Using remote sensing and Earth system models to improve air quality and public health in megacities

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NASA Health and Air Quality Annual Meeting

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Milken Institute School of Public Health
THE GEORGE WASHINGTON UNIVERSITY

Objective and Team

Objective: Meet the needs of U.S. and international organizations to quantitatively assess air pollution health impacts and mitigation benefits in cities

1. Improve and verify estimates of **urban $PM_{2.5}$, ozone, and NO_2 concentrations** and **NOx and SOx emissions** for 5 pilot cities using NASA satellite data from MODIS, MISR, CALIPSO, OMI, as well as TROPOMI and GEOS-Chem
2. Estimate **15-year trends** in $PM_{2.5}$, ozone, and NO_2 exposures and associated mortality and morbidity burdens in cities
3. Expand the national-scale **tool used by the Climate and Clean Air Coalition** to estimate health benefits of mitigation policies to the urban scale
4. In partnership with stakeholders, apply the new tools to **assess health benefits of air quality policy** options in these three pilot cities

Science Team
Dr. Susan Anenberg (PI)
Dr. Daven Henze (Co-I/ Institutional PI)
Dr. Patrick Kinney (Co-I/ Institutional PI)

+ Dr. Dan Goldberg, Dr. Arash Mohegh, Omar Nawaz, Veronica Southerland, Danny Malashock, Maria Castillo, Nigel Martis

Air Quality Management Team

CCAC Supporting National Action Planning (SNAP) Initiative
Dr. Charles Heaps (Co-I), Dr. Chris Malley and Dr. Johan Kuylenstierna (Collaborators)
Urban LEAP-IBC programming, maintenance, application, local training and capacity building

CCAC/WHO Urban Health Initiative (UHI)
Sandra Cavalieri (Collaborator)
Communicate exposure and burden of disease estimates, provide perspective from CCAC city initiatives

Vital Strategies
Dr. Tom Matte (Collaborator)
Translate health science underlying Urban LEAP-IBC to local officials, make connections with sustainable cities initiatives

City governments
Accra (Daniel Tutu)
Dhaka (Tanvir Ahmed)
Paris (Elsa Martayan, Olivier Chretien)
Santiago (Carmen Gloria Contreras, Priscilla Ulloa)
Washington, DC (Cecily Beall)

Connections to other key urban air quality management end-users:

U.S. EPA
Amanda Curry-Brown, Sara Terry

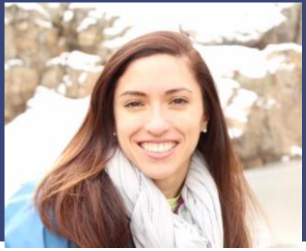
World Bank Pollution Management and Environmental Health Program (PMEH)
Dr. Gary Kleiman

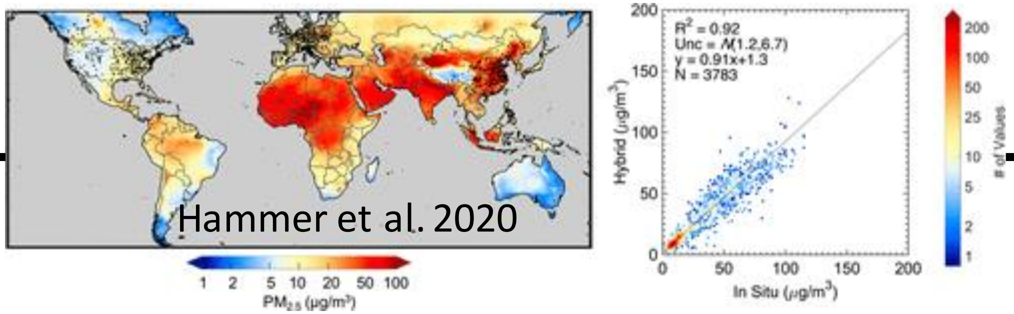
CCAC Diesel Initiative
Ray Minjares

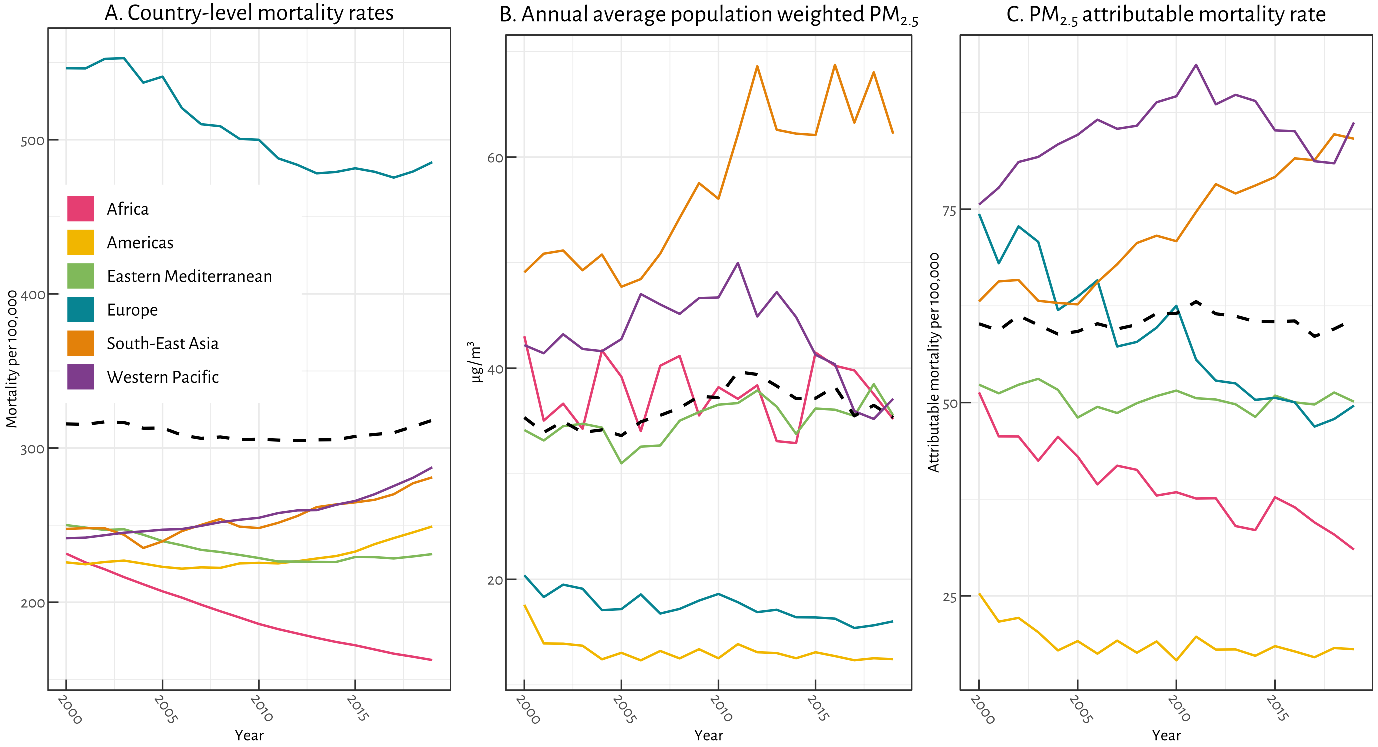
Global Urban Air Pollution Observatory
Sophie Bonnard, Elsa Martayan

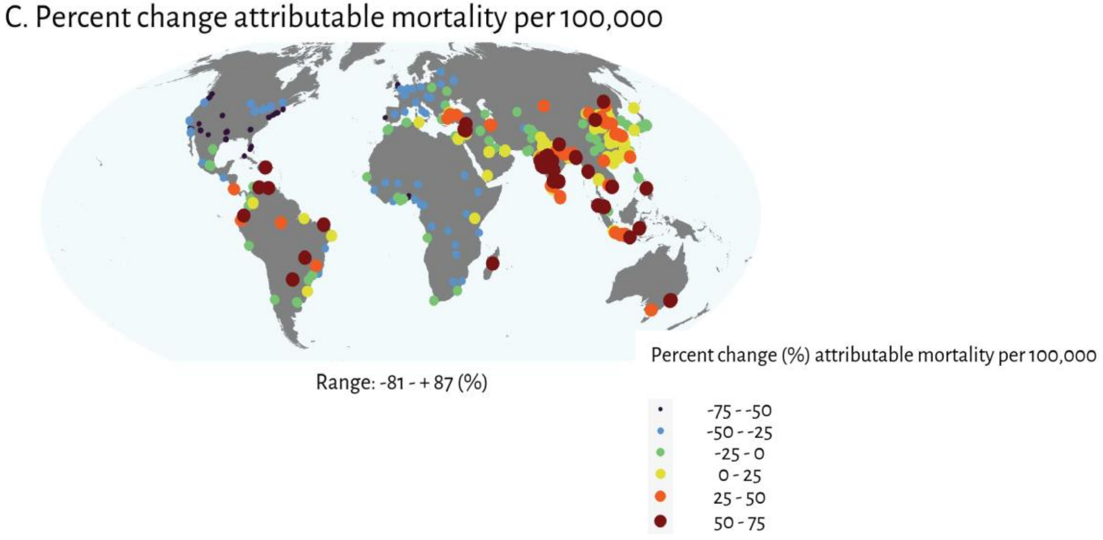
Clean Air Institute
Juan Castillo

$PM_{2.5}$ mortality trends in ~13,000 cities, 1990-2019







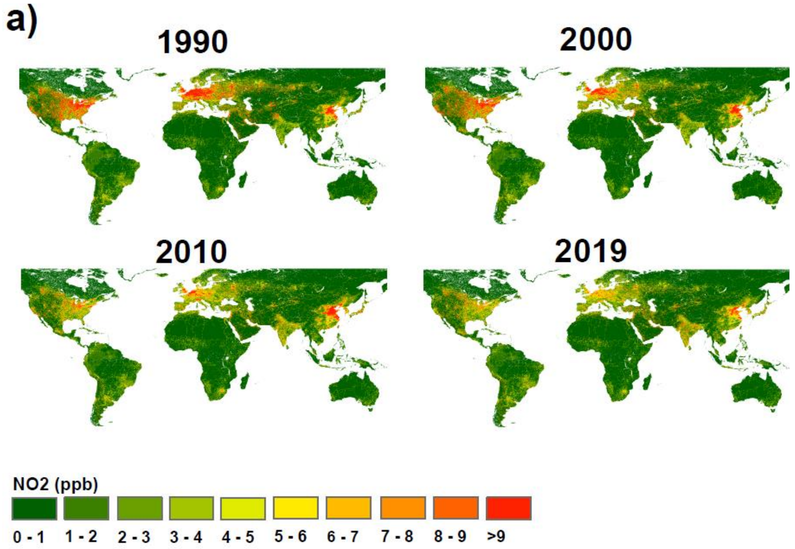


Now being used by C40 Cities to track air pollution in cities worldwide

Southerland et al. under review

NO_2 and pediatric asthma incidence trends in 13,000 cities, 1990-2019

NO_2 concentrations (1km, 1990-2020): land use regression of 2010-2012 average (Larkin et al. 2017) + OMI and MERRA-2 to scale to more years



Now being used by Institute for Health Metrics and Evaluation in add NO_2-pediatric asthma as new risk-outcome pair in the Global Burden of Disease Study

Anenberg, Mohegh et al., Lancet Planetary Health, forthcoming

Satellite-derived NOx emissions in 80 cities, 2005-2020

Aura OMI NO_2 Data (v4) Show Urban Trends (2009-2018) Are Consistent With Those From Bottom-Up Inventory in High-Income Countries, but not in Low-Moderate Income Countries

Dan Goldberg (George Washington U.), Susan Anenberg (George Washington U.), David Streets (Argonne Natl Lab) et al.

Figure (bottom): Differences between NO_x emissions estimates derived from the Aura Ozone Monitoring Instrument (OMI) NO_2 data and the bottom-up inventories are primarily driven by cities in Low-Moderate Income Countries (LMIC), including in Africa, China, India, Latin America, and the Middle East, where uncertainties in bottom-up emission estimates are high. Agreement between satellite-derived trends and the inventories, where uncertainties are relatively low, are generally consistent for High-Income Countries (HIC; e.g., US, Canada, Europe).

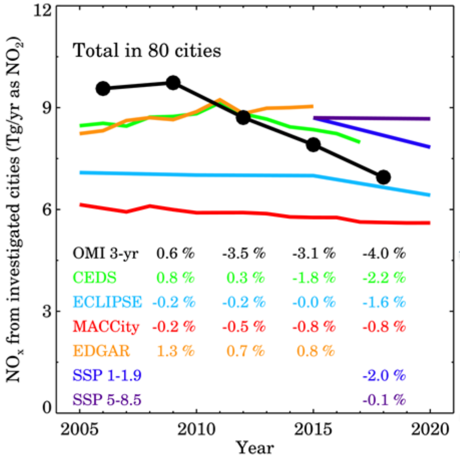
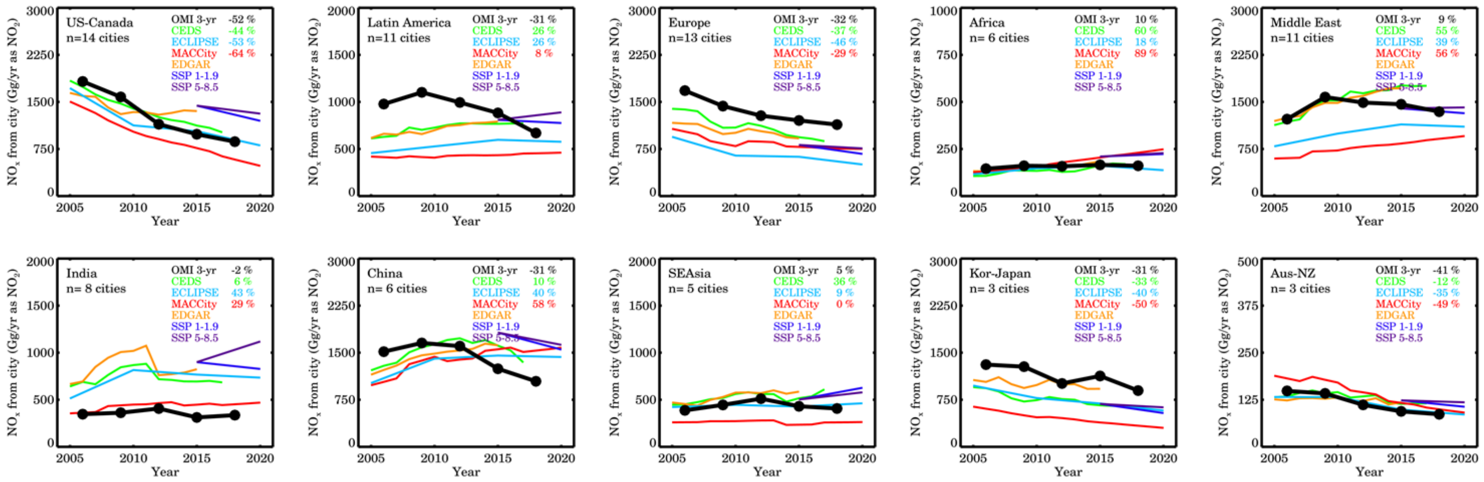


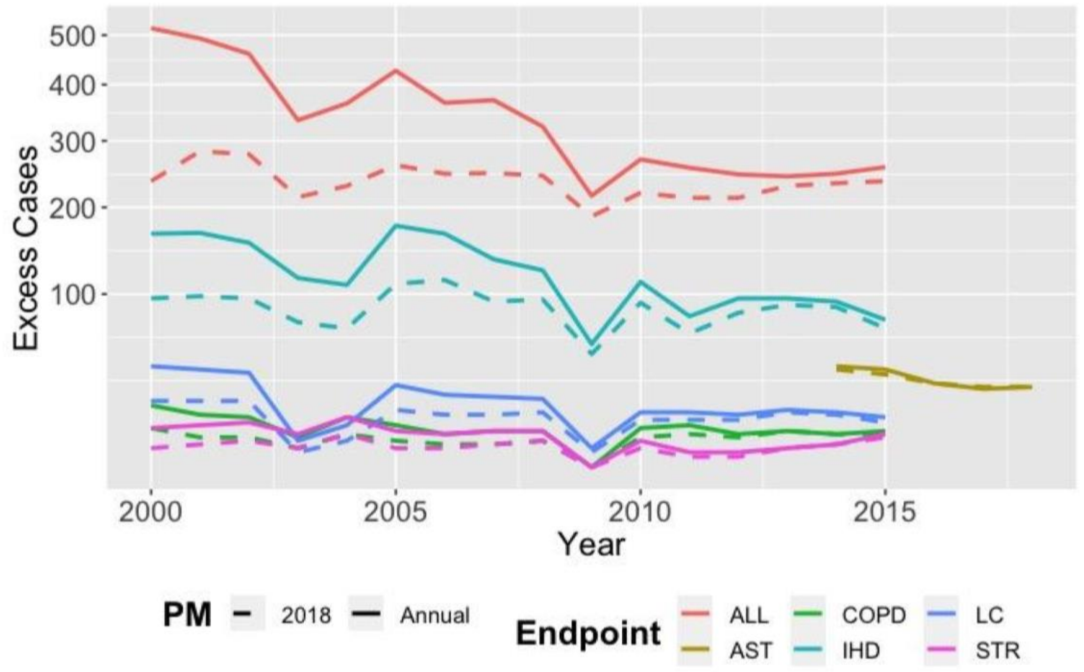
Figure (left): OMI-derived global urban NO_x emissions in 80 cities dropped 3.1 – 4.0% yr^{-1} between 2009 – 2018, while bottom-up emission inventories show a 0 – 2.2% yr^{-1} drop over the same timeframe.



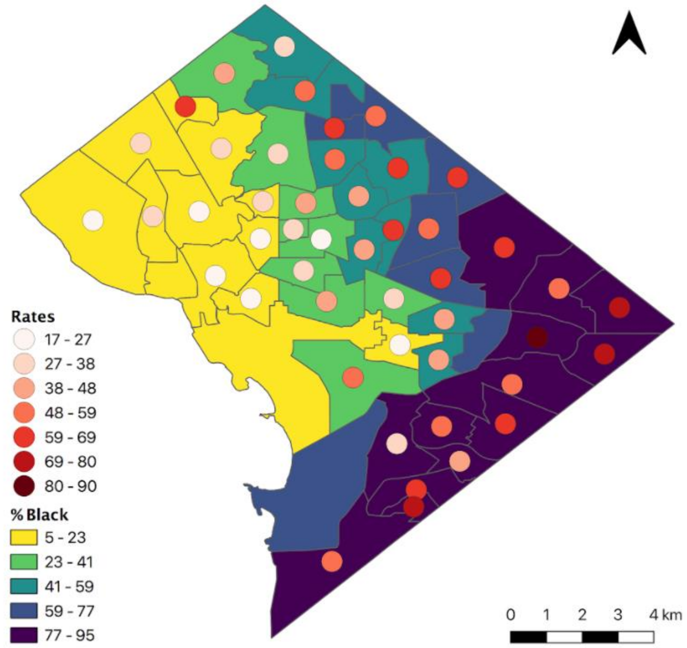
- OMI-derived urban trends (2009-2018) in NO_x emissions agree well with trends from bottom-up inventories in High-Income Countries (HIC).
- However, urban trends in Low-Moderate Income Countries (LMIC) showed much large disagreement.
- Given the relatively high agreement between the trends in the HIC, the satellite-derived trends in the LMIC likely provide better constraints in these regions, which have no or less reliable data on NO_x emission sources in most LMIC, than many of the bottom-up inventories.

Deep dive for Washington, DC: Disparities in $PM_{2.5}$ mortality rates

Temporal trend in $PM_{2.5}$-attributable mortality using satellite-derived $PM_{2.5}$ concentrations



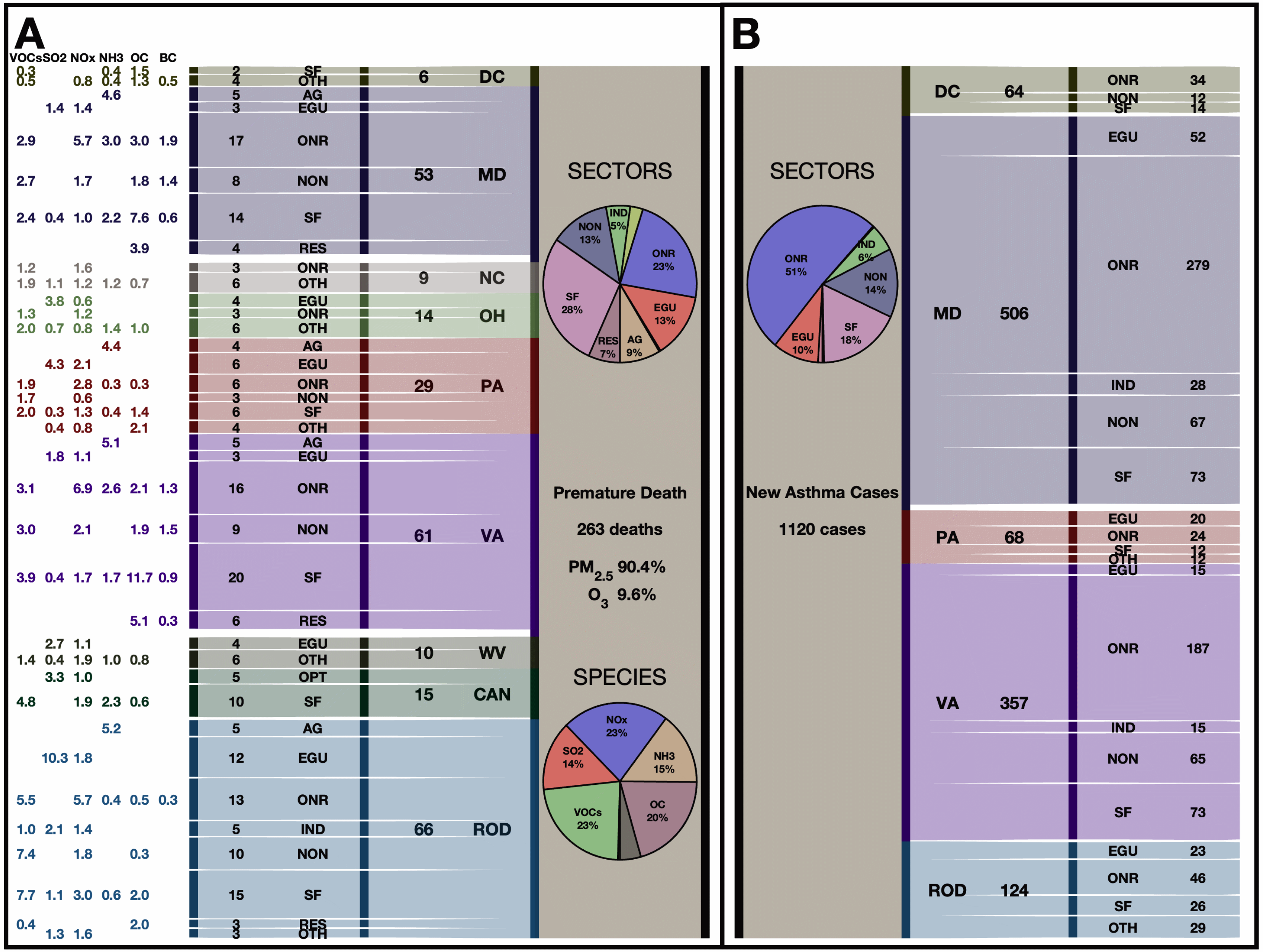
Spatial pattern of $PM_{2.5}$-attributable mortality



Discussing results of DC deep dive with Maryland and DC governmental stakeholders – mitigation, EJ mapping, monitor placement

Castillo et al. *GeoHealth*, forthcoming

Contributions to Annual $PM_{2.5}$ in DC for 2011 and 2016



Sector Abbreviations

AG – Agriculture

EGU – Electrical Generation Unit

ONR - On-road

IND – Industry

NON – Non-road

SF – Surface Emissions

RES – Residential

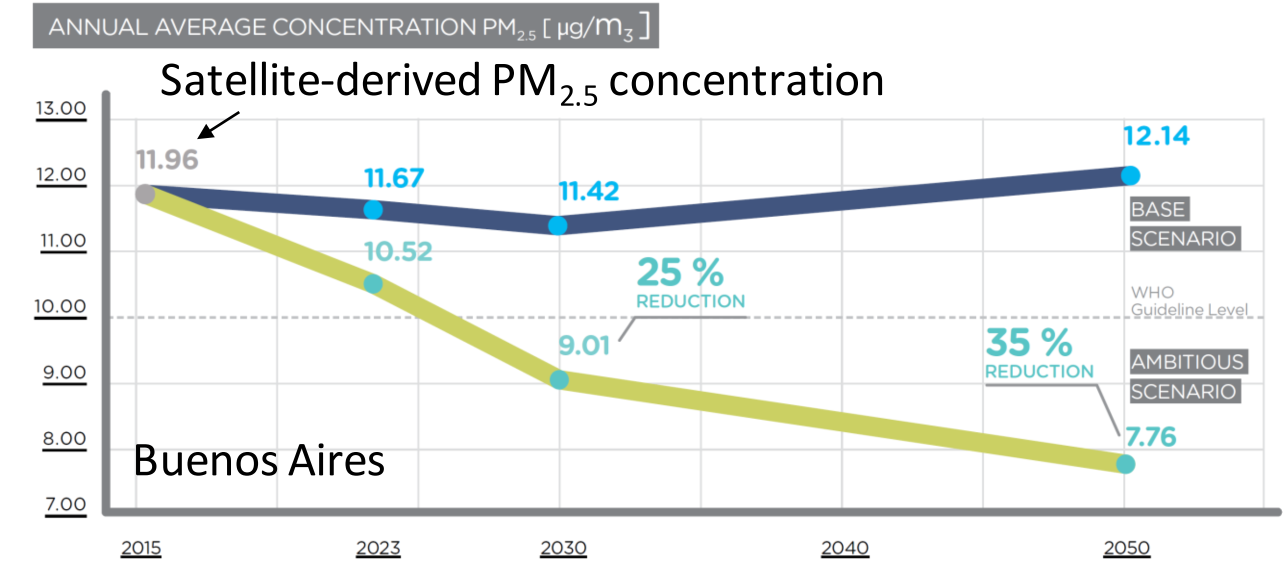
Similar analysis for Santiago coming soon!

Nawaz et al. under review

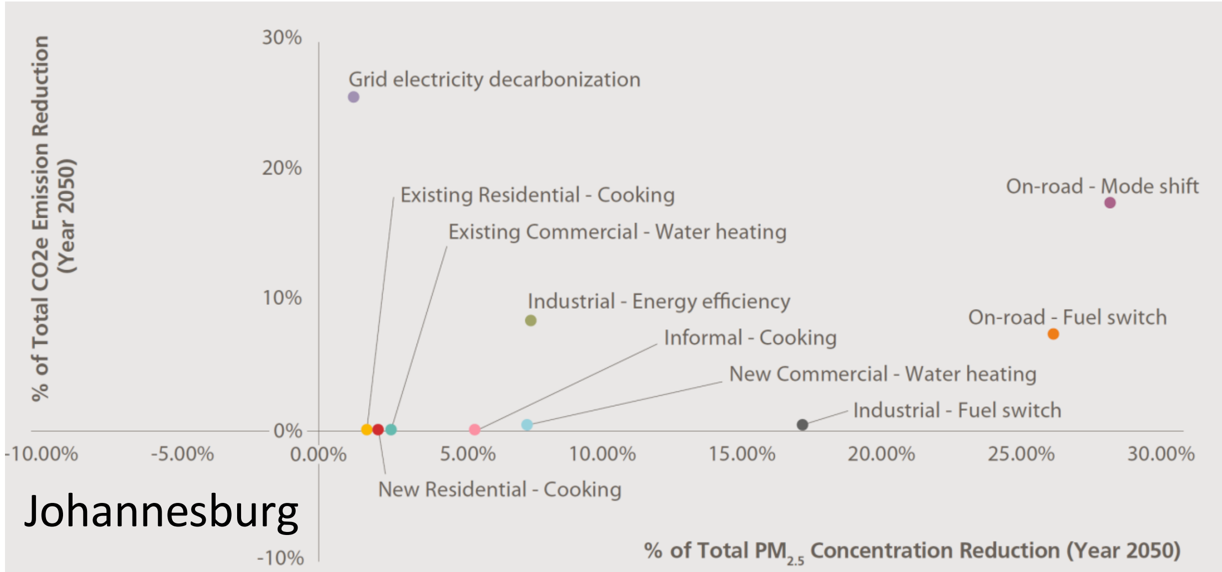
Stockholm Environment Institute (SEI) and Climate and Clean Air Coalition (CCAC)

- Major upgrade to SEI's Low Emissions Analysis Platform (LEAP) in 2020 that includes:
  - Integrated Benefits Calculator (IBC)
  - Urban capability
- LEAP-IBC used for National Action Planning on short-lived climate pollutants by the CCAC
- Methods described by Kuylenstierna et al. under review:
  - GEOS-Chem Adjoint emissions to concentration sensitivities
  - Satellite-derived $PM_{2.5}$ to transition from global model resolution to urban scale
  - Global Burden of Disease methods for health impacts

Integrating $PM_{2.5}$ into urban climate action plans



https://cdn.locomotive.works/sites/5ab410c8a2f42204838f797e/content_entry5c8ab5851647e1[...]4e5a4f200a691392e/files/PAC_2050_-_ENGLISH_.pdf?1623076753



https://www.joburg.org.za/departments_/Documents/EISD/City%20of%20Johannesburg%20-%20Climate%20Action%20Plan%20%28CAP%29.pdf

Cities that have included $PM_{2.5}$ into climate action plans:

- Accra, Ghana
- Addis Ababa, Ethiopia
- Buenos Aires, Argentina
- Guadalajara, Mexico
- Johannesburg, South Africa
- Lima Peru

Catalyzing urban action with public data

Milken Institute School of Public Health
THE GEORGE WASHINGTON UNIVERSITY

HAQAST

URBAN AIR QUALITY VISUALIZATIONS

Select Options to Visualize Data:

Select Country:
United States of America

Select City:
Washington D.C.

Select City ID:
860

Select Pollutant:
PM 2.5

Visualize Data

Select Options to Download Data:

Select Pollutant:
Choose an option

Select all

Select Year:
Choose an option

Select all

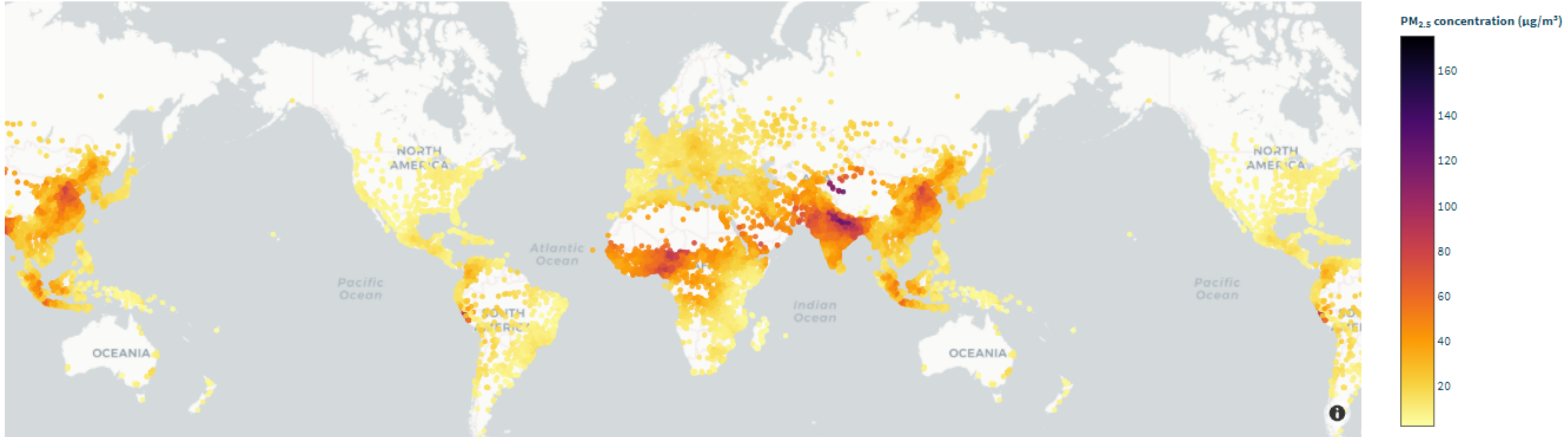
Select Country:

Description

This website provides estimates of fine particulate matter ($PM_{2.5}$), ozone, and nitrogen dioxide (NO_2) concentrations and associated disease burdens in >13,000 urban areas globally from 2000-2019. Methods are consistent with the Global Burden of Disease 2019 study, to the extent possible. Please visit our More Information and Acknowledgements section below.

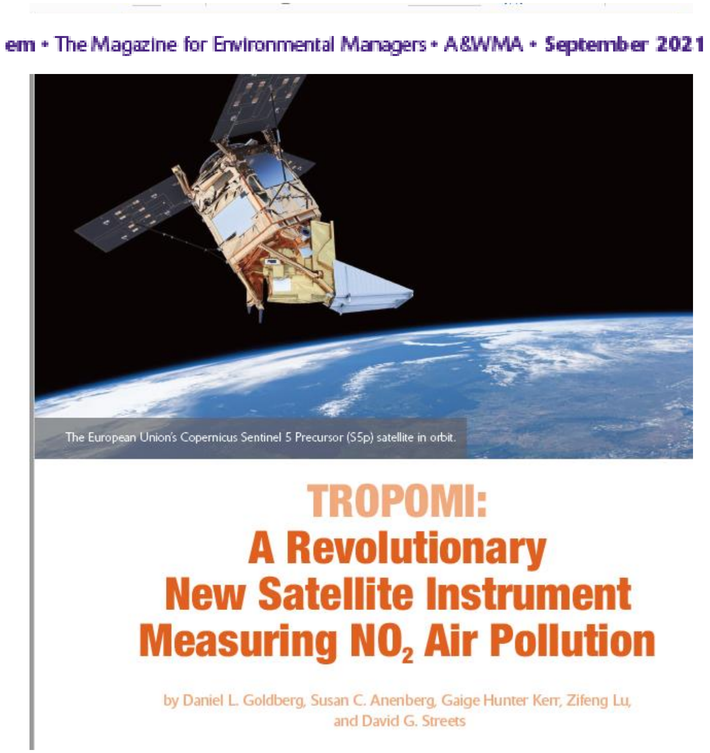
Data Visualizations

Annual Average $PM_{2.5}$ Concentration (µg/m³)



Successes and challenges

- Successes:
  - Cross-sectional analyses of $PM_{2.5}$, ozone, NO_2 health impacts and NOx emissions in cities
  - Deep-dive for Washington, DC
  - Stakeholder achievements: SEI/CCAC Urban LEAP-IBC, C40 Clean Air Declaration, C40 Climate Action Planning
- Next priorities (scale/replication supplement):
  - Replicate DC modeling in more cities (Santiago, Los Angeles)
  - Integrate urban AQ/burden dataset into stakeholder web dashboards
  - Automate updating of NO_2 concentrations and urban AQ/burden datasets
- Challenges: local-scale health data, changing stakeholder/policy landscape
- Started at ARL 6 (Nov. 2018), plan to get to ARL 9 (Oct. 2022), advanced to ARL 7 in May 2020 and ARL 8 in Aug 2021 as Urban LEAP-IBC model was released, urban $PM_{2.5}$ disease burdens have been integrated into C40 Cities' operations, and website built to share urban AQ results.



Thanks!

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Manuscript/Publications

In preparation:

- Malashock, D., O. Cooper, K.-L. Chang, J.J. West, S.C. Anenberg (2021) Ozone concentrations and attributable mortality in cities worldwide. In preparation.
- Von Salzen, S.C. Anenberg, et al. (2021) Mitigation of near-term Arctic warming accelerated by air quality improvements. In preparation.
- Rao, S., S. Anenberg, A. Diz Lois Palomares, Z. Klimont, A. Mohegh, S. Tsyro (2021) Global scenarios of pediatric asthma incidence due to NO2 in 2050. In preparation.

Under review:

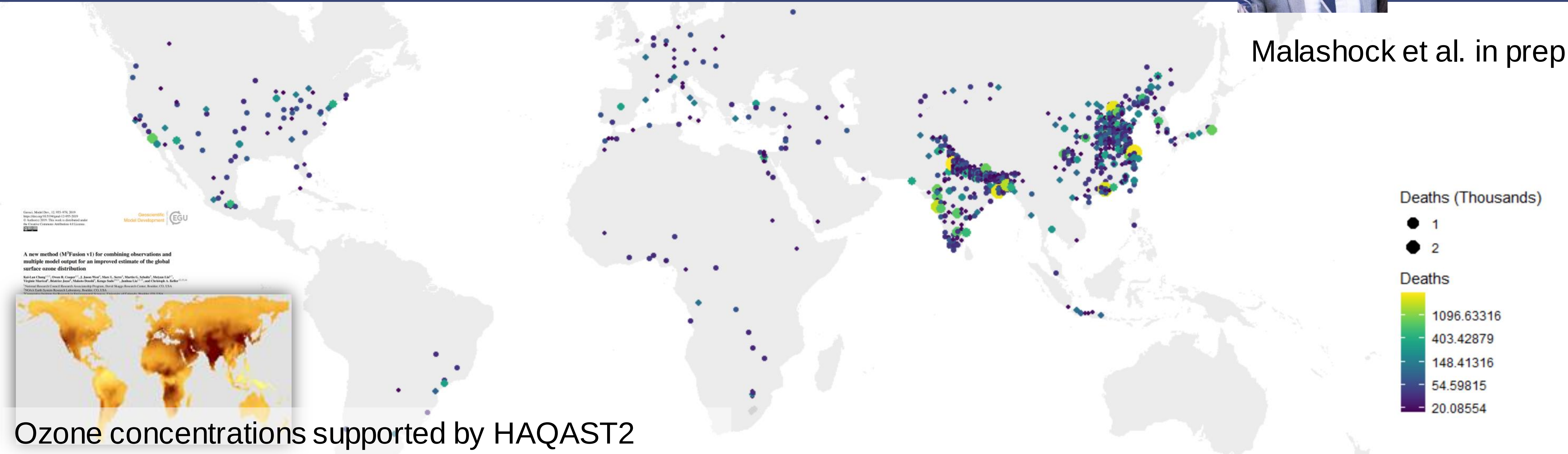
- Apte, J.S., S Seraj, S.E. Chambliss, M. Hammer, S.C. Anenberg, A. van Donkelaar, R.V. Martin, M. Brauer (2021) Air inequality: Global divergence in urban fine particulate matter. Under review.
- Southerland, V.A., S.C. Anenberg, M. Brauer, A. Mohegh, M. Hammer, R. Martin, A. van Donkelaar, J. Apte (2021) Global urban temporal trends in fine particulate matter (PM2.5) and attributable health burdens. Under review.
- Nawaz, O., S, Anenberg, D. Goldberg, D. Jo, B. Nault, J. Jimenez, H. Cao, C. Harkins, Z. Qu (2021) Impacts of sectoral, regional, species and day-specific emissions on air pollution and public health in Washington DC. Under review.

Published:

1. Castillo, M.D., P.L. Kinney, V. Southerland, A. Arno, K. Crawford, A. van Donkelaar, M. Hammer, R.V. Martin, S.C. Anenberg (2021) Estimating intra-urban inequities in PM2.5-attributable health impacts: A case study for Washington, DC. *GeoHealth*, in press.
2. Anenberg, S.C., A. Mohegh, D.L. Goldberg, M. Brauer, K. Burkart, P. Hystad, A. Larkin, S. Wozniak, L. Lamsal (2021) Long-term trends in urban NO2 concentrations and associated pediatric asthma cases: estimates from global datasets. Lancet Planetary Health, n press.
3. Goldberg, D.L., S.C. Anenberg, L.N. Lamsal, Z. Lu, E.E. McDuffie, S.J. Smith, D.G. Streets (2021) Urban NOx emissions around the world declined faster than anticipated between 2005 and 2019. Environmental Research Letters, in press.
4. Arctic Monitoring and Assessment Program (AMAP), 2021 (chapter lead author). “Health and Ecosystem Impacts” Chapter 8 in: AMAP 2021 Assessment: Arctic climate, air quality, and health impacts from short-lived climate forcers (SLCFs). Tromsø, Norway. (Anenberg was Chapter Lead Author)
5. Anenberg, S.C., G.H. Kerr, D.G. Goldberg (2021) Leveraging satellite data to address air pollution inequities. EM Magazine, in press.
6. Goldberg, D.G., S.C. Anenberg, G.H. Kerr, Z. Lu, D.G. Streets (2021) TROPOMI: A revolutionary new satellite instrument measuring NOx air pollution. EM Magazine, in press.
7. Holloway, T., D. Miller, S. Anenberg, M. Diao, B. Duncan, A. Fiore, D. Henze, J. Hess, P. Kinney, Y. Liu, J. Neu, S. O’Neill, R.B. Pierce, A. Russell, D. Tong, J.J. West, M. Zondlo (2021) Satellite monitoring for air quality and health. Annual Review of Biomedical Data Science, In press.
8. Malley, C.S., W.K. Hicks, J.C.I. Kuylenstierna, E. Michaelopoulou, A. Molotoks, J. Slater, C.G. Heaps, S. Ulloa, J. Veysey, D.T. Shindell, D.K. Henze, O. Nawaz, S.C. Anenberg, B. Mantlana, T.P. Robinson (2021) Integrated assessment of global climate, air pollution, and dietary, malnutrition and obesity health impacts of food production and consumption between 2014 and 2018. *Environmental Research Communications*, in press.
9. Goldberg, D., S. Anenberg, G.H. Kerr, A. Mohegh, Z. Lu, D.G. Streets (2021) TROPOMI NO2 in the United States: A detailed look at the annual averages, weekly cycle, effects of temperature, and correlation with surface NO2 concentrations. Earth’s Future, https://doi.org/10.1029/2020EF001665.
10. Southerland, V.A., S.C. Anenberg, M. Harris, J. Apte, Hystad, A. van Donkelaar, R. Martin, M. Beyers, A. Roy (2021) Assessing the distribution of air pollution health risks within cities: a neighborhood-scale analysis leveraging high resolution datasets in the Bay Area, California. Environmental Health Perspectives, https://doi.org/10.1289/EHP7679.
11. Kuylenstierna, J.C.I., C.G. Heaps, T. Ahmed, H.W. Vallack, W.K. Hicks, M.R. Ashmore, C.S. Malley, G. Wang, E.N. Lefevre, S.C. Anenberg, F. Lacey, D.T. Shindell, U. Bhattacharjee, D.K. Henze (2020) Using the LEAP-IBC tool to assess air quality and climate co-benefits of emission reduction strategies: A case study for Bangladesh. Environment International, 145, 106155, doi:10.1016/j.envint.2020.106155.
12. Goldberg, D.L., S.C. Anenberg, Z. Lu, D.G. Streets, D. Griffin, C.A. McLinden (2020) Disentangling the impact of the COVID-19 lockdowns on urban NO2 from natural variability. Geophysical Research Letters, doi:10.1029/2020GL089269.
13. Nawaz, M. O., and D. K. Henze (2020) Premature deaths in Brazil associated with long-term exposure to PM2.5 from Amazon fires between 2016-2019, GeoHealth, doi: 10.1029/2020GH000268.

Ozone mortality in ~13,000 cities, 1990-2019

Malashock et al. in prep



Ozone concentrations supported by HAQAST2

Top 5 Cities with the Greatest Ozone-attributable Deaths by Region in 2017						
No.	Oceania (n=30)	Latin America & Caribbean (n=428)	Africa (n=653)	Europe (n=763)	N. America (n=302)	Asia (n=2941)
1	Sydney, Australia (9.2)	Mexico City, Mexico (497.3)	Cairo, Egypt (498.6)	Madrid, Spain (306.2)	Los Angeles, CA, USA (829.5)	New Delhi, India (2840)
2	Melbourne, Australia (8.6)	SÃ£o Paulo, Brazil (314.9)	Johannesburg, South Africa (167.2)	Milan, Italy (165.9)	New York, NY, USA (389.5)	Shanghai, China (2619.6)
3	Brisbane, Australia (3.3)	Buenos Aires, Argentina (128.2)	Kinshasa, DRC (109.7)	Naples, Italy (150.7)	Phoenix, AZ, USA (326)	Kolkata, India (2422.1)
4	Perth, Australia (2.9)	Curitiba, Brazil (83.5)	Algiers, Algeria (66)	Athens, Greece (138.9)	Chicago, IL, USA (234.5)	Beijing, China (2364.7)
5	Adelaide, Australia (2.5)	Ciudad JuÃ¡rez, Mexico (61.6)	Mbuji-Mayi, DRC (65.7)	Guadalajara, Spain (128.5)	San Diego, CA, USA (186.7)	Guangzhou, China (2179.5)