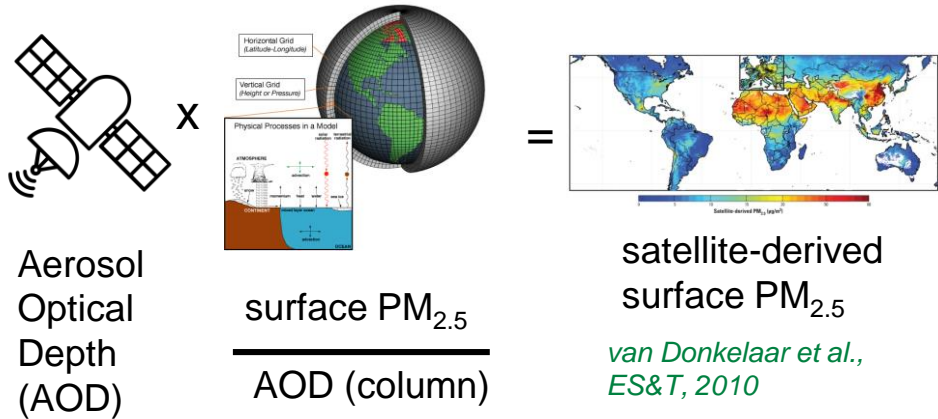


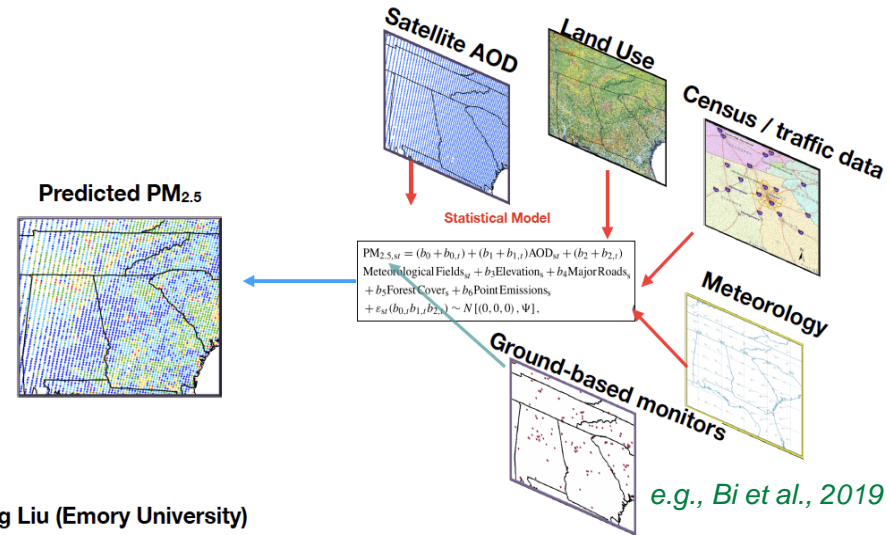
Figure 1 of Brauer et al., ES&T, 2016

# Satellite instruments do not measure “nose-level” air pollution. Near-surface air concentrations must be derived

## 1. Geophysical Approach



## 2. Statistical Approach



→ Key assumptions in both approaches; we'd like quantitative uncertainty estimates

# A new approach to uncertainty quantification: Combine publicly available datasets



COLUMBIA

MAILMAN SCHOOL  
OF PUBLIC HEALTH

INPUT  
EXPOSURE  
DATASETS

Daily  $PM_{2.5}$

Bi et. al 2019



Di et. al 2021



EQUATES  
(EPA Air  
QUALity Time  
SEries)



FAQSD  
(Fused Air  
Quality Surface  
Downscaling)



WRF-CMAQ  
with AOD, CO  
(R. Kumar et. al  
2021)



*Paisley et al., 2022; Liu et al., 2019*

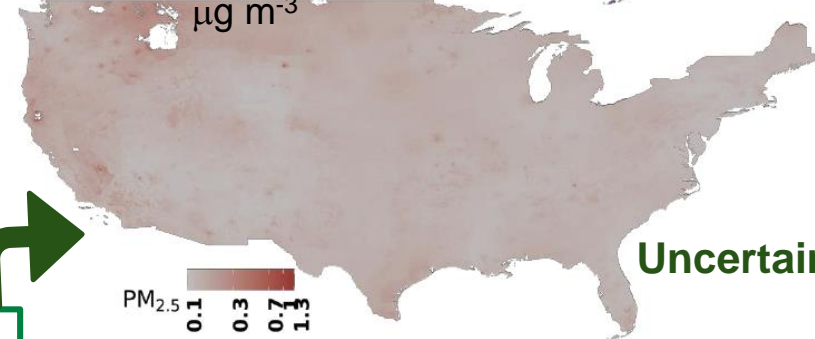
## Bayesian Nonparametric Ensemble

& bneR collaborative workflow tool (*Benavides et al., J. Env. Mgmt, 2025*)

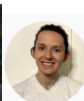
## BNE products: 2015 annual mean $PM_{2.5}$



Best Estimate



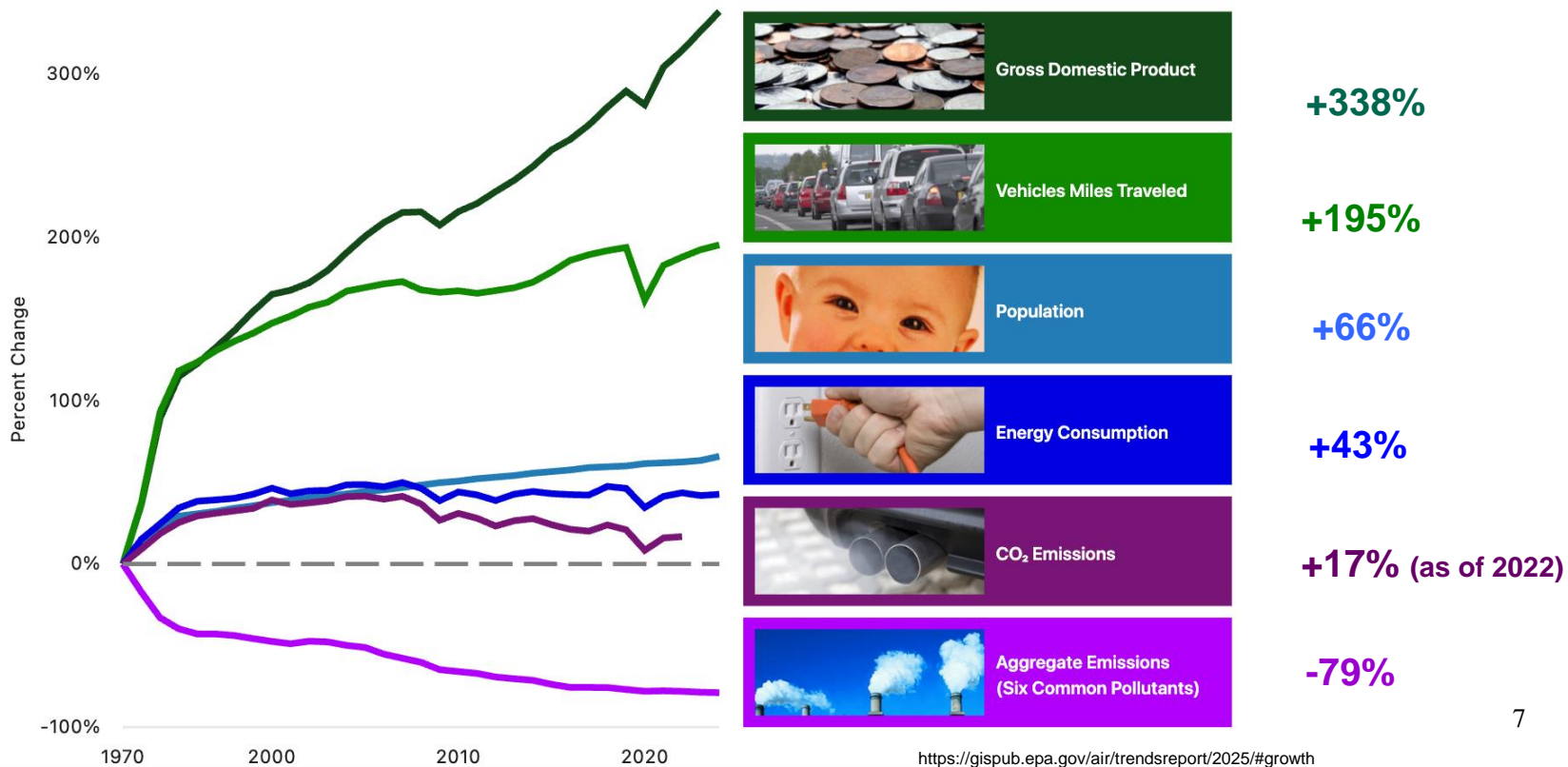
Uncertainty



[M. Kioumourtzoglou](#)  
[J. Benavides](#)  
[V. Kumar](#)  
[C. Carrillo-Gallegos](#)

# Celebrating success: Cleaner air alongside economic growth

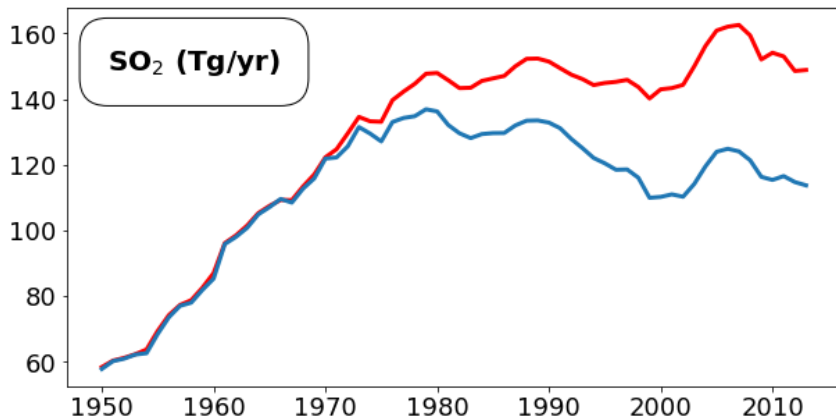
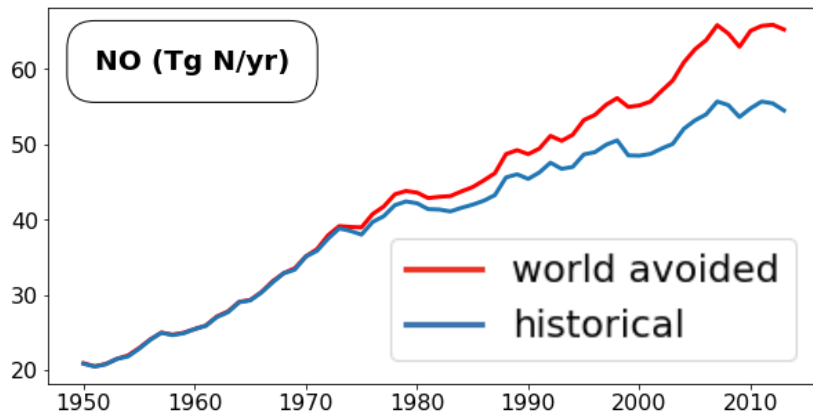
Comparison of Growth Areas and Declining Emissions  
1970-2024



# An alternate measure of success:

## A counterfactual 'world-avoided' U.S. air pollutant emission scenario

### Global Air Pollutant Emissions



Fully-coupled chemistry-climate 13-member initial-condition ensembles (CESM2-WACCM6)

NCAR | COMMUNITY EARTH SYSTEM MODEL <sup>CESM</sup>

Scenario	Emissions	Years
<b>HIST</b>	CMIP6 CEDS historical	1950–2013
<b>USfrozenEF</b> c/o S. Smith (PNNL)	“world-avoided”	1970–2013

See Fiore et al. (*Env. Res.: Climate*, 2022) for details on HIST ensemble

*Elkins et al., npj Clean Air, 2025*

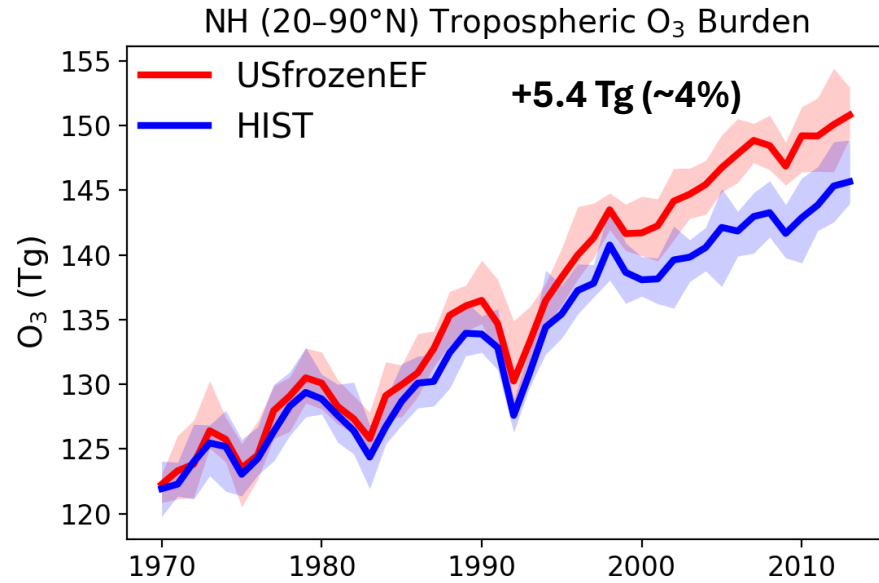
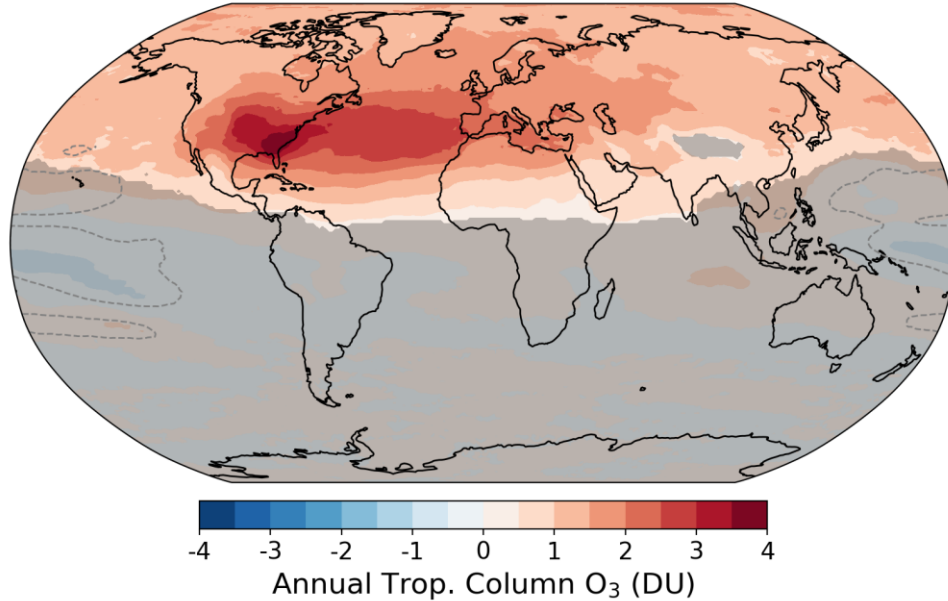


# NH tropospheric ozone response is robust to internal variability

NH: +1.5 DU (~4 %)

US: +2.3 DU (~6 %)

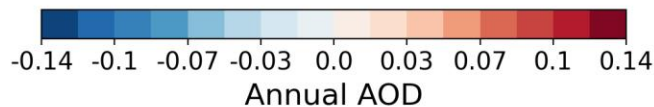
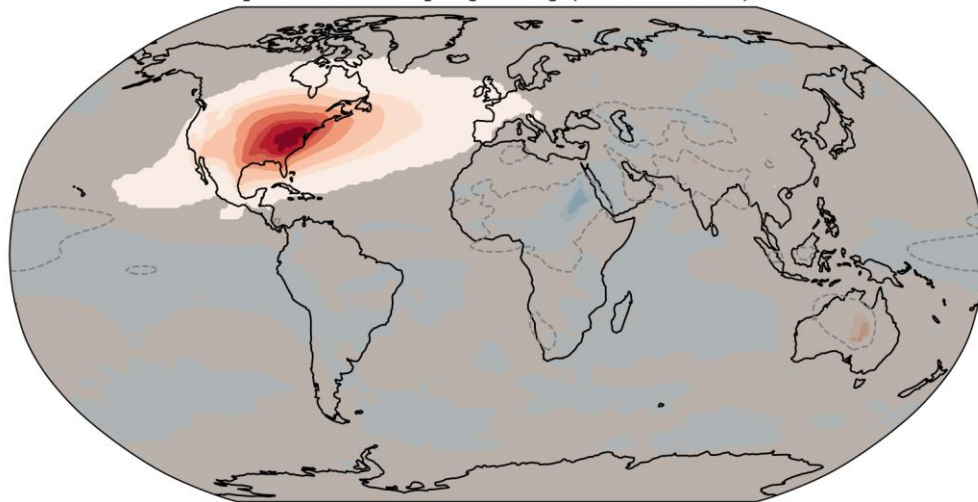
[USfrozenEF] - [HIST] (2004-2013)



# Aerosol response is localized near the source region

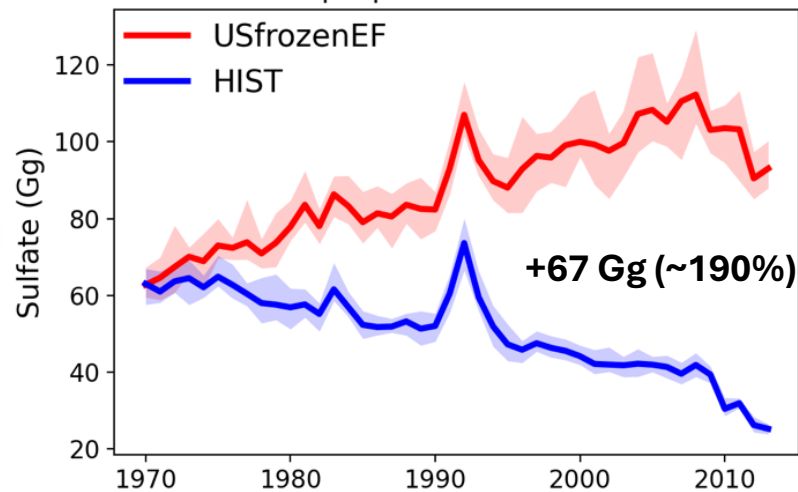
**US: +0.06 (~100%)**

[USfrozenEF] - [HIST] (2004-2013)



$\Delta AOD_{\text{sulfate}} \sim 90\% \text{ of } \Delta AOD_{\text{total}}$

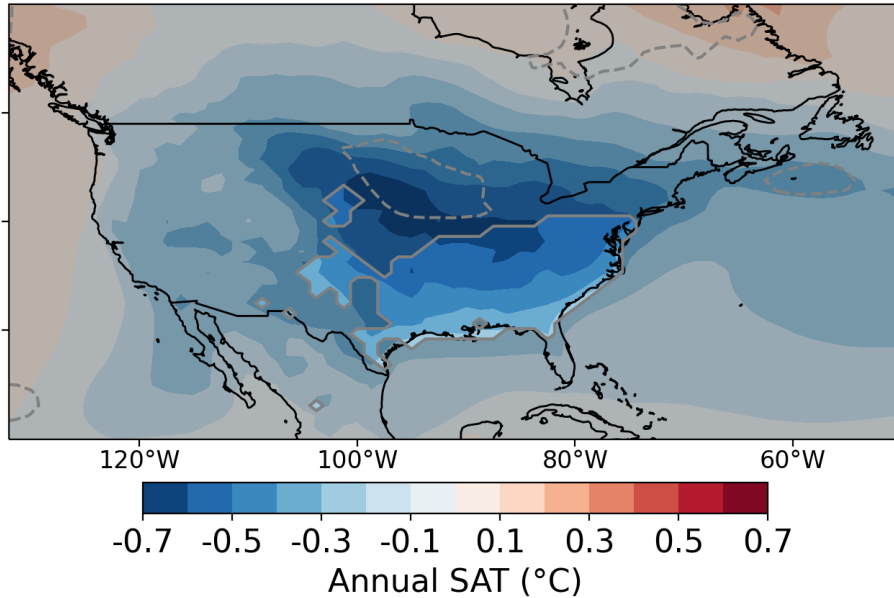
US Tropospheric Sulfate Burden



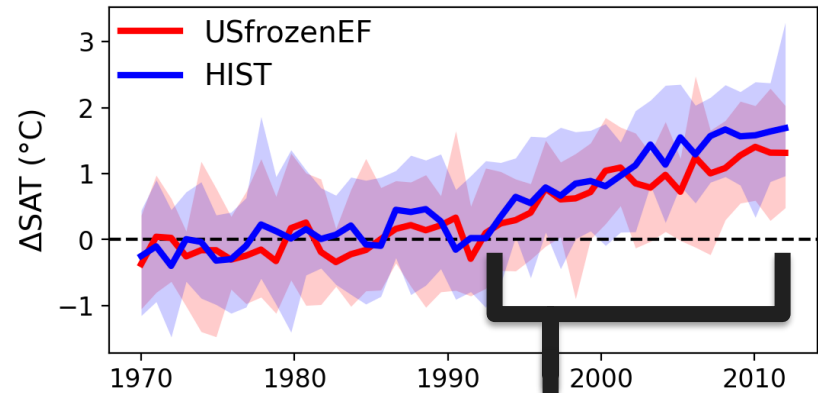
# Stronger regional masking of GHG-driven warming in [USfrozenEF] relative to [HIST]; signal detection challenging amidst internal variability

US avg: -0.4 °C

[USfrozenEF] - [HIST] (2004-2013)



US  $\Delta$ SAT since 1950-1969

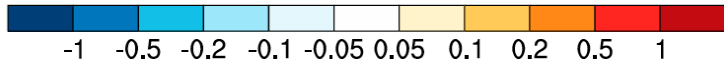
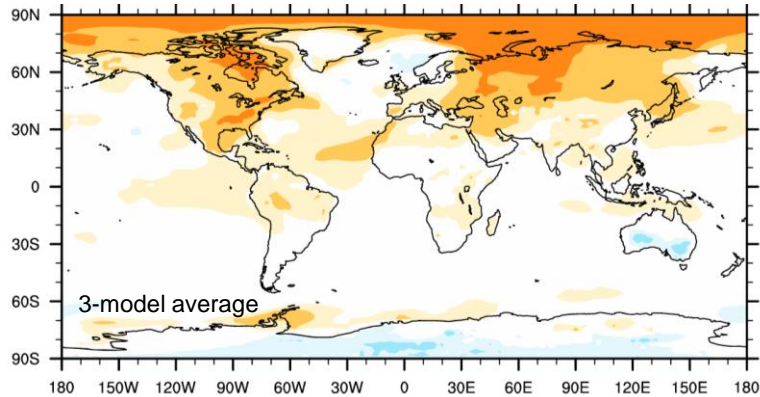


0.2 °C per decade slower warming in [USfrozenEF] than [HIST] from 1990-2013



# Earlier work demonstrates the global reach of regional air pollution: Tropical rain belt over Africa shifts when NH warms relative to SH (Synergy?)

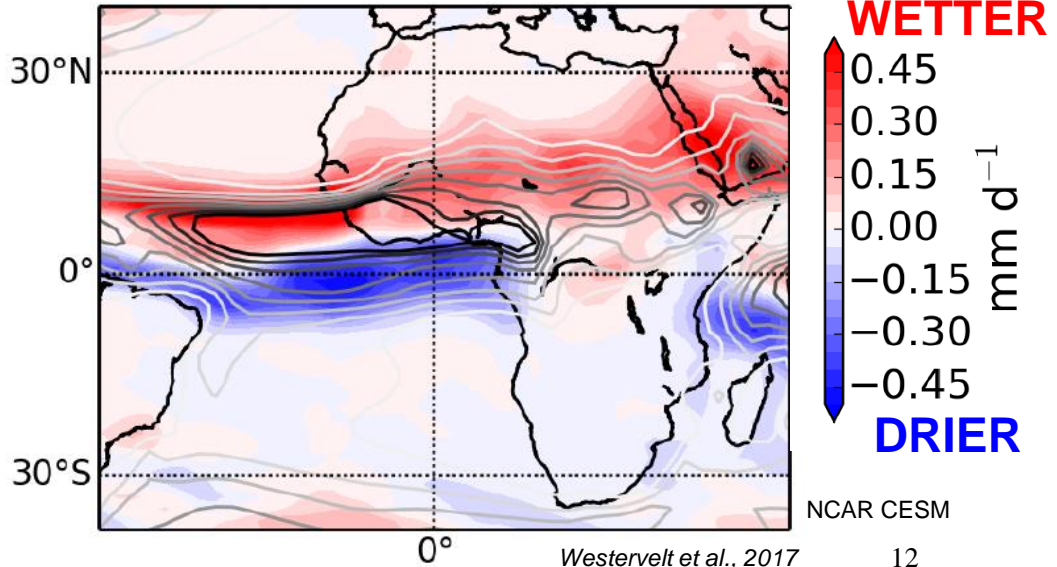
N. Hemisphere warms more than S Hemisphere



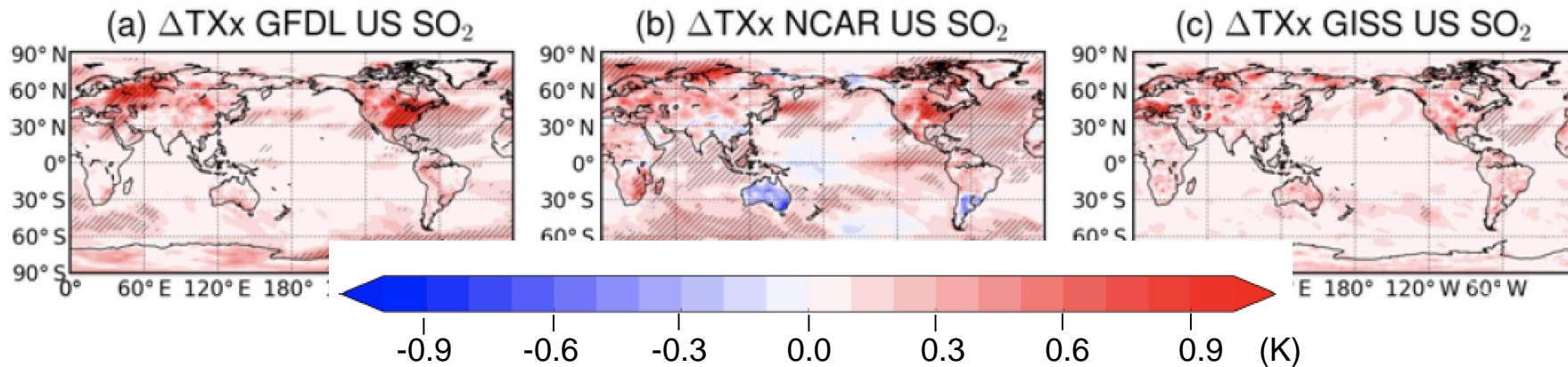
Conley et al., 2018



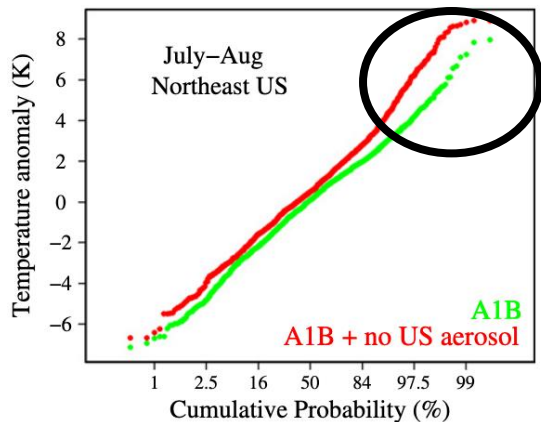
Rainfall increases over the Sahel



# Tradeoff: Hottest day of the year warms by as much as +1 °C locally when U.S. SO<sub>2</sub> emissions are shut off



*Westervelt et al., ACP, 2020*



Consistent with earlier work that simply removed the entire U.S. aerosol column

*Mickley et al., Atm. Env., 2012*

# Air Quality-Climate-Health Connection: Wildfires!

And a policy question:  
Is ozone produced in transit or after  
smoke mixes with urban  $\text{NO}_x$ ?

June 7, 2023: Canadian  
wildfire plumes hit NYC



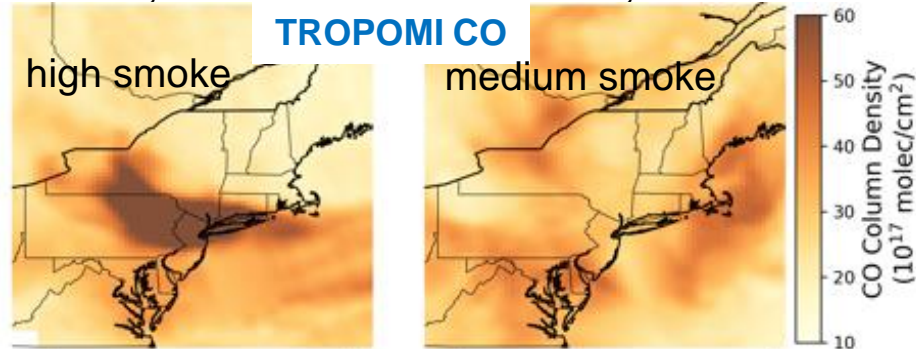
New York City on Wednesday. COPYRIGHT 2023 THE ASSOCIATED

PHOTOS: ALL RIGHTS RESERVED

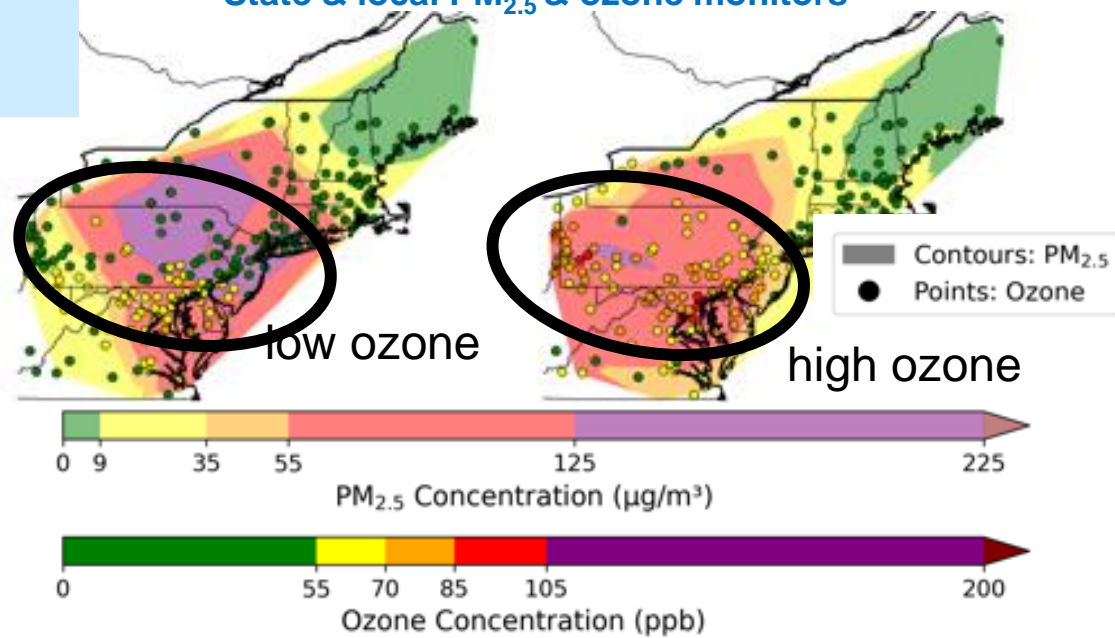
J. Palmo **\*\*Work in progress\*\***

June 7, 2023

June 29, 2023



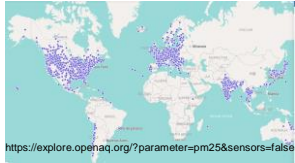
State & local  $\text{PM}_{2.5}$  & ozone monitors



# Some thoughts on tapping synergies while identifying tradeoffs with air quality – health – climate connections

## 1. Continue to expand observing capacity

- many world regions severely under-monitored
- uncertainty in concentration (& exposure) propagates to health studies
- new opportunities to extract process-level insights by combining computational advances + ever-longer records (e.g., satellite)



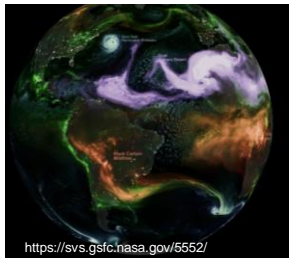
## 2. Characterize and understand compound risks (e.g. extreme events)

- Wildfires: At the nexus of climate-health-air quality
- Heat: Air pollution may both drive and respond to temperature extremes



## 3. Assess multiple impacts from health-motivated emission controls

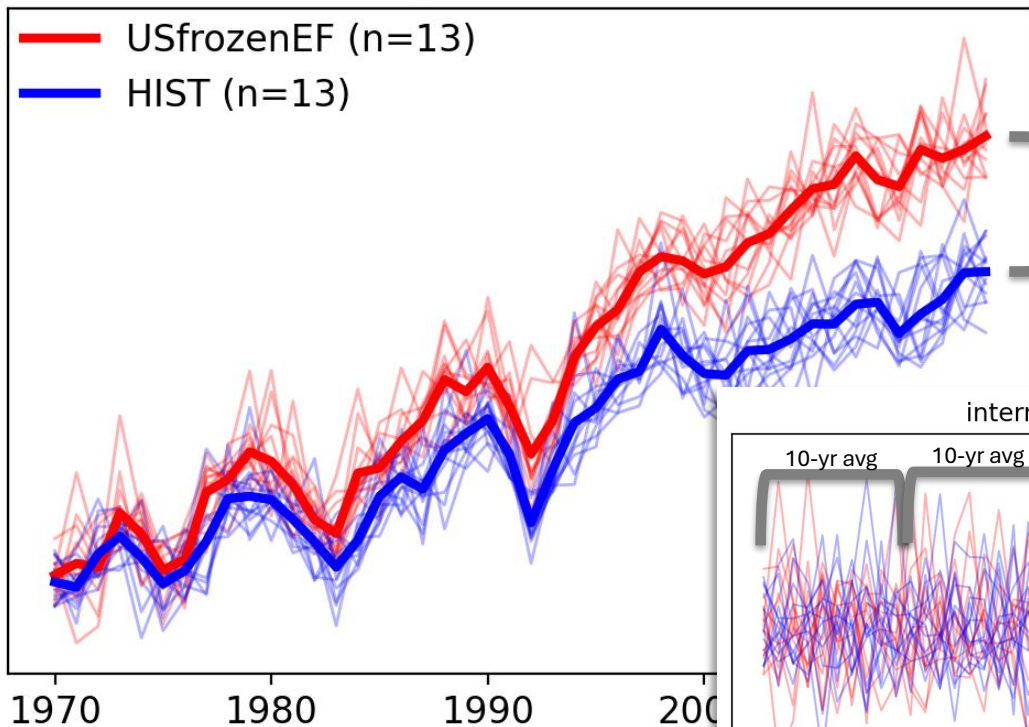
- place climate/health/ecosystem/air quality changes in the context of natural variations
- diagnose system *sensitivities*
- develop tools that can rapidly assess impact (reduced-form models, emulators)





# Our initial-condition ensemble modeling approach allows us to test for robustness relative to naturally-arising internal variability

chemistry or climate variable

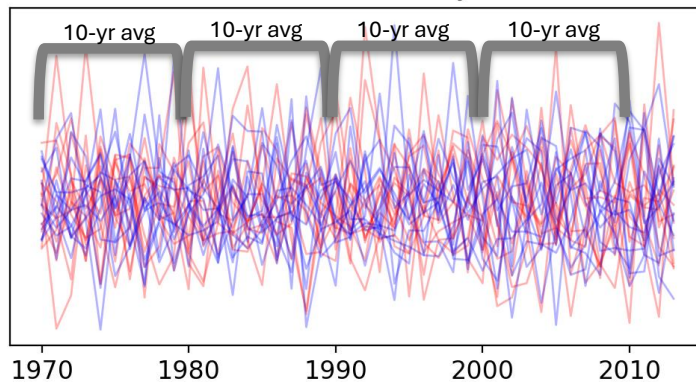


End-of-time period (2004-2013)  
ensemble mean difference:

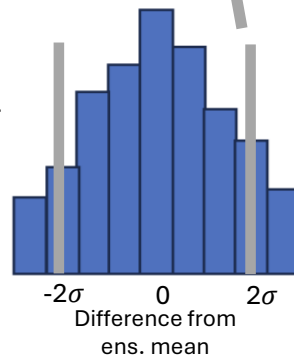
$$[\text{USfrozenEF}] - [\text{HIST}]$$

signal  
noise

internal variability



# of samples



c/o S. Elkins