Perspectives on Satellite-Based $PM_{2.5}$

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DALHOUSIE UNIVERSITY
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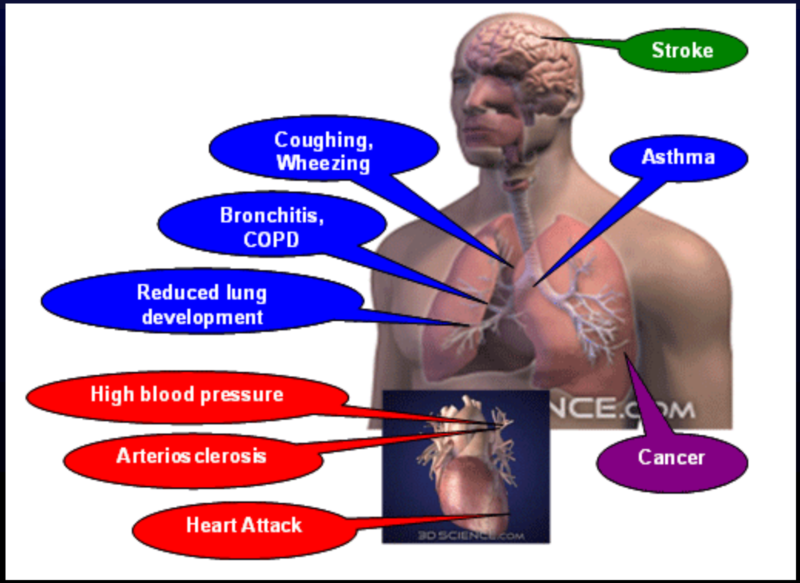
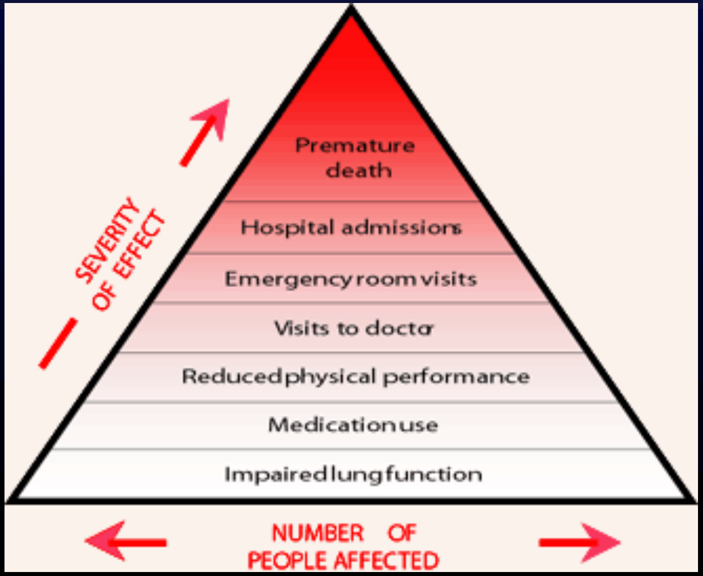
HAQAST Meeting, LDEO
28 November 2017

Long-Term Exposure to Fine Particulate Matter ($PM_{2.5}$) Affects Longevity

- $PM_{2.5}$ leading environmental risk factor for global burden of disease with 4 million attributable deaths (Global Burden of Disease, 2016)
- Annual global welfare costs projected to rise from US$3 trillion in 2015 to US$18-25 trillion in 2060 (OECD, 2016).
- Annual mean $PM_{2.5}$ concentrations included in UN Sustainable Development Goals (2016)
- WHO International Agency for Research on Cancer declares particulate matter is a leading cause of cancer deaths (2013)

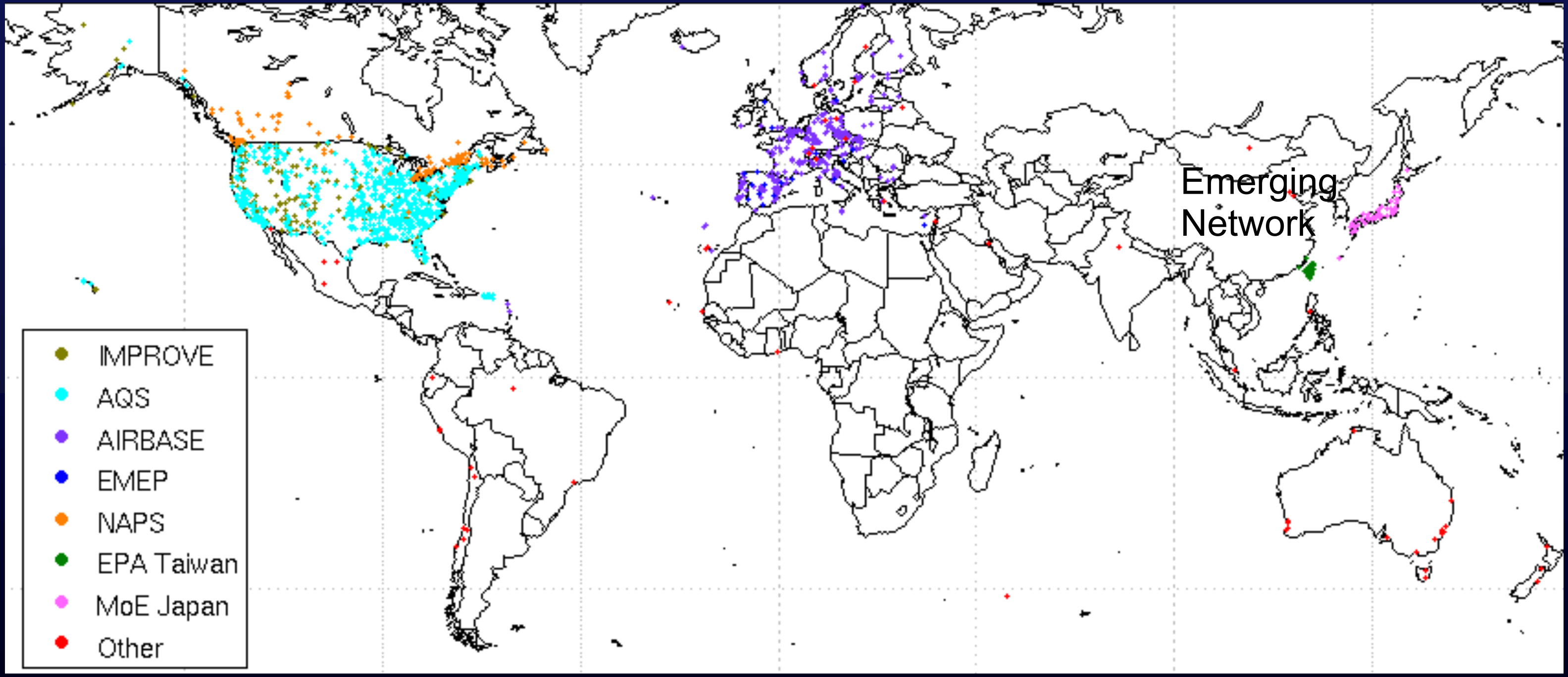




Vast Regions Have Insufficient $PM_{2.5}$ Measurements for Exposure Assessment

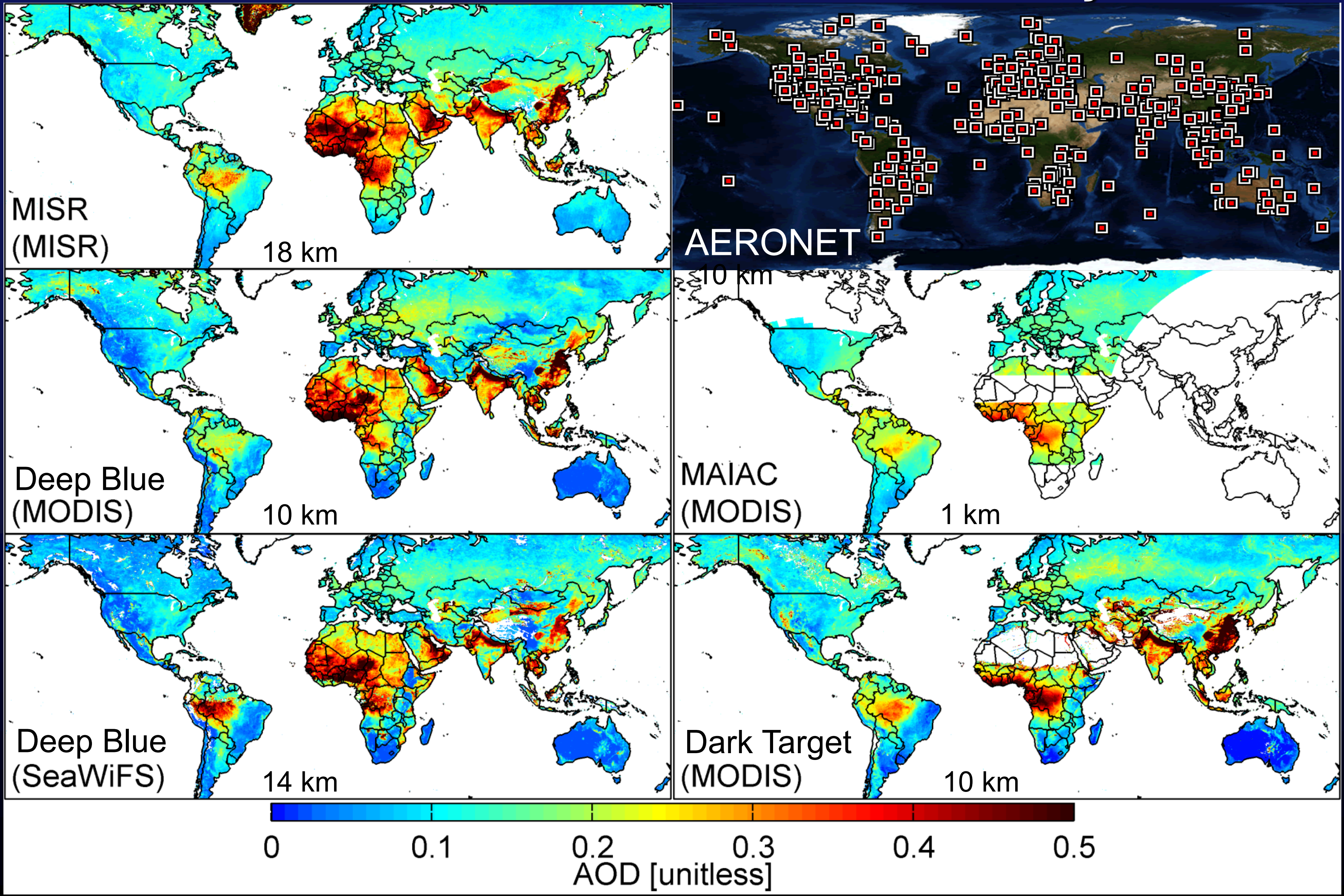
Most countries have no $PM_{2.5}$ monitoring

Locations of Publicly Accessible Long-Term $PM_{2.5}$ Monitoring Sites



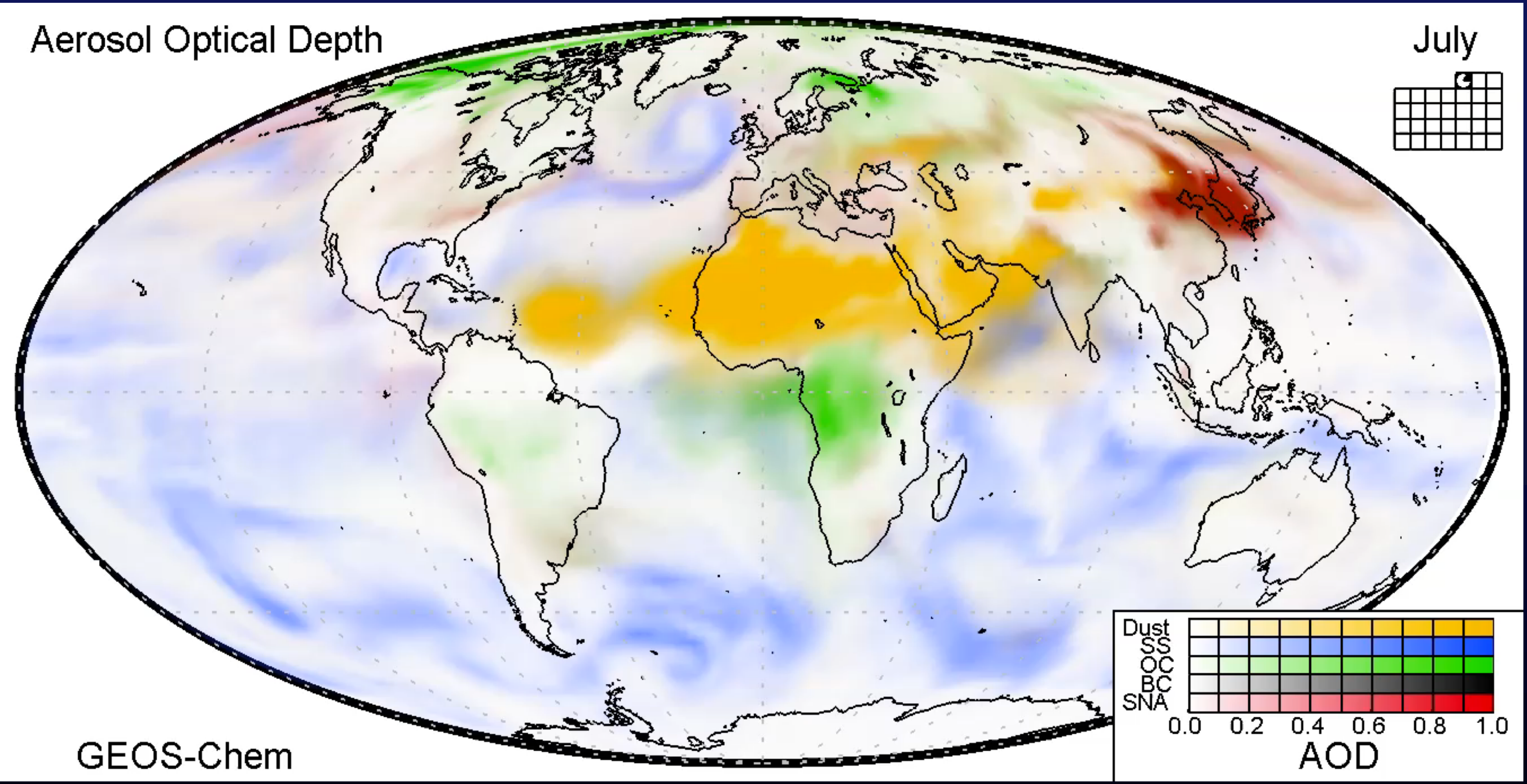
Long-Term (2001-2010) Aerosol Optical Depth (AOD)

Use AERONET AOD to Assess Relative Accuracy & Combine



van Donkelaar et al., ES&T, 2016

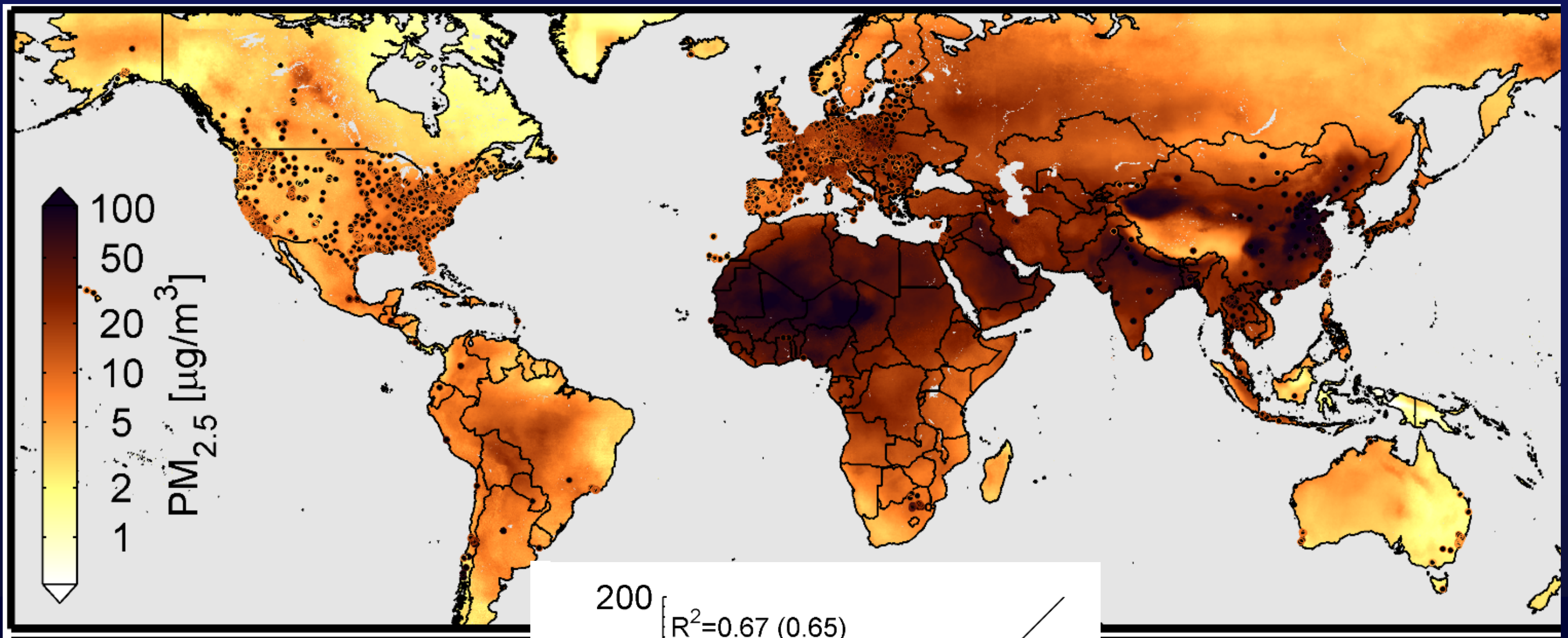
Apply Chemical Transport Model (GEOS-Chem) to Calculate Solution to $PM_{2.5} = f(x,y,t,AOD)$

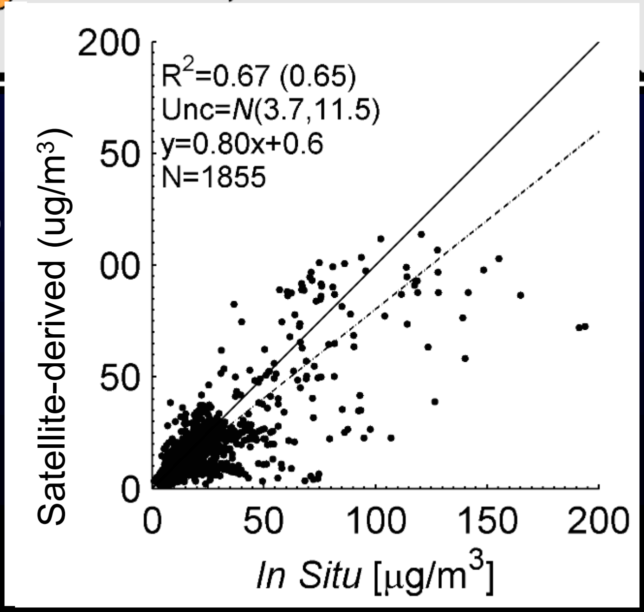


Aaron van Donkelaar

Satellite-Derived $PM_{2.5}$ for 2010

Promising Consistency with In Situ, & Room for Improvement





Without GEOS-Chem:

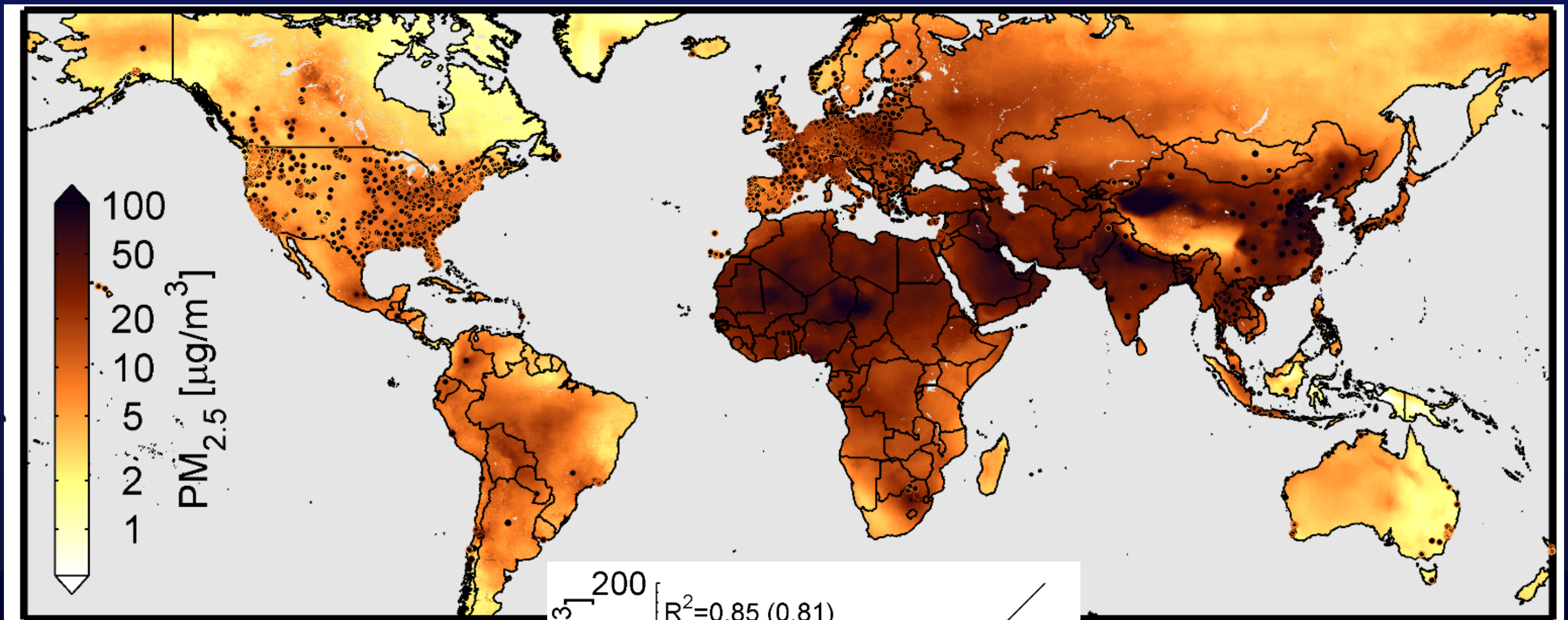
Single algorithm AOD: r^2 = 0.32 - 0.39

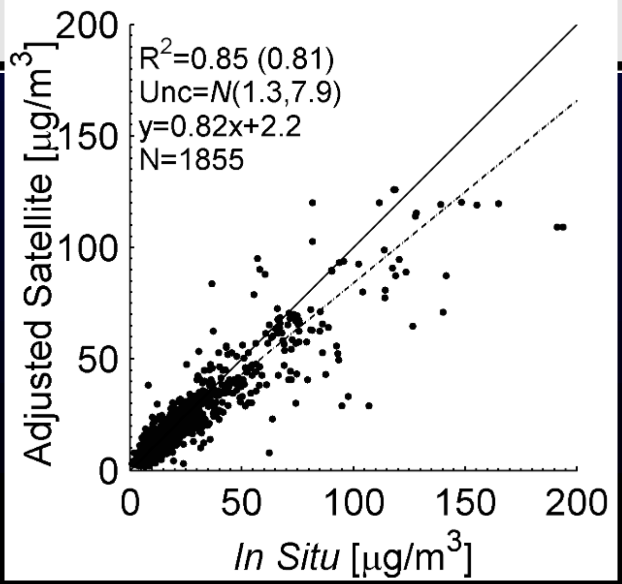
Combined AOD: r^2 = 0.45

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

van Donkelaar et al., ES&T, 2016

Statistical Fusion with Ground-Based Monitors Further Improves Consistency; Still Room for Improvement





Explained $PM_{2.5}$ variance:

Single algorithm AOD: 32-39%

Combined AOD: 6-13%

CTM $PM_{2.5}$ = *f*(AOD): 20%

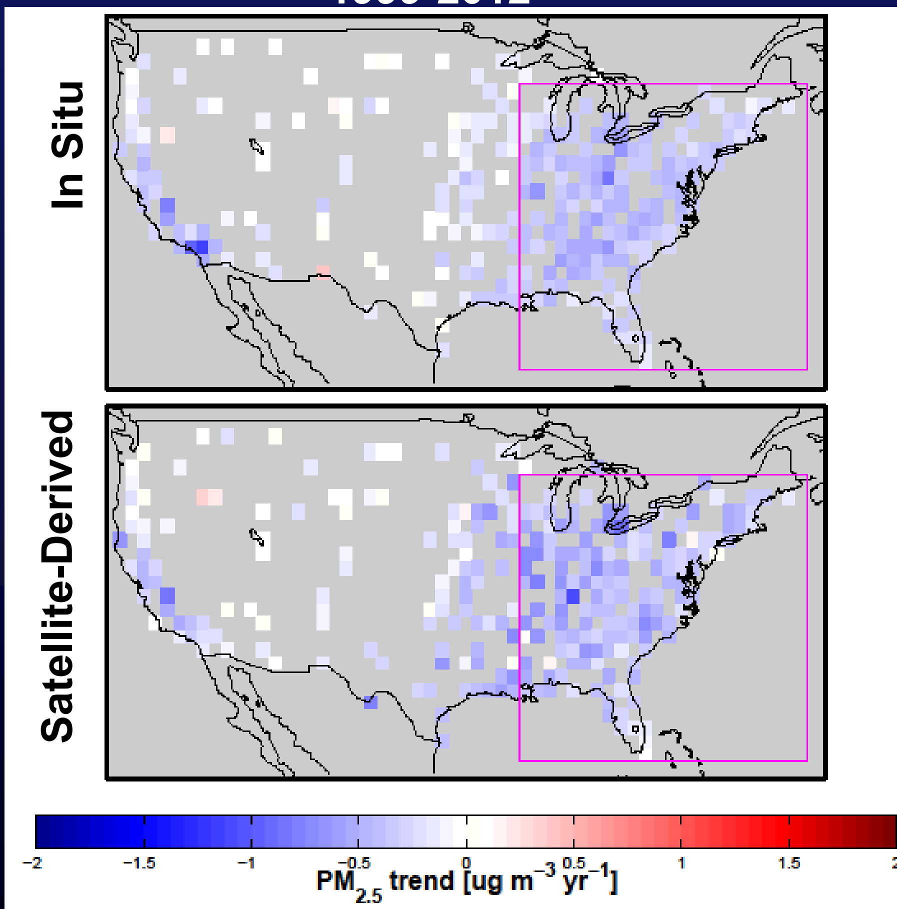
Statistical fusion: 16%

Out of sample R^2=0.81

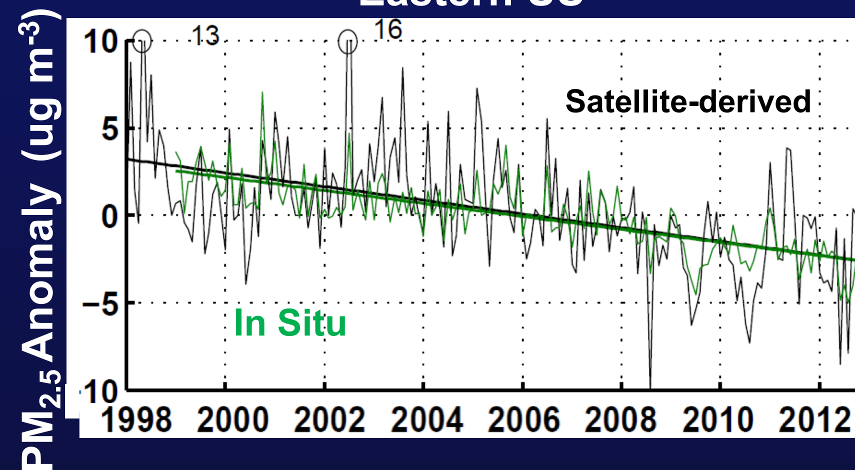
van Donkelaar et al., ES&T, 2016

Consistent Trends in Satellite-Derived and In Situ $PM_{2.5}$ *If* Include Temporal $PM_{2.5}$ = f(AOD) from CTM (GEOS-Chem)

1999-2012



Eastern US



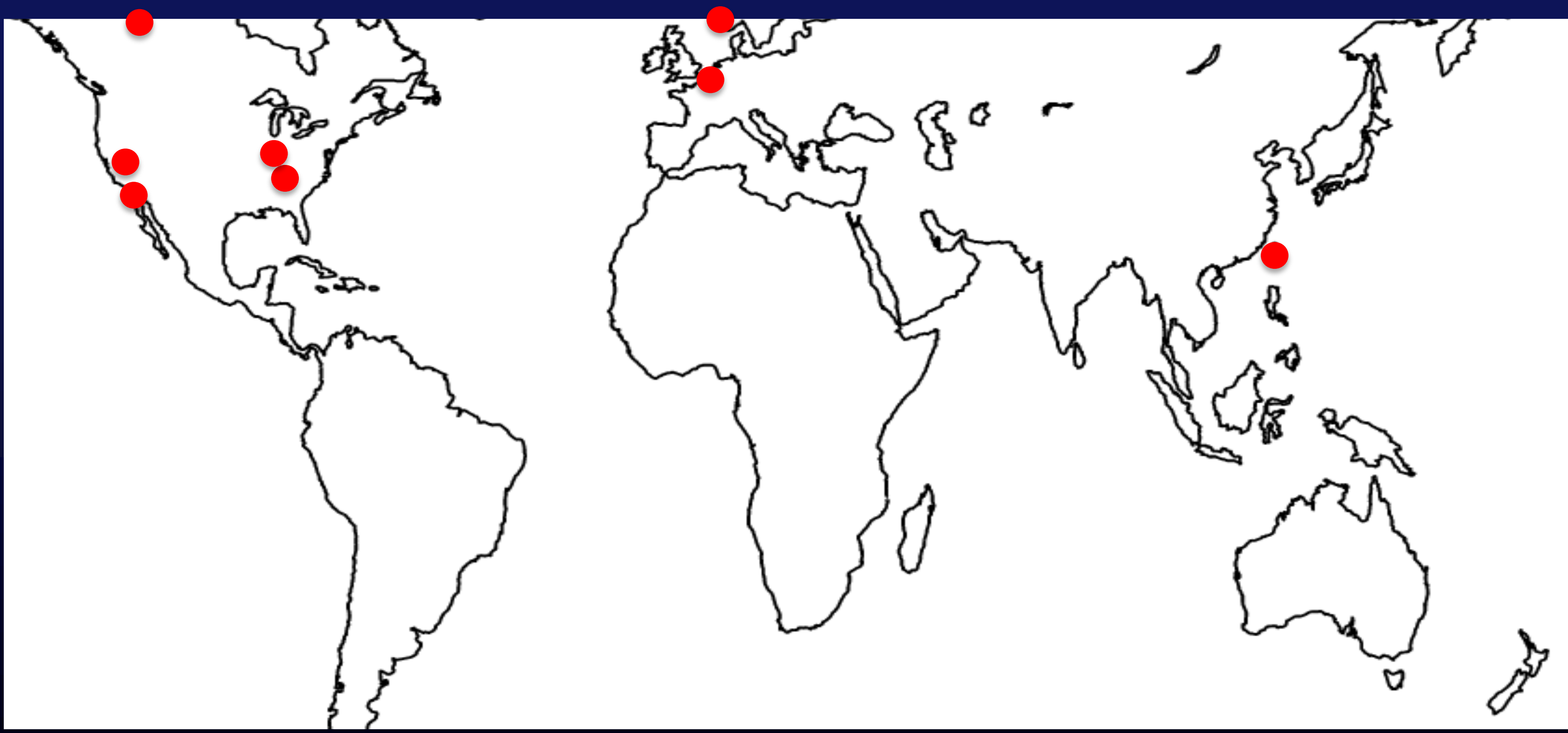
In Situ (1999-2012)
0.37 ± 0.06 (95% CI) $\mu g\ m^{-3}\ yr^{-1}$

Satellite-Derived (1999-2012)
0.36 ± 0.13 (95% CI) $\mu g\ m^{-3}\ yr^{-1}$

If constant $PM_{2.5}$ / AOD, trend degrades: 0.22 ± 0.09 $\mu g\ m^{-3}\ yr^{-1}$

Boys et al., ES&T, 2014

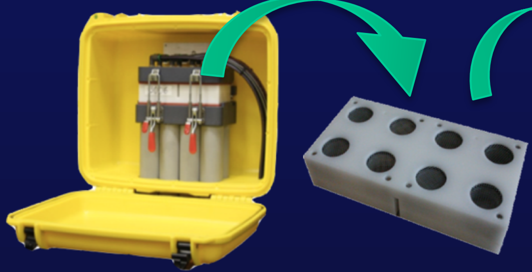
Few Collocated Measurements of $PM_{2.5}$ & AOD



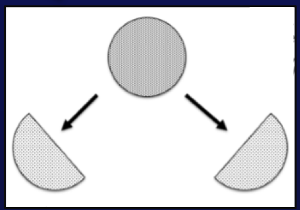
Data for 2012

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)



Mass (35% RH)
Black Carbon



Ions (IC)

Metals (ICP-MS)

Organics (AMS)

3-λ nephelometer (AirPhoton) Scatter

AOD from Sunphotometer (e.g. AERONET)

SPARTAN
Global Particulate Matter Network

Surface/Column — Diurnal — Mass Scattering Efficiency

$$\frac{\mathrm{PM}_{2.5}}{\mathrm{AOD}} = \left(\frac{b_{sp,overpass}}{\mathrm{AOD}_{overpass}}\right)\left(\frac{b_{sp,24h}}{b_{sp,overpass}}\right)\left(\frac{\mathrm{PM}_{2.5,24\mathrm{h}}}{b_{sp,24h}}\right)$$

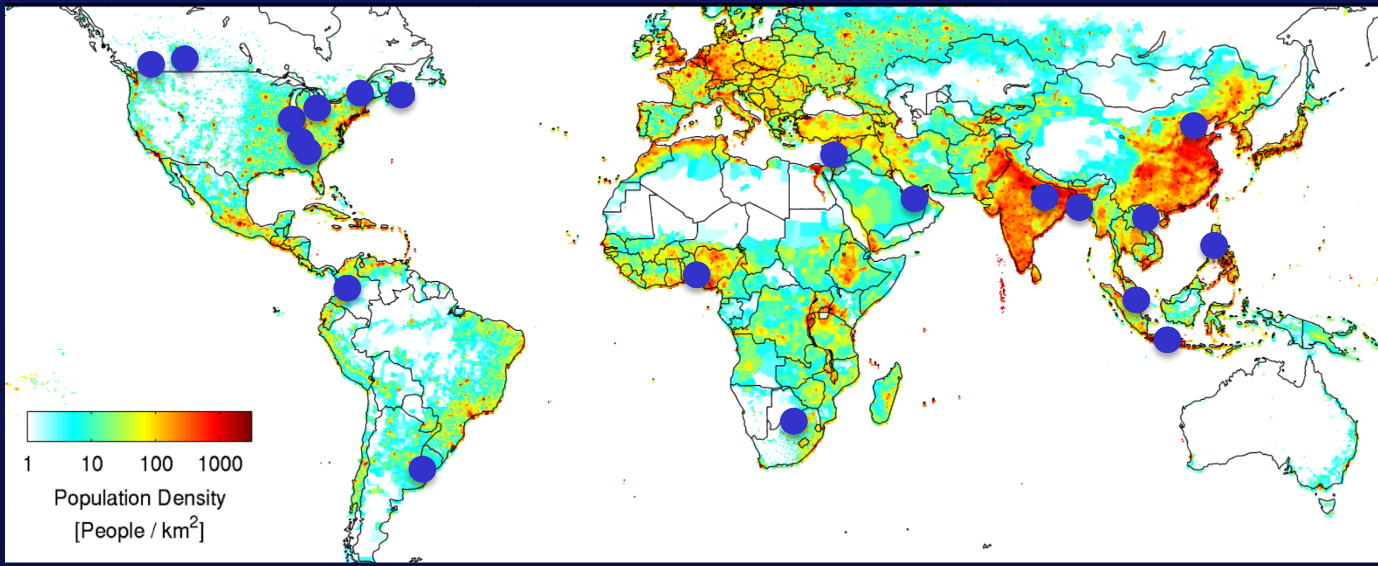
b_{sp} = nephelometer measurements of aerosol scatter

overpass = satellite overpass time

www.spartan-network.org

Snider, Weagle, et al., AMT, 2015

SPARTAN: An Emerging Global Network to Evaluate and Enhance Satellite-Based Estimates of $PM_{2.5}$



An IGAC Activity

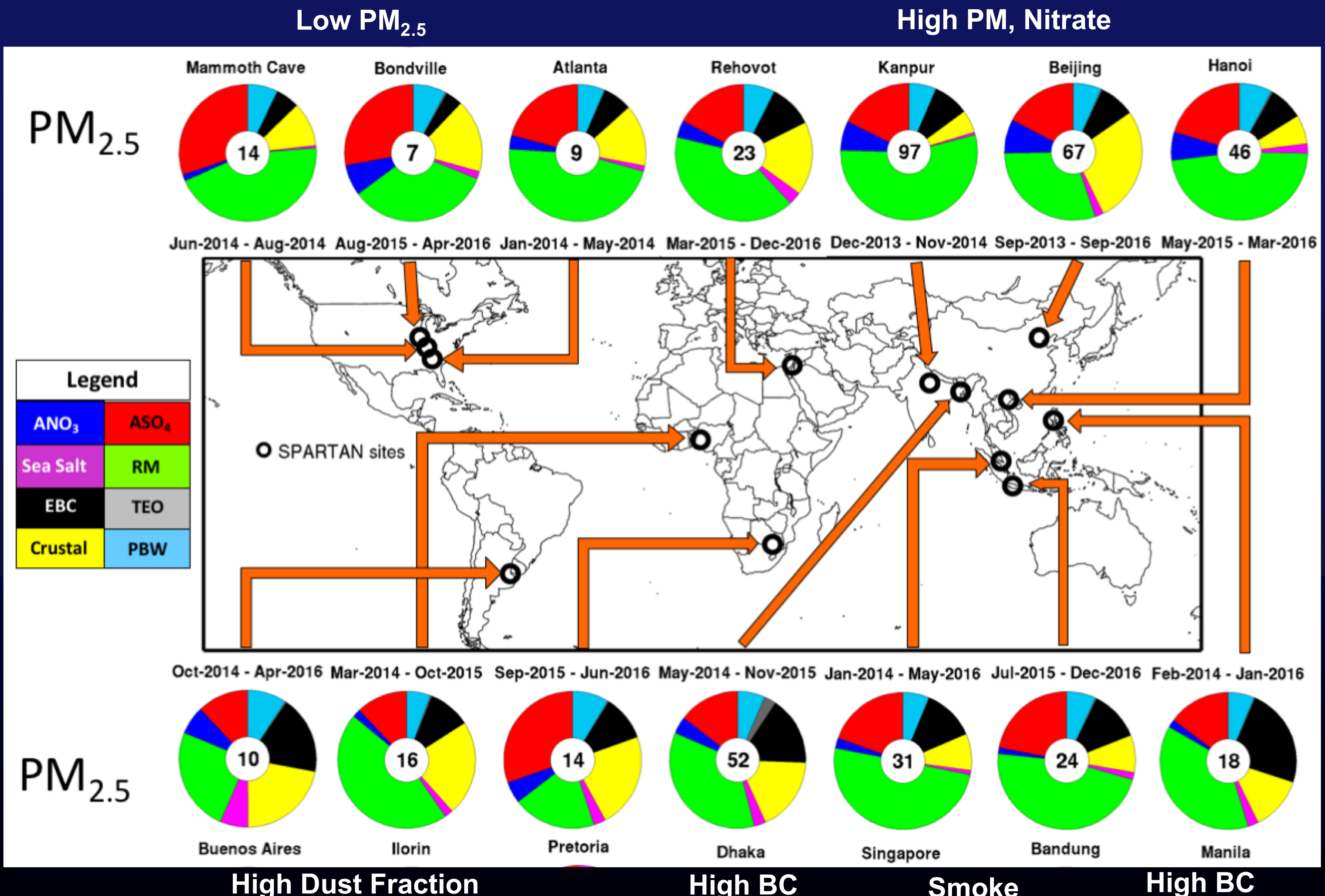
Globally consistent $PM_{2.5}$ mass and composition network

	Coal, Traffic	Fires	Agriculture	Sea Spray	Mineral Dust
SPARTAN Measurements	SO_4^{2-}, Pb, As, V, Zn, BC	K	NH_4^+	Na^+	Al, Fe, Mg, Ti

www.spartan-network.org

Snider et al., AMT, 2015

Initial SPARTAN $PM_{2.5}$ Mass and Composition (>1500 filters)



Data publicly available at spartan-network.org

Middle contains $PM_{2.5}$ Mass in ug/m^3

Snider et al., ACP, 2016

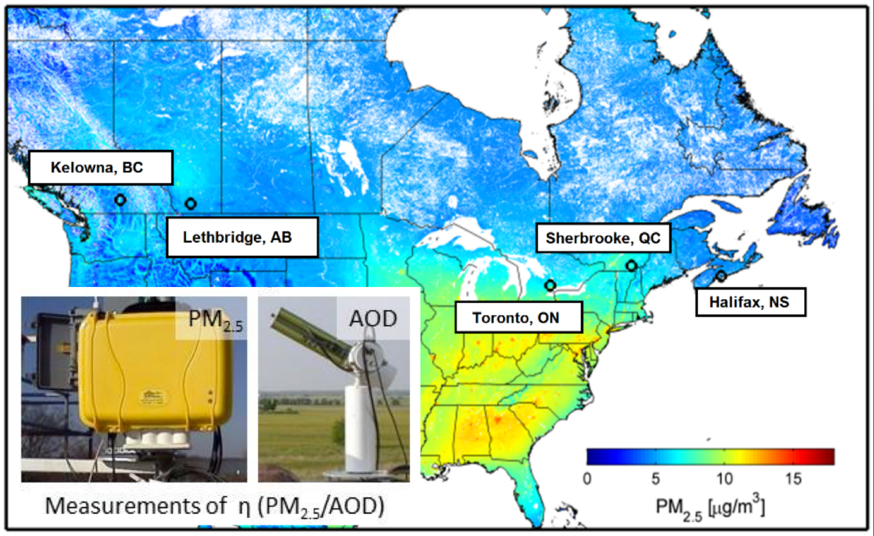
Mortality due to Air Pollution at Low levels of Exposure (MAPLE)

- Apply novel individual estimates of $PM_{2.5}$ exposure to several large population-based cohorts (2.5M & 3.5M)
  - Majority of Canadian population lives in areas with relatively low ambient $PM_{2.5}$ concentrations (<12μg/m^3)
- Characterize relationship between $PM_{2.5}$ exposure with (all cause / cause-specific) mortality
- Characterize shape of concentration-mortality association in subjects whose average past 3-20 years of exposure < specified concentrations

MAPLE

HEALTH EFFECTS INSTITUTE

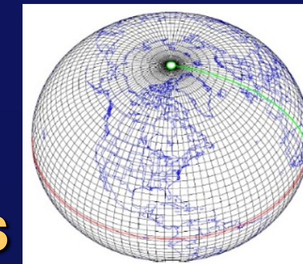
Michael Brauer, Rick Burnett, Scott Weichenthal, Daniel Crouse, Randall V. Martin, Perry Hystad, Anders Erickson, Jeffrey R. Brook, Michael Tjepkema, Lauren Pinault



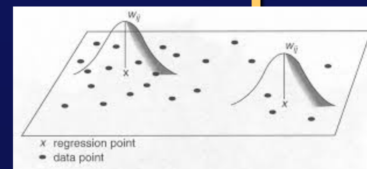
Some Emerging Satellite Datasets

- Ongoing global aerosol monitoring (e.g. VIIRS on NPP)
- Improved aerosol algorithms (e.g. MAIAC with global 1km AOD)
- Finer resolution trace gas information (e.g. TROPOMI for NO_2), 2017 launch
- Diurnal information (e.g. geostationary constellation; launch in few years)
- Additional information on aerosol composition (e.g. MAIA 2020 launch)

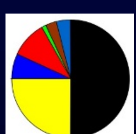
Key Challenge for All These Datasets:
Relate Columnar Satellite Observation to Ground-level Mass



Satellites offer high quality global columnar observations with information about $PM_{2.5}$ when interpreted with models



Ground-based collocated measurements of AOD, $PM_{2.5}$ mass, $PM_{2.5}$ scatter, and $PM_{2.5}$ composition key to improving global satellite-based estimates of $PM_{2.5}$



Exciting opportunities for source apportionment, connections with low cost sensors, and health applications

SPARTAN
Global Particulate Matter Network