Global Estimates of Long-Term Fine Particulate Matter Concentrations Derived from Multiple Data Sources

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Vast Regions Have Insufficient PM$_{2.5}$ Measurements for Exposure Assessment

No One Knows Where is the City with the Highest PM$_{2.5}$ Concentrations

Density of Long-Term PM$_{2.5}$ Monitoring Sites

Many countries have no PM$_{2.5}$ monitoring

Global population-weighted distance to monitor = 220 km

Martin et al., AE, 2019
Long-Term (1998-2018) Aerosol Optical Depth (AOD)

Use AERONET AOD to Assess Relative Accuracy & Combine

![Map of aerosol optical depth with percentage contributions for various sources including MISR (MISR), Dark Target (MODIS), Deep Blue (MODIS), MAIAC (MODIS), Deep Blue (SeaWiFS), and GEOS-Chem (SIMULATED).]

Population-weighted Contribution Inset

AERONET

Hammer, van Donkelaar, et al., ES&T, 2020
Apply Chemical Transport Model (GEOS-Chem) to Calculate Solution to PM$_{2.5}$ = $f(x,y,t,AOD)$

Simulate suite of processes relating AOD&PM$_{2.5}$: e.g. aerosol vertical profile, mass scattering efficiency, hygroscopicity, relative humidity, chemical composition, diurnal variation, irregular sampling

Coincident sampling with observations
Geophysical Satellite-Derived PM$_{2.5}$ for 2015

If GEOS-Chem AOD/PM$_{2.5}$ excluded: $R^2 \rightarrow 0.73$
If only single satellite AOD retrieval: $R^2 \rightarrow 0.5-0.7$

Information source for:

Global Burden of Disease
OECD Regional Well Being Index
World Health Organization
World Bank
HEI State of Global Air
UNICEF
Energy Policy Institute

Hammer, van Donkelaar, et al., ES&T, 2020
Similarity Between Annual Mean AOD and PM$_{2.5}$ Encouraging for Satellite-Derived PM$_{2.5}$

$R^2 = 0.83$

Hammer, van Donkelaar, et al., ES&T, 2020
Satellite-Derived PM$_{2.5}$ Timeseries (1998-2018)

**Eastern U.S.**
- $\text{slope}_{1998-2018} = -0.44 \pm 0.05 \, \mu g \, m^{-3} \, yr^{-1}$
- $\text{slope}_{1998-2018} = -0.43 \pm 0.03 \, \mu g \, m^{-3} \, yr^{-1}$

**East Asia**
- $\text{slope}_{2011-2018} = -3.67 \pm 0.38 \, \mu g \, m^{-3} \, yr^{-1}$
- $\text{slope}_{2011-2012} = 0.93 \pm 0.19 \, \mu g \, m^{-3} \, yr^{-1}$
- $\text{slope}_{1998-2018} = -0.22 \pm 0.19 \, \mu g \, m^{-3} \, yr^{-1}$

**Europe**
- $\text{slope}_{1998-2018} = -0.15 \pm 0.03 \, \mu g \, m^{-3} \, yr^{-1}$

**India**
- $\text{slope}_{1998-2018} = 1.13 \pm 0.15 \, \mu g \, m^{-3} \, yr^{-1}$
- $\text{slope}_{2005-2013} = 2.44 \pm 0.44 \, \mu g \, m^{-3} \, yr^{-1}$
- $\text{slope}_{2005-2010} = 0.55 \pm 0.7 \, \mu g \, m^{-3} \, yr^{-1}$
- $\text{slope}_{1998-2007} = 0.93 \pm 0.39 \, \mu g \, m^{-3} \, yr^{-1}$

Hammer, van Donkelaar, et al., ES&T, 2020
Statistical Fusion with Ground-Based Monitors Further Improves Consistency; Still Room for Improvement

Error likely driven by modeled relation between AOD and PM$_{2.5}$

Statistical fusion explains ~10% of variance

Hammer, van Donkelaar, et al., ES&T, 2020
Complex Relation of “Dry” PM$_{2.5}$ with AOD

Affected by aerosol properties, vertical structure, elevation
Dry (35% RH) vs ambient relative humidity (RH)
Ground-level vs column aerosol
Elevated topography

GEOS-Chem Simulation of PM$_{2.5}$/AOD for 1998-2018

\[ \eta = \frac{\text{PM}_{2.5}}{\text{AOD}} \text{ (\mu g m}^{-3}\text{)} \]

Model sampled coincidently with satellite observations
PM$_{2.5}$ calculated at 35% RH

Hammer et al., ES&T, 2020
Surface Particulate Matter Network (SPARTAN): Measures PM$_{2.5}$ Mass & Composition at Sites Measuring AOD

Semi-autonomous PM$_{2.5}$ & PM$_{10}$ Impaction Sampling Station (AirPhoton)

3-λ nephelometer (AirPhoton) Scatter

AOD from Sunphotometer (e.g. AERONET)

Mass (35% RH)
BC (HIPS); BrC (UV-Vis)
Ions (IC)
Metals (XRF)
Organics (AMS, FTIR) in progress

Surface/Column

\[
\frac{\text{PM}_{2.5}}{\text{AOD}} = \left( \frac{b_{sp,\text{overpass}}}{\text{AOD}_{\text{overpass}}} \right) \left( \frac{b_{sp,24h}}{b_{sp,\text{overpass}}} \right) \left( \frac{\text{PM}_{2.5,24h}}{b_{sp,24h}} \right)
\]

\[b_{sp} = \text{nephelometer measurements of aerosol scatter}\]
\[\text{overpass} = \text{satellite overpass time}\]

www.spartan-network.org
Snider, Weagle, et al., AMT, 2015
Conclusions

• Growing interest in global estimates of PM$_{2.5}$

• Increasing consistency of global annual satellite-derived PM$_{2.5}$ concentrations with ground-based measurements

• Need for dedicated measurements of the relationship of AOD with PM$_{2.5}$ mass, scatter, and chemical composition to evaluate and improve simulations of the AOD to PM$_{2.5}$ relationship & to better understand relationships at shorter timescales