Leveraging satellite-derived air quality datasets for environmental health applications

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Milken Institute School of Public Health

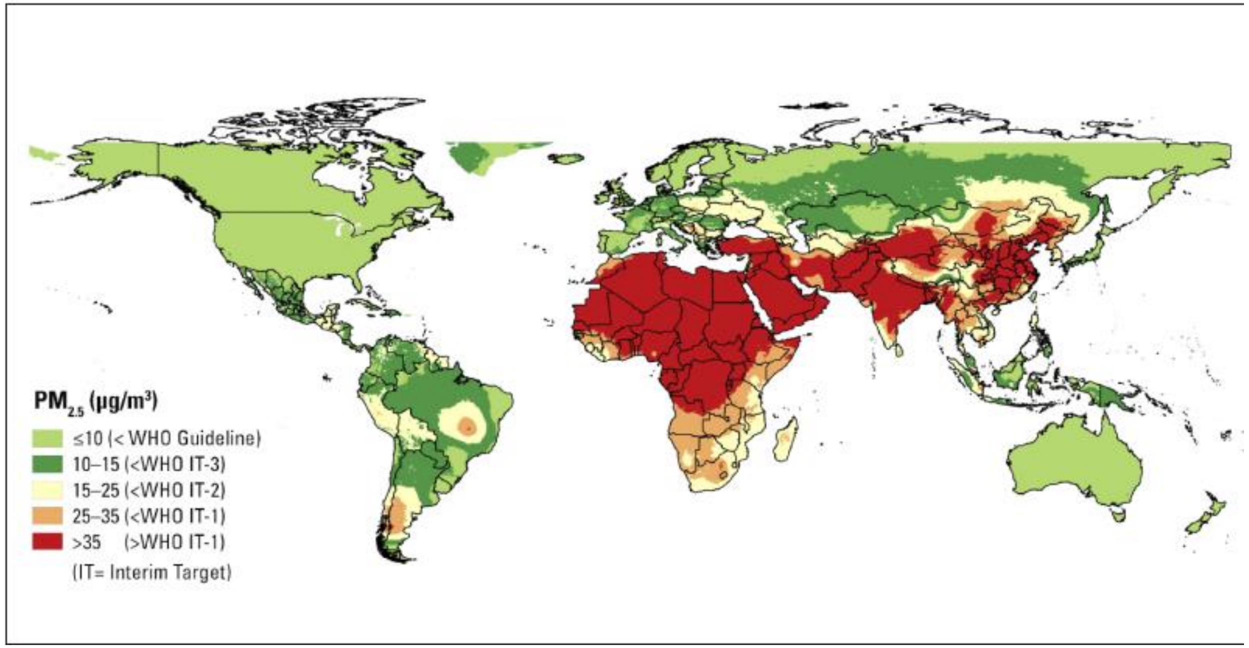
THE GEORGE WASHINGTON UNIVERSITY

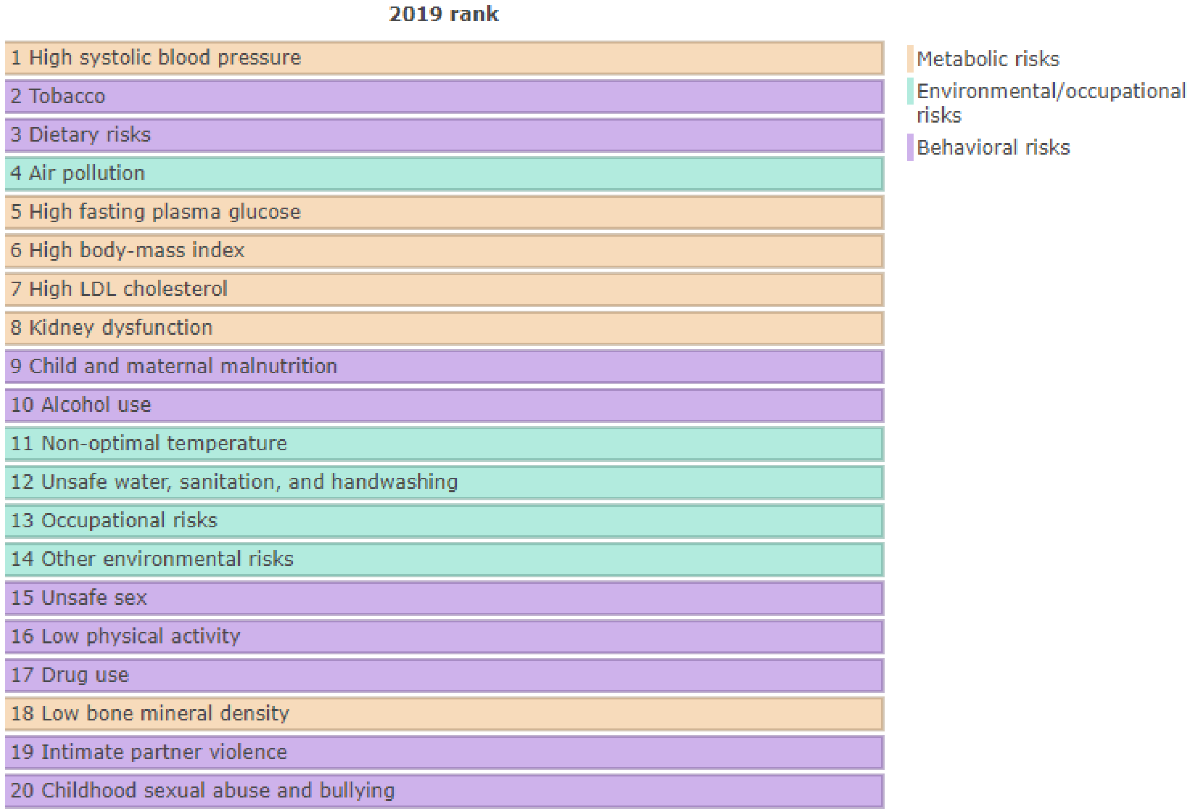
Outline

- Why is satellite remote sensing so useful for understanding health impacts of air pollution?
- Tracking global air quality and climate change indicators
  - Urban air quality and health
  - “Natural” sources of $PM_{2.5}$
- Environmental justice: exposure between the monitors
- Epidemiology: understanding concentration-response relationships
- Limitations and future directions

Air pollution continues to be a leading health risk factor in nearly all countries

>90% of people worldwide live with $PM_{2.5}$ concentrations above the World Health Organization guideline



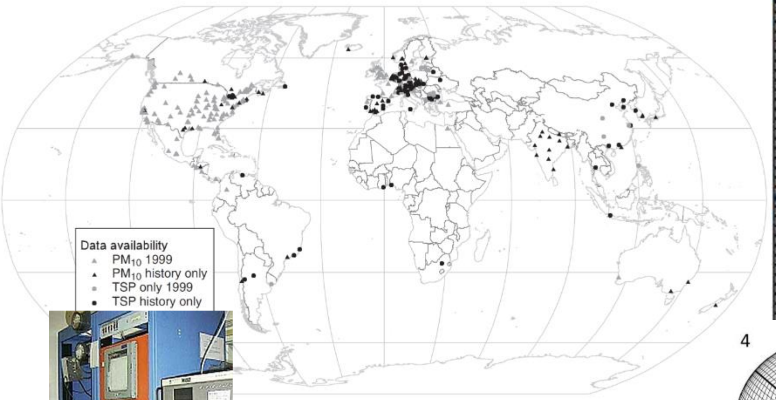


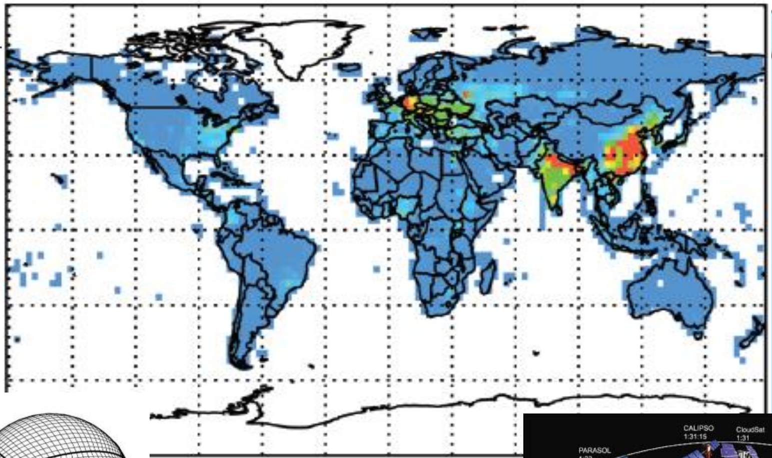
Health Effects Institute, State of Global Air 2019 Report (2019)

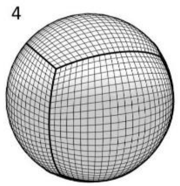
GBD 2019 Study
https://vizhub.healthdata.org/gbd-compare/

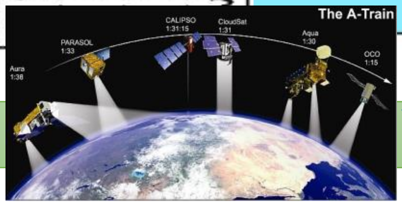
Satellite remote sensing has transformed our ability to understand air pollution disease burdens globally

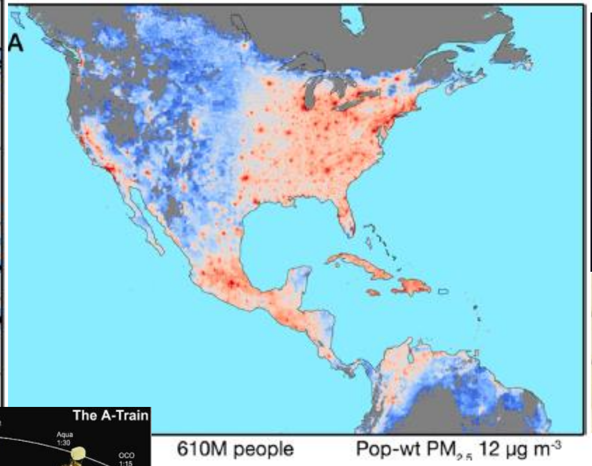
Figure 17.1 Cities from which data on exposure to PM_{10} or TSP during 1985–1999 are available from monitoring cites

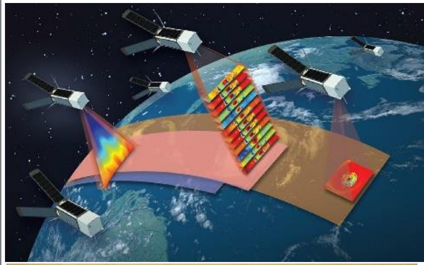












2004: **Surface air quality monitors**, 800,000 premature deaths associated with urban $PM_{2.5}$ (Cohen et al. 2004)

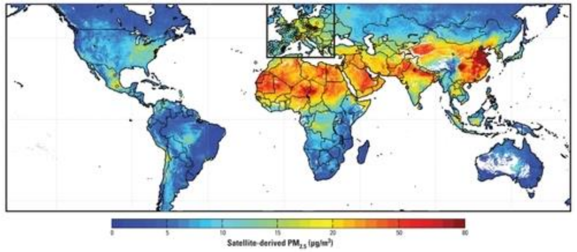
2010: **Global chemical transport model**, 3.7 million $PM_{2.5}$ and 700,000 ozone deaths globally (Anenberg et al. 2010)

2012: **Satellite observations, global chemical transport model, and ground observations combined,** 3.2 million $PM_{2.5}$ and 152,000 ozone deaths (Lim et al. 2012)

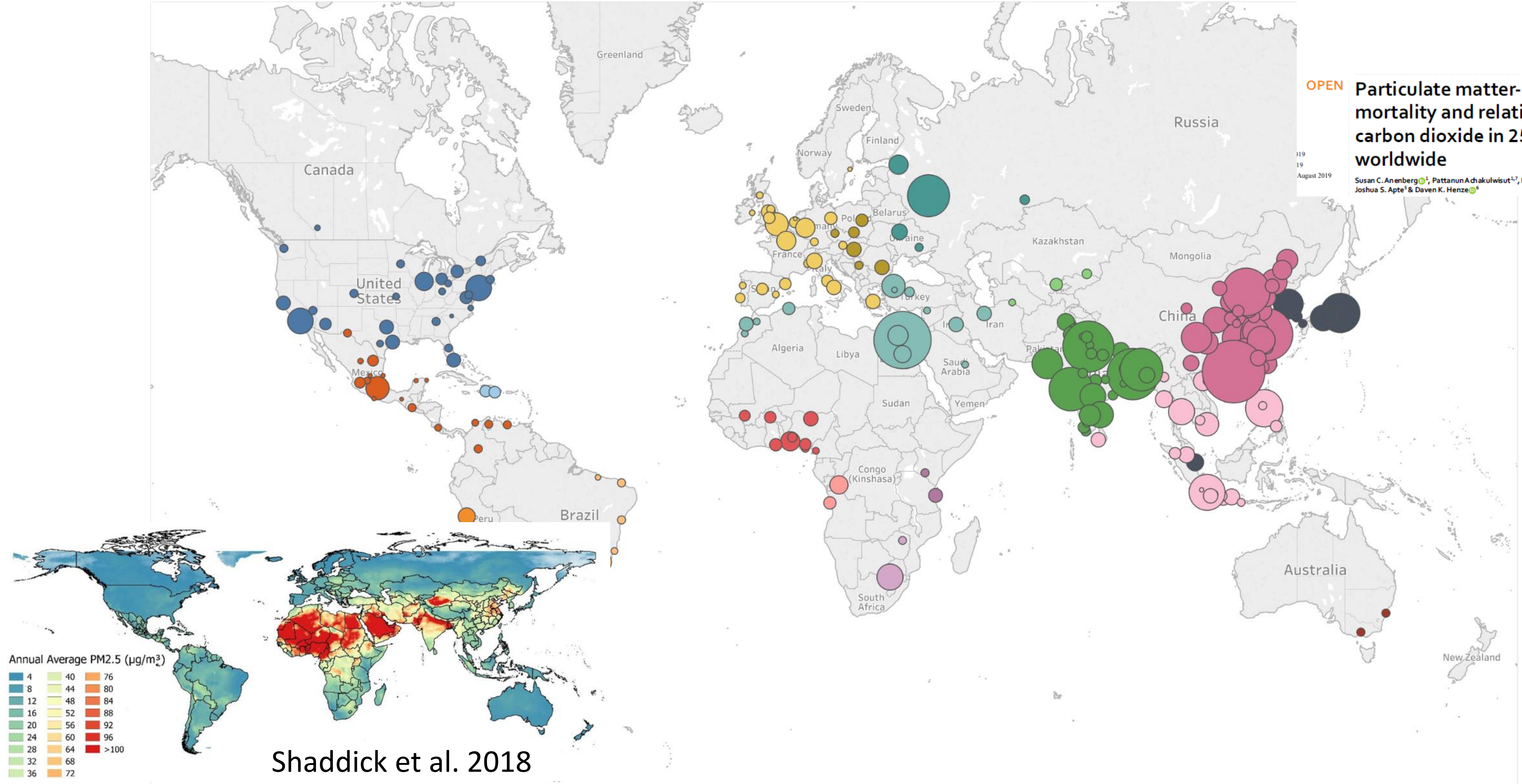
2016-2020: **methods refined,** ~4 million $PM_{2.5}$ and 200,000 ozone deaths (Forouzanfar et al. 2016, etc.)

Future: geostationary satellites, low-cost sensors, mobile monitoring, ???

2010: **Global $PM_{2.5}$ concentrations from satellite AOD** (van Donkelaar et al. 2010)



$PM_{2.5}$ mortality in 250 cities worldwide



SCIENTIFIC REPORTS
natureresearch

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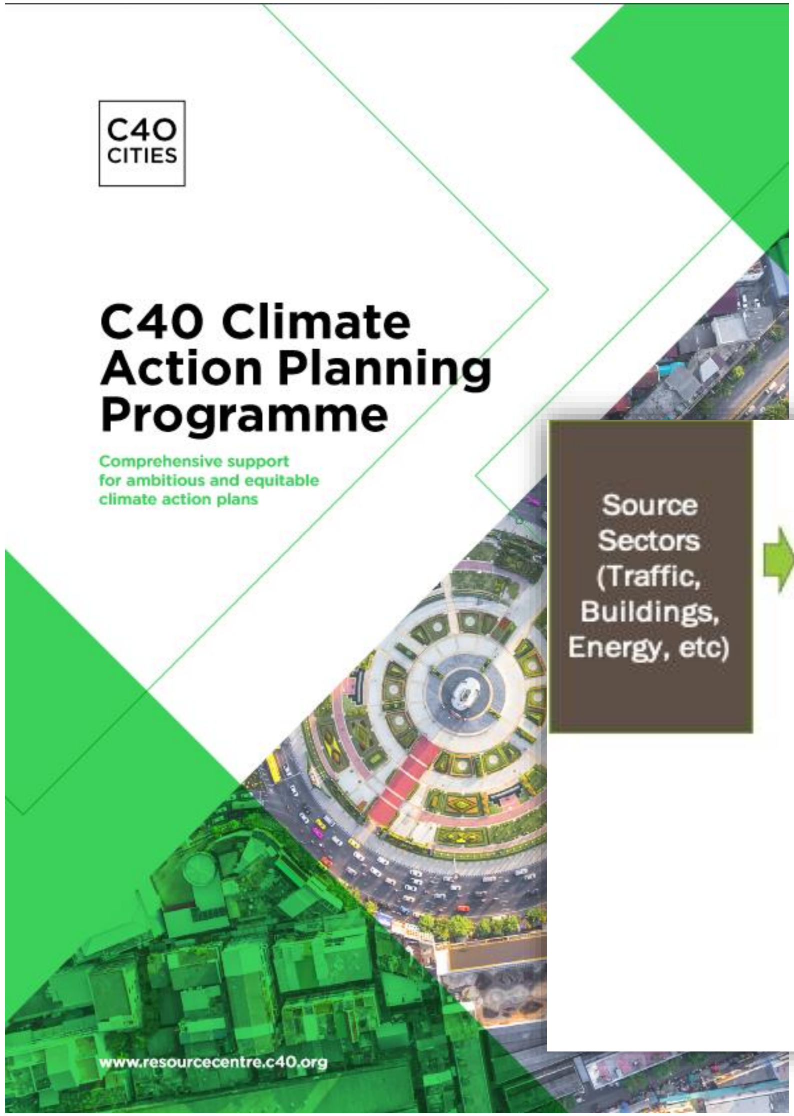
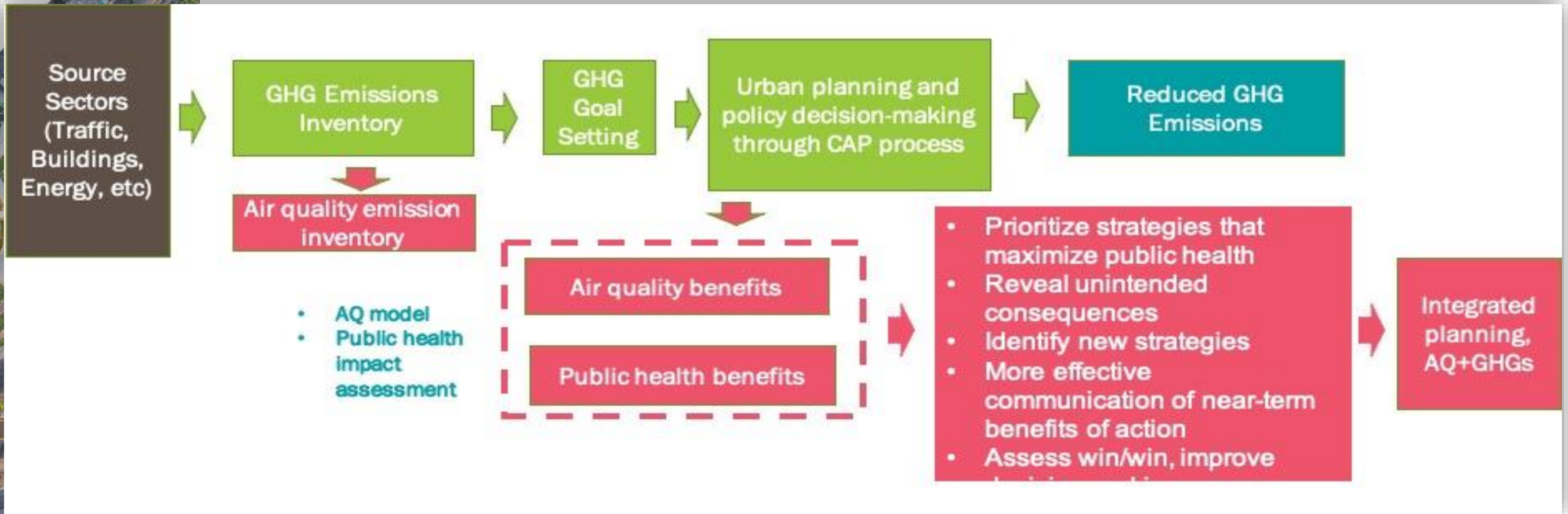
Particulate matter-attributable mortality and relationships with carbon dioxide in 250 urban areas worldwide

Susan C. Anenberg[1], Pattanun Achakulwisut[1,7], Michael Brauer[2,3], Daniel Moran[4], Joshua S. Apte[5] & Daven K. Henze[6]

Shaddick et al. 2018

New decision-support tool: Pathways-AQ



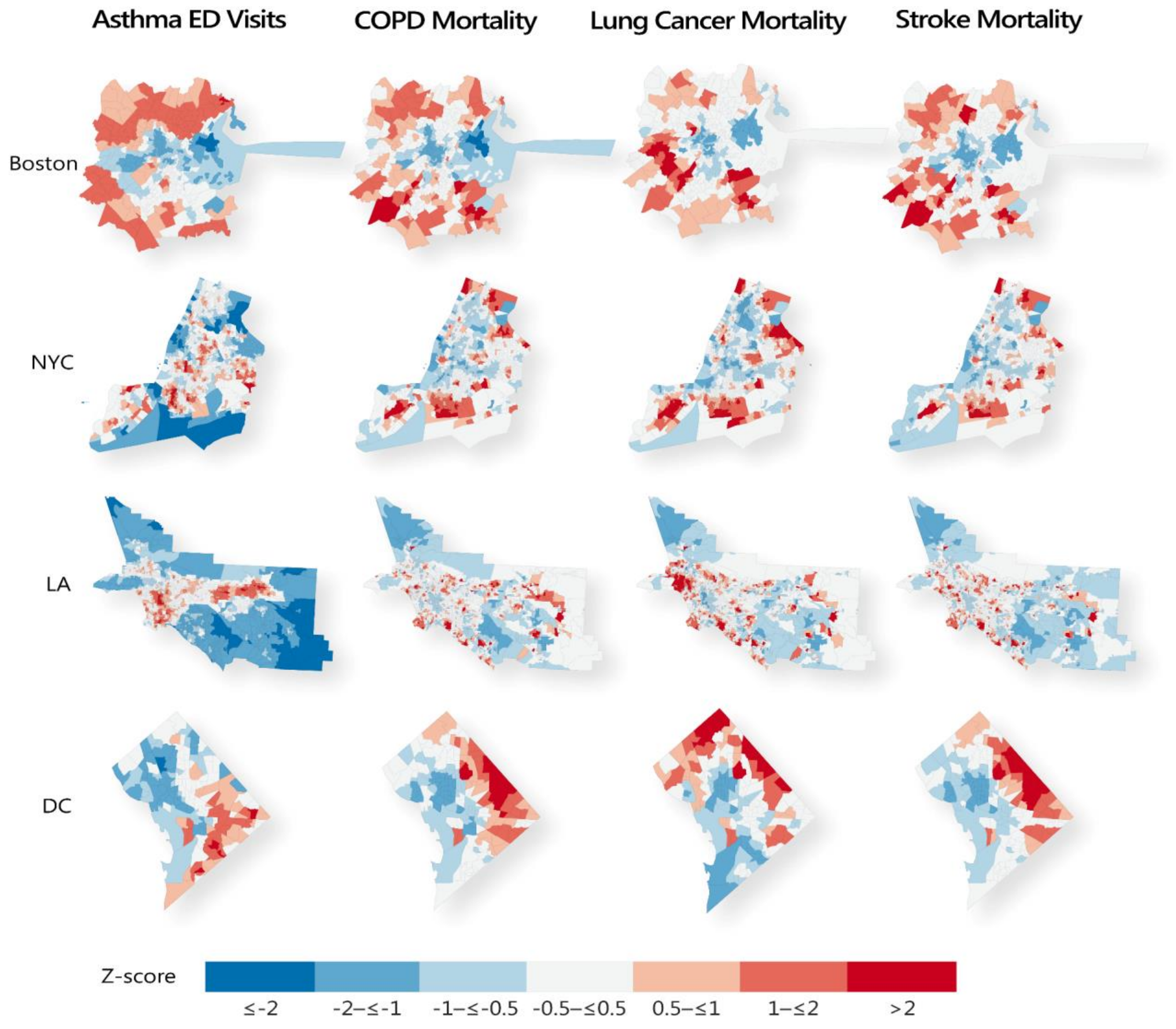


Identifying air pollution exposure inequities

Heterogeneity in $PM_{2.5}$-attributable cases per 100,000 people at census tract level

$PM_{2.5}$ at 0.01° x0.01°
(van Donkelaar et al. 2016)

Census tract disease rates from CDC 500 Cities
(https://www.cdc.gov/500cities/)



HAQAST

Preliminary results.
Do not cite or quote.

Tracking indicators of air quality and climate change

GeoHealth

RESEARCH ARTICLE

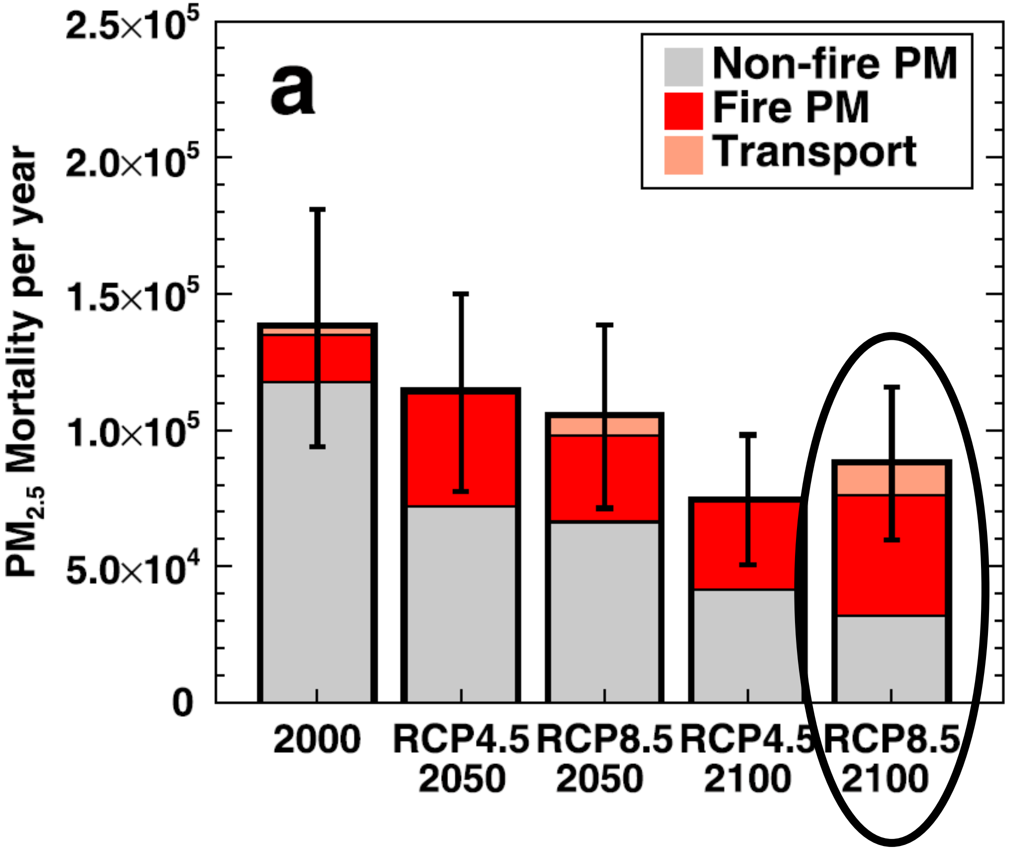
10.1029/2018GH000144

Future Fire Impacts on Smoke Concentrations, Visibility, and Health in the Contiguous United States

B. Ford[1], M. Val Martin[2], S. E. Zelasky[3], E. V. Fischer[1], S. C. Anenberg[4], C. L. Heald[5,6], and J. R. Pierce[1]

Key Points:

- We provide the first estimates of future smoke health and visibility



AGU ADVANCING EARTH AND SPACE SCIENCE

GeoHealth

COMMENTARY

10.1029/2020GH000270

Using Satellites to Track Indicators of Global Air Pollution and Climate Change Impacts: Lessons Learned From a NASA-Supported Science-Stakeholder Collaborative

Susan C. Anenberg[1], Matilyn Bindl[2], Michael Brauer[3,4], Juan J. Castillo[5,6], Sandra Cavalieri[7], Bryan N. Duncan[8], Arlene M. Fiore[9], Richard Fuller[10], Daniel L. Goldberg[1], Daven K. Henze[11], Jeremy Hess[12], Tracey Holloway[2], Peter James[13], Xiaomeng Jin[9], Iyad Kheirbek[14], Patrick L. Kinney[15], Yang Liu[16], Arash Mohegh[1], Jonathan Patz[2], Marcia P. Jimenez[13], Ananya Roy[17], Daniel Tong[18], Katy Walker[19], Nick Watts[20], and J. Jason West[21]

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Key Points:

- The NASA Health and Air Quality Applied Science Team "Indicators" Tiger Team developed satellite-based air quality and climate indicators
- Participatory knowledge production can lead to more useful information for stakeholders but requires continuous engagement and flexibility
- Ground measurements are still needed, and sustained collaboration between the researchers and stakeholders over time remains a challenge

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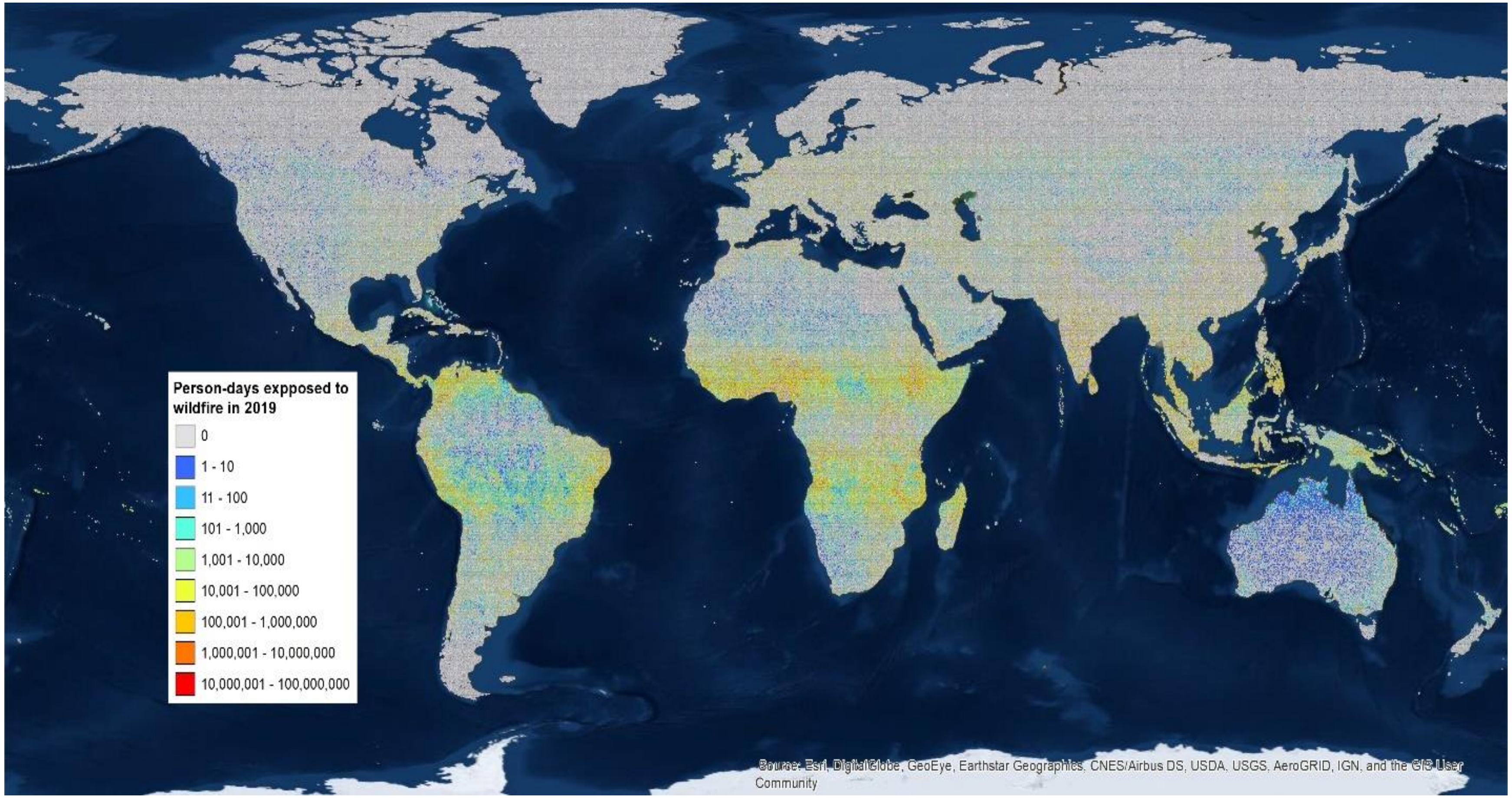
Investigation: Susan C. Anenberg, Michael Brauer, Juan J. Castillo, Sandra Cavalieri, Bryan N. Duncan, Arlene M. Fiore, Richard Fuller, Daniel L.
(continued)

Abstract The 2018 NASA Health and Air Quality Applied Science Team (HAQAST) "Indicators" Tiger Team collaboration between NASA-supported scientists and civil society stakeholders aimed to develop satellite-derived global air pollution and climate indicators. This Commentary shares our experience and lessons learned. Together, the team developed methods to track wildfires, dust storms, pollen counts, urban green space, nitrogen dioxide concentrations and asthma burdens, tropospheric ozone concentrations, and urban particulate matter mortality. Participatory knowledge production can lead to more actionable information but requires time, flexibility, and continuous engagement. Ground measurements are still needed for ground truthing, and sustained collaboration over time remains a challenge.

Plain Language Summary Recent advances in satellite remote sensing enable observation-based tracking of climate change and air pollution with relatively high spatial resolution globally. The 2018 NASA Health and Air Quality Applied Science Team (HAQAST) "Indicators" Tiger Team launched a collaboration between ~20 NASA-supported scientists and civil society stakeholders to develop satellite-derived global air pollution and climate indicators. This Commentary demonstrates the range of air quality and climate change tracking uses for satellite data and shares our experience and lessons learned, which can inform future problem-driven science-stakeholder collaborative efforts. Together, the team developed methods to track wildfires, dust storms, pollen, urban green space, nitrogen dioxide concentrations and asthma burdens, tropospheric ozone concentrations, and urban fine particulate matter mortality. Lessons learned include that participatory knowledge production can lead to more actionable information for stakeholders but requires time and dedicated attention. Stakeholder engagement is valuable at each stage, from developing more nascent data sets to operationalizing mature data sets. Flexibility is critical, since stakeholder needs evolve and new synergies emerge when there are engagements across a wide range of stakeholders and teams. However, additional ground measurements are needed to ground truth satellite observations, and

Satellite-based population direct exposure to wildfire

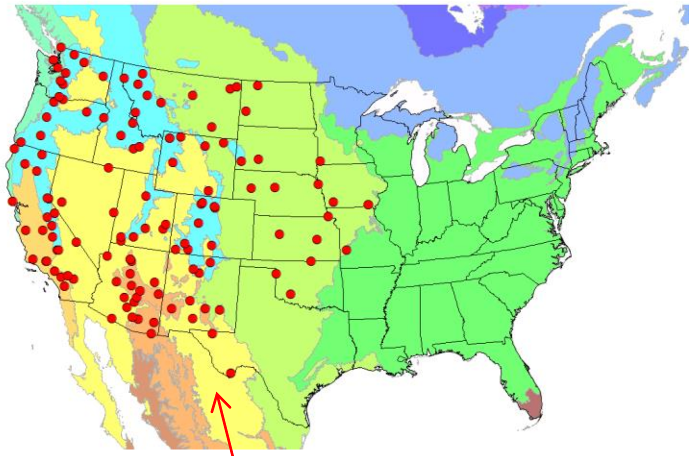


Slide courtesy Yang Liu
(speaking on Thursday!)

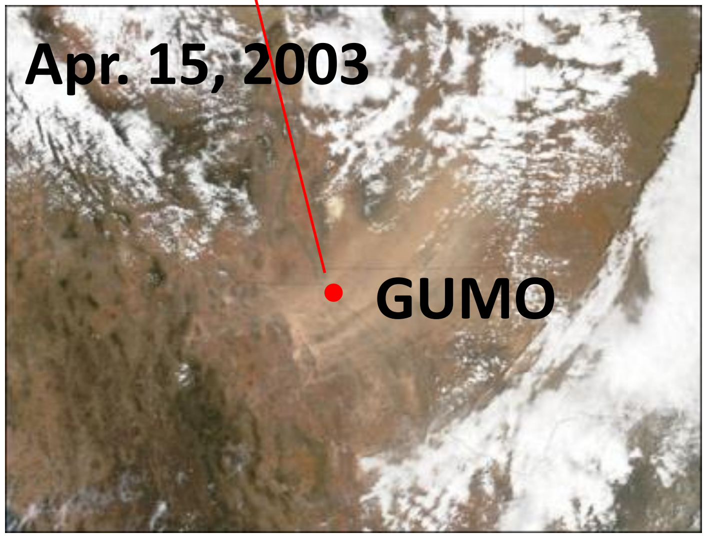
Watts et al. Lancet. 2020

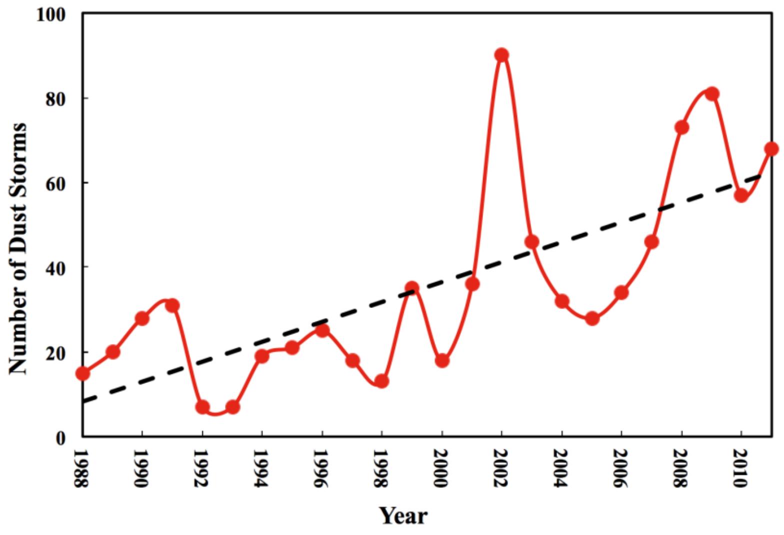
Dust Storm and Valley fever Spikes

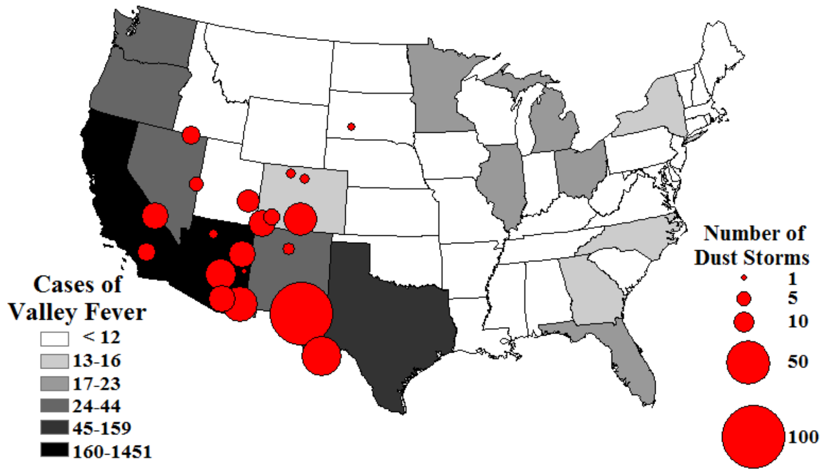
Ground Network



MODIS Dust



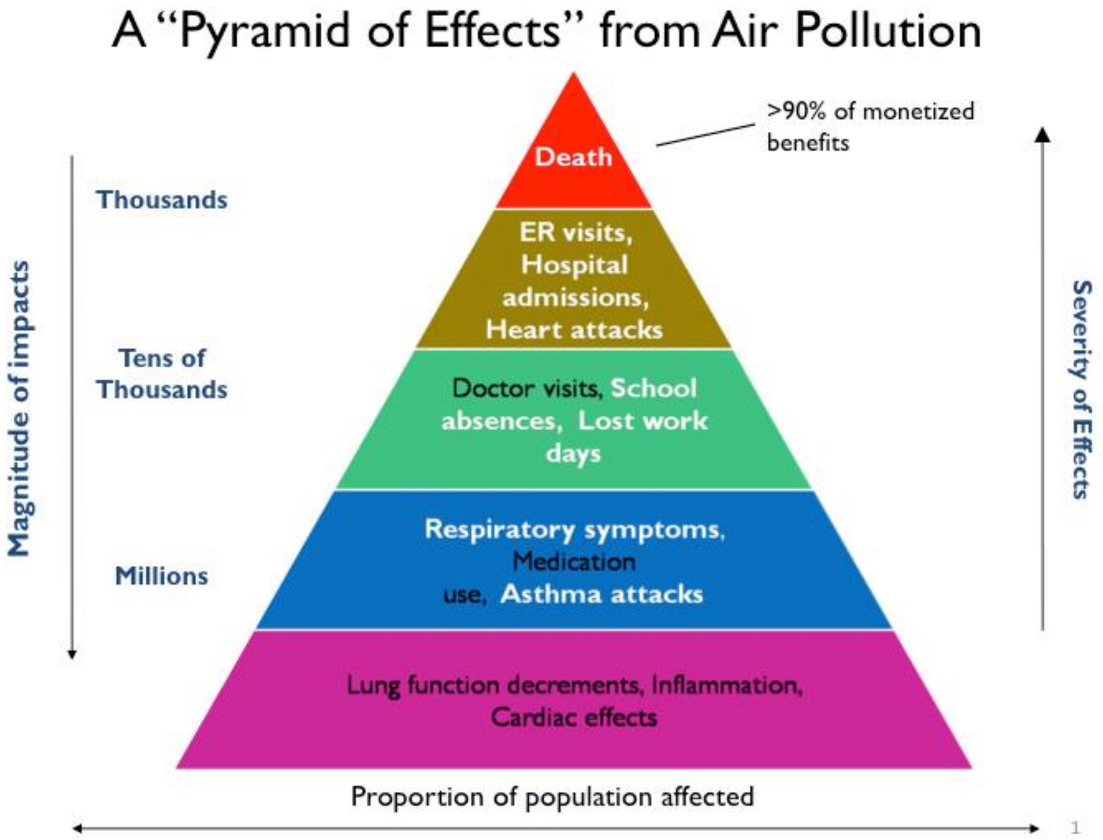




(Source: Tong et al., GRL, 2017)

Slide courtesy Daniel Tong

Health effects of air pollution: the knowns



https://www.epa.gov/benmap/how-benmap-ce-estimates-health-and-economic-effects-air-pollution

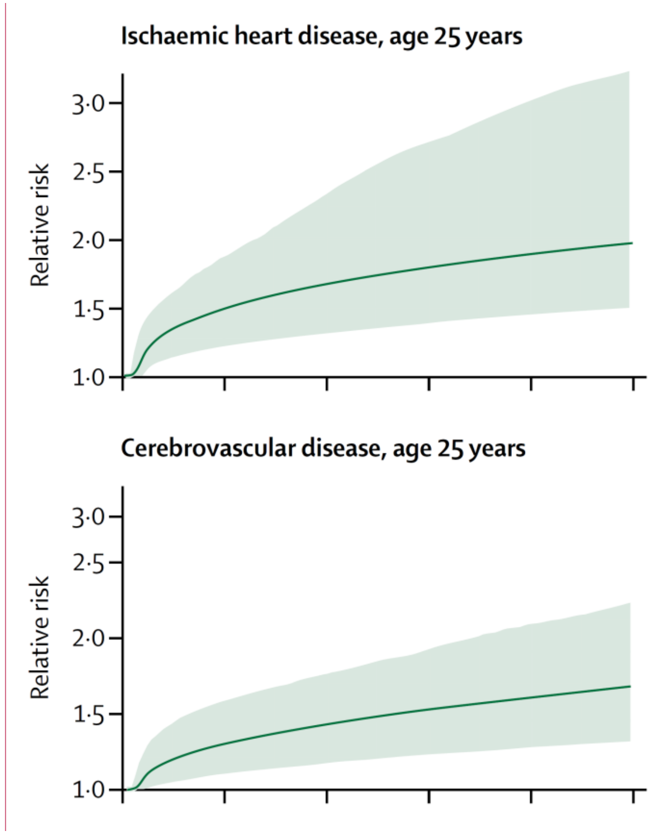
$PM_{2.5}$ causal and likely causal effects (U.S. EPA ISA 2020)

- Mortality
- Cardiovascular disease
- Cancer
- Respiratory disease
- Nervous system

The unknowns… Concentration-response relationships at HIGH and LOW concentrations

Integrated exposure response curves

3-4 million $PM_{2.5}$ deaths

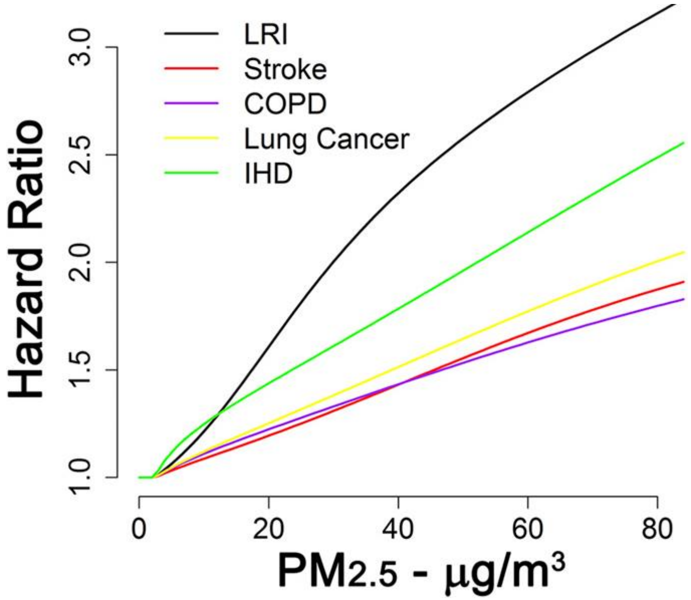


Cohen et al. 2017

Curves using ambient air pollution studies only

8.9 million $PM_{2.5}$ deaths

(more linear at high end)

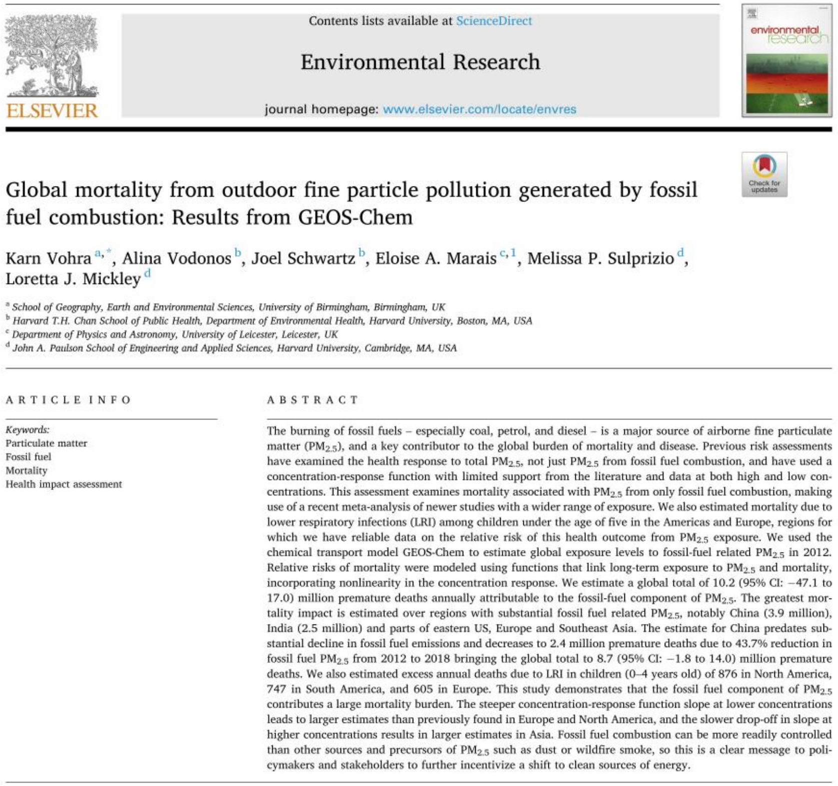


Burnett et al. 2018

Considering concentrations < GBD counterfactual (2.4-5.9 µg/m³)

10.2 million $PM_{2.5}$ deaths

(steep curve at low end)



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ELSEVIER

Global mortality from outdoor fine particle pollution generated by fossil fuel combustion: Results from GEOS-Chem

Karn Vohra[a,*], Alina Vodonos[b], Joel Schwartz[b], Eloise A. Marais[c,1], Melissa P. Sulprizio[d], Loretta J. Mickley[d]

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[b] Harvard T.H. Chan School of Public Health, Department of Environmental Health, Harvard University, Boston, MA, USA
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ARTICLE INFO

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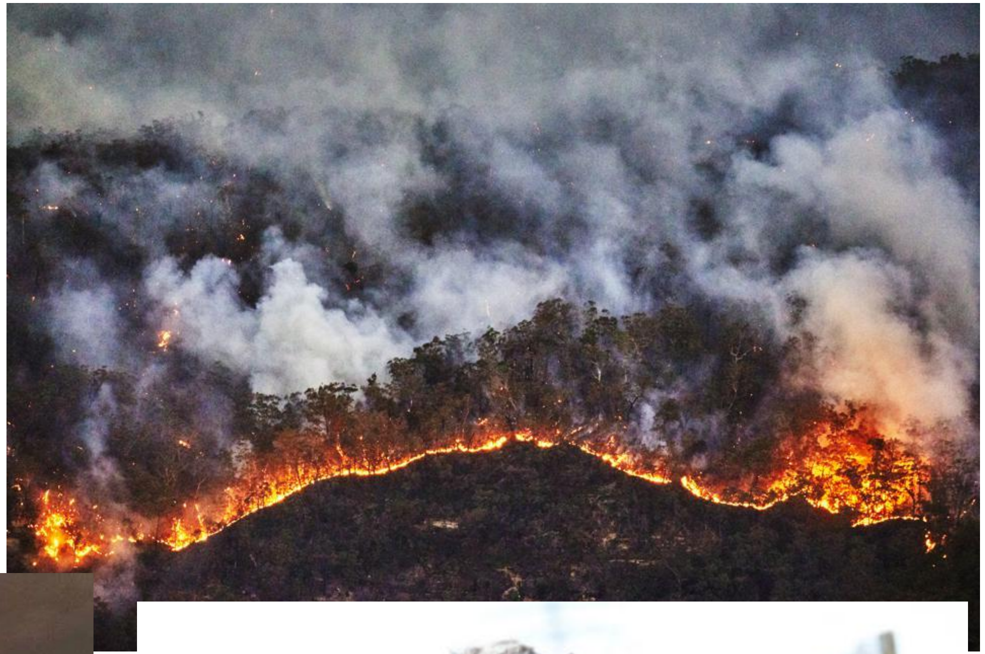
Fossil fuel
Mortality
Health impact assessment

ABSTRACT

The burning of fossil fuels – especially coal, petrol, and diesel – is a major source of airborne fine particulate matter ($PM_{2.5}$), and a key contributor to the global burden of mortality and disease. Previous risk assessments have examined the health response to total $PM_{2.5}$, not just $PM_{2.5}$ from fossil fuel combustion, and have used a concentration-response function with limited support from the literature and data at both high and low concentrations. This assessment examines mortality associated with $PM_{2.5}$ from only fossil fuel combustion, making use of a recent meta-analysis of newer studies with a wider range of exposure. We also estimated mortality due to lower respiratory infections (LRI) among children under the age of five in the Americas and Europe, regions for which we have reliable data on the relative risk of this health outcome from $PM_{2.5}$ exposure. We used the chemical transport model GEOS-Chem to estimate global exposure levels to fossil-fuel related $PM_{2.5}$ in 2012. Relative risks of mortality were modeled using functions that link long-term exposure to $PM_{2.5}$ and mortality, incorporating nonlinearity in the concentration response. We estimate a global total of 10.2 (95% CI: −47.1 to 17.0) million premature deaths annually attributable to the fossil-fuel component of $PM_{2.5}$. The greatest mortality impact is estimated over regions with substantial fossil fuel related $PM_{2.5}$, notably China (3.9 million), India (2.5 million) and parts of eastern US, Europe and Southeast Asia. The estimate for China predates substantial decline in fossil fuel emissions and decreases to 2.4 million premature deaths due to 43.7% reduction in fossil fuel $PM_{2.5}$ from 2012 to 2018 bringing the global total to 8.7 (95% CI: −1.8 to 14.0) million premature deaths. We also estimated excess annual deaths due to LRI in children (0–4 years old) of 876 in North America, 747 in South America, and 605 in Europe. This study demonstrates that the fossil fuel component of $PM_{2.5}$ contributes a large mortality burden. The steeper concentration-response function slope at lower concentrations leads to larger estimates than previously found in Europe and North America, and the slower drop-off in slope at higher concentrations results in larger estimates in Asia. Fossil fuel combustion can be more readily controlled than other sources and precursors of $PM_{2.5}$ such as dust or wildfire smoke, so this is a clear message to policymakers and stakeholders to further incentivize a shift to clean sources of energy.

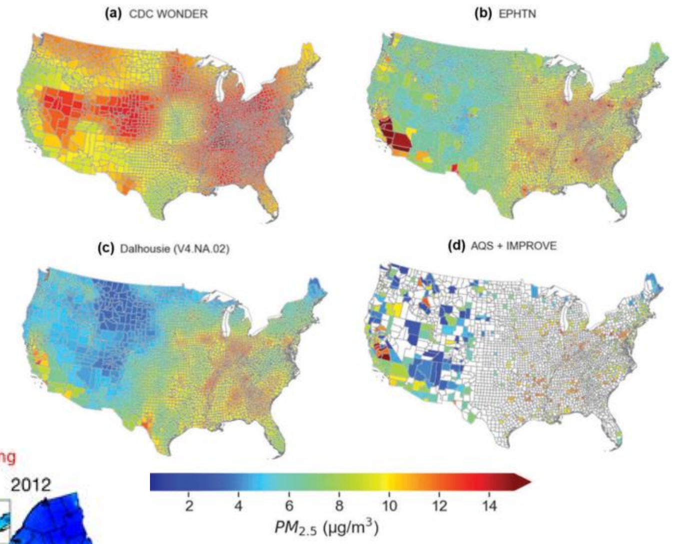
Vohra et al. 2021

The unknowns… health effects of air pollution mixtures, interactive effects with other environmental risk factors

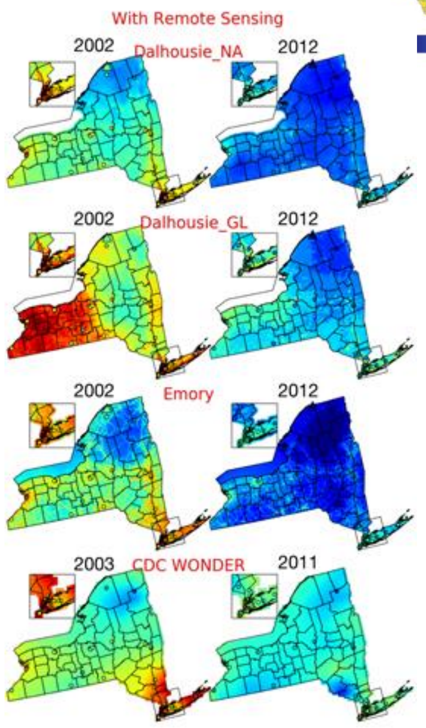


Concluding thoughts

- Satellite remote sensing has transformed environmental health surveillance capabilities
- Limitations of satellite data for health applications
  - Temporal coverage/flyover time
  - Spatial resolution
  - Ability to discern components/mixtures
  - There is still disagreement between surface concentration estimates from different methods
- Some thoughts for future directions
  - Important to have continuous record of remote sensing datasets
  - Use remote sensing to screen areas for locating ground monitors, integrating multiple datasets



Diao et al. 2019

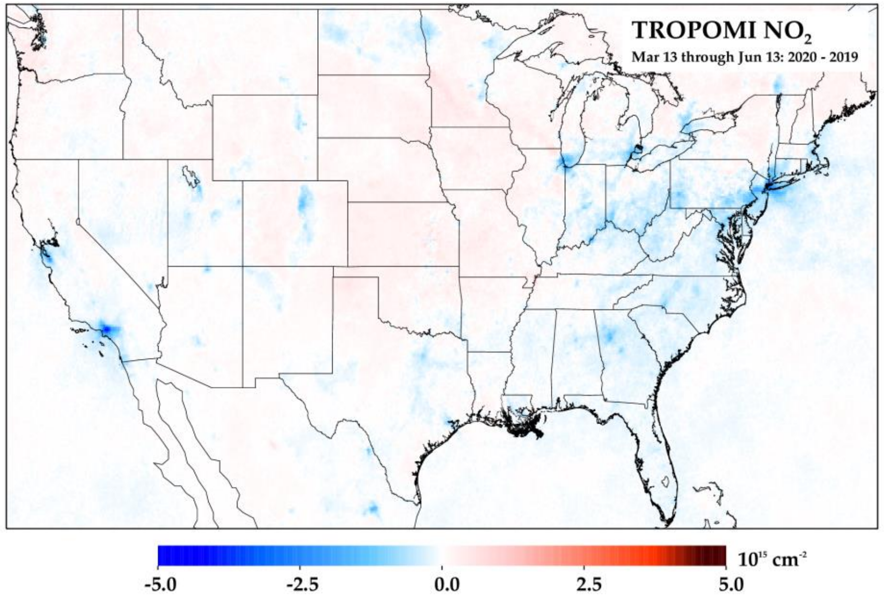


Jin et al. 2019

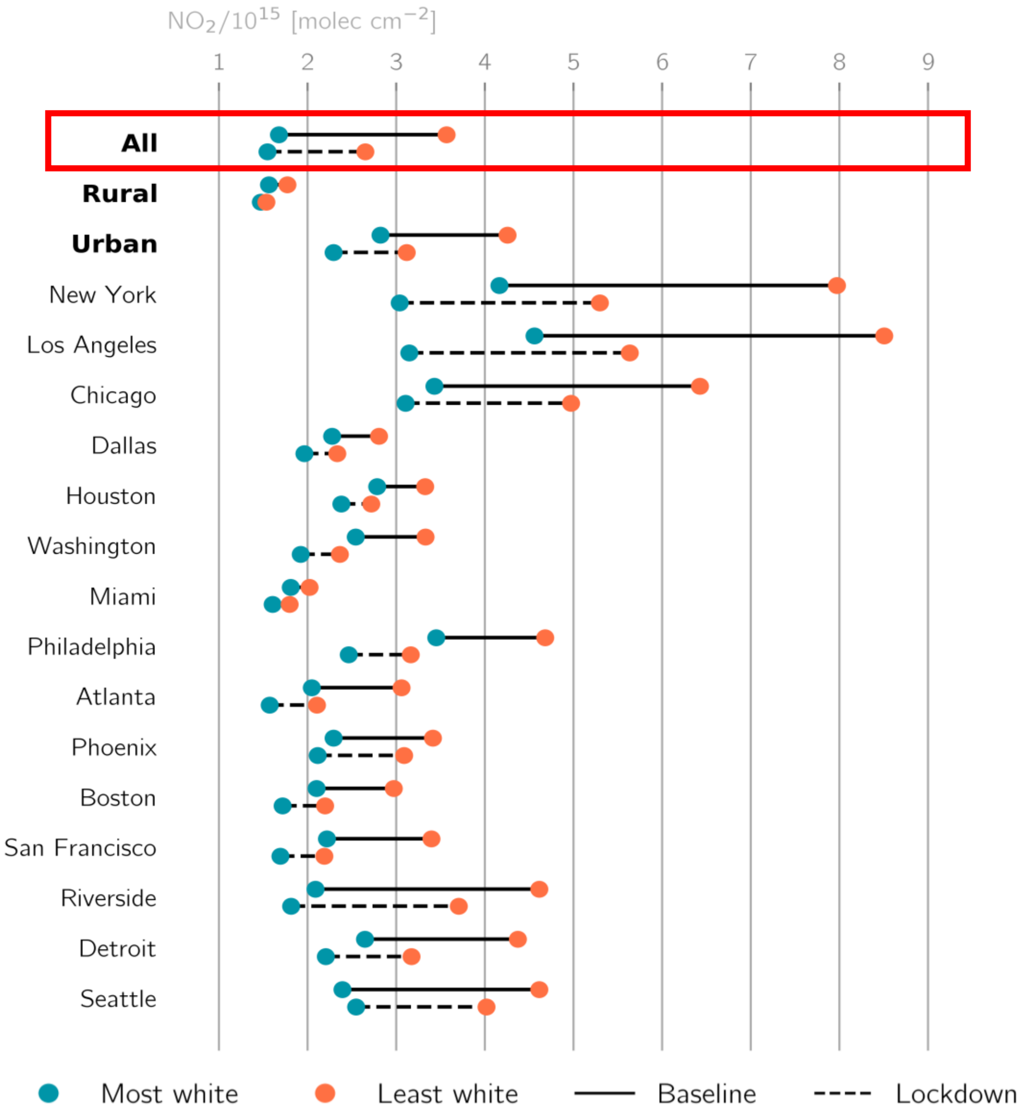
extra

Identifying air pollution exposure inequities (NO_2)

In many cities, the post-lockdown NO_2 amounts in the least white communities are still ~50% larger than the pre-lockdown NO_2 amounts in the most white communities



https://www.essoar.org/doi/pdf/10.1002/essoar.10504561.3

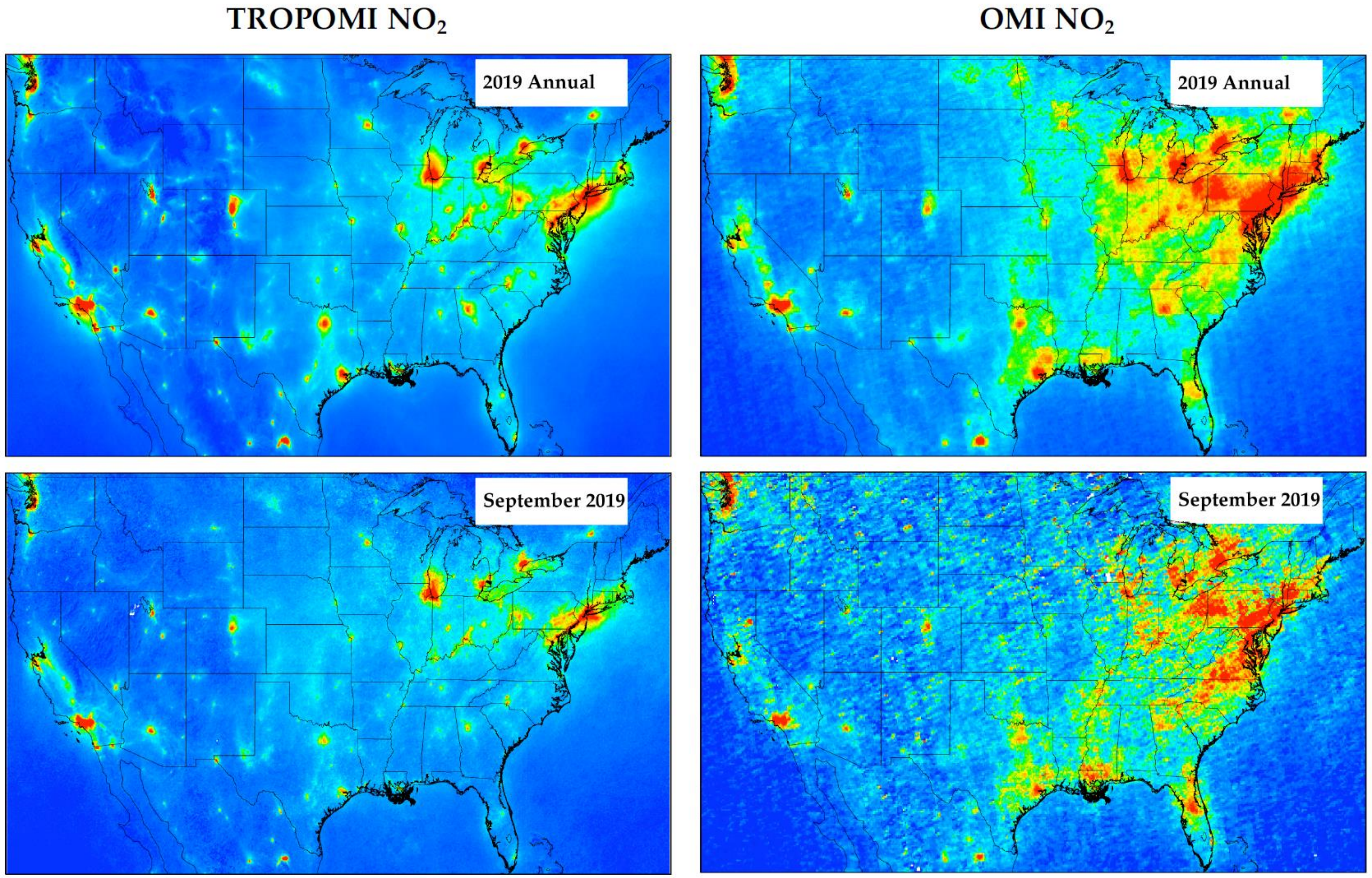


Most (top decile)
Least (bottom decile)

Progression of satellite capabilities over time

TEMPO NO_2

?



Goldberg et al. 2021