Global, Long-term Insight into $PM_{2.5}$ Exposure using Aerosol Optical Depth

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Building on, and with the help and many, many others…

NASA Aerosol and Clouds, Convection, and Precipitation (ACCP) Air Quality Workshop
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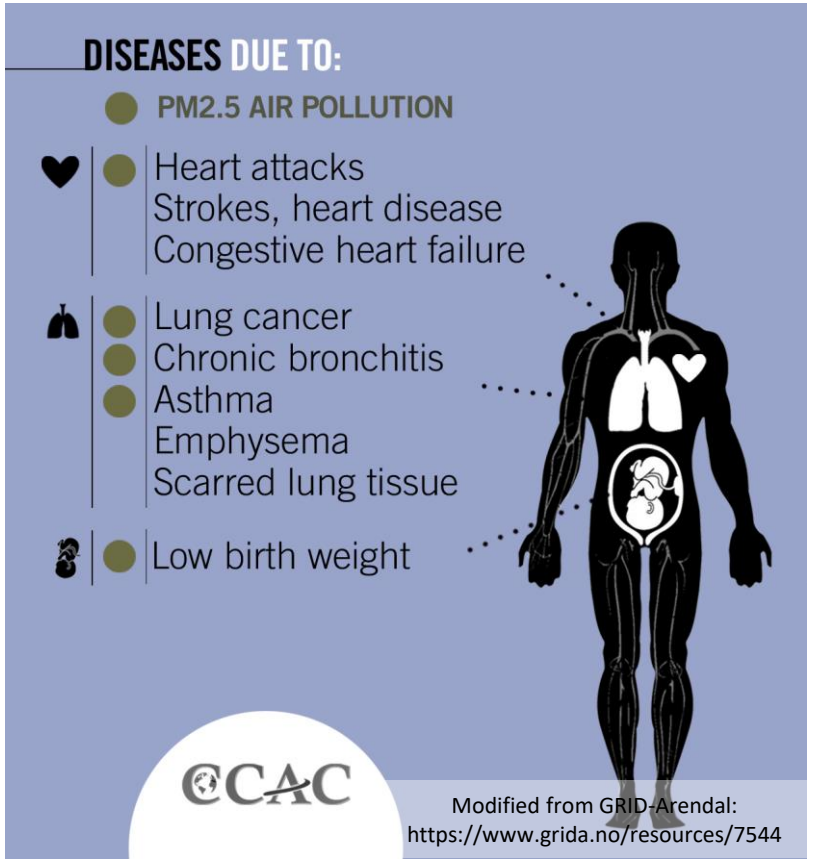
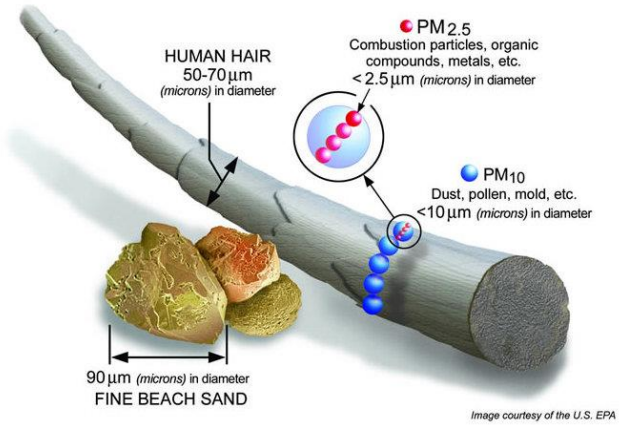
Washington University in St. Louis

DALHOUSIE UNIVERSITY

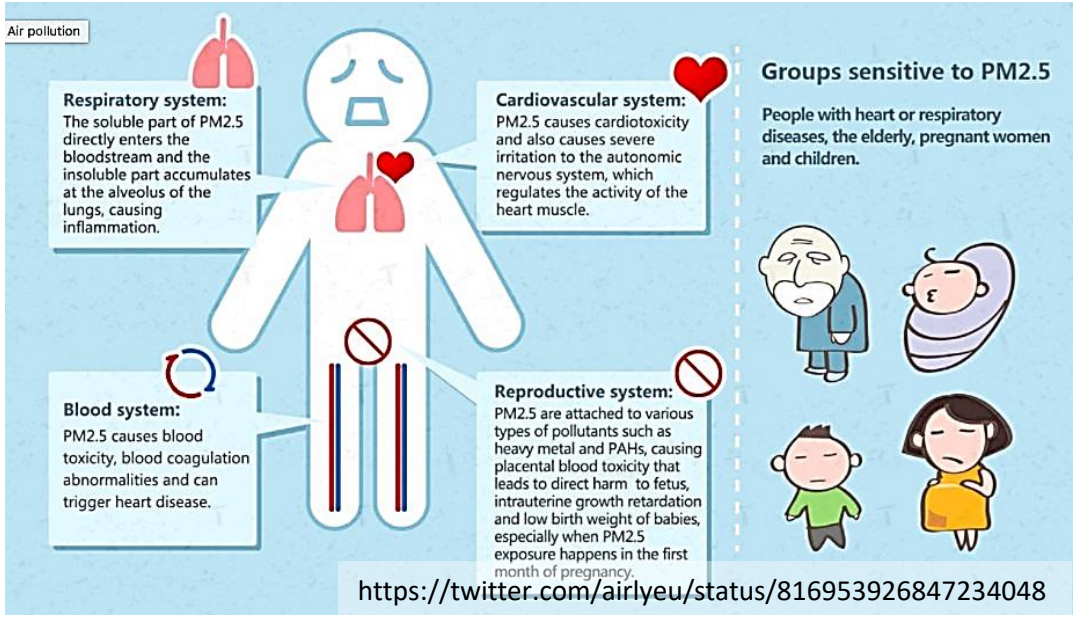
Fine aerosol ($PM_{2.5}$) affects human health and longevity



Modified from GRID-Arendal: https://www.grida.no/resources/7544

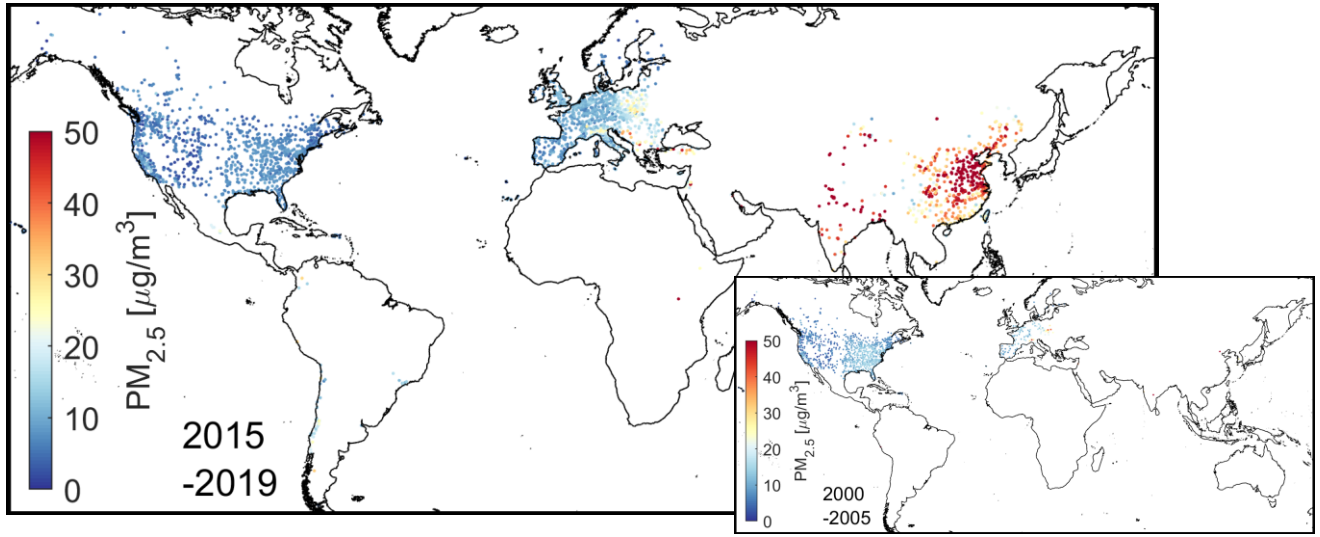


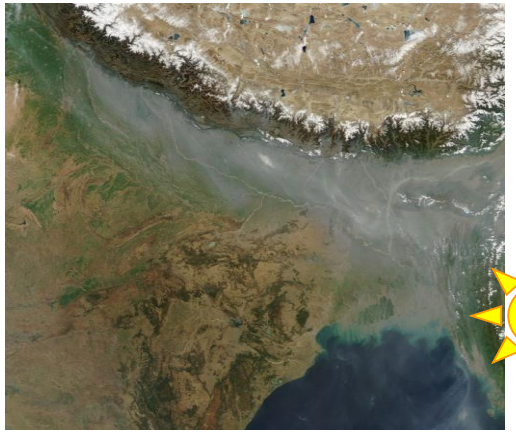
$PM_{2.5}$-related deaths (GBD 2017)	2007	2017
All Cause	2,580,000	3,080,000
Lower respiratory infections	425,000	461,000
Tracheal, bronchus, and lung cancer	199,000	256,000
Ischaemic heart disease	676,000	852,000
Ischaemic stroke	216,000	261,000
Intracerebral hemorrhage	277,000	330,000
Subarachnoid hemorrhage	42,900	50,100
Chronic obstructive pulmonary disease	707,000	819,000
Diabetes mellitus type 2	33,000	46,800



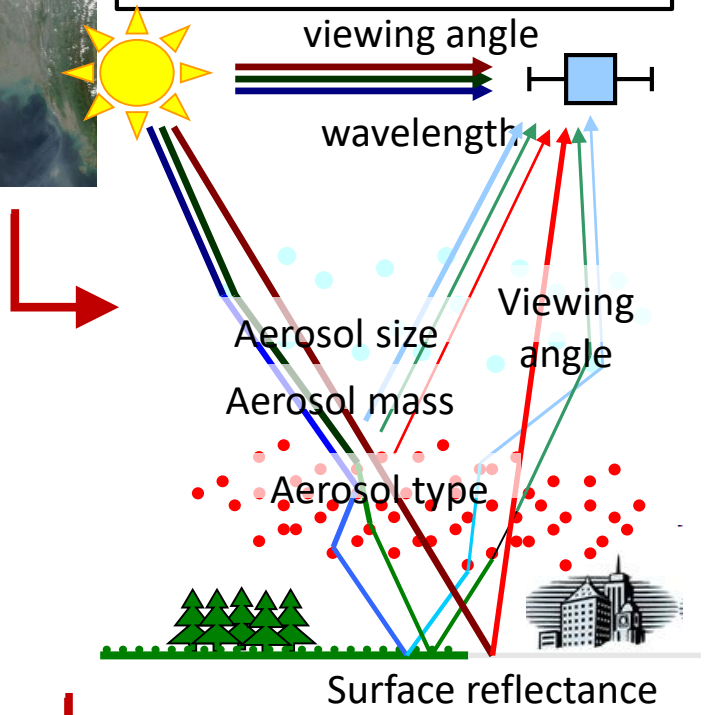
https://twitter.com/airlyeu/status/816953926847234048

Satellites offer more coverage than ground monitors

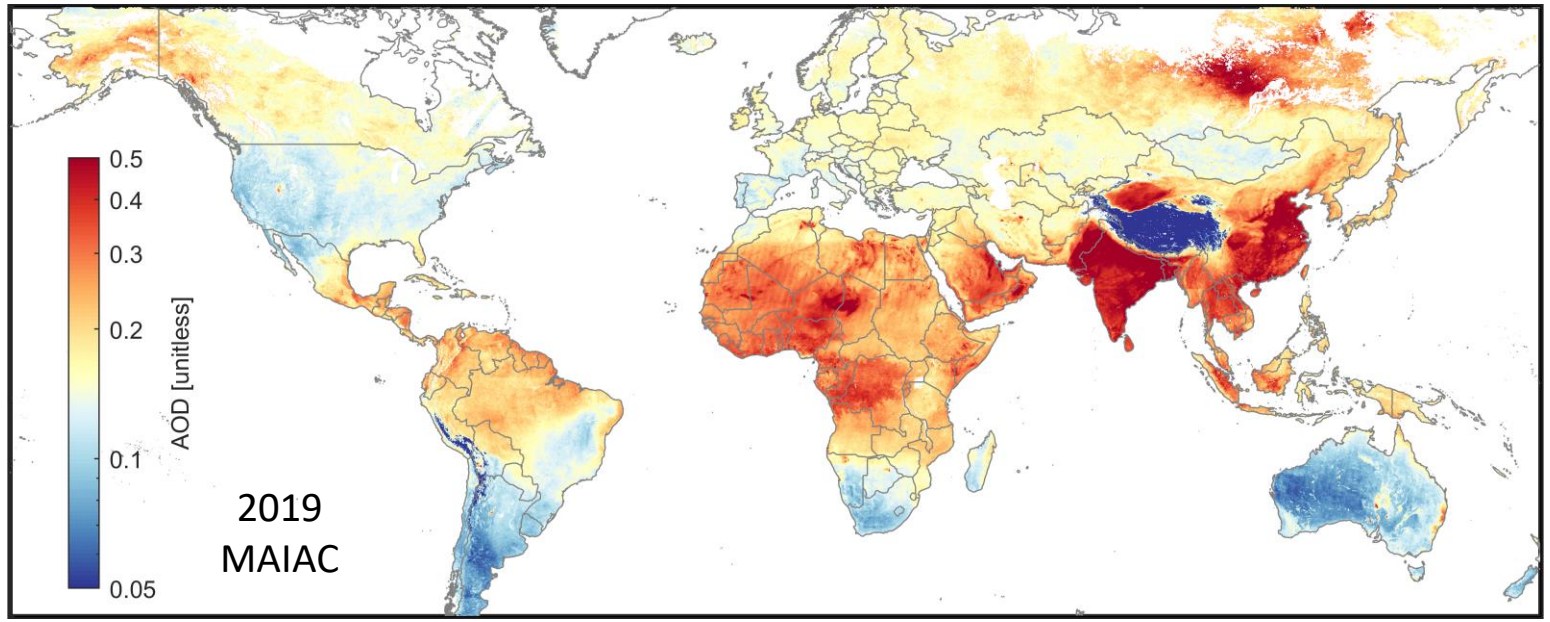


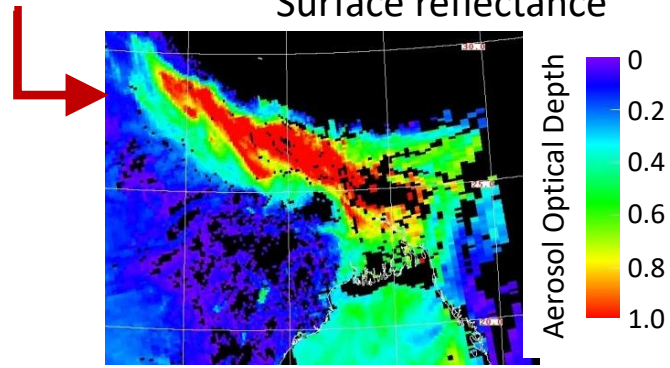


Extinction due to aerosol in the atmospheric *column* is called Aerosol Optical Depth (AOD)



Only 10% of countries have more than 3 ground monitors per million people





Satellite-based Aerosol Optical Depth (AOD) retrievals have much greater coverage.

Satellite-based AOD has its own challenges…

First part of talk

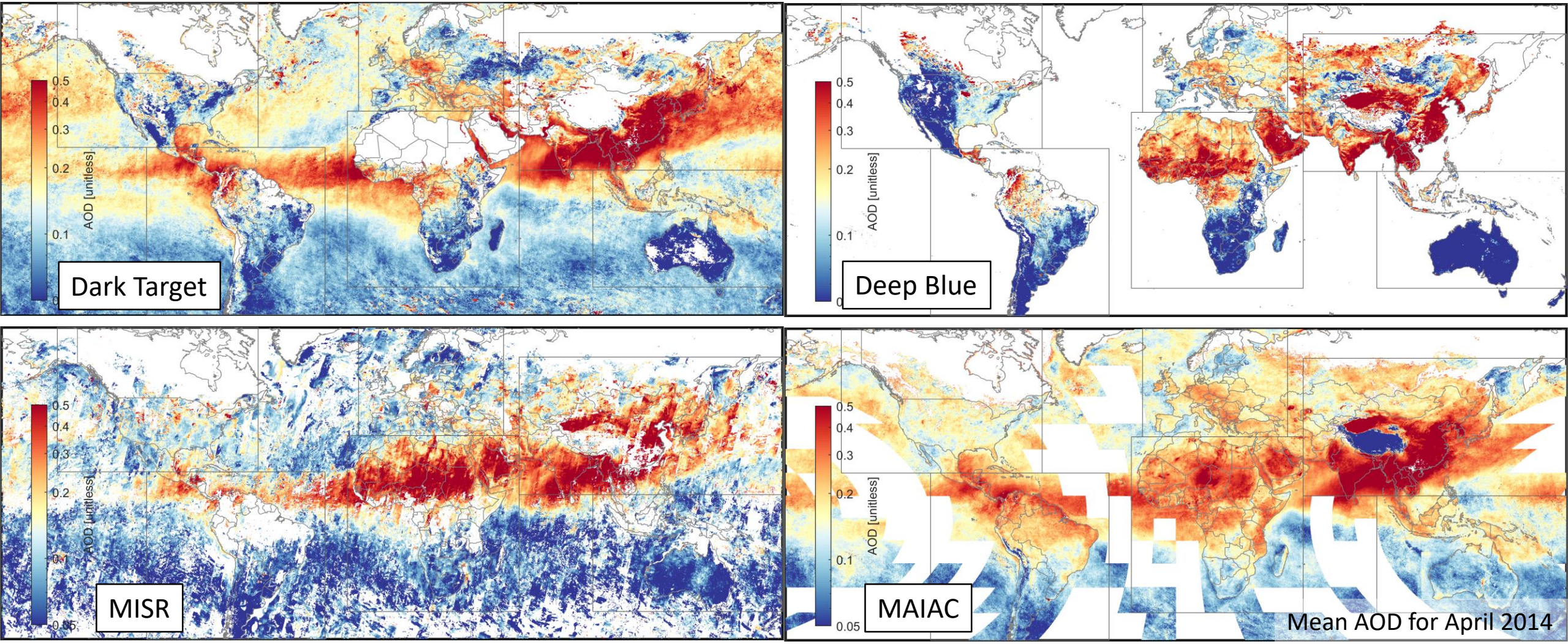
- AOD accuracy varies with both retrieval/instrument and location/conditions
  - Unclear which AOD dataset is best
- AOD is not $PM_{2.5}$
  - AOD optically represents all aerosol in the entire column
  - Need a way to relate to $PM_{2.5}$ at the surface

…but offers unparalleled richness

Second part of talk

Different AOD datasets have different strengths/weaknesses

Differences result from instrumentation, methodology and sampling

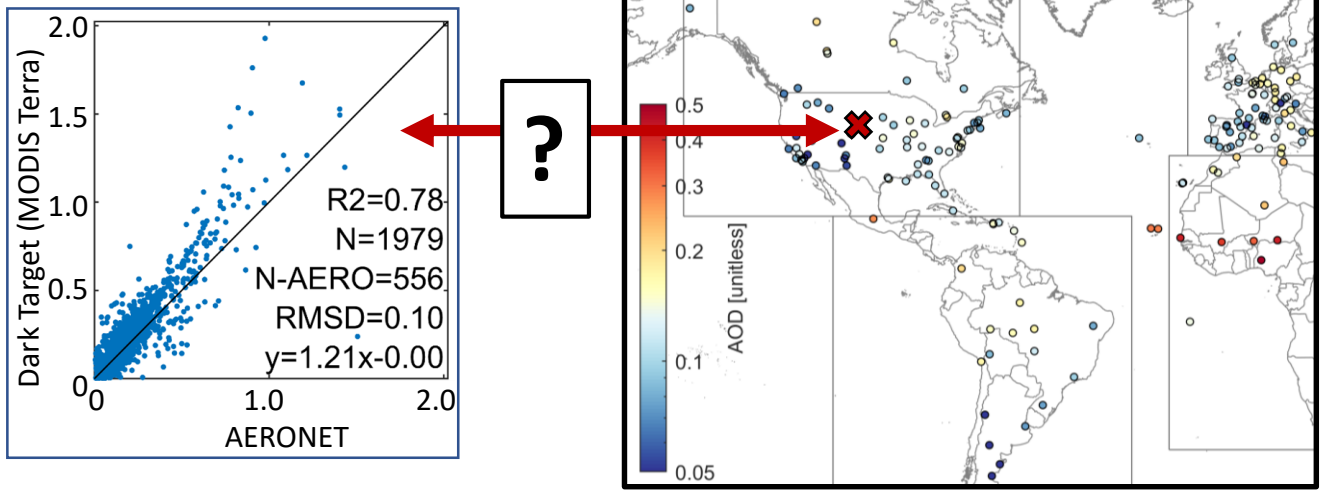


How can AERONET locations tell us about unmonitored locations?

- Global network of sun photometers
- > 25 years of data
- High accuracy (AOD within ±0.01)
- Standard data source for AOD validation

surface reflectance is a major uncertainty source for remote sensing

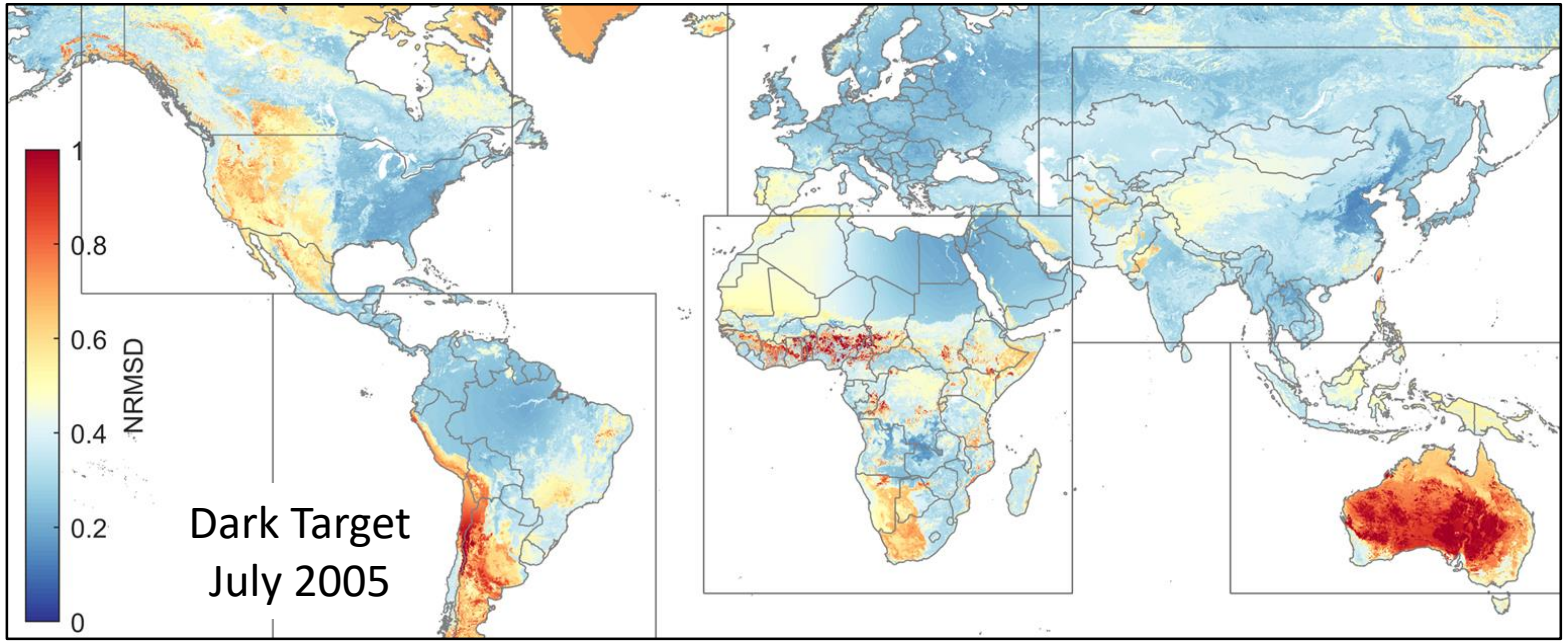
For any location on earth, which points are relevant?



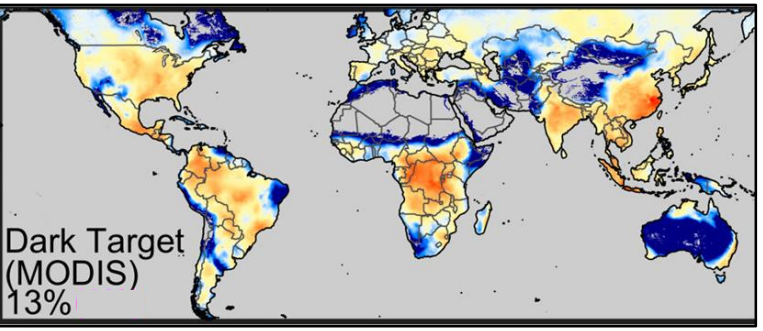
Month-specific AERONET-SATELLITE AOD subset comparisons are categorized and/or weighted by:

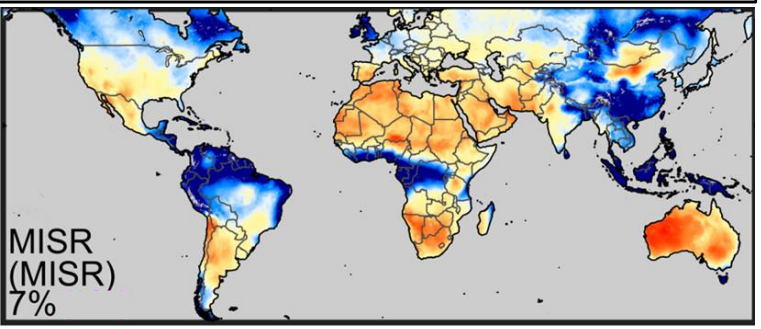
- Land type
- Normalized Difference Vegetation Index
- Proximity
- Season

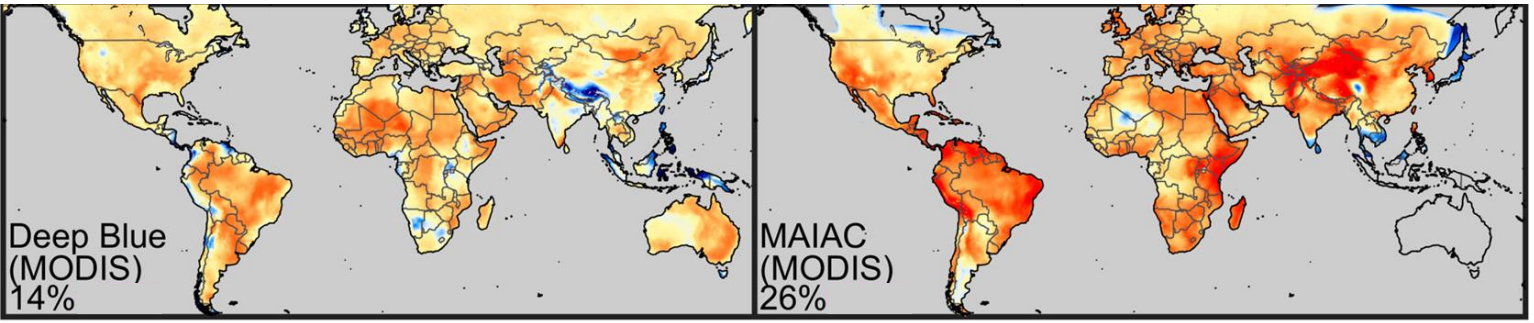
Continuous, Consistent, Global Error Definition

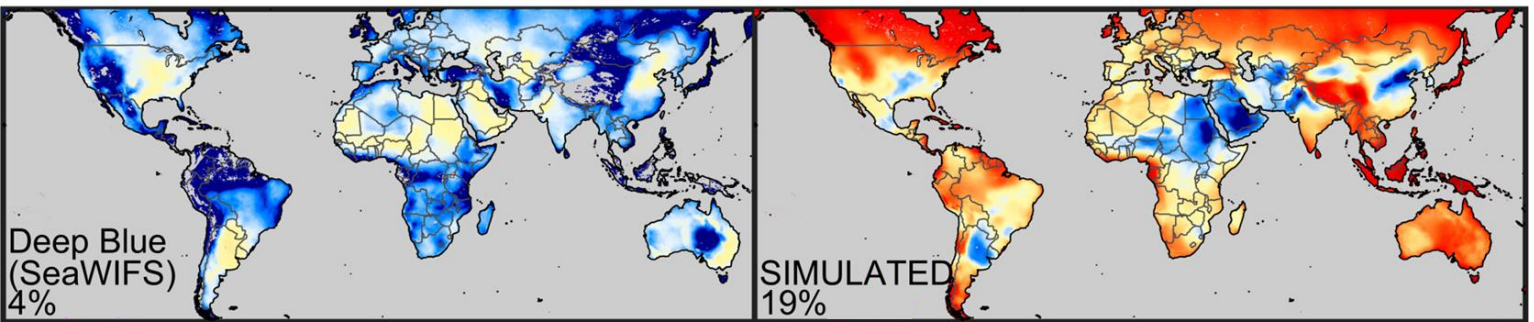


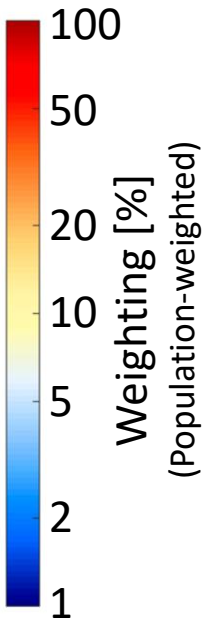
Global Evaluation: Use each dataset at it's best

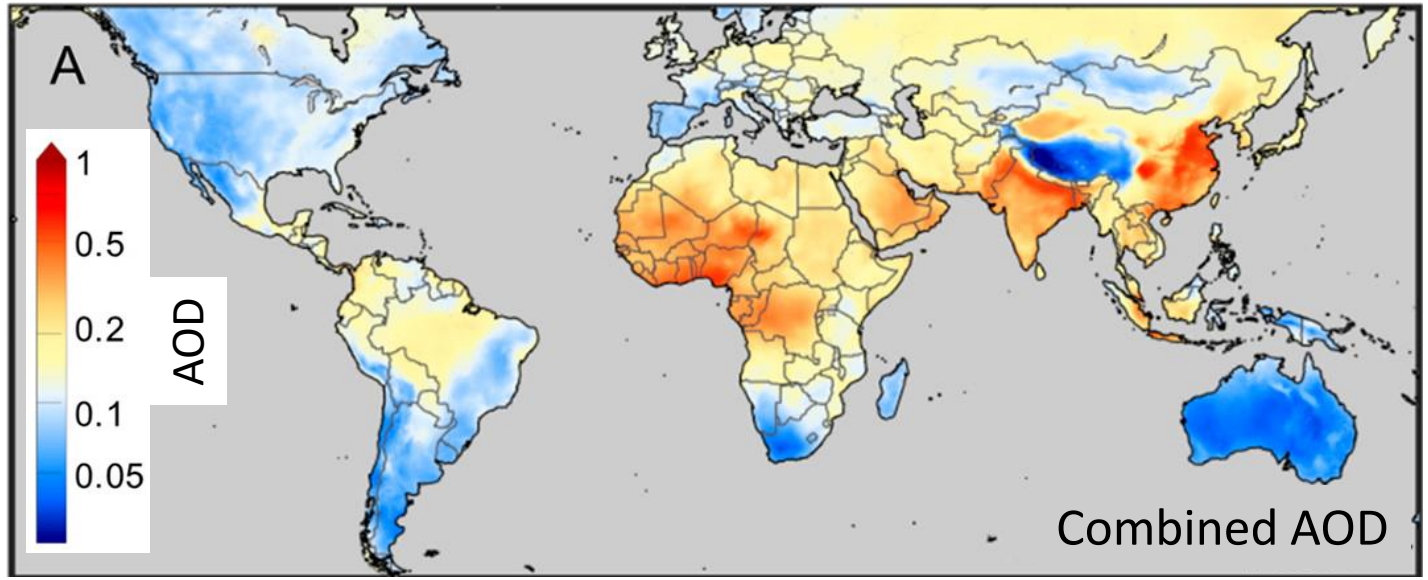












Combine all AOD sources weighted by NRMSD^{-1}, bias correction^{-1}, data density:

$$AOD = \frac{\sum_{n=1}^{N} \frac{1}{NRMSD_n} \times \left[\frac{\Delta AOD_{adj,n}}{AOD_n}\right]^{-1} \times N_{obs,n}^2 \times AOD_n}{\sum_{n=1}^{N} \frac{1}{NRMSD_n} \times \left[\frac{\Delta AOD_{adj,n}}{AOD_n}\right]^{-1} \times N_{obs,n}^2}$$

Hammer et al., ES&T, 2020

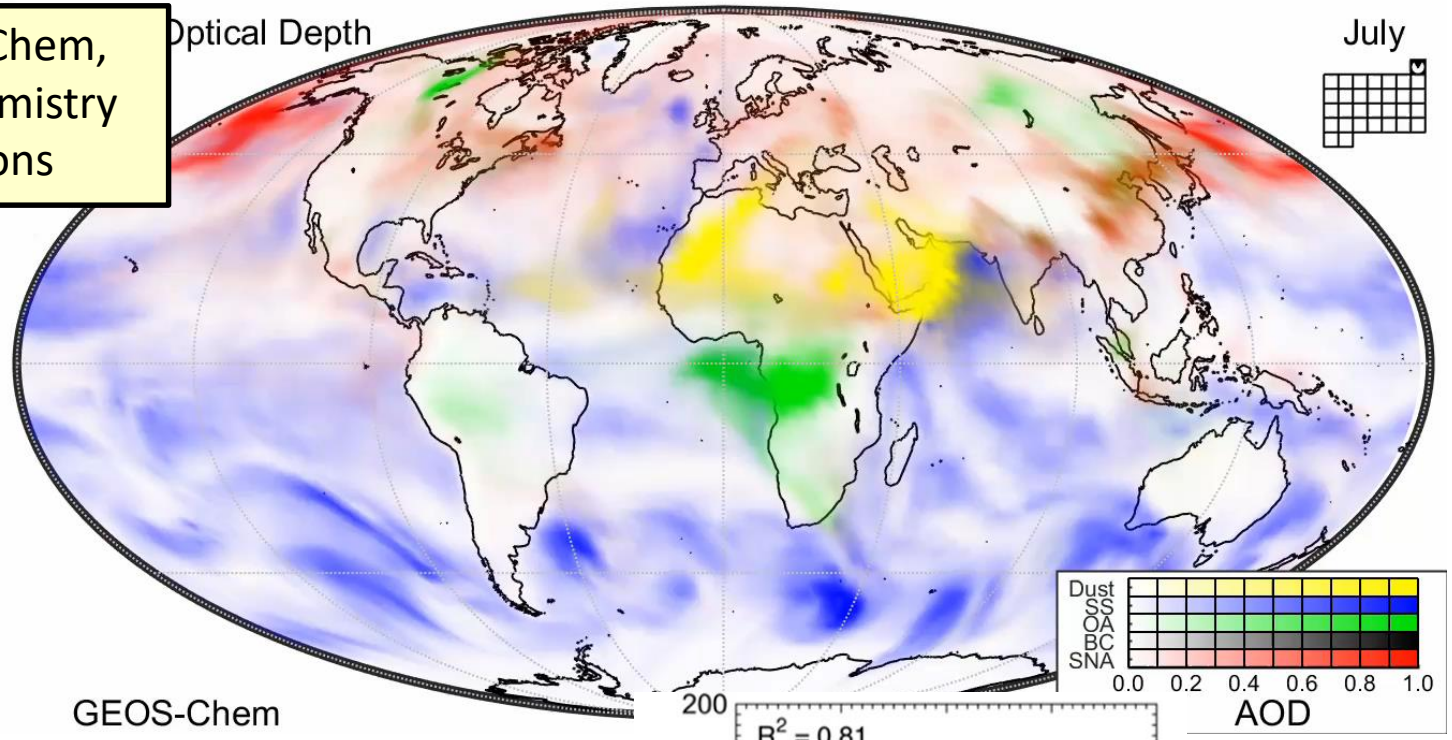
The aerosol column (AOD) is related to surface $PM_{2.5}$

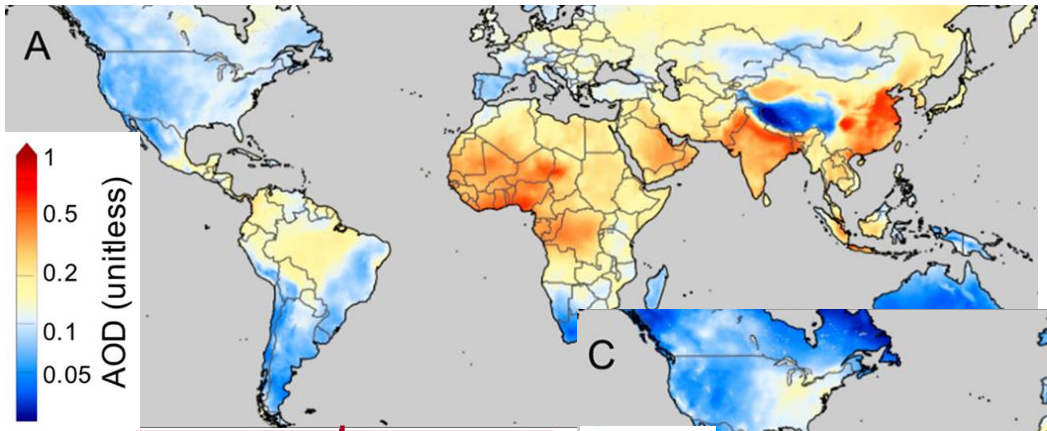
We relate satellite-based retrievals of *aerosol optical depth* (AOD) to $PM_{2.5}$ using a global chemical transport model.

Chemical Transport Models (CTMs), such as GEOS-Chem, combine the equation that govern atmospheric chemistry and physics with global meteorology and emissions

GEOS-Chem

- Detailed aerosol-oxidant model
- 50-100 tracers, 100's reactions
- Assimilated meteorology
- Resolution of between ½° x 2/3° (nested) to 2° x 2½° (global)

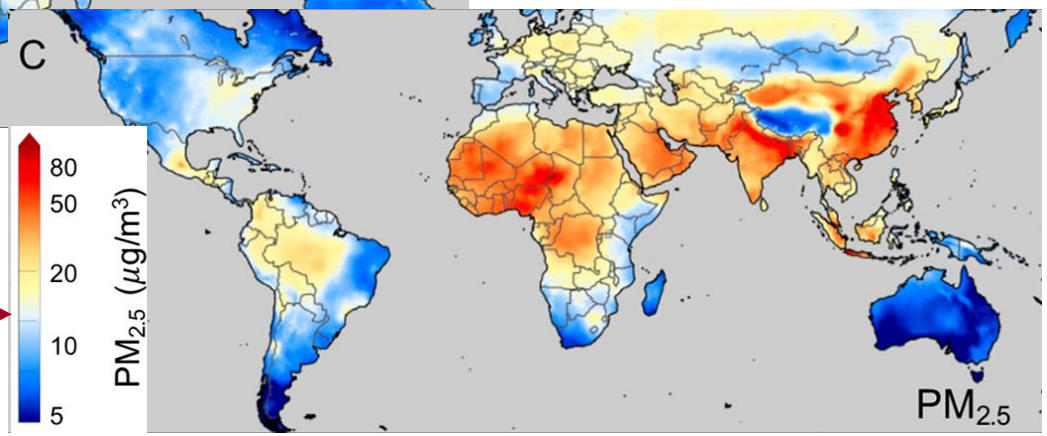


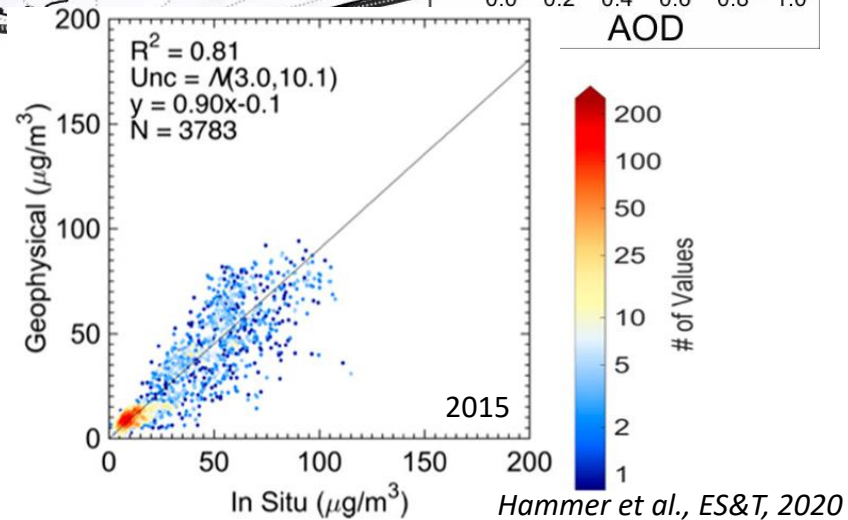


$PM_{2.5} = f(x,y,t) \cdot AOD$

$f(x,y,t)$

- vertical structure
- aerosol type
- meteorology
- diurnal effects

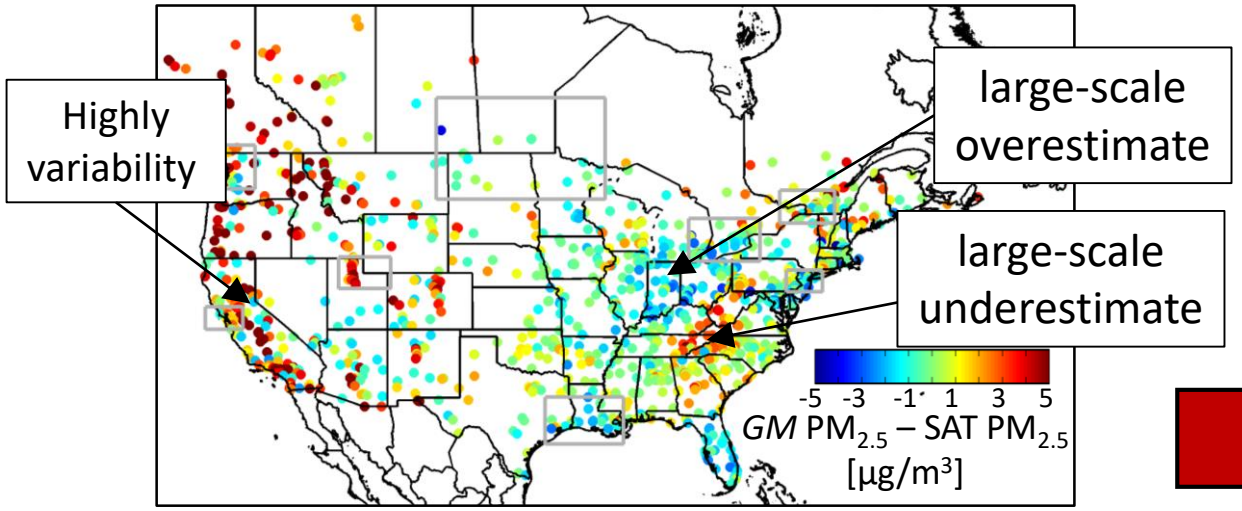




Hammer et al., ES&T, 2020

Ground monitors offer an additional source of information

Hybrid Geophysical-Statistical $PM_{2.5}$ estimates interpret the residual bias between *ground monitors* (*GM*) and geophysical $PM_{2.5}$ with a statistical framework

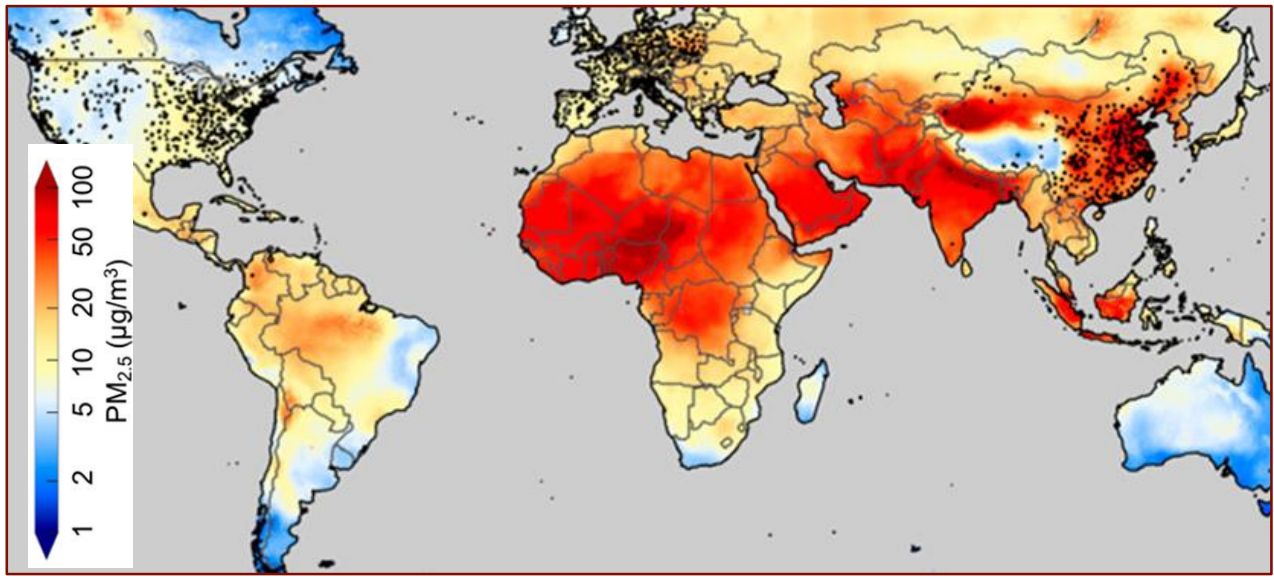


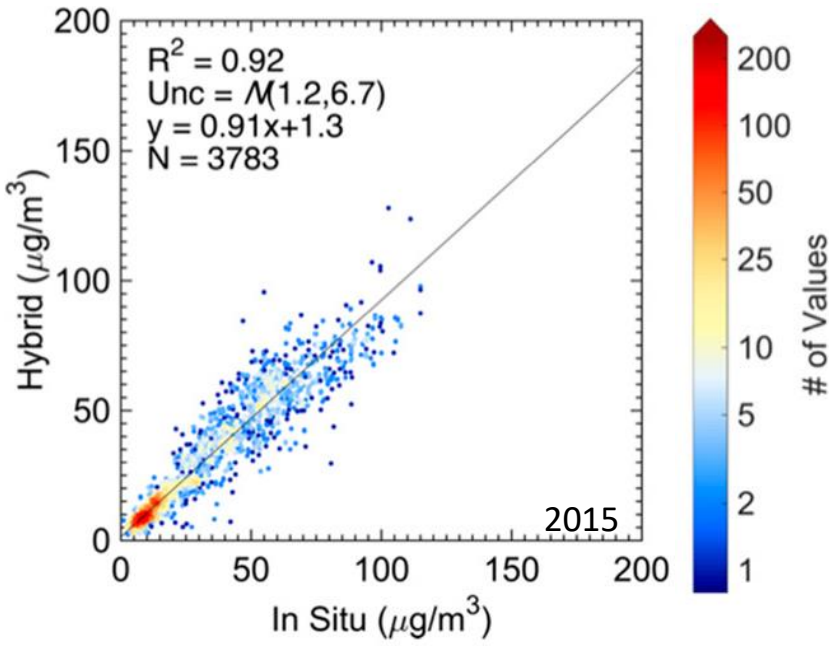
Geographically Weighted Regression (GWR) provides a spatio-temporally varying, linear regression to:

$$(GM\ PM_{2.5} - SAT\ PM_{2.5}) = \Sigma\beta_i SPEC_i + \beta_{ED} ED + \beta_{ULT} ULT$$

ULT: Urban Land Type
ED: Local Elevation Difference with GEOS-Chem grid
SPEC: Speciated $PM_{2.5}$ concentrations
β: predictor-specific, spatially varying coefficients

van Donkelaar et al., ES&T, 2015

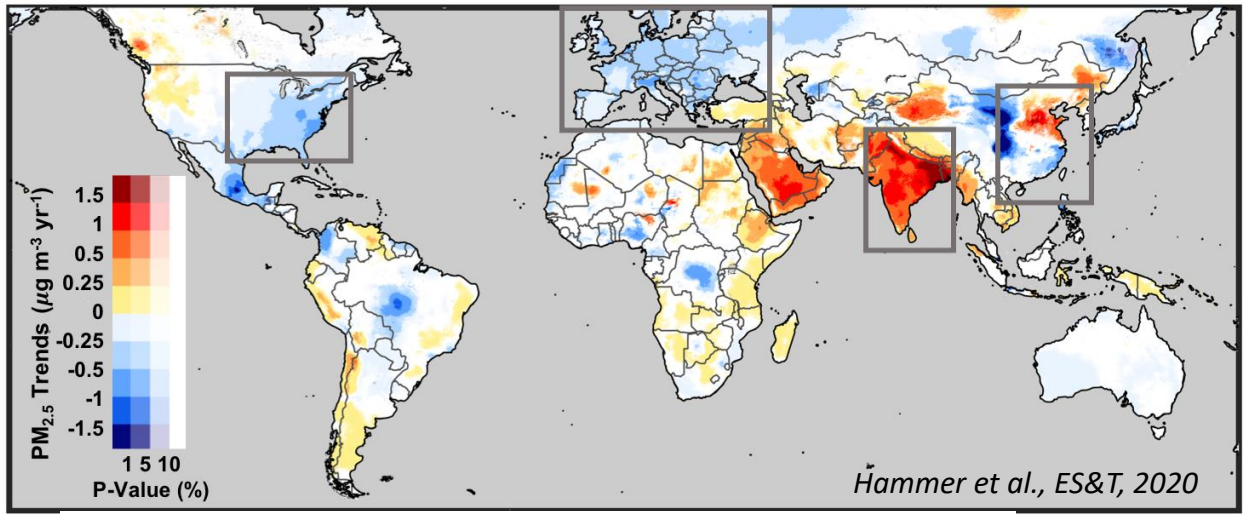


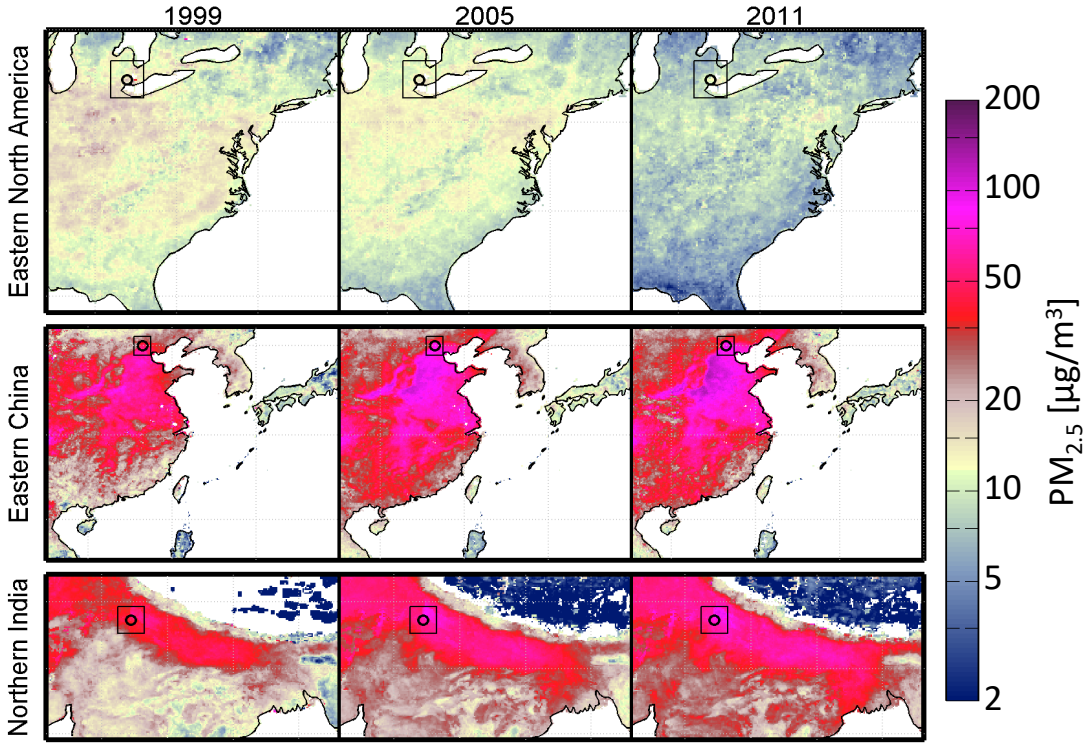


*ONLY INCLUDES CROSS VALIDATED SITES

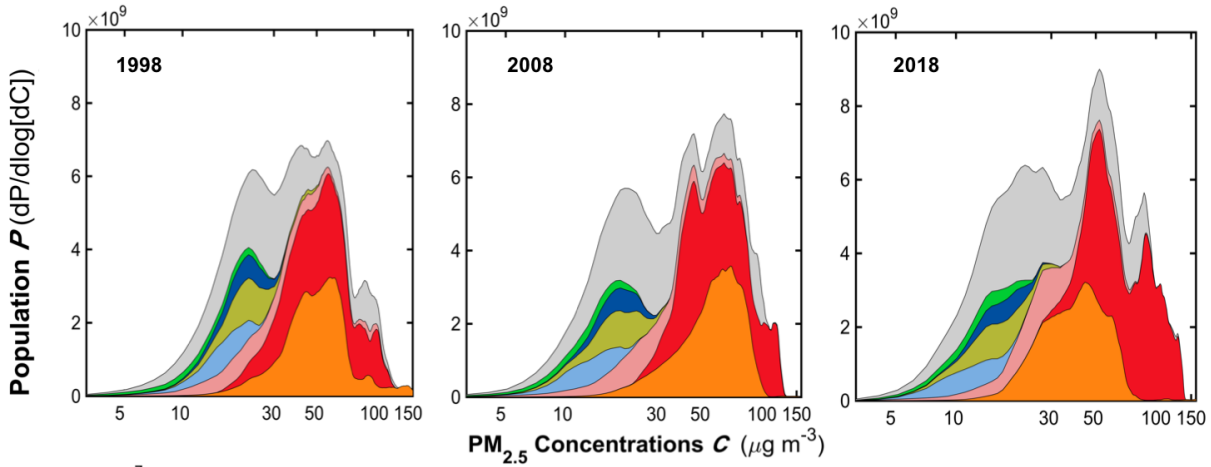
Hammer et al., ES&T, 2020

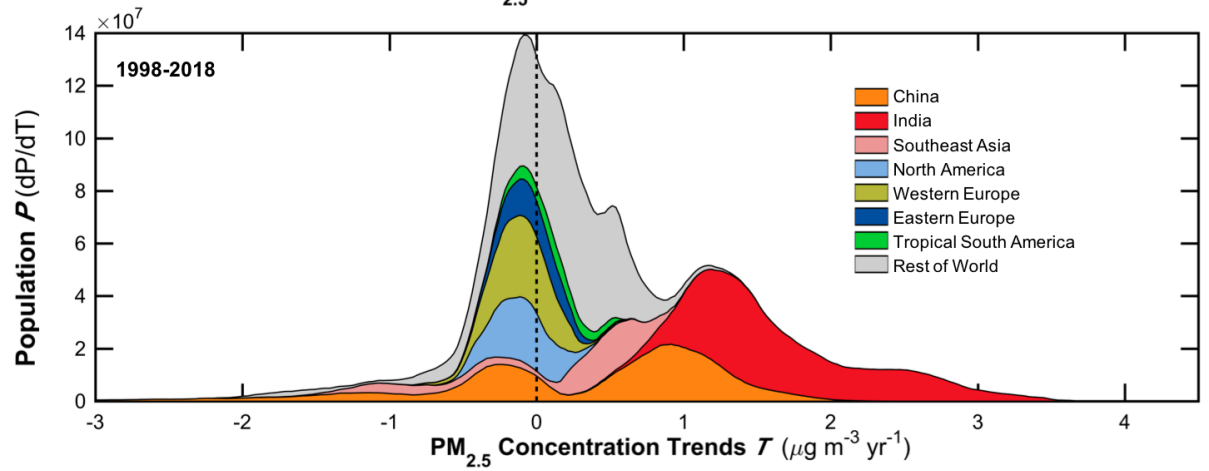
Data offers unique and consistent long-term view



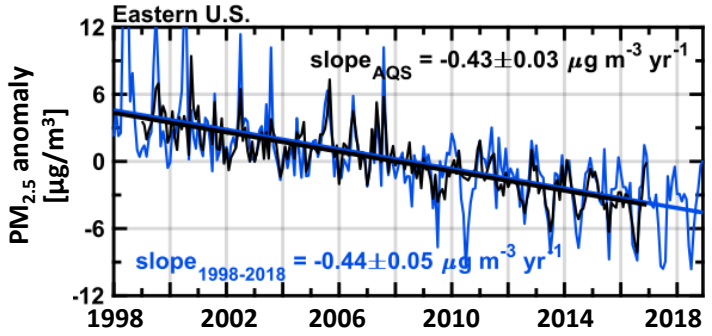


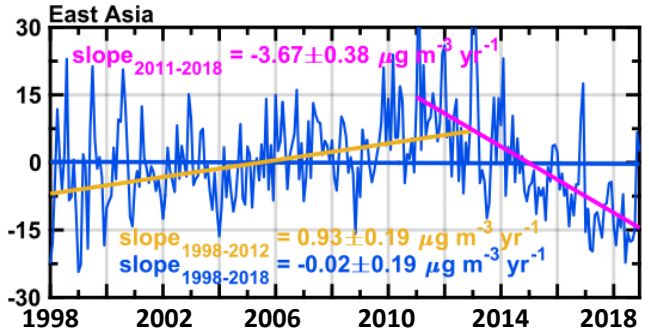
van Donkelaar et al., EHP, 2015



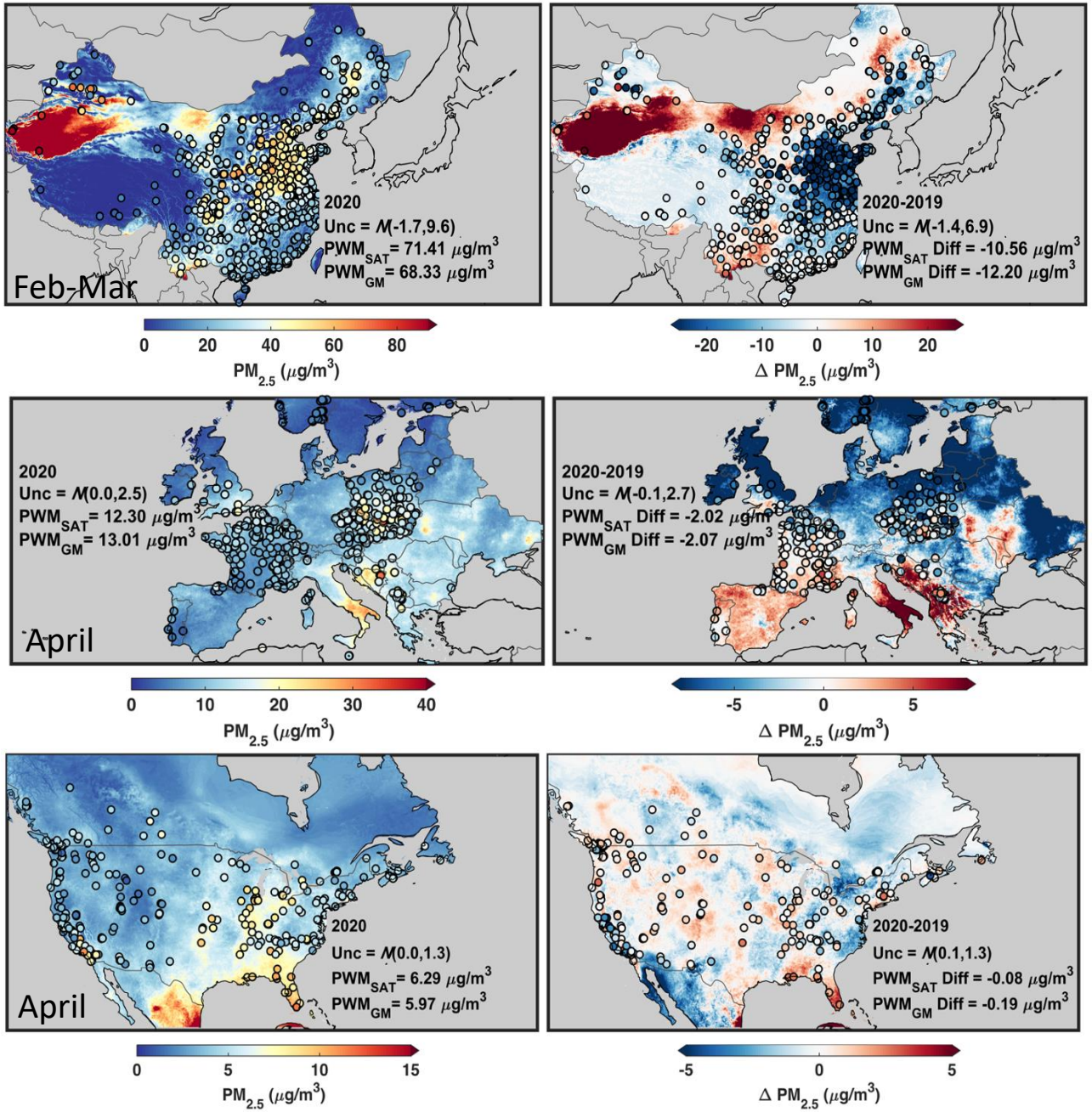


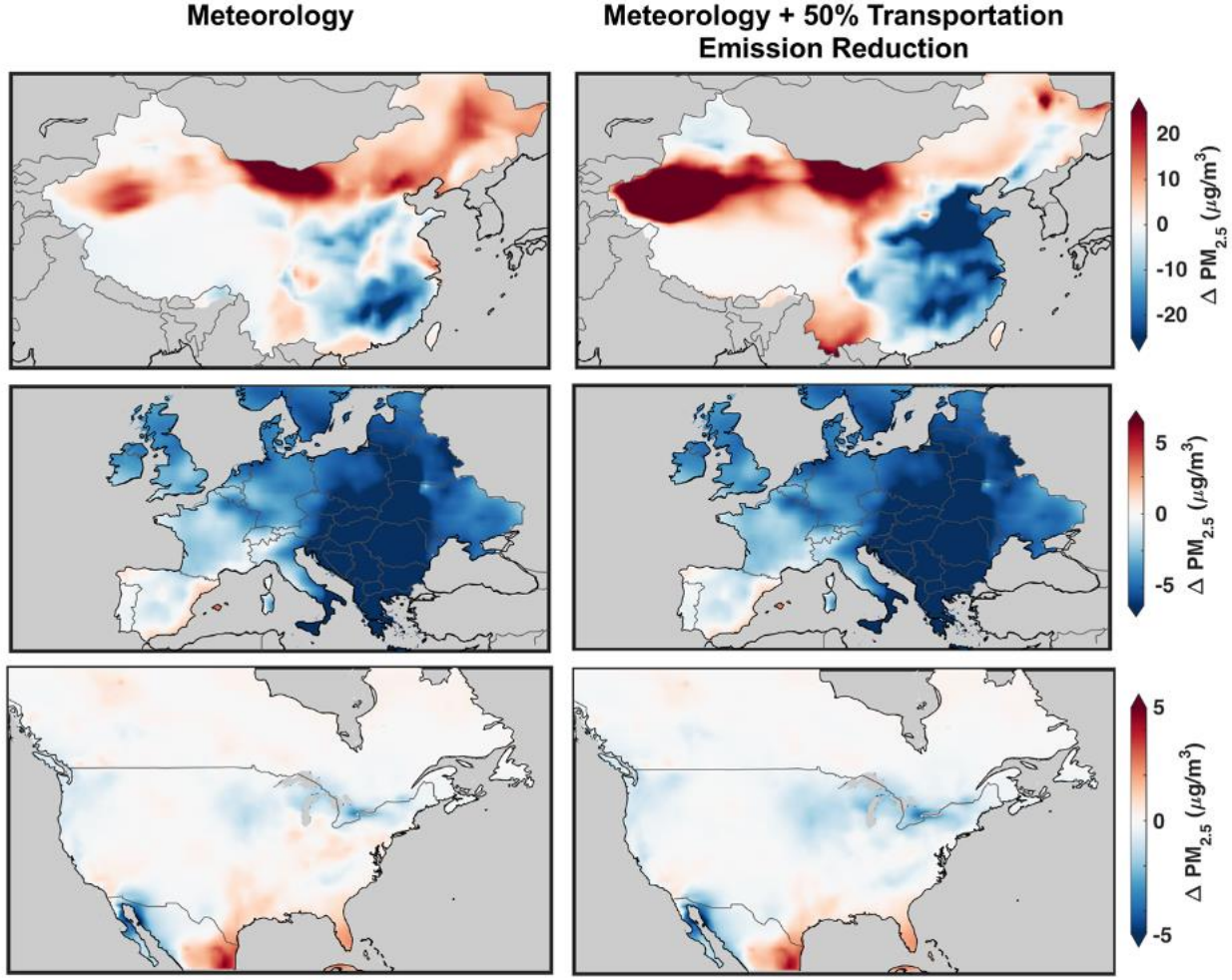
Hammer et al., ES&T, 2020





Meteorology impacted $PM_{2.5}$ during COVID-19 lockdowns



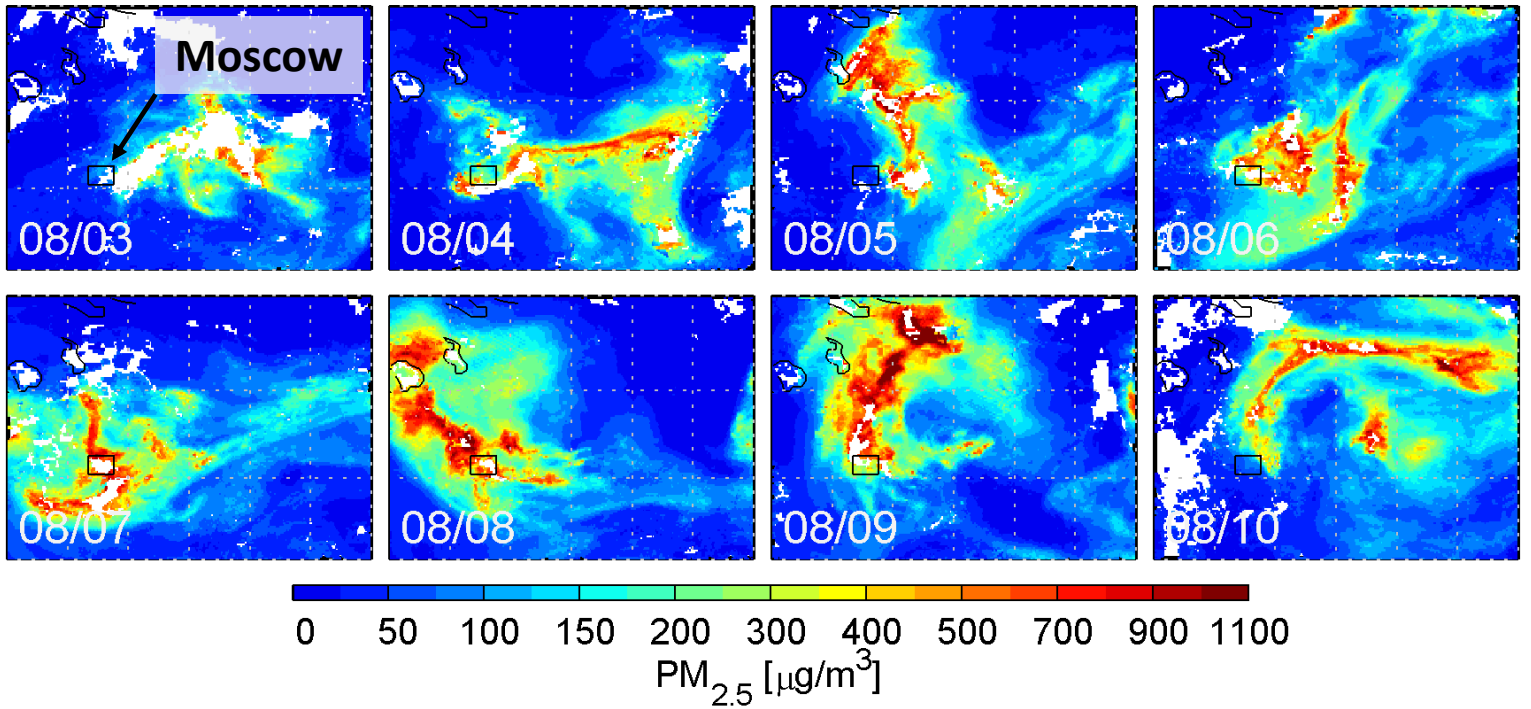


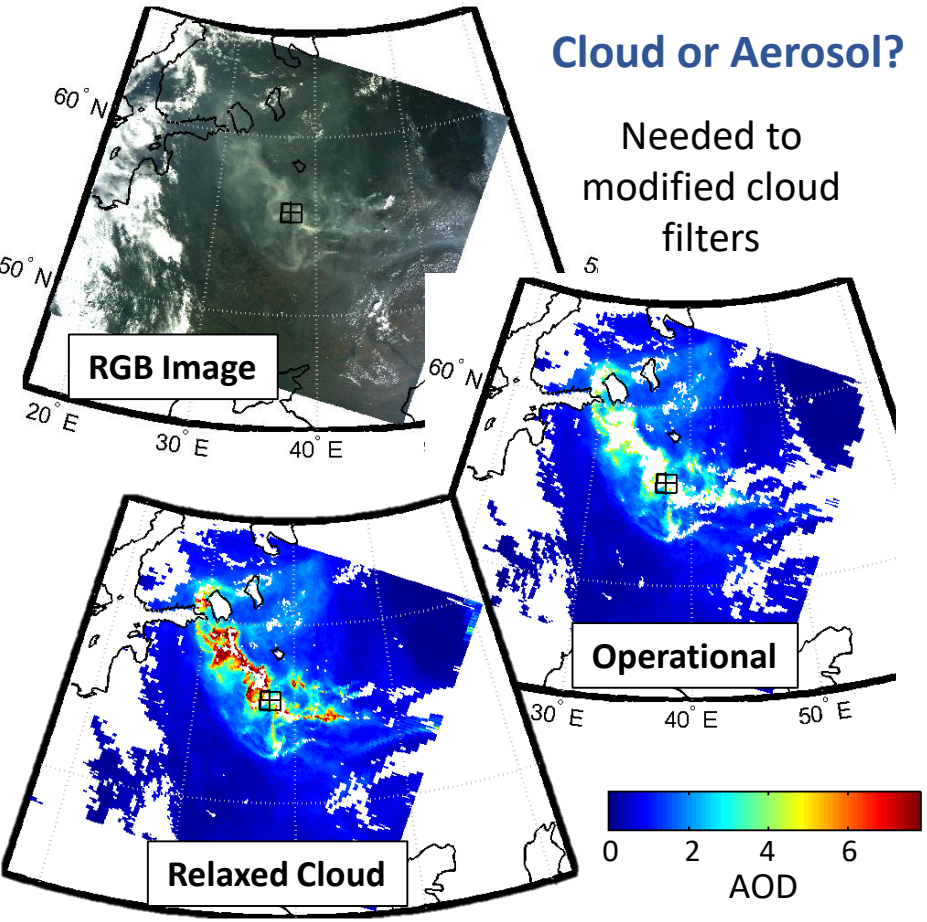
Changes in $PM_{2.5}$ during lockdown is largely associated with meteorology and transportation emissions.

Hammer et al., submitted

Case Study: Moscow Wildfire Summer 2010

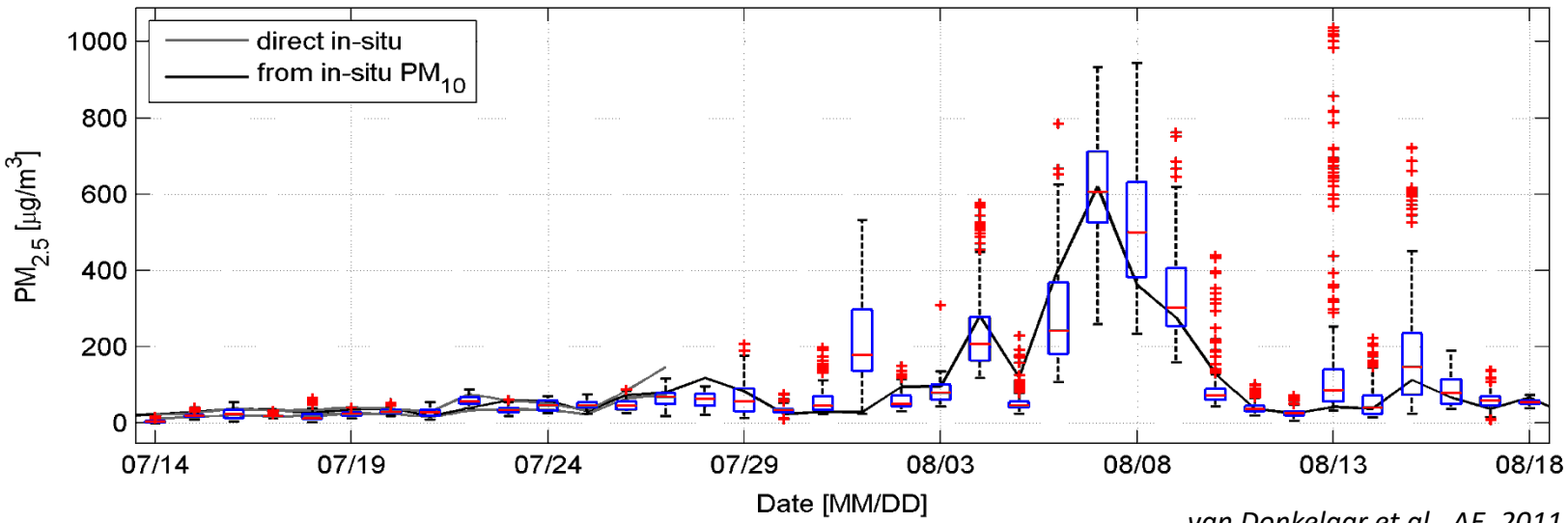
- Hottest in recorded history at that time
- Widespread wildfires
- State of emergency declared
- Thousands of buildings destroyed
- Daily deaths in Moscow doubled





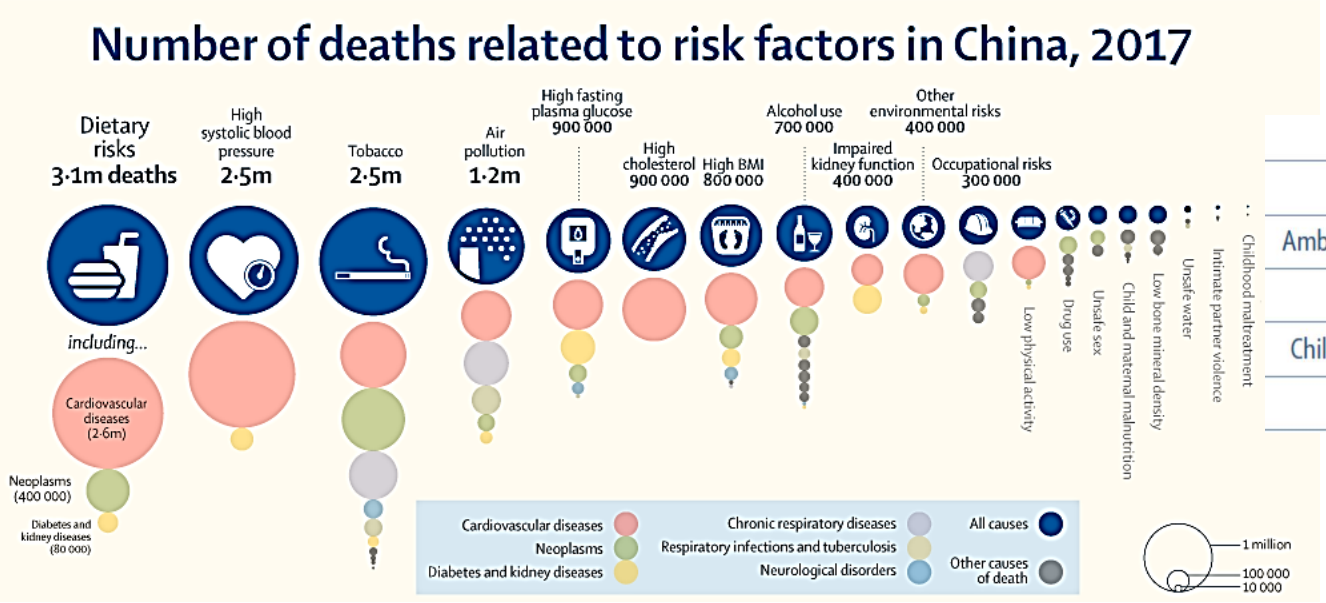
Cloud or Aerosol?

Needed to modified cloud filters

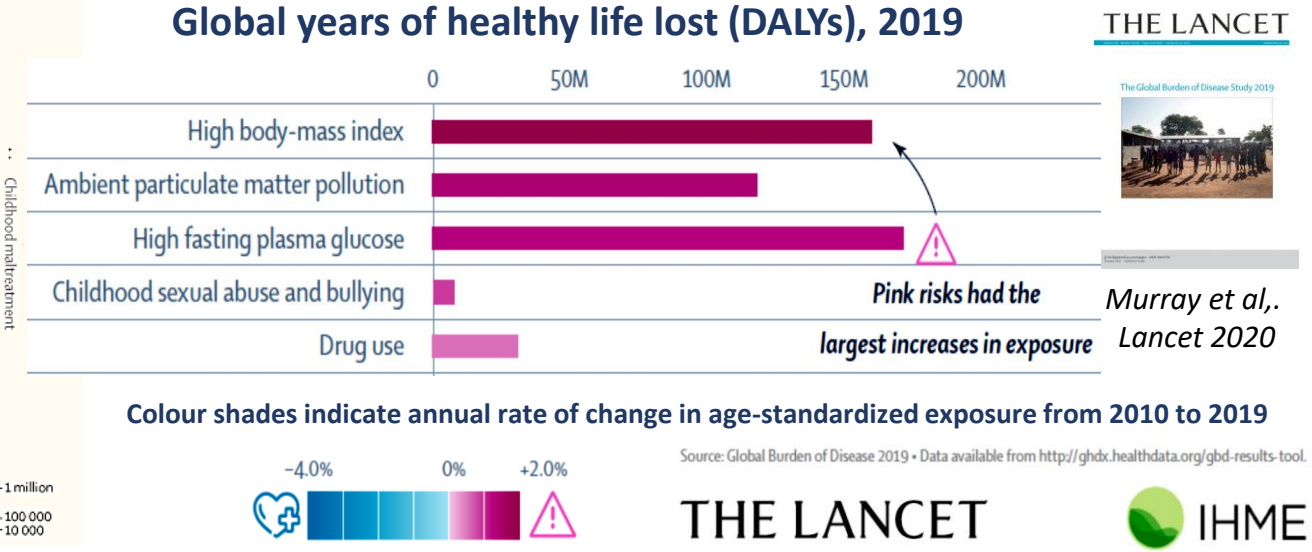


van Donkelaar et al., AE, 2011

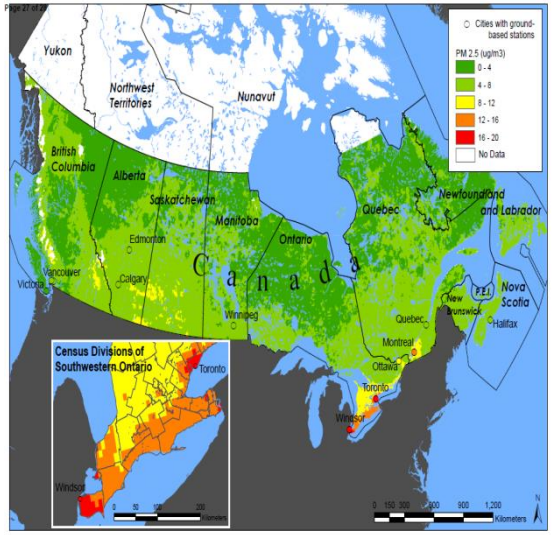
Global impact of global data



Global Burden of Disease - $PM_{2.5}$ causal role in 3 million deaths per year



Inform Epidemiological Studies:

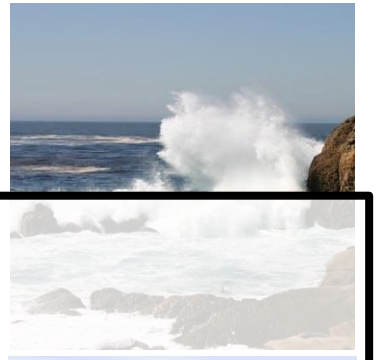


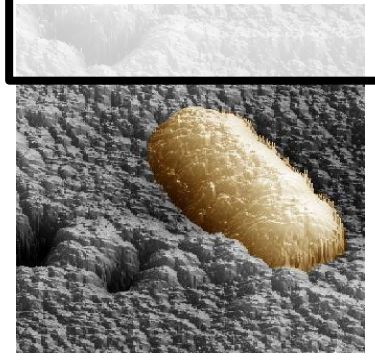
Crouse et al., EHP, 2012

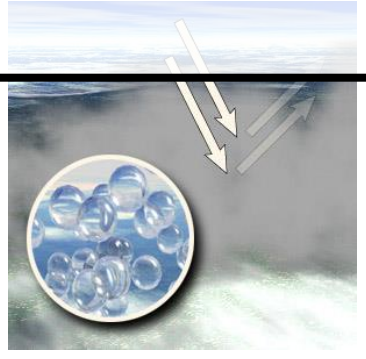
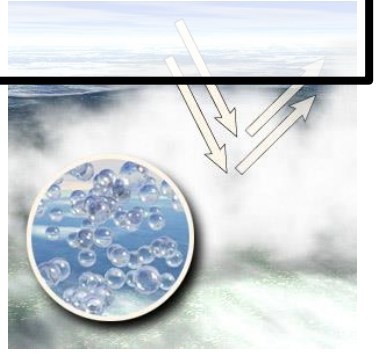
- COVID-19 associations (Chakrabarty, 2020)
- Cardiovascular Disease (Chen, EHP, 2020)
- Childhood asthma (Anderson et al., 2012; Lavigne et al., 2018)
- Lung cancer (Hystad et al., 2012)
- Mortality in California (Jerrett et al., 2013)
- Diabetes (Brook et al., 2013; Chen et al., 2013; Paul et al., 2020)
- Dementia (Chen et al., 2017; Ilango et al., 2019)
- Adverse birth outcomes (Fleischer et al., 2014; Qiao et al., 2019; Wang et al., 2019; Han et. Al, 2020)
- Maternal Exposure and Childhood Cancer (Lavigne et al., 2017)
- Hypertension (Chen et al., 2013)
- Low $PM_{2.5}$ effects (Crouse et al., 2012; Pinault et al., 2016; Pinault et al., 2019)
- Psychological Distress (Pinault et al., 2020)
- Heart Failure (Bai et al., 2019)

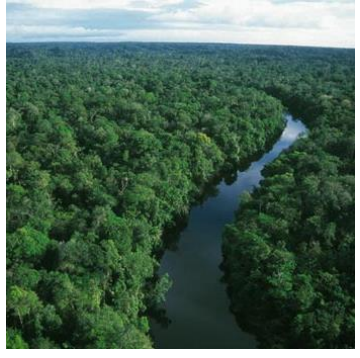









Thanks!