Global Estimates of Fine Particulate Matter from Satellite

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Aerosols have many sources

- Oceans
- Deserts
- Forests
- Volcanos
- Vehicles
- Industry
Aerosol impact our world

Visibility

Fertilization

Acid Rain

Climate

Health
PM$_{2.5}$ affects human health and longevity

- Life expectancy increases 7 months per 10 μg/m$^3$ decrease in long-term exposure
- Dominates global environmental mortality by 2030
Previous Global Burden of Disease Report for 2000 Impaired by Insufficient Global Observations of Fine Particulate Matter (PM$_{2.5}$)

Estimate air pollution in urban areas causes:
• ~1 million deaths (~1%)
Could not estimate effects outside of urban areas for 2000 report

How to capture rural populations?

Cohen et al., 2005
Global *in situ* monitors are sparse...

...but chemical transport models offer global coverage...

Chemical Transport Models (CTMs) combine the equation that govern atmospheric chemistry and physics with global meteorology and emissions.
Global *in situ* monitors are sparse...

...and remote sensing offers global observation at high resolution.

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

**Aerosol size**

**Aerosol mass**

**Aerosol type**

**Viewing angle**

**Wavelength**

**Surface reflectance**

**Aerosol Optical Depth**

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MODIS Aqua February 5\(^{th}\), 2006
AOD is related to PM$_{2.5}$

...but how to separate surface aerosol from column concentrations?

PM$_{2.5}$/AOD ratio is a function of:
- vertical structure
- aerosol type/hygroscopicity
- meteorology

Multiple approaches:
- surface monitors calibration
- empirical relations
- CTM model output
Model output can be used in different ways

"Unconstrained":
• Combined MODIS, MISR AOD
• Apply simulated AOD/PM$_{2.5}$
• *van Donkelaar et al.*, *EHP*, 2010
  • MODIS/MISR, 2001-2006
  • Good representation of magnitude (error = 1μg/m$^3$+27%)
  • Unavailable after 2006
• *Boys et al.*, submitted
  • SeaWiFS&MISR, 1998-2012
  • Successful representation of trends

"Optimal Estimation":
• Error-constrained MODIS, simulated AOD
• AERONET-based error estimates
• Consistent optical properties
• Local reflectance information
• CALIOP-adjusted AOD/PM$_{2.5}$
• *van Donkelaar et al.*, *JGR*, 2013
  • 2004-2010
  • Good representation of magnitude (error = 1μg/m$^3$+25%)
  • Unavailable before 2004

Optimal estimation constrains AOD retrieval by error:

$$
J(\text{AOD}) = \left( \frac{\text{AOD} - \text{AOD}_a}{\sigma_a} \right)^2 + \left( \frac{d\rho}{d\text{AOD}_a} \right) \frac{\text{AOD}}{\sigma_e}^2
$$

*a posteriori* AOD
*a priori* AOD
observed TOA reflectance
*a priori* error
observational error
Unified PM$_{2.5}$ combines strengths of each dataset

Unconstrained (UC)
- 2001-2006 mass

Optimal Estimation (OE)
- 2004-2010 mass

SeaWiFS&MISR
- 1998-2012 annual variation/trend

UC&OE
- Weight by error over each land-cover type
- 2001-2010 mass

UC&OE + SeaWiFS&MISR
- Apply relative variation from SeaWiFS/MISR
- 1998-2012 annual mass

van Donkelaar et al., submitted.
Consistent Trends in Satellite-Derived and In Situ PM$_{2.5}$

- Satellite-Derived (1999-2012):
  - $0.36 \pm 0.13 \mu g m^{-3} yr^{-1}$

- In Situ (1999-2012):
  - $0.37 \pm 0.06 \mu g m^{-3} yr^{-1}$

Boys et al., submitted
Well correlated globally; potential bias at high PM$_{2.5}$

Satellite-derived PM$_{2.5}$ [$\mu$g/m$^3$]

Global:
- $1-\sigma$ error = 1 $\mu$g/m$^3$ + 47%
- $y = 0.68x + 1.1$
- $n = 210$
- $r = 0.81$

Europe:
- $1-\sigma$ error = 1 $\mu$g/m$^3$ + 21%
- $y = 0.78x + 1.7$
- $n = 512$
- $r = 0.73$

van Donkelaar et al., submitted.
Time series highlight global changes
Significant global PM$_{2.5}$ trends can be seen.
Changes in Long-term Population-Weighted Ambient PM$_{2.5}$
Clean Areas are Improving; High PM$_{2.5}$ Areas are Degrading

WHO Guidelines and Interim Targets

1998-2012 exposure trend [μg/m$^3$/yr]

van Donkelaar et al., submitted.
Global impact of global data

Global Burden of Disease 2010

- 488 authors from 303 institutions in 50 countries
- Inclusion of rural populations
- \( \text{PM}_{2.5} \) causal role in 3 million deaths per year

Inform Epidemiological Studies:

- Global childhood asthma (Anderson et al., 2012)
- Lung cancer in Canada (Hystad et al., 2012)
- Mortality in California (Jerrett et al., 2013)
- Diabetes (Brook et al., 2013; Chen et al., 2013)
- Global adverse birth outcomes (Fleisher et al., in press)
- Hypertension (Chen et al., in press)
- Low \( \text{PM}_{2.5} \) cardiovascular mortality (Crouse et al., 2012)
Questions?