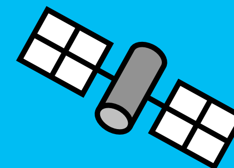


Linking diurnal variation in air quality with health: opportunities with geostationary platforms

Allan C. Just PhD

Assistant Professor

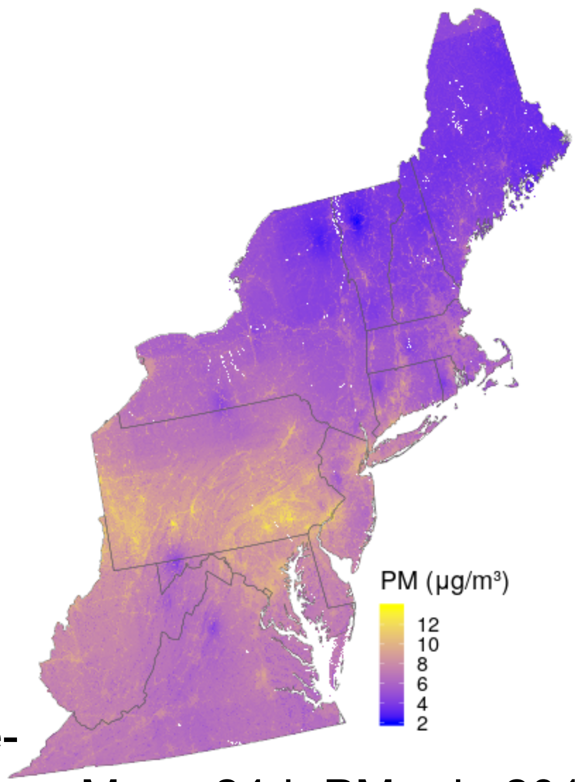
Department of Environmental Medicine and Public Health

Icahn School of Medicine at Mount Sinai

Satellite AOD to model ground level $PM_{2.5}$ for health studies

- Our daily models generate billions of predictions
- Using Machine-Learning algorithms to make our models flexible and scalable
- But great care is needed to avoid overfitting

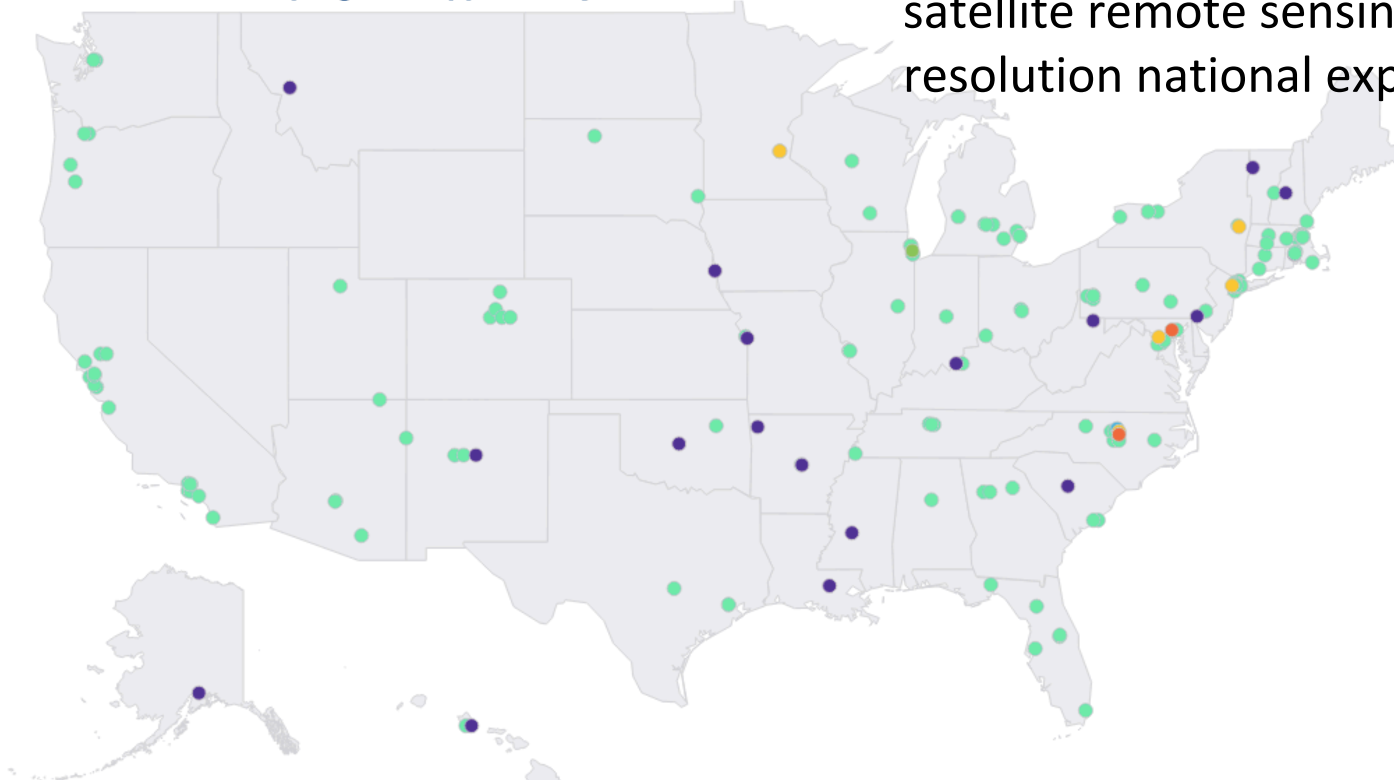
Example health application: linking daily $PM_{2.5}$ and temperature at the residence for 800,000 births in a state-wide registry; critical windows for fetal growth impacts



Mean 24-h $PM_{2.5}$ in 2015

ECHO
Environmental influences on Child Health Outcomes
A program supported by the NIH

New Grant: awarded April 2018
Opportunities and Infrastructure Fund (OIF)
"ECHO-wide platform for studying air pollution, temperature, and greenness using satellite remote sensing with daily high-resolution national exposure estimates"



~50,000 kids
<u>Outcomes</u>:
Perinatal
Neurodevelopment
Obesity
Respiratory

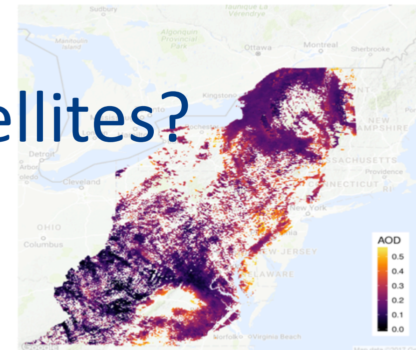
Machine-learning to refine AOD
an opportunity for geostationary satellites?

remote sensing

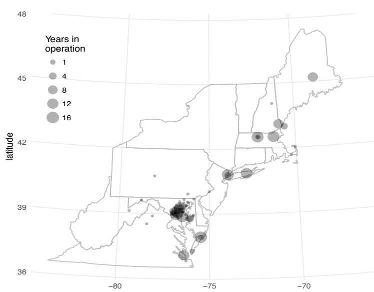
Article

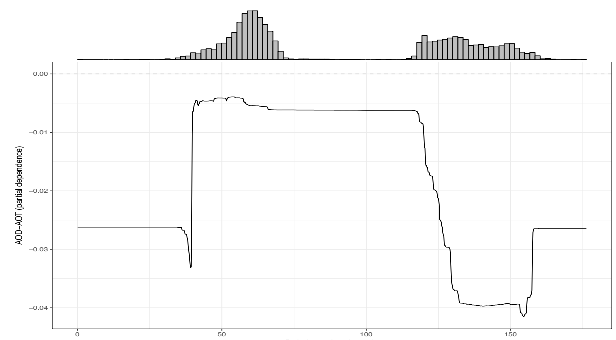
Correcting Measurement Error in Satellite Aerosol Optical Depth with Machine Learning for Modeling $PM_{2.5}$ in the Northeastern USA

Allan C. Just [1,*], Margherita M. De Carli [1], Alexandra Shtein [2], Michael Dorman [2], Alexei Lyapustin [3] and Itai Kloog [2]



- Trained 3 machine learning approaches predicting MAIAC AOD minus AERONET AOT
- **Best model – tuned XGBoost decreased RMSE in testing AOT data by 44%**
- **Correlation of corrected AOD & EPA 24-hr $PM_{2.5}$ increased 10 percentage points**
- Most important predictors included relative azimuth, AOD uncertainty, and AOD difference in 30-210km moving windows





Just et al. *Remote Sens*. 2018, 10(5), 803 https://doi.org/10.3390/rs10050803

Fine particulate air pollution ($PM_{2.5}$) is a major risk factor for chronic AND ACUTE health impacts

- 2.9 million deaths in 2017 from chronic ambient $PM_{2.5}$ (HEI & IHME 2019)

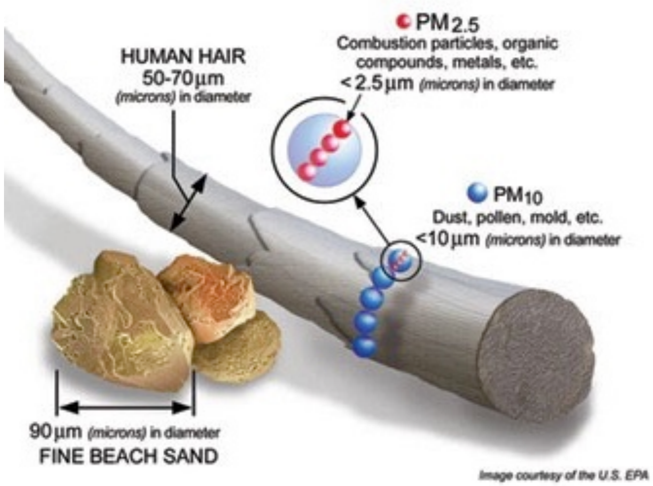
- Virtually all major health endpoints are impacted by $PM_{2.5}$

- Acute health impacts may be understudied

  No one breathes 24-hour averaged air

- Geostationary satellites - unique opportunity!

  (and challenges!)



ENVIRONMENTAL Science & Technology

Article
pubs.acs.org/est

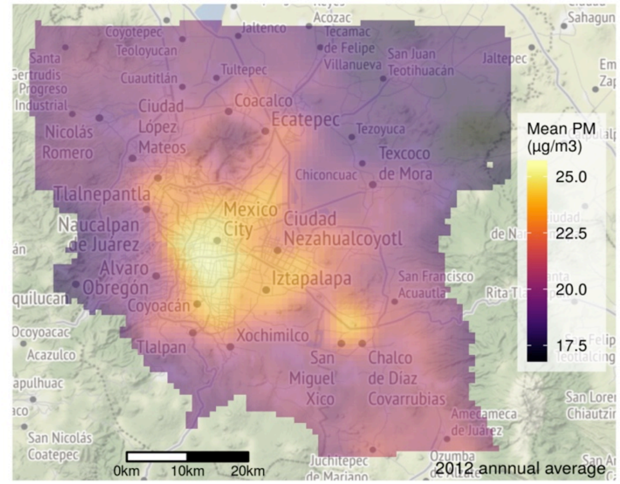
Just et al. *Environ Sci Technol*. 2015

Using High-Resolution Satellite Aerosol Optical Depth To Estimate Daily $PM_{2.5}$ Geographical Distribution in Mexico City

Allan C. Just,*,† Robert O. Wright,‡ Joel Schwartz,† Brent A. Coull,§ Andrea A. Baccarelli,† Martha María Tellez-Rojo,∥ Emily Moody,⊥ Yujie Wang,# Alexei Lyapustin,∇ and Itai Kloog¶

Key features

- Daily estimates on a 1km * 1km grid 2004-2014
- Midafternoon Aqua MAIAC AOD and LUR
- Cross-validated R^2 of 0.72



10 ug/m^3 higher $PM_{2.5}$ in lag 0-1 days associated with 3.43% (0.10-6.28) higher cerebrovascular mortality

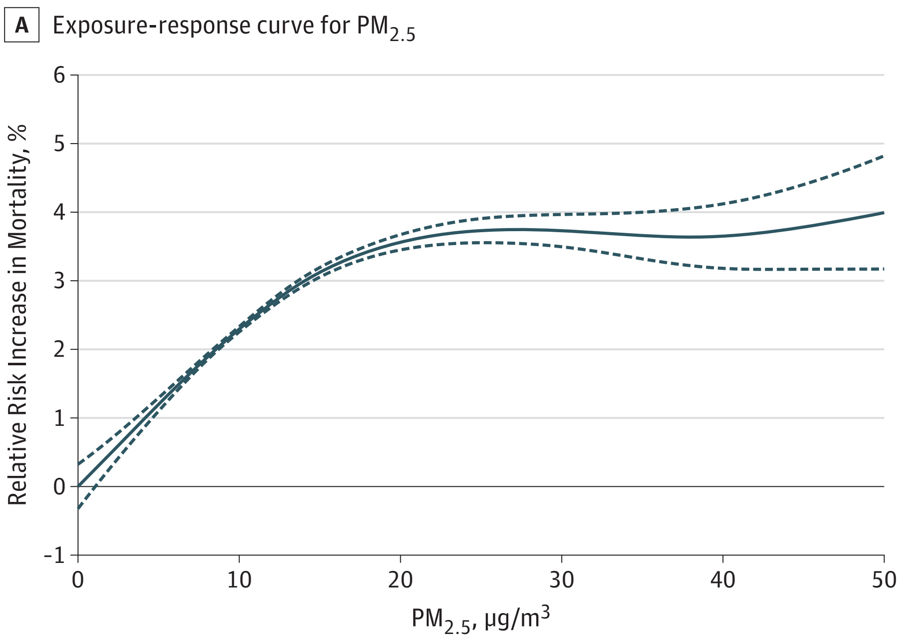
Stroke

Cardiovascular and Cerebrovascular Mortality Associated With Acute Exposure to $PM_{2.5}$ in Mexico City

Iván Gutiérrez-Avila, MSc; Leonora Rojas-Bracho, ScD; Horacio Riojas-Rodríguez, PhD; Itai Kloog, PhD; Allan C. Just, PhD; Stephen J. Rothenberg, PhD

Gutierrez-Avila et al. *Stroke*. 2018

Qian Di et al show acute mortality at low concentrations using lag01 (48 hour) average $PM_{2.5}$ in national Medicare case-crossover analysis



They selected lag01 from best fit (AIC)

What if peak exposures mattered?

Harder to estimate peak exposures

The mean is a worse estimator for the max as you go higher (heteroskedasticity)

Di Q, Dai L, Wang Y, Zanobetti A, Choirat C, Schwartz JD, Dominici F. Association of Short-term Exposure to Air Pollution With Mortality in Older Adults. *JAMA*. 2017;318(24):2446-56.

The agreement of the mean with the hourly maximum can vary quite a lot!

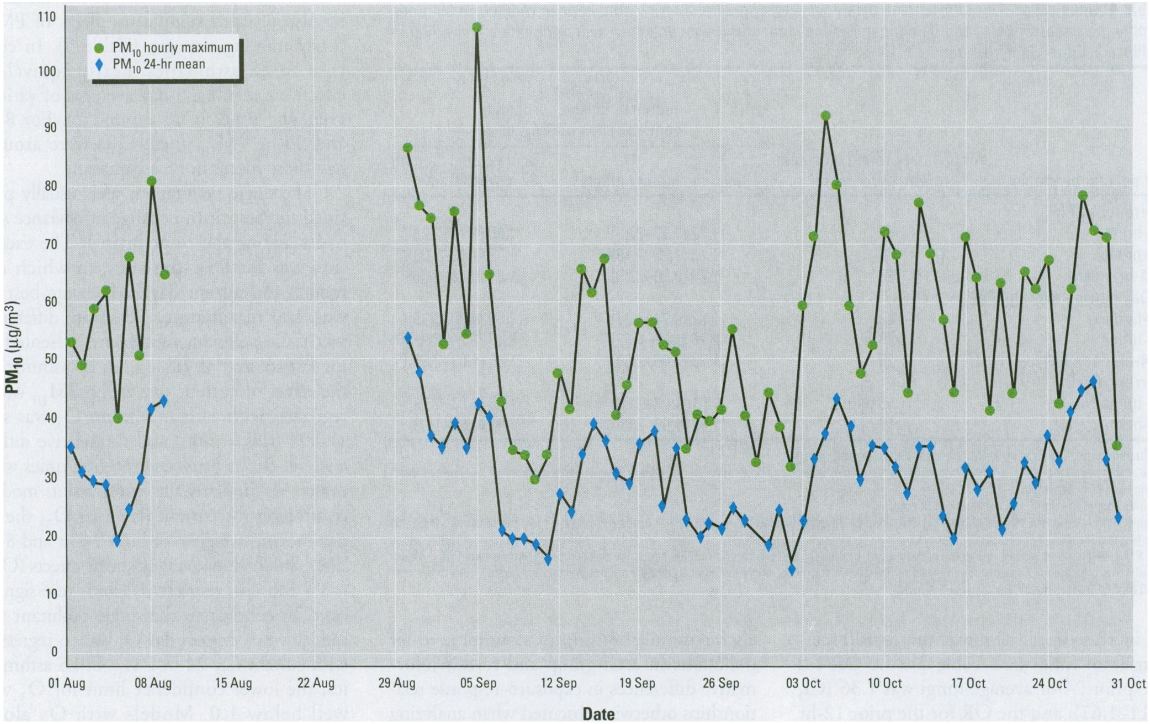


Figure 1. Time plot of daily tapered-element oscillating microbalance (TEOM) PM_{10} in the Alpine Asthma Panel Study, August to October 1995: comparison of maximum hourly with 24-hr average PM_{10}.

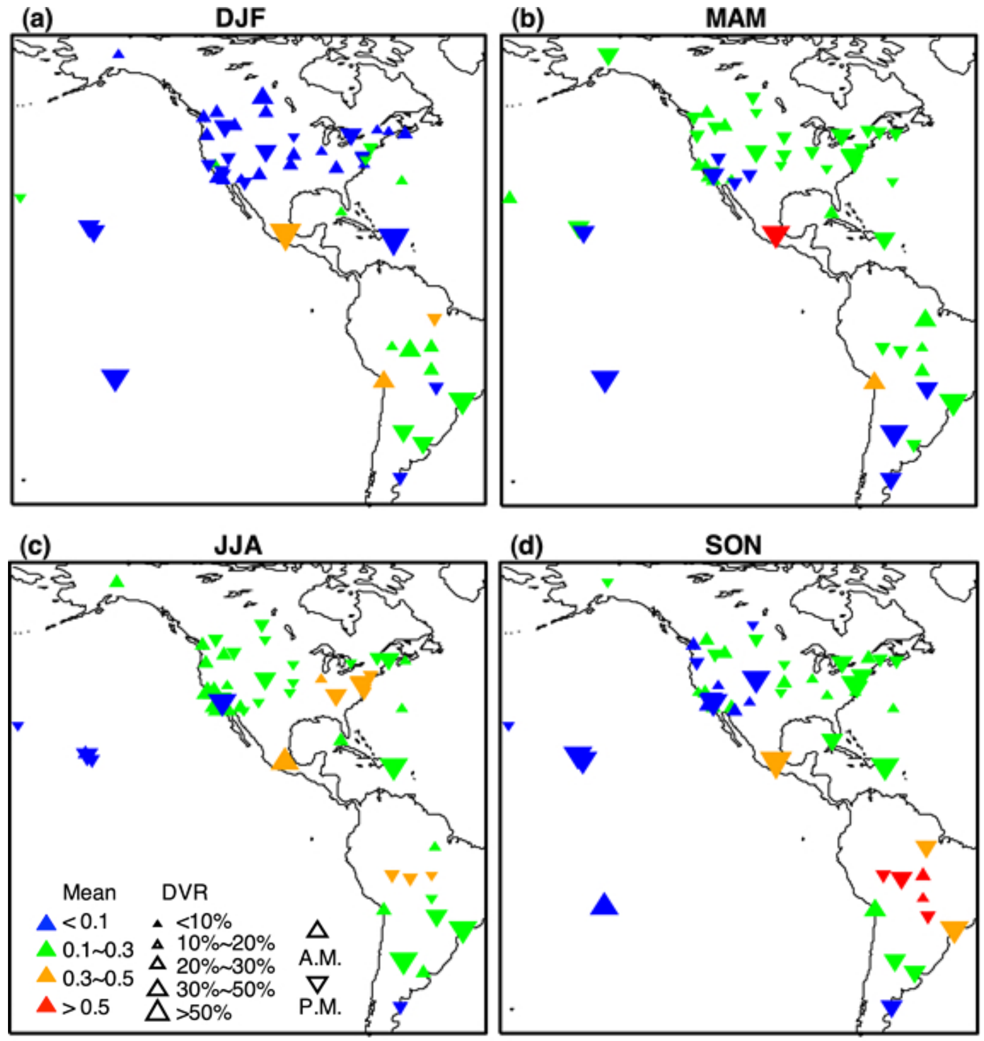
(Delfino et al. *Env Health Persp* 1998)

Aerosol optical depth varies within-day at AERONET stations

Color is seasonal mean AOD in bins

Size of triangle is AOD daytime variation range defined as a difference of maximum and minimum hourly percentage departure from the daily mean AOD

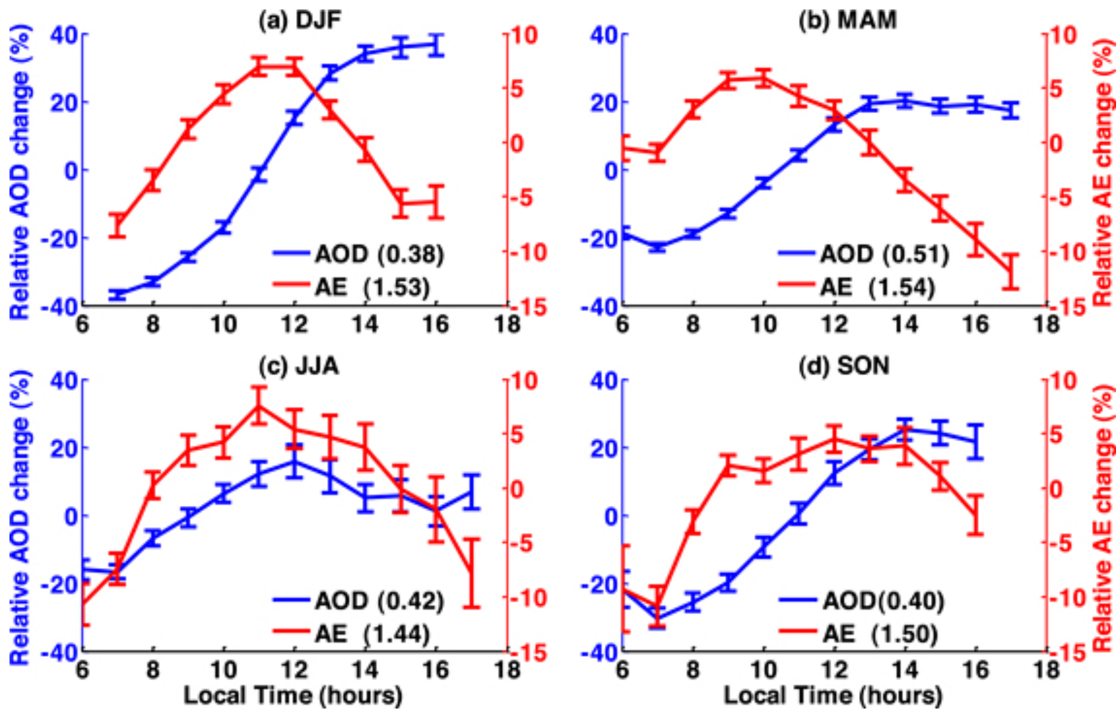
upside triangle for higher morning AOD
downside triangle for higher afternoon AOD



(Zhang et al., *JGR Atmos* 2012)

Mexico City is a prime example for within-day variation

AOD (blue lines) accumulates throughout the day



Percentage deviations of hourly AOD at 440 nm and Ångström exponent over 440–870 nm range, relative to the daily mean in four seasons. Vertical bar is the standard error of measurements per hour. Seasonal mean AOD and AE shown in the figure.

(Zhang et al., *JGR Atmos* 2012)

Metropolitan Area of the Valley of Mexico population >21.3 million people

Hourly stations

29 for NO_2
34 for O_3
31 for SO_2
21 for $PM_{2.5}$

Mexico City summary for remote sensing, air pollution, and health

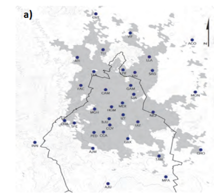
Ivan Gutierrez-Avila PhD (INSP) and Allan Just PhD (Mount Sinai) *2019-06-04*

Speciated Ground Measurements

- **Ongoing work: speciation** being measured through formal collaboration of government agency (SEDEMA) and academic UNAM using TAG-GC/MS instrument
- **Black carbon** measurements from 7 sites for 3 years (1 day in 6); hourly at 1 site (2015-2017; *available online*); run by a Gov agency (SEDEMA) that still has this capability
- **Inorganic ions** in winter 2014 during AERAS campaign (1 site; hourly; *available online*)

Regulatory Stations

- 40 stations in two governmental networks measuring all criteria pollutants and meteorological parameters; *data online*



LIDAR

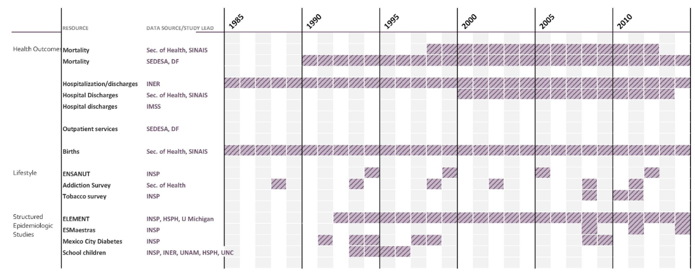
- One station with Vaisala CL31 ceilometer since 2008; UNAM

AERONET

- *Mexico_City* (colocated with $PM_{2.5}$ station *CCA* at UNAM); level 2.0 AOD available on 58% of days since 1999

Health Studies

- **NIH-funded cohorts** (e.g. PROGRESS cohort); myriad **administrative data** (e.g. $PM_{2.5}$ and cerebrovascular mortality publication *Stroke* 2018); and **health registries;**
- **Strong ongoing involvement from Mount Sinai, Harvard, University of Michigan public health researchers studying air pollution, among others**



(image credit: **Mexico City-Harvard Alliance for Air Quality and Public Health**)

Key local partners

- Atmospheric Monitoring System of Mexico City (SIMAT); governmental
- National Autonomous University of Mexico (UNAM); academic
- National Institute of Public Health of Mexico (INSP); governmental research
- Environmental Commission of the Megalopolis (CAMe); governmental regulatory

More detailed information and links available in our full length Google Doc

Geostationary opportunities for exposure science

- Gap filling satellite coverage
  - Multiple shots to see through cloud breaks
  - Helpful where you expect little within-day variation
- Improved data quality from time-series information
  - Borrow information from retrievals close together in time
- Monitoring rapidly changing conditions (e.g. forest fires)
  - Hard to set up health studies – often rural
- Quantifying within-day air pollutant concentrations
  - Helpful where you expect meaningful within-day variation

Short-term variation in air pollution is understudied

Previous satellite-based estimates have relied on LEO single-overpass AOD

estimate 24-hour average $PM_{2.5}$ to reflect regulatory standards / methods?

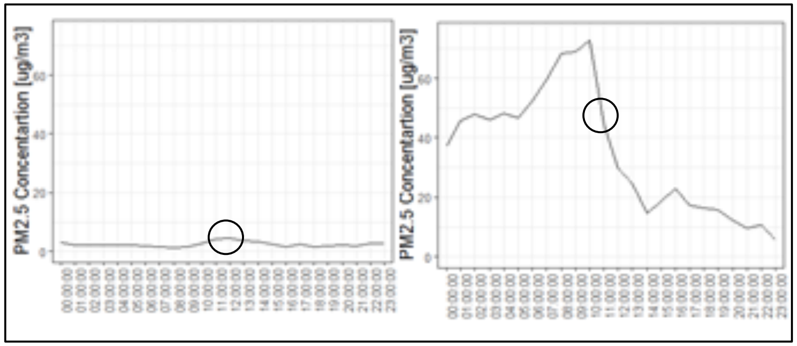


Photo credit: archive.epa.gov

“In fact, prior to recent EPA regulatory proposals for tightening the NAAQS for PM and O_3, the EPA's Clean Air Science Advisory Committee advised the EPA to give a scientific rationale for the 24hr PM_{10} averaging time in the NAAQS” – Delfino et al. *EHP* 1998

Environmental Epidemiology

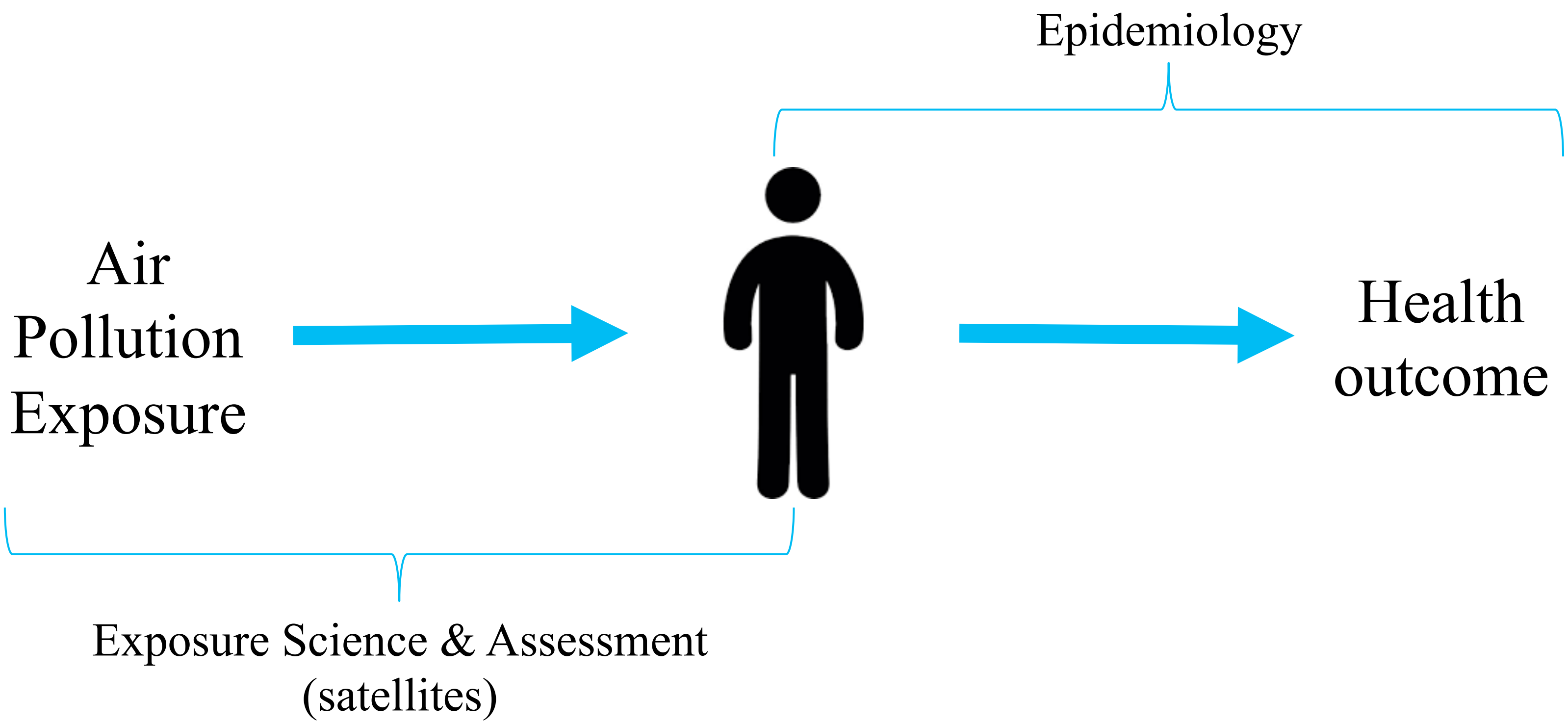
Epidemiology

Average
Air
Pollution
Exposure

Health
outcome

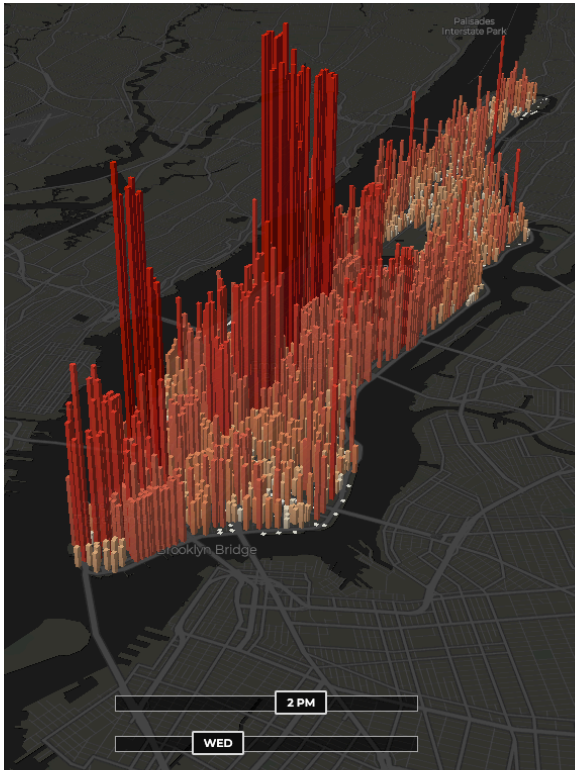
Exposure Science & Assessment
(satellites)

Environmental Epidemiology



Diurnal Patterns in Behavior & Biology

- ▶Human activity and physiology varies diurnally
- ▶Cardio-respiration decreases during sleep
  - – Lowers inhalation exposure and circulation



Manhattan Population Explorer
Justin Fung: manpopex.us

Biological mechanisms for sub-daily cardiovascular response

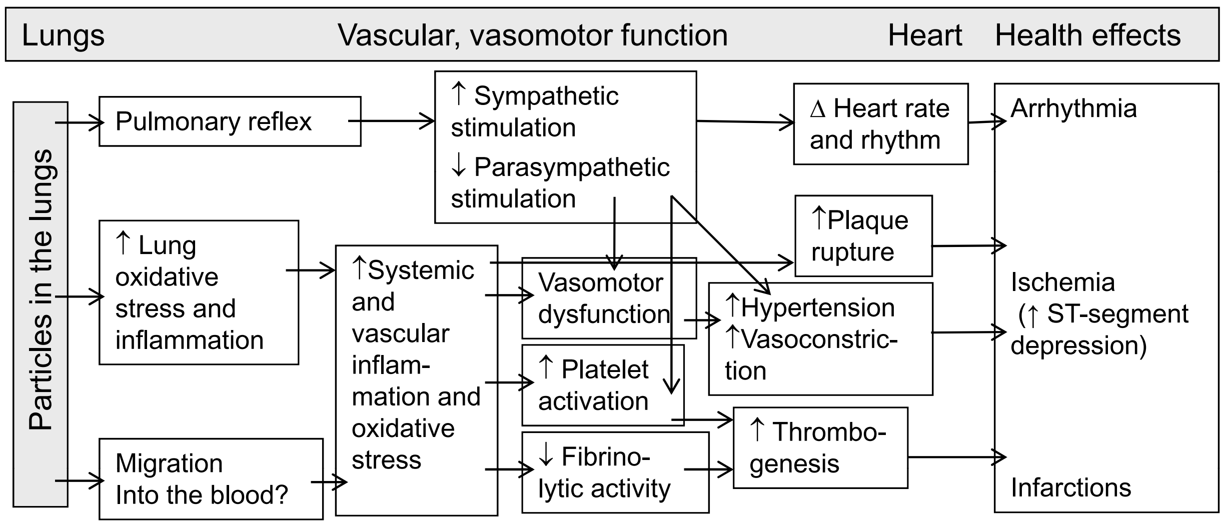


Figure 1 Likely mechanisms whereby sub-daily exposures of fine particles (PM) induce acute cardiovascular effects (arrhythmia, ischemia and infarction). Adapted from Brook et al. [1] and Mills et al [3].

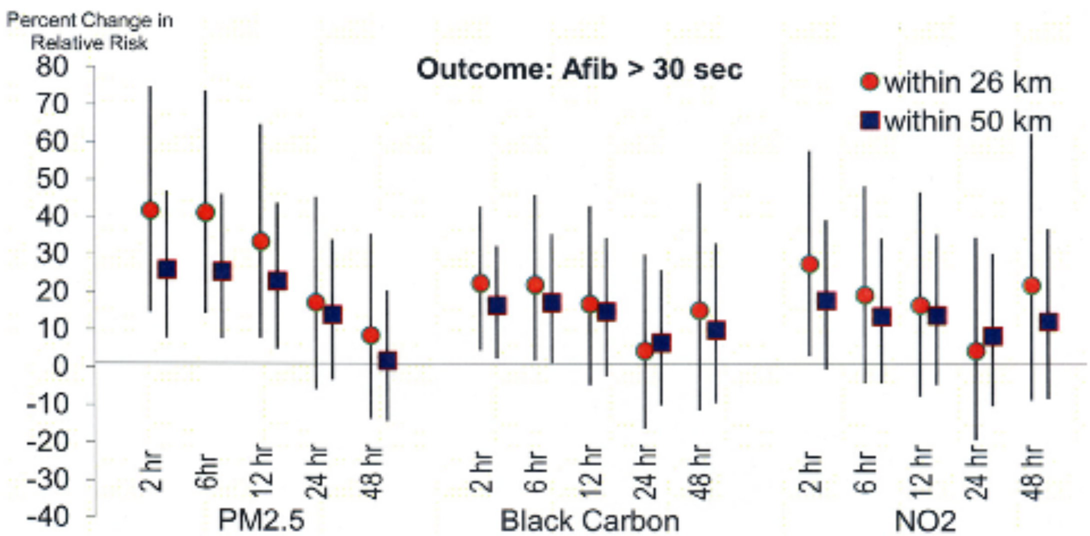
Burgan *et al.* Cardiovascular effects of sub-daily levels of ambient fine particles: a systematic review. *Environmental Health* 2010

Tools in understanding within-day behavioral and biological parameters for studying health responses

- Biometric tracking
  - Activity trackers (e.g. Fitbit)
  - Ambulatory blood pressure monitors
  - Sleep trackers
- Cell phones
- Implantable cardioverter-defibrillators
- Health records

Examples of short-term cardiovascular exposure-response in air pollution epidemiology

Case-crossover matched on hour and day of week in 176 patients with implantable cardioverter-defibrillators with 328 episodes of atrial fibrillation

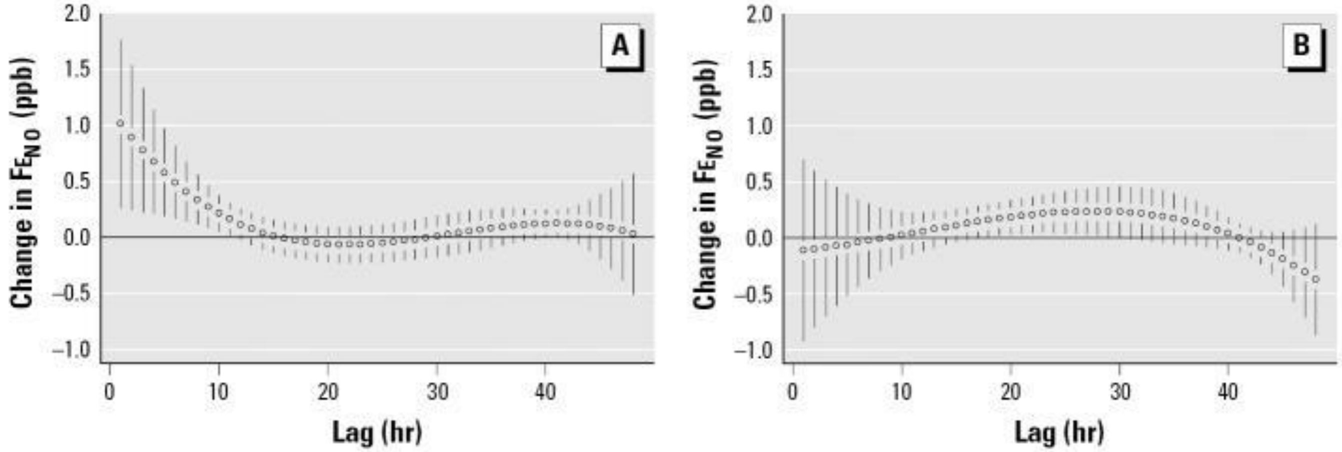


Risk of atrial fibrillation with Air Pollution in Patients Living Within 26 km of the Air Pollution Monitoring Site

(Link et al., *JACC* 2013)

Airway inflammation ~ $PM_{2.5}$ with responses within hours

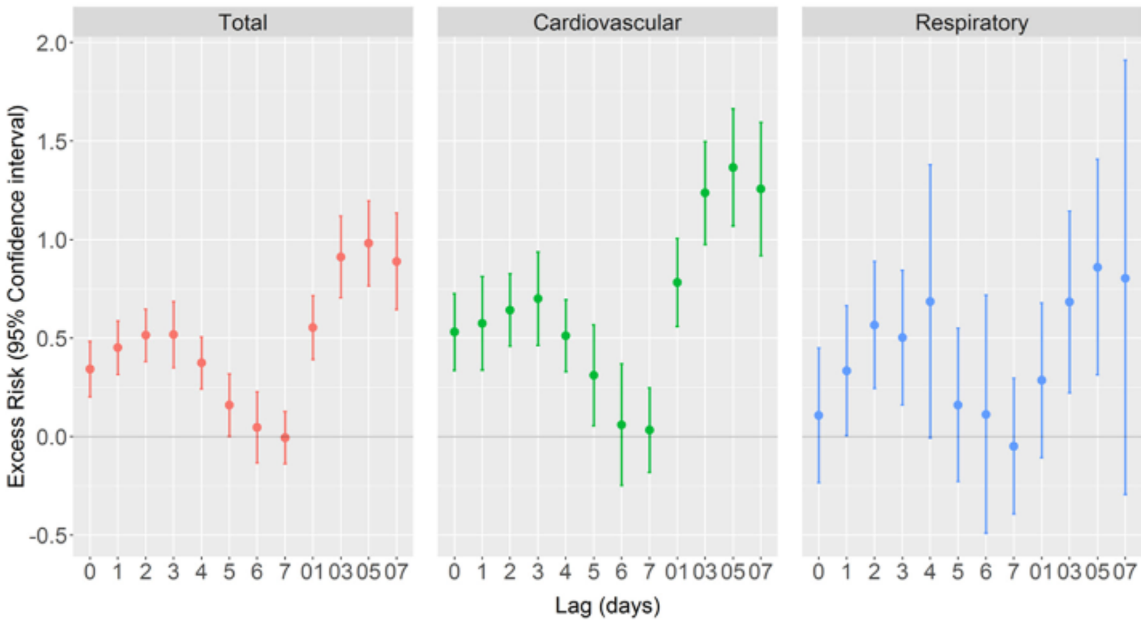
Exhaled Nitric Oxide (airway inflammation) in asthmatic children panel study with repeated measures (n=10 and n=9)



Polynomial distributed lag model shows change in Fe_{NO} per 10-μg/m^3 increase in $PM_{2.5}$
(*A*) in subjects not prescribed ICS and (*B*) in subjects prescribed ICS therapy
Model adjusted for temperature, relative humidity, and age
TEOM readings were averaged from three central sites for hourly lags from 1 to 48

(Mar et al. *Env Health Persp* 2005)

Example of short-term mortality exposure-response in air pollution epidemiology



Percentage of daily mortality increase associated with each 10 μg/m³ increase of hourly peak $PM_{2.5}$ concentrations along different lag days in the Pearl River Delta region, China, 2013-2015.

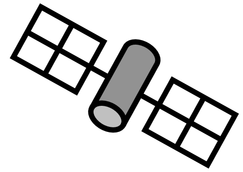
"We observed a greater mortality burden using hourly peak $PM_{2.5}$ than daily mean $PM_{2.5}$, with an estimated 12,915 (95% CI: 9,922 to 15,949) premature deaths attributable to hourly peak $PM_{2.5}$, and 7,951 (95% CI: 5,067 to 10,890) to daily mean $PM_{2.5}$ in the Pearl River Delta (PRD) region during the study period."

(Lin et al., *Atmos Env* 2017)

Challenges of collecting within-day exposure and health data

- No remote sensing for air pollutants after dark
- Space-time resolution tradeoffs (coverage and orbit characteristics)
  - Epidemiologists are (overly) focused on spatial resolution
  - Cohorts often recruited from smallish regions (e.g. via a hospital)
- Quality of real-time $PM_{2.5}$ sensors for ground truth / calibration
  - (even nephelometers and TEOMS)
- Within-day time-resolved health data are harder to come by
  - Lag times are variable (e.g. going to hospital after stroke)
- Human behavior
  - Willingness/ability to seek healthcare outside business hours

Acknowledgments



Lab group at Mount Sinai

- Jonathan Heiss
- Johnathan Rush
- Kodi Arfer
- Nicholas DeFelice
- Iván Gutiérrez-Avila
- Elena Colicino
- Laura McGuinn
- Sandy Wong
- Daniel Carrión

Major External Collaborators

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- Itai Kloog

NASA Goddard Space Flight Center

- Alexei Lyapustin
- Yujie Wang

Columbia Mailman School of Public Health

- Andrea Baccarelli
- Marianthi Kioumourtzoglou

Harvard Chan School of Public Health

- Joel Schwartz
- Brent Coull

Instituto Nacional de Salud Publica (INSP), Mexico

- Martha Tellez-Rojo

No one breathes 24-hour averaged air

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