Global Change Impacts on Air Quality and Health

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XLVI MIT Global Change Forum
Physical and Health Impacts
March 28, 2024

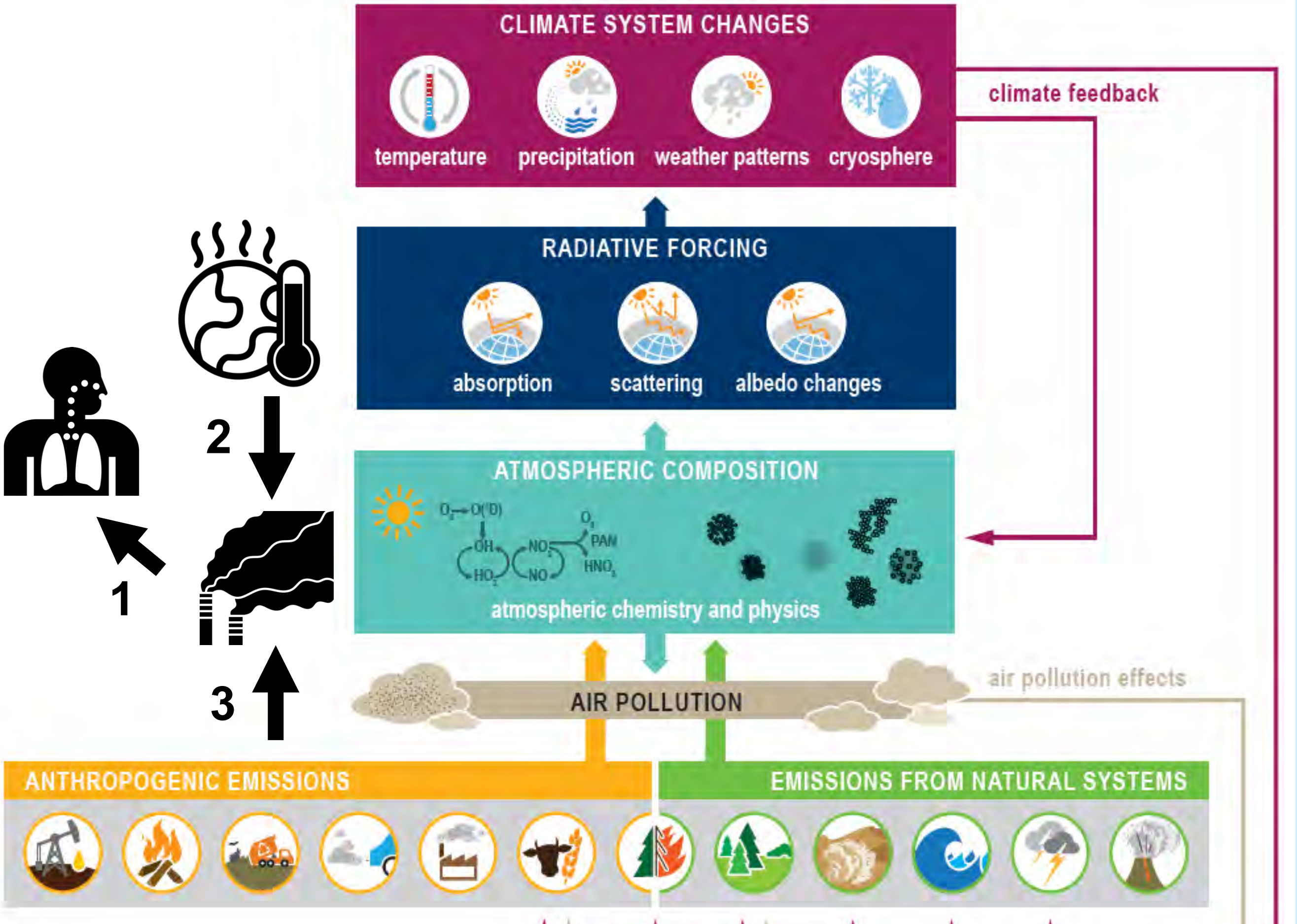


Figure 6.1
IPCC AR6 Ch6 (Szopa et al., 2021)

Exposure to air pollution is a leading risk factor for premature mortality

FIGURE 1 Global ranking of risk factors by total number of deaths from all causes in 2019.

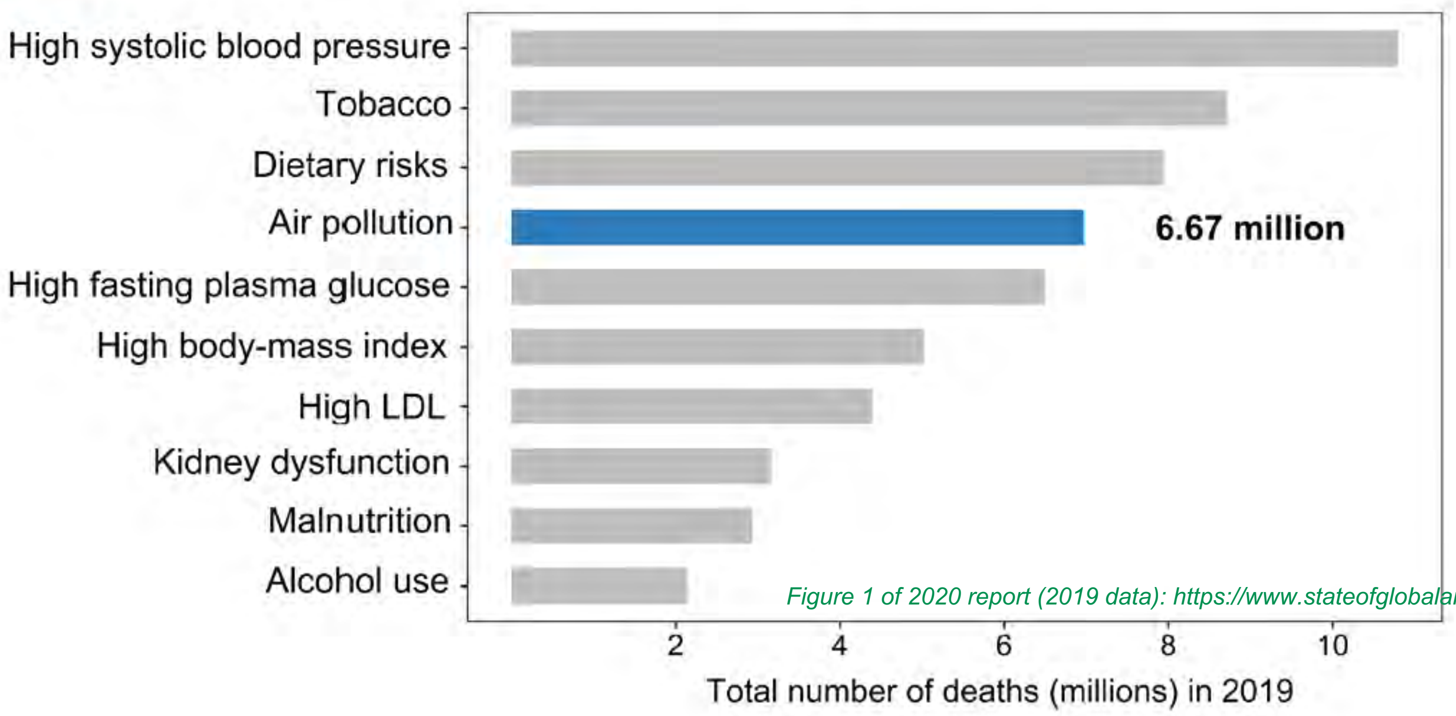
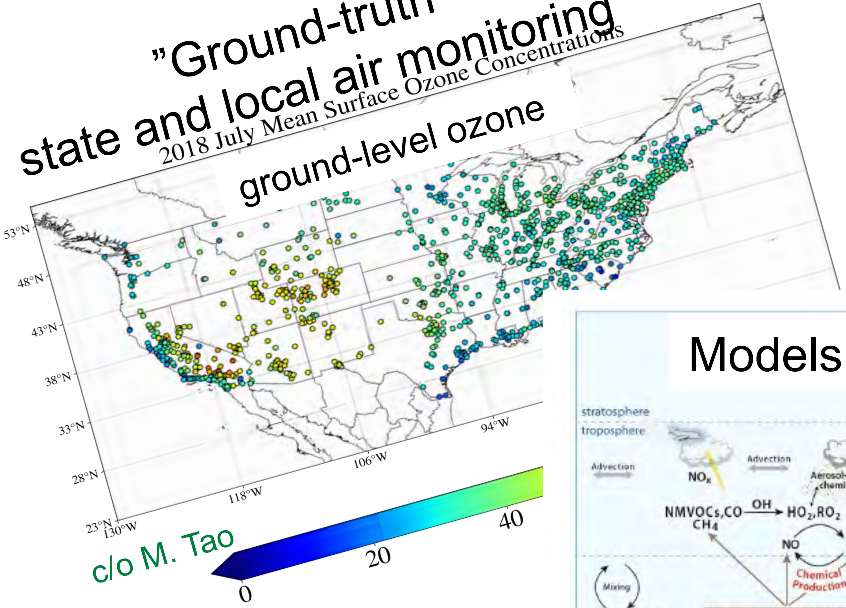


Figure 1 of 2020 report (2019 data): https://www.stateofglobalair.org/resources

→ Top air pollutants are fine particulate matter (aerosols) and tropospheric ozone

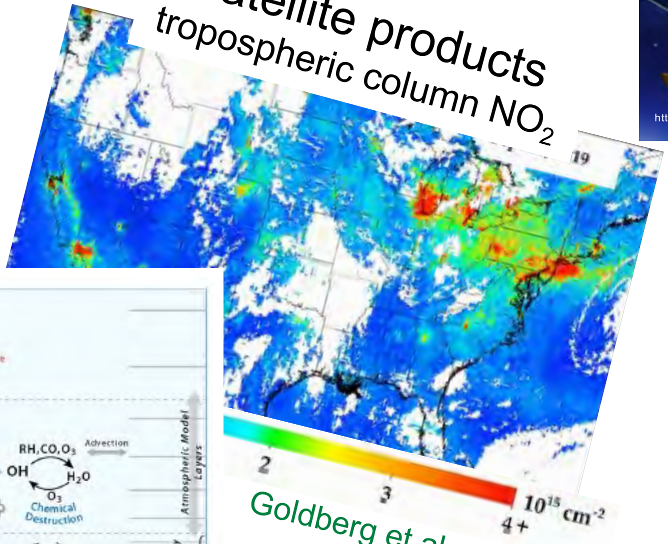
Key Challenge #1: Uncertainties in quantifying exposure to the two top air pollutants (ozone and fine particles)

"Ground-truth"
state and local air monitoring



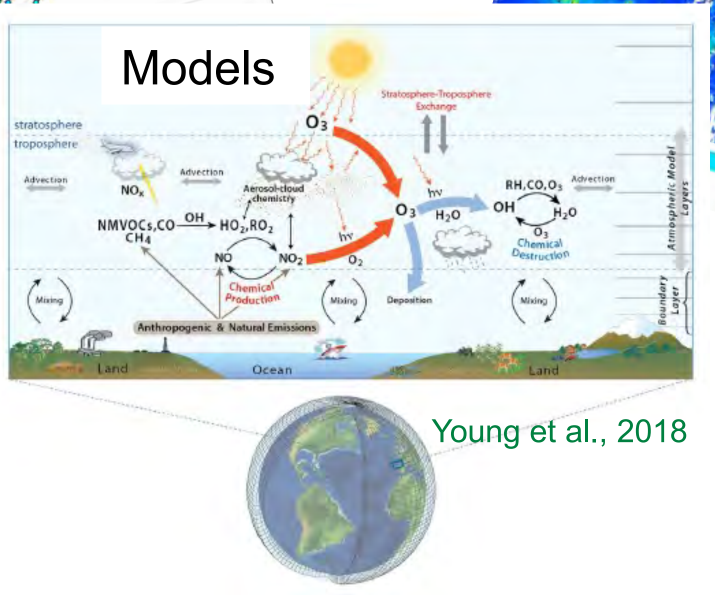
c/o M. Tao

Satellite products
tropospheric column NO_2

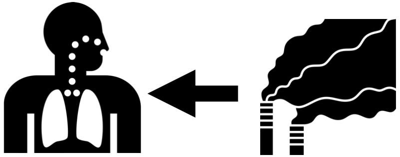


Goldberg et al., 2021

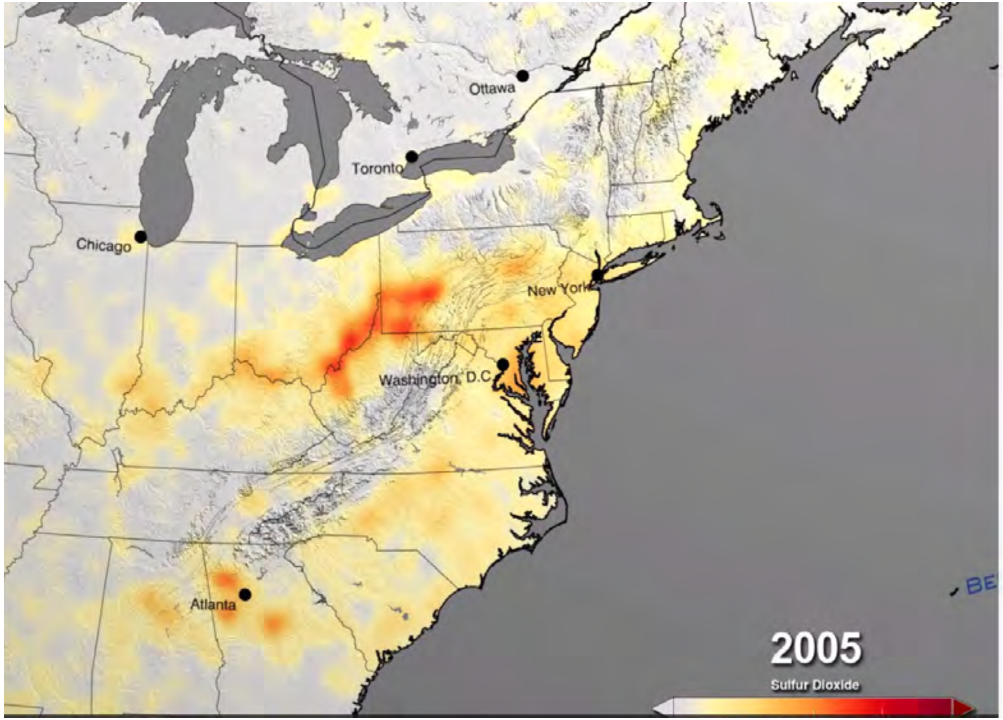
Models

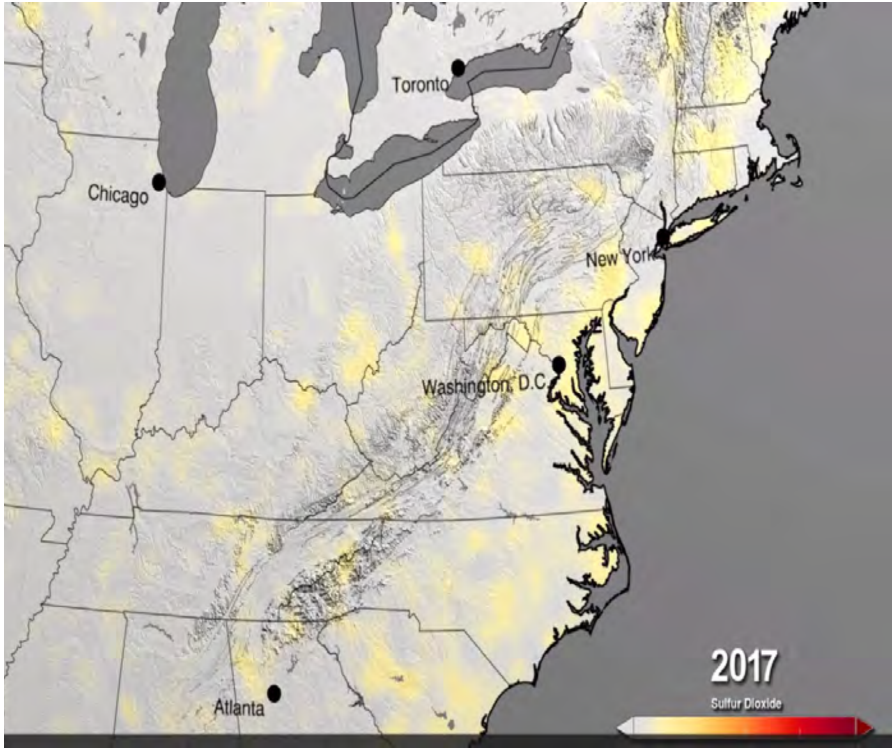


Young et al., 2018



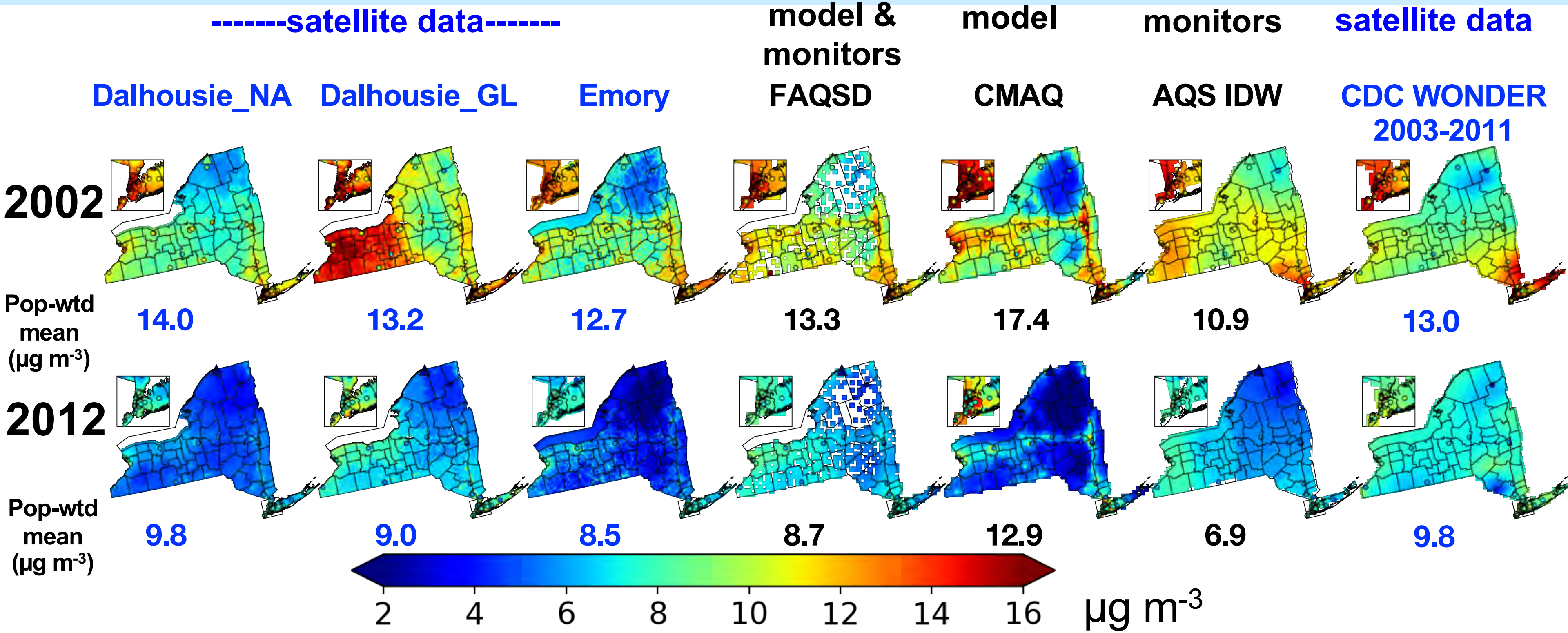
The view from space: Declining sources of fine particles in recent decades over some world regions (e.g., sulfur dioxide (SO_2) over eastern U.S.A.)





OMI/Aura product, https://airquality.gsfc.nasa.gov/

Air pollutant ($PM_{2.5}$) concentrations are needed to implement air quality standards & for use in health impact studies, but uncertain



→ Consistent decrease observed in seven $PM_{2.5}$ products despite discrepancies

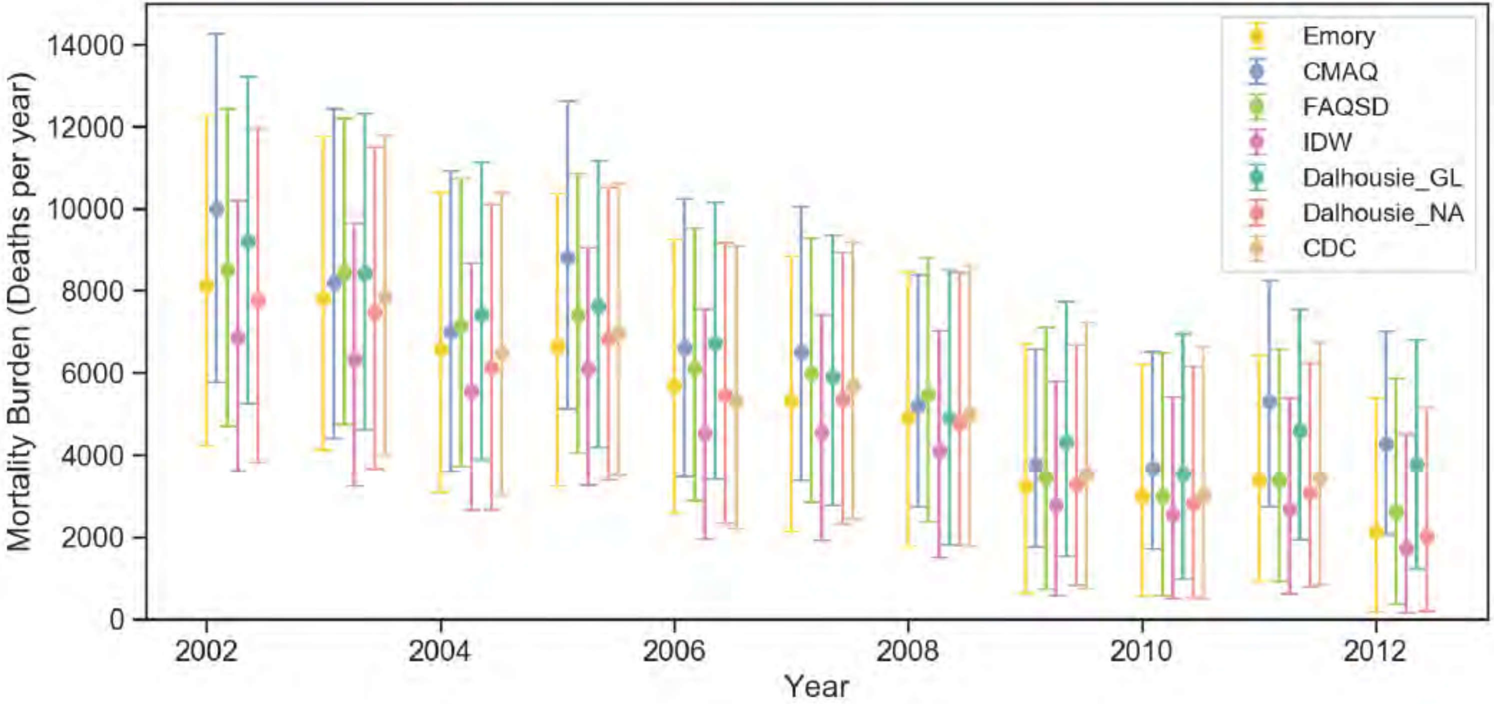
(by 4.2-4.6 μg m^{-3}; 25-36%) despite 6 μg m^{-3} range in population-weighted mean $PM_{2.5}$ in 2002

Jin et al., Environ. Res. Lett., 2019

Robust finding across all $PM_{2.5}$ datasets: Lower $PM_{2.5}$ in 2012 vs. 2002 saves lives in New York State (annual mortality burden decreased by >60% from 2002 to 2012)

Excess mortality burden attributed to $PM_{2.5}$ exposure* =

Baseline Mortality × Attributable Fraction (Relative Risk, function of $PM_{2.5}$) × Population



*Uses GBD 2010 methods; integrated exposure-response model of Burnett et al (2014) developed from a meta-analysis; Ischemic Heart Disease (IHD) is the leading cause

Jin et al., Environ. Res. Lett., 2019

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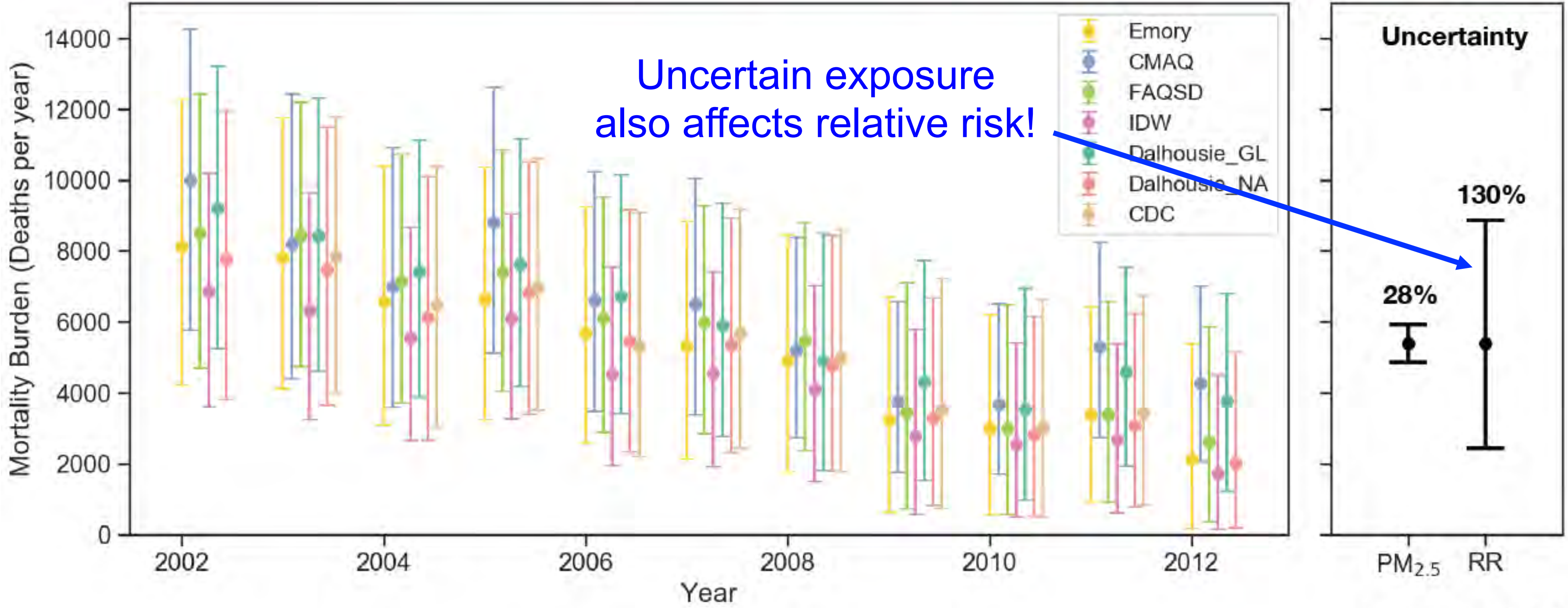

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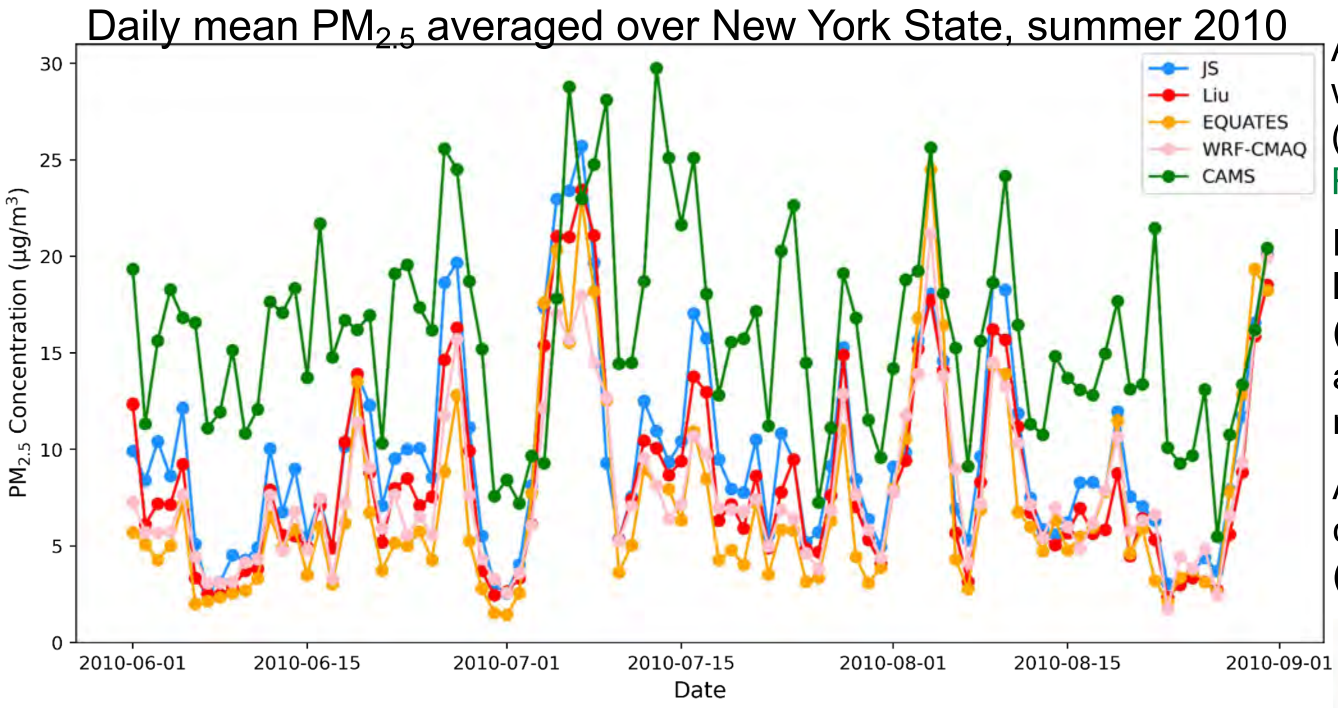
Jin et al., Environ. Res. Lett., 2019

Publicly available datasets of daily mean surface $PM_{2.5}$ over New York State: Which one should be selected for health studies?



Atmospheric chemistry models with chemical data assimilation (WRF-CMAQ 12 km; CAMS Reanalysis ~75 km)

Machine-learning + satellite + land-use variables + monitors (Bi et al., 2018, 1km) + atmospheric chemistry models (Di et al., 2019 1km)

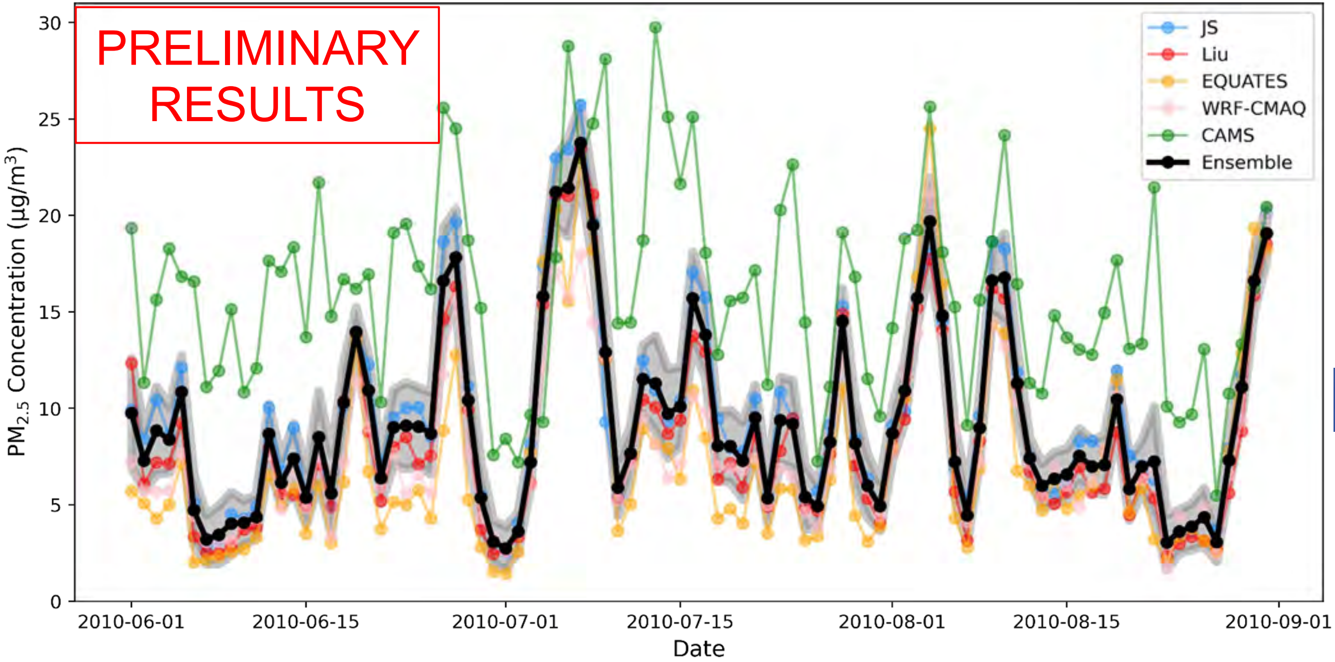
Air quality model without chemical data assimilation (U.S. EPA EQUATES 12 km)

Carlos Carrillo-Gallegos

MIT DEPARTMENT OF EARTH, ATMOSPHERIC AND PLANETARY SCIENCES

A new statistical approach (Bayesian Non-parametric Ensemble, BNE) **to generate a best estimate + uncertainty by combining multiple exposure products**

Daily mean $PM_{2.5}$ averaged over New York State, summer 2010



→ *To be used in epidemiological studies (with NYS DOH)*

Marianthi-Anna Kioumourtzoglou

Sebastian Rowland

Jaime Benavides

Vijay Kumar

COLUMBIA | MAILMAN SCHOOL OF PUBLIC HEALTH

Nation-wide BNE developed under NIEHS support to Kioumourtzoglou [Liu et al., 2019; Paisley et al., 2022]

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Ozone and particulate matter events sometimes co-occur with heat waves, modulated by synoptic-scale weather

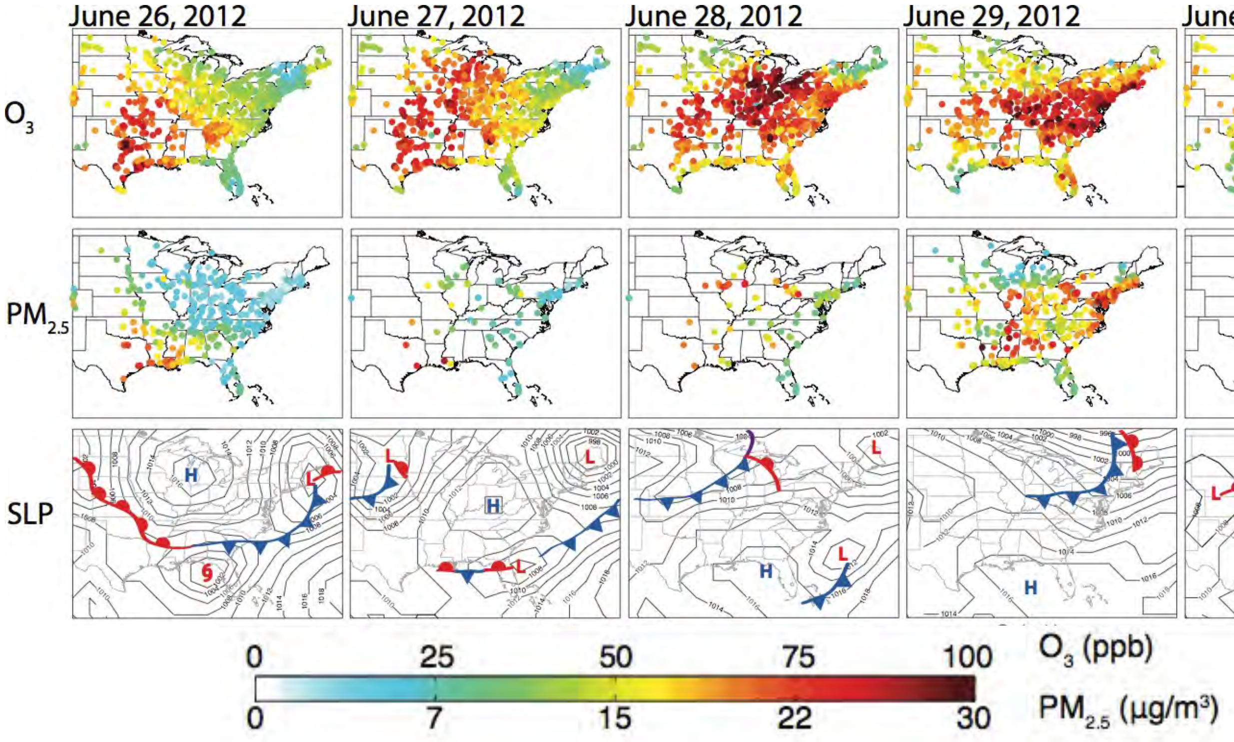
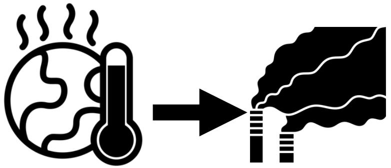


Figure 7 of Fiore, Naik, Leibensperger, JAWMA, 2015

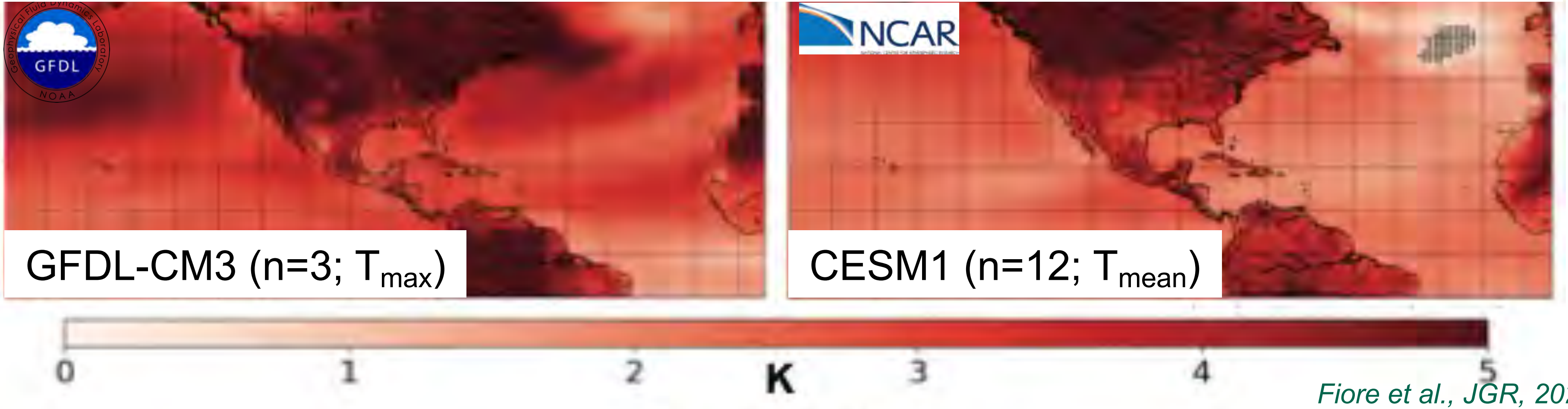
Warmer climate:
→ more heat waves
→ more pollution?

e.g., Kirtman et al. 2013 (IPCC AR5 WG1 Ch 11)

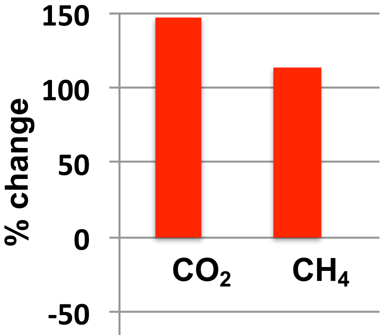


Key Challenge #2: Uncertain responses of air pollution to global change

Change in summertime 2m Temp simulated by two global chemistry-climate models



Fiore et al., JGR, 2022



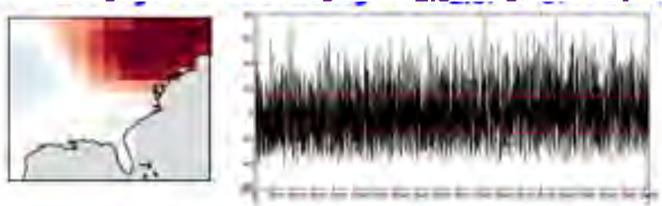
2006 → 2100 Climate change scenario "RCP8.5_WMGG"

- **PM (& ozone in GFDL CM3) precursor emissions held at 2005 levels**
- Greenhouse gas pathways prescribed following RCP8.5
- Sea salt, dust, DMS, lightning NO_x tied to model meteorology
- Biogenic & wildfires emissions held constant
- Aerosols (& ozone in GFDL CM3) affect simulated meteorology

Approach: Diagnose changes in frequency & duration of pollution (and heat) events in two chemistry-climate (climate-aerosol only for NCAR) models

Daily fields archived from **GFDL CM3 chemistry-climate** & **NCAR climate-aerosol** models

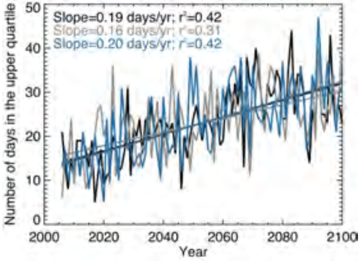
EOF analysis on daily $PM_{2.5}$, O_3, Temp.



- Identify regions that vary coherently
- Reduces size of dataset for analysis

Fiore et al., JGR, 2022

Time series analysis: Identify changes in frequency and duration of regional-scale events

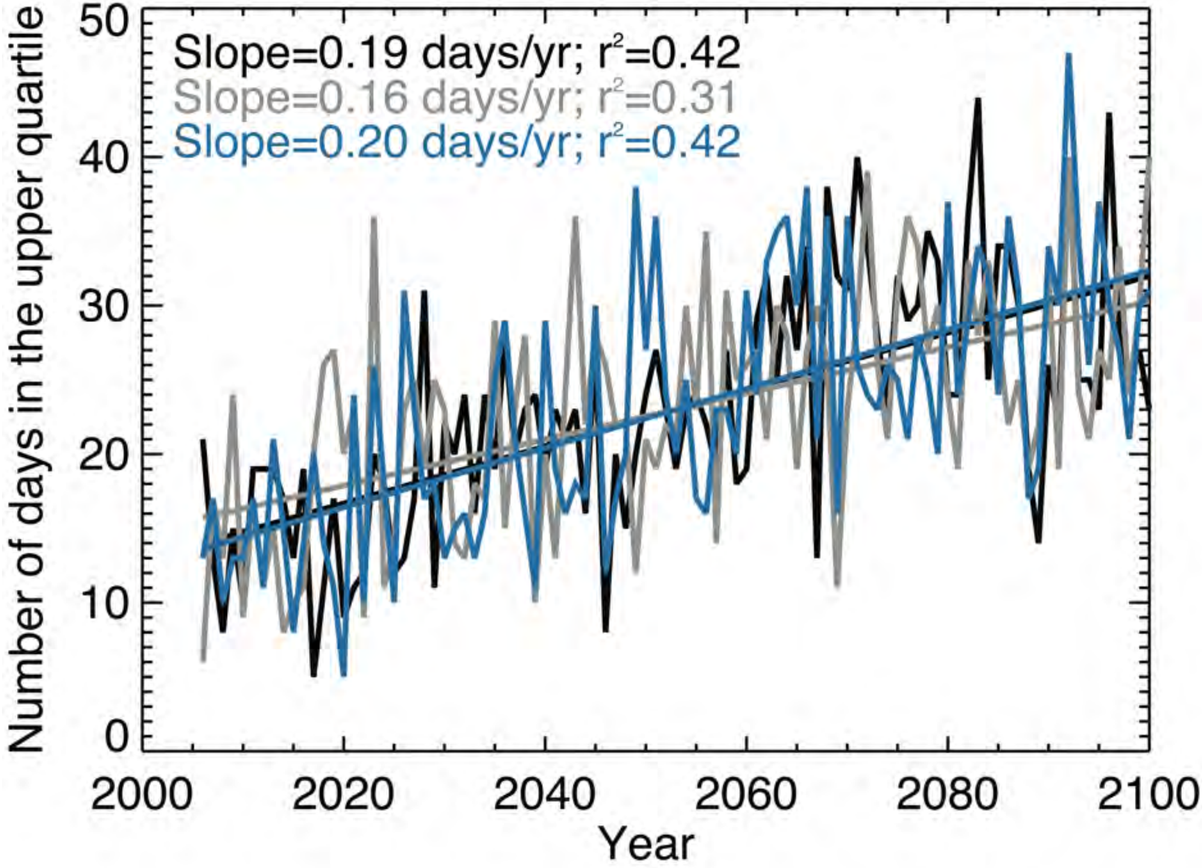


Select periods (year, decade) for: downscaling (**dynamical**, statistical); investigate processes; bias correction; extreme value theory methods…

Information for air quality (and climate?) management

Goal: tap spatial coverage and statistical power of initial condition ensembles in global (chemistry-) climate models to investigate air quality-climate linkages

The Northeast principal component shows more $PM_{2.5}$ excursions into the upper quartile later in the 21st century



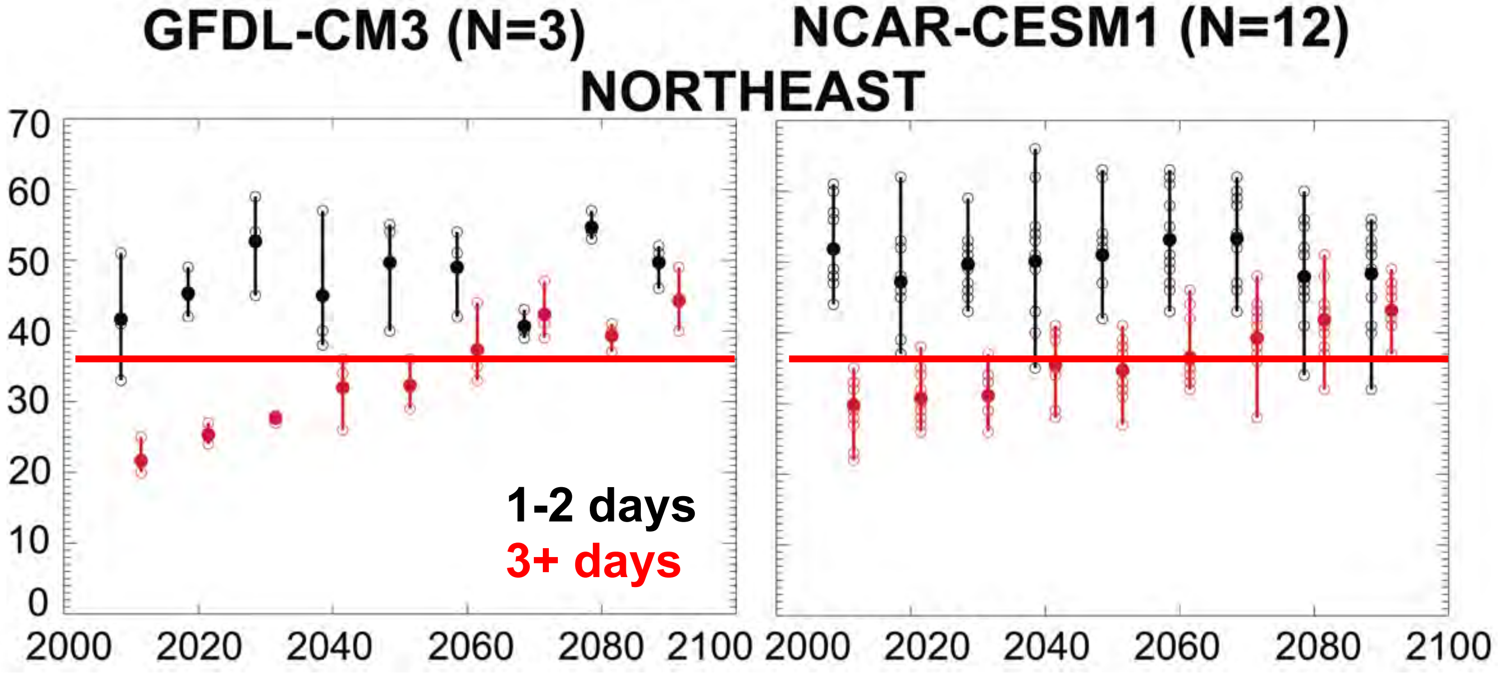
Occurs in GFDL CM3 RCP8.5_WMGG ensemble members **#1**, **#2**, and **#3**, implying a forced climate signal

Fiore et al., JGR, 2022

Two models simulate increasing duration of longer upper quartile summertime $PM_{2.5}$ events over the Northeast U.S.A. under rising greenhouse gases

NUMBER OF UPPER QUARTILE "EVENTS"

(Totaled over each decade; then averaged over all ensemble members)

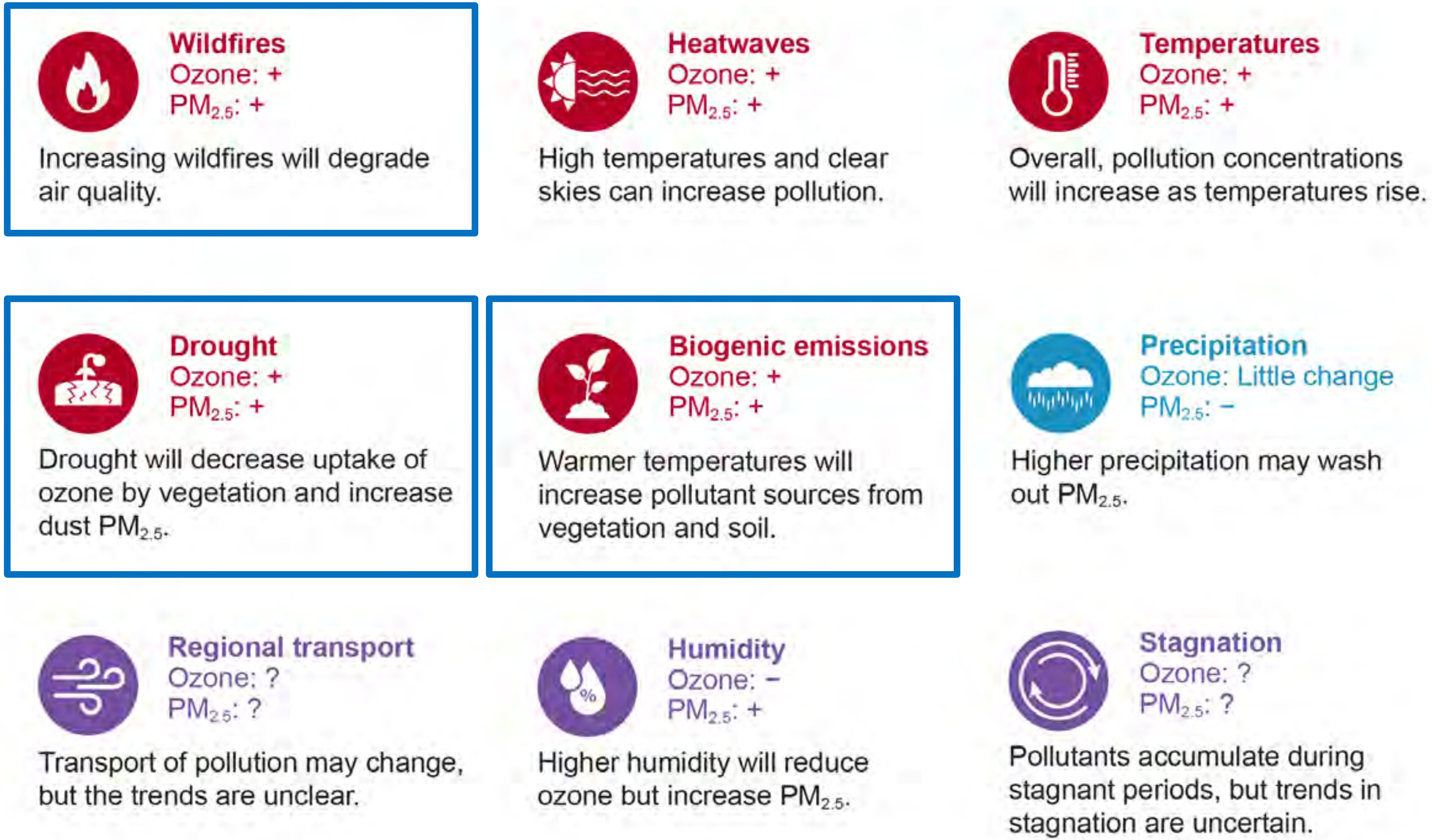


G. Milly

Fiore et al., JGR, 2022

Climate change will hamper efforts to Improve U.S. Air Quality
–Key Message 1 from Air Quality Chapter of the Fifth National Climate Assessment (2023)

Figure 14.1. Climate change will have varying effects on ozone and fine particulate matter ($PM_{2.5}$) concentrations over the United States, including through impacts on weather-sensitive emissions

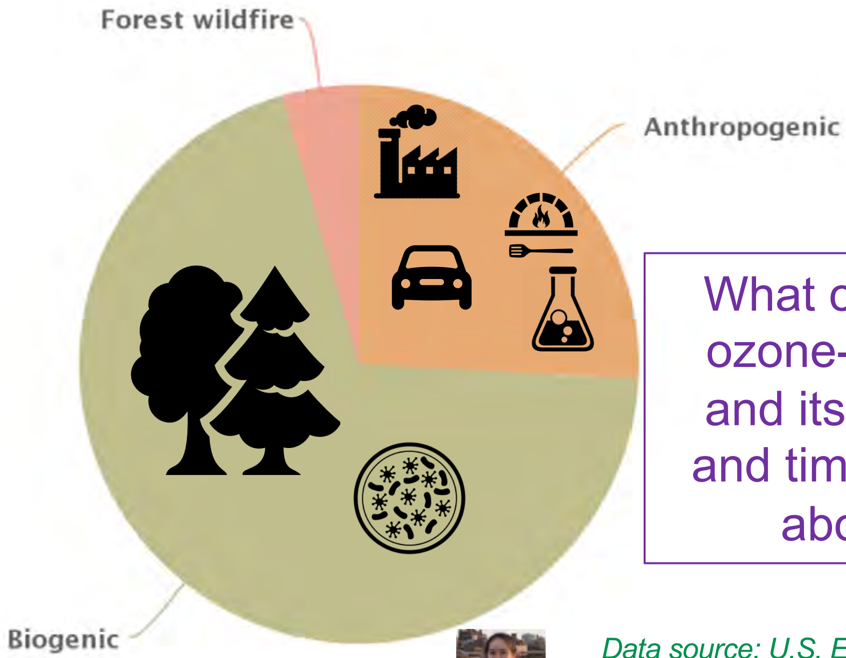


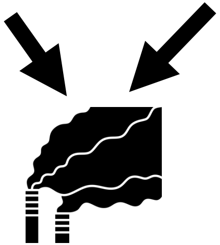
*Feedbacks (mostly) neglected in our prior work

Key challenge #3: Uncertainty in precursor emissions and formation chemistry matters for designing effective ground-level ozone abatement strategies

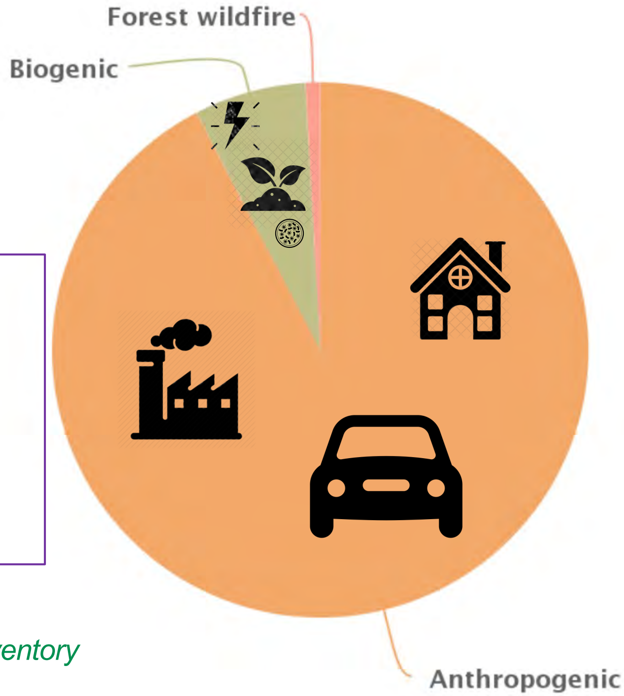
Volatile Organic Compounds (VOCs)
E.g., Isoprene (C_5H_8), methane (CH_4)

Nitrogen Oxides (NO_x)
$= NO + NO_2$





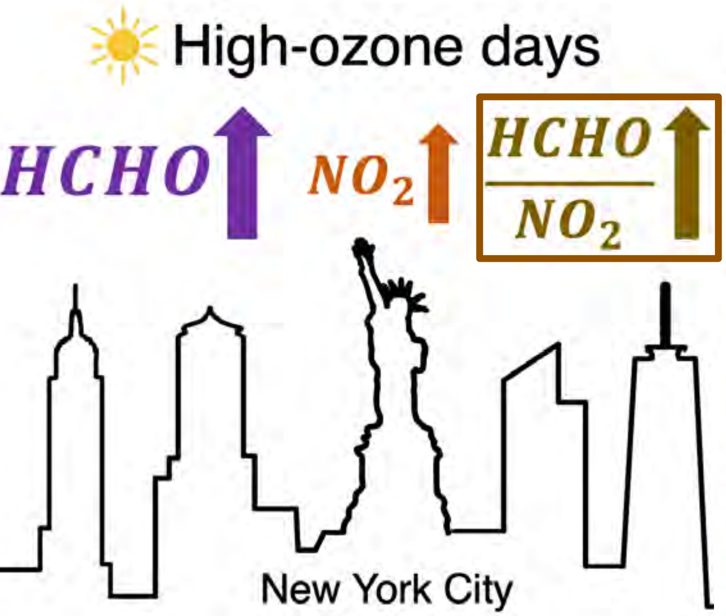
What can we learn about ozone-forming chemistry and its changes in space and time from instruments aboard satellites?



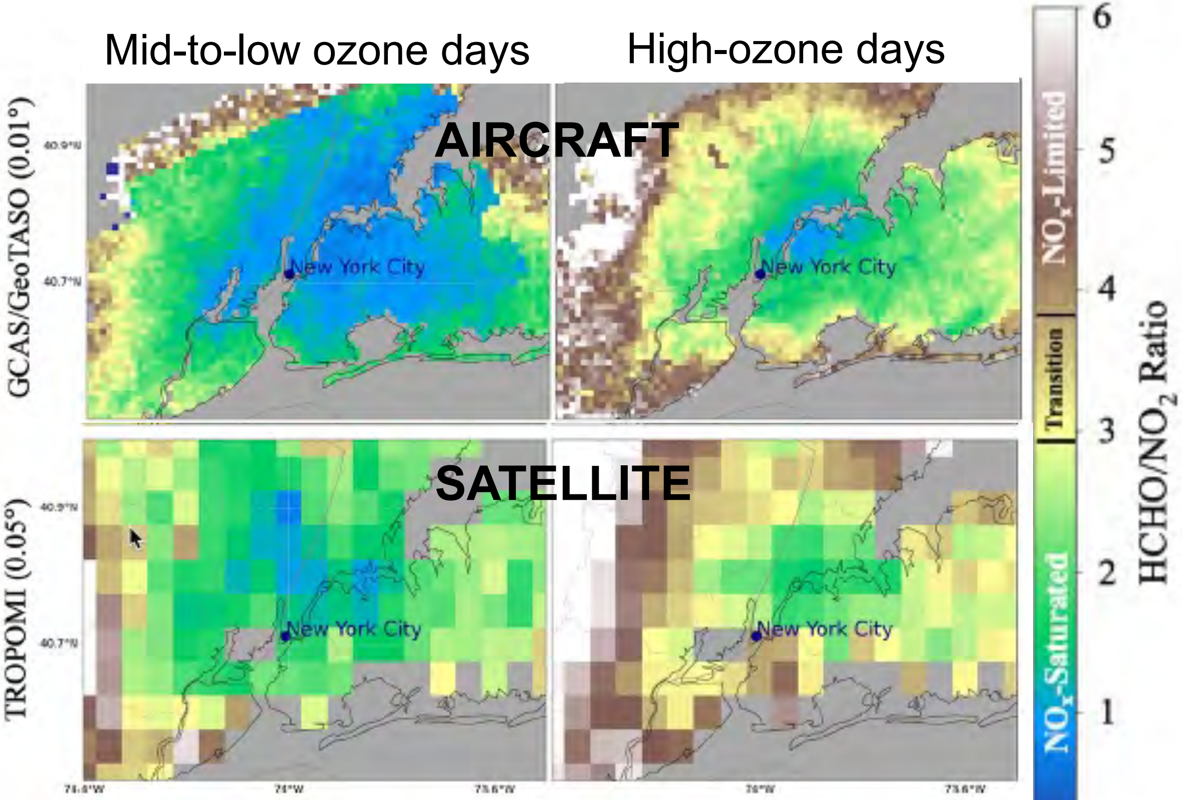
Data source: U.S. EPA 2014 National Emissions Inventory

Slide c/o M. Tao, Columbia

Satellite and airborne datasets imply enhanced sensitivity of local ozone smog formation to NO_x emission controls over NYC area on the highest-ozone days



Madankui Tao
(Grad student, Columbia)

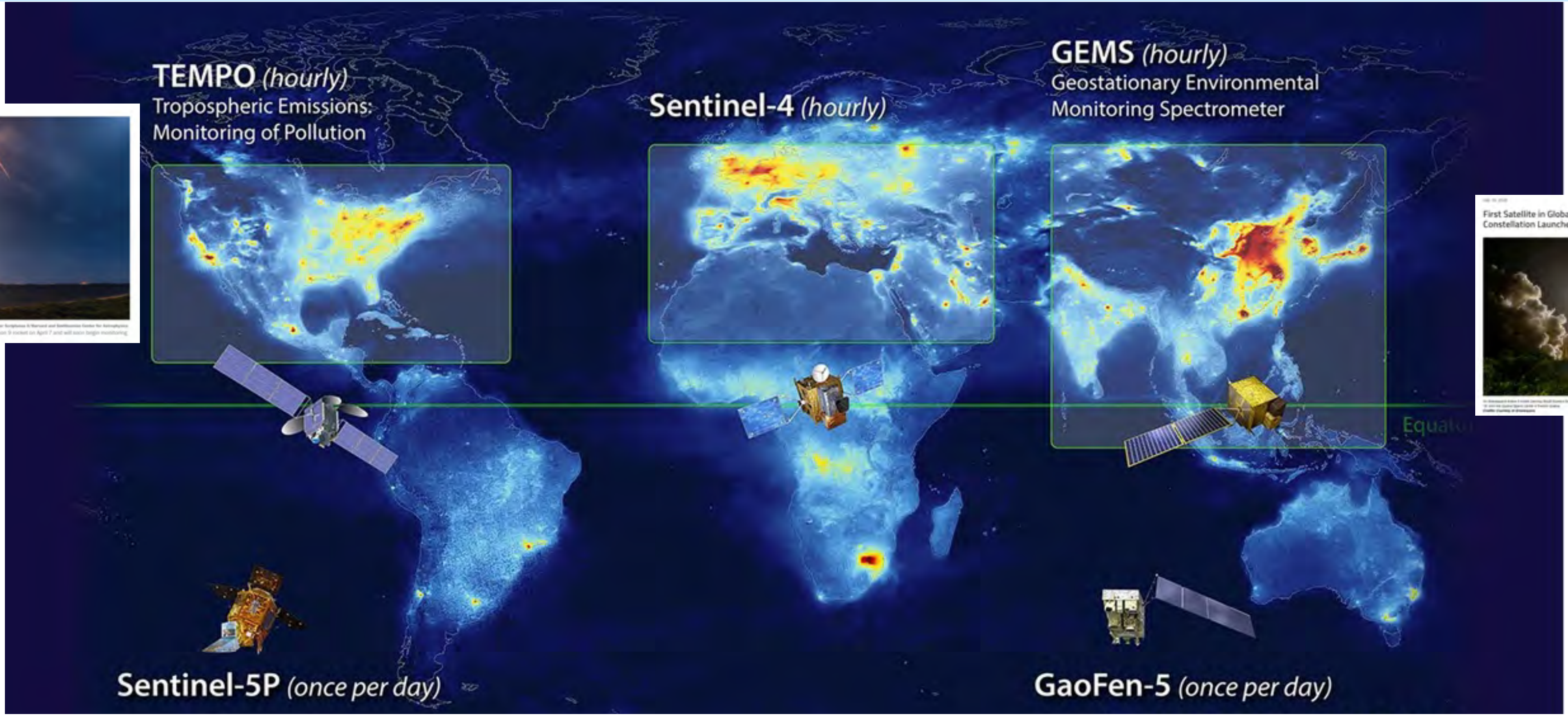


Summer 2018

Tao et al., ES&T 2022

Looking forward… new 'eyes in the sky' to observe air pollutants throughout daylight hours

TEMPO
launched
4/7/2023



GEMS
Launched
2/2020

We seek to identify new applications of satellite data for understanding local-to-regional ozone chemistry and co-exposure to multiple pollutants & heat

[e.g., Tao et al., submitted; Tao et al., ES&T 2022; Jin et al., ES&T 2020]

NASA HEALTH AND AIR QUALITY APPLIED SCIENCES TEAM

Connecting NASA Data and Tools with Health and Air Quality Stakeholders

HAQAST

Current HAQAST 'Tiger Team' on

Analysis to support air quality and health TEMPO applications for surface ozone

10 HAQAST Pis/Co-Is + their teams;

12+ AQ/health organizations;

other scientific collaborators

www.haqast.org

HAQAST Massachusetts

HEI and HAQAST Early Career Health and Atmospheric Science Workshop

June 3, 2024 @Massachusetts Institute of Technology

This Health Effects Institute and HAQAST workshop is geared toward early career researchers in atmospheric science and remote sensing interested in building connections and creating health-relevant research proposals. We will cover some of the key challenges in using satellite data for health applications, ways people overcome these challenges, and opportunities for funding and collaboration.

NASA HAQAST Public Meeting

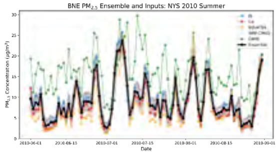
June 4-5, 2024 @Massachusetts Institute of Technology

The Health and Air Quality Applied Sciences Team (HAQAST) works to connect NASA satellite data and products with public health experts and air quality managers. Our public meetings are opportunities to grow these two-way dialogues in which stakeholders share their research needs and priorities, and scientists share their resources, insights, and new discoveries. This meeting will highlight how satellite data can inform climate change adaptation and mitigation, new satellite data and applications from TEMPO, applications for satellite data in a changing regulatory landscape, and more!

More information and registration at:
haqast.org/haqast-massachusetts

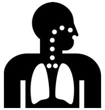
NASA HAQAST HEI

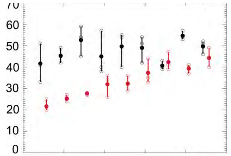
Some closing thoughts on Key Challenges in understanding Global Change Impacts on Air Quality and Health



#1: Uncertainty in air pollution (co-)exposures

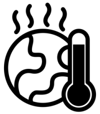
→ Opportunities with novel approaches to fuse datasets but fundamental constraint of insufficient independent data for validation

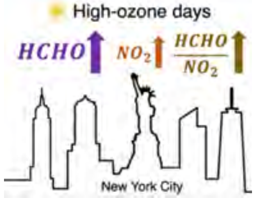




#2: Uncertainty in air pollution response to climate (and other global) change

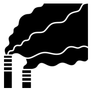
→ Many processes in play, with net balance likely to vary in space and time; some processes missing from current Earth System models



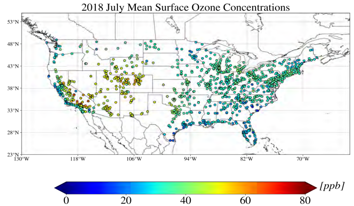


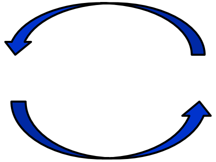
#3: Uncertainty in ozone precursors, formation chemistry *and sinks*

→ Transformative new satellite data coming online next month but careful work needed to determine information content

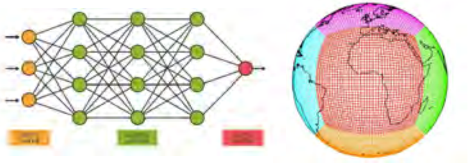


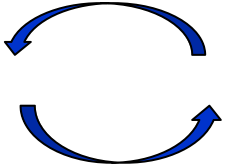
In situ OBS





MODELS





SATELLITES