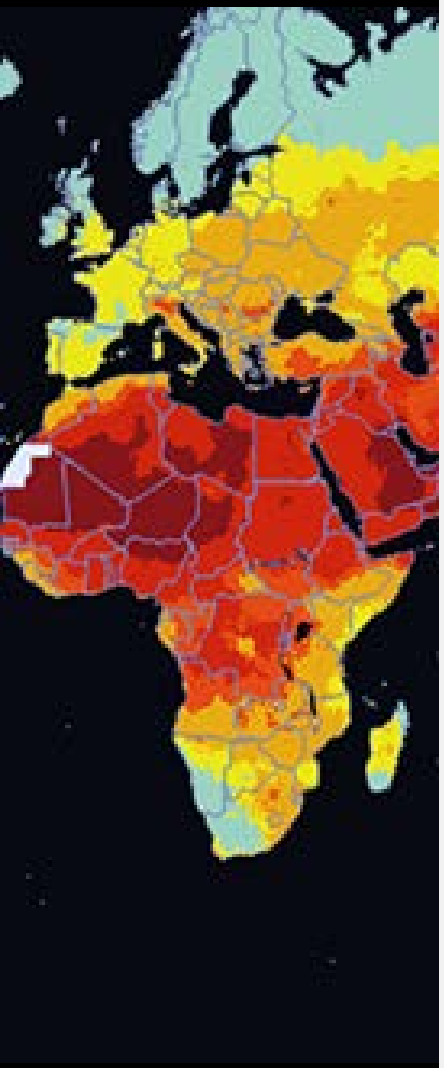


National Aeronautics and
Space Administration

ARSET

Applied Remote Sensing Training

http://arset.gsfc.nasa.gov

@NASAARSET

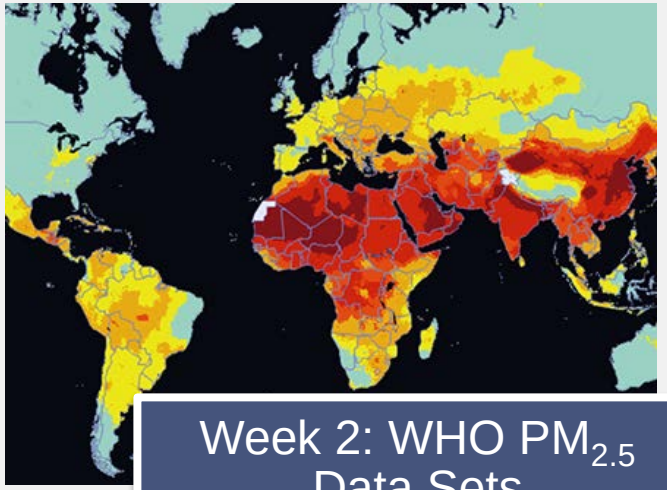
World Health Organization $PM_{2.5}$ Estimates

March 15-29, 2017

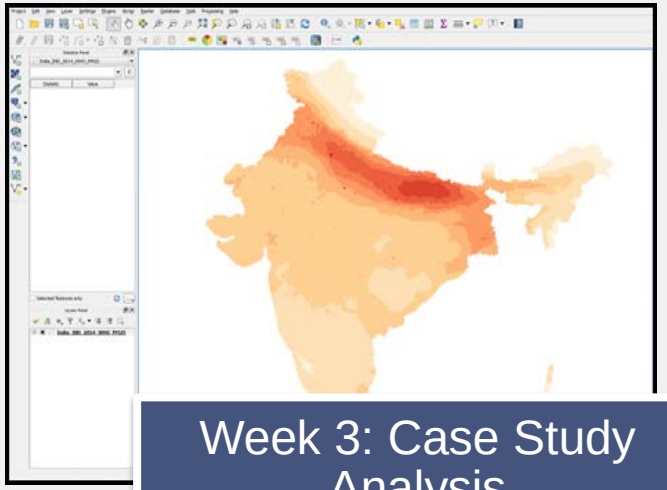
Melanie Follette-Cook, Pawan Gupta

Webinar Series Agenda

Week 1: ARSET Remote Sensing and SDGs



Week 2: WHO $PM_{2.5}$ Data Sets



Week 3: Case Study Analysis

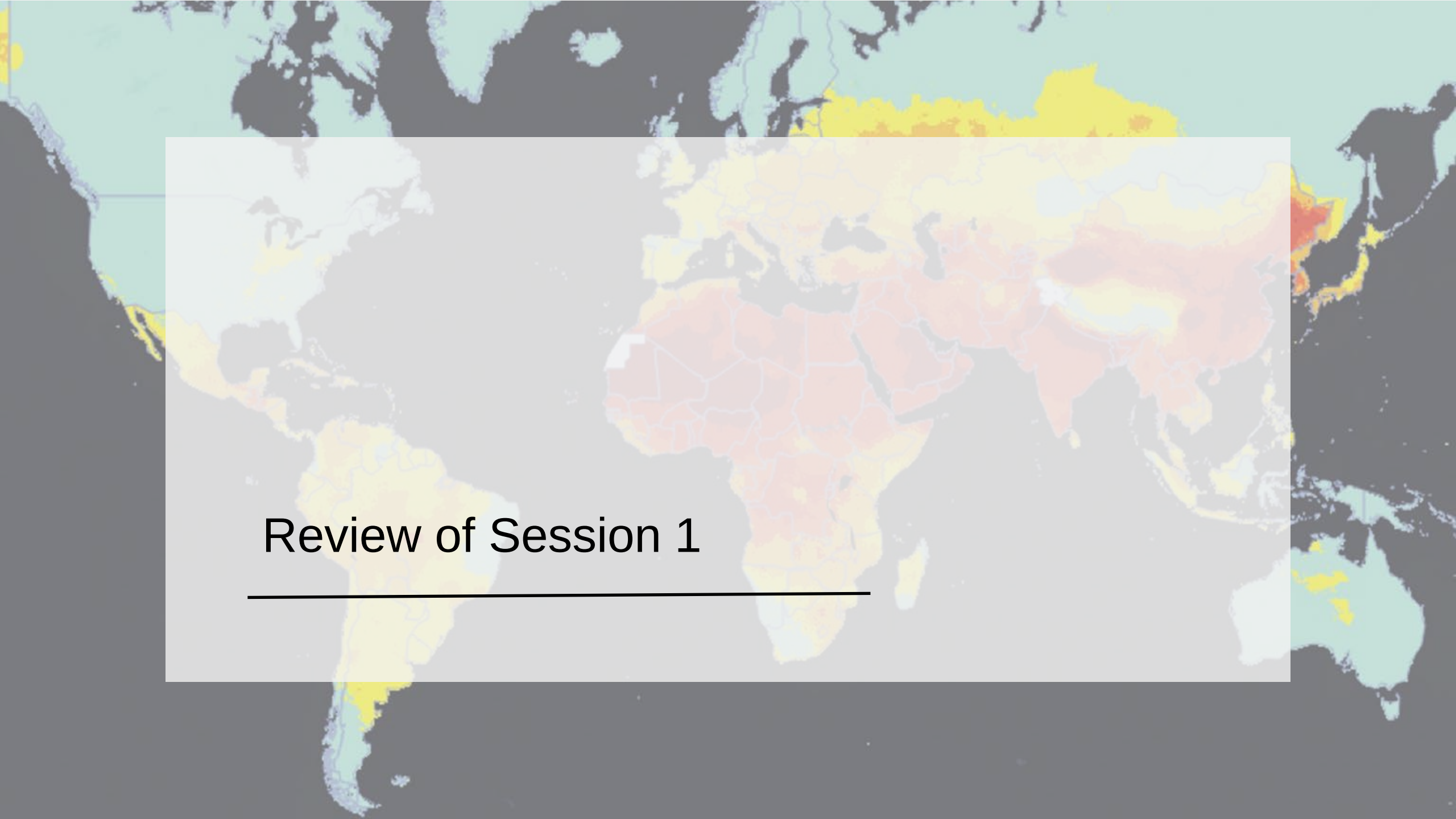
Session 2: Outline

1. Brief review of Session 1
2. Introduction to the Data Integration Model for Air Quality (DIMAQ)
3. Review of Available World Health Organization (WHO) Tools

Today's Instructor: Melanie B. Follette-Cook, Ph.D.
GESTAR/Morgan State University, Code 614
NASA Goddard Space Flight Center
Greenbelt, MD 20771, USA
melanie.cook@nasa.gov
http://arset.gsfc.nasa.gov/people/melanie-follette-cook

Learning Objectives

1. Learn about the DIMAQ model used to calculate $PM_{2.5}$ estimates as well as the various datasets that are used as inputs
2. Learn about several online tools to access and view the WHO estimates



Review of Session 1

UN Sustainable Development Goals (SDGs)

Transforming Our World: The 2030 Agenda for Sustainable Development

Goal 3 – Good Health and Well Being

- Target 3.9; Indicator 3.9.1
- Mortality rate attributed to household and ambient air pollution (annual mean levels of air pollution (fine particulate matter [$PM_{2.5}$]))

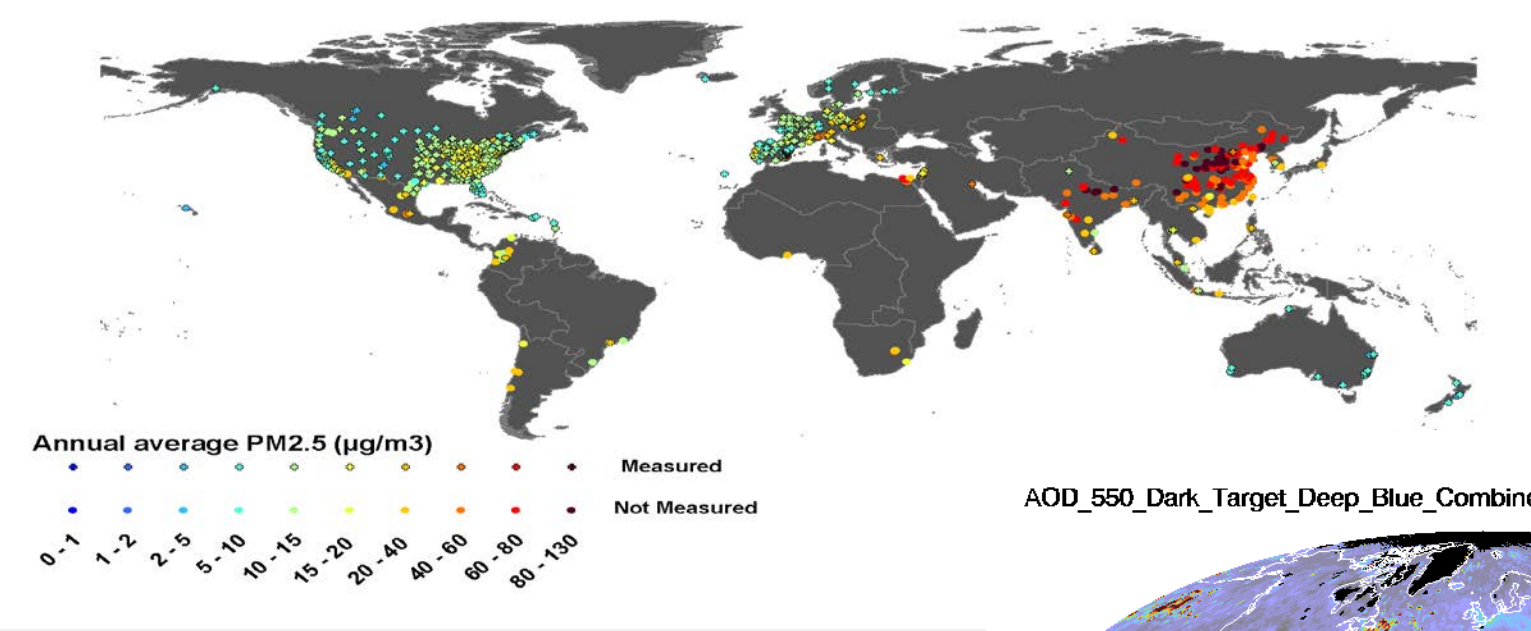
Goal 11 – Sustainable Cities and Communities

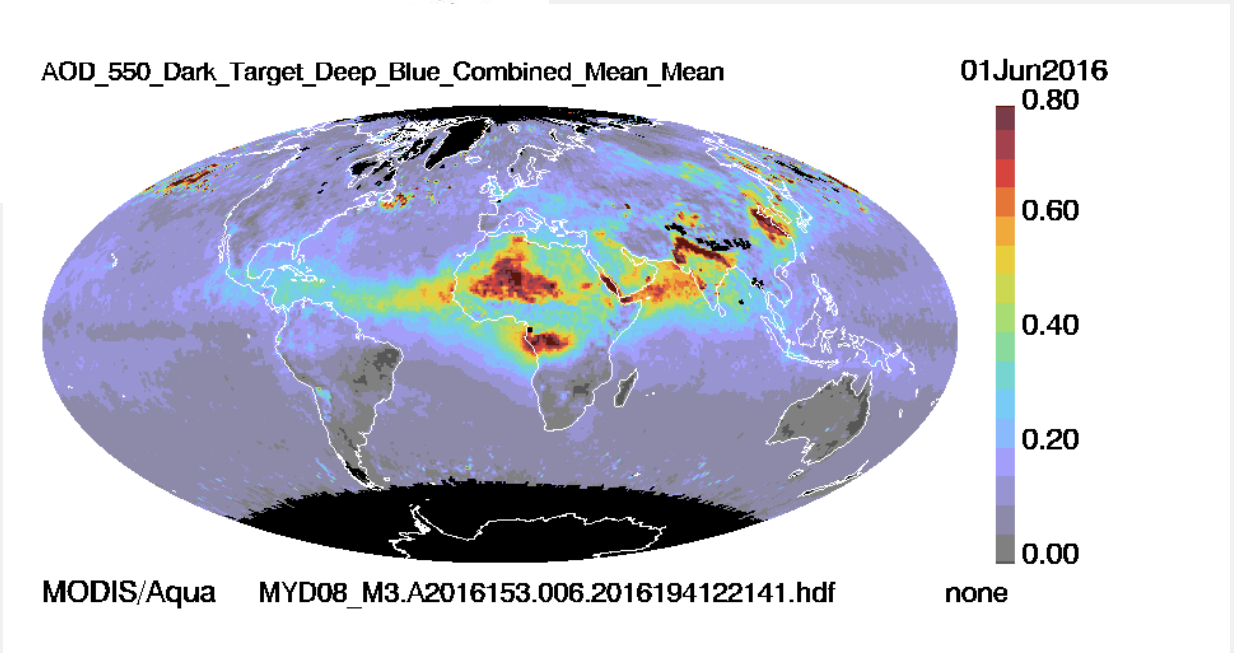
- Target 11.6; Indicator 11.6.2
- Annual mean levels of fine particulate matter (e.g. $PM_{2.5}$ and PM_{10}) in cities (population weighted)

Text adapted from "Transforming our world: the 2030 Agenda for Sustainable Development"

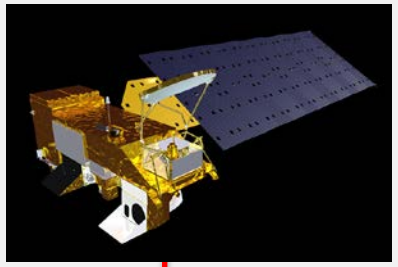
Remote Sensing of Aerosols

Aerosol Optical Depth (AOD) from Satellite

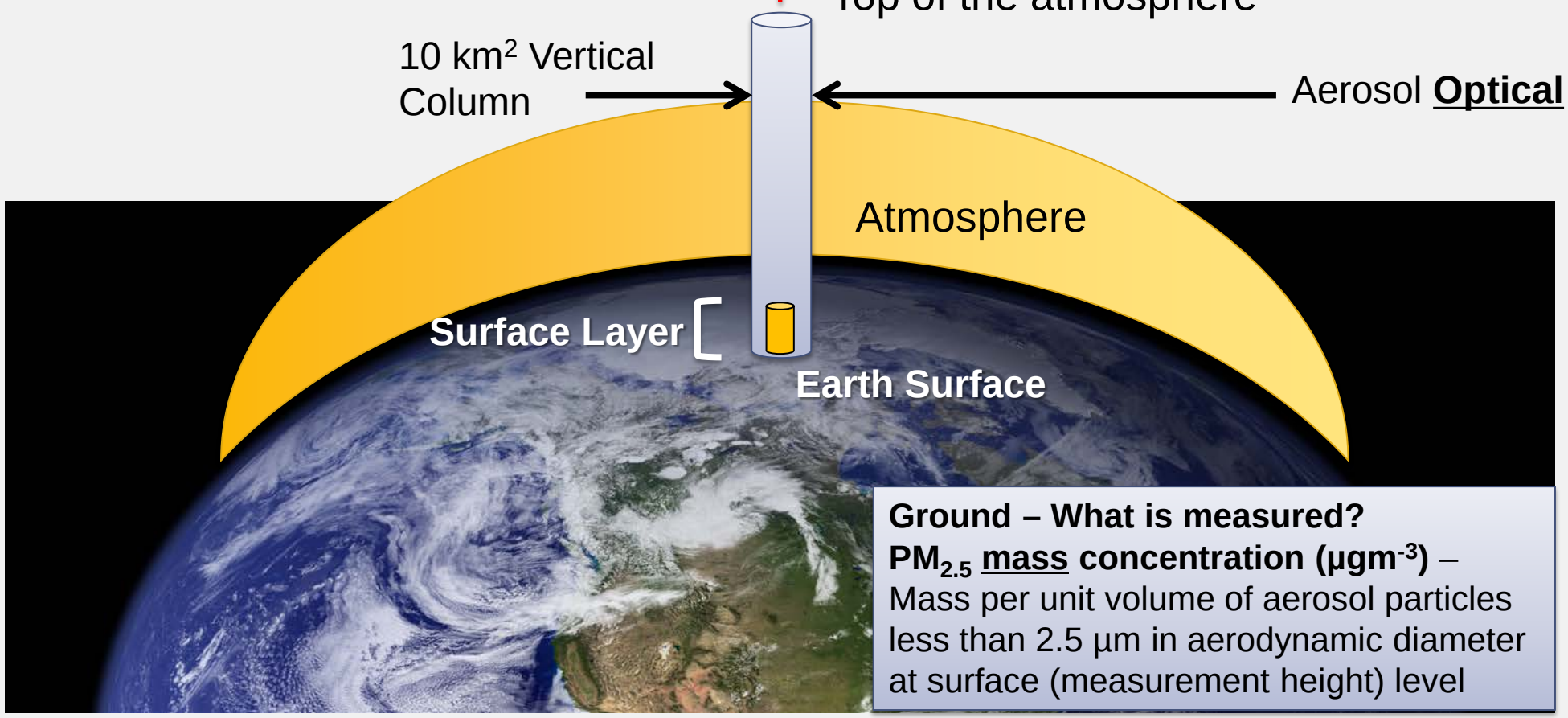




Remote Sensing of Aerosols
Satellite vs. Ground



Satellite – What is measured?
AOD – Column integrated value (top of the atmosphere to surface) - Optical measurement of aerosol loading – unitless. AOD is function of shape, size, type and number concentration of aerosols



Ground – What is measured?
$PM_{2.5}$ mass concentration (μgm^{-3}) – Mass per unit volume of aerosol particles less than 2.5 µm in aerodynamic diameter at surface (measurement height) level

Remote Sensing of Aerosols

AOD-PM Relationship

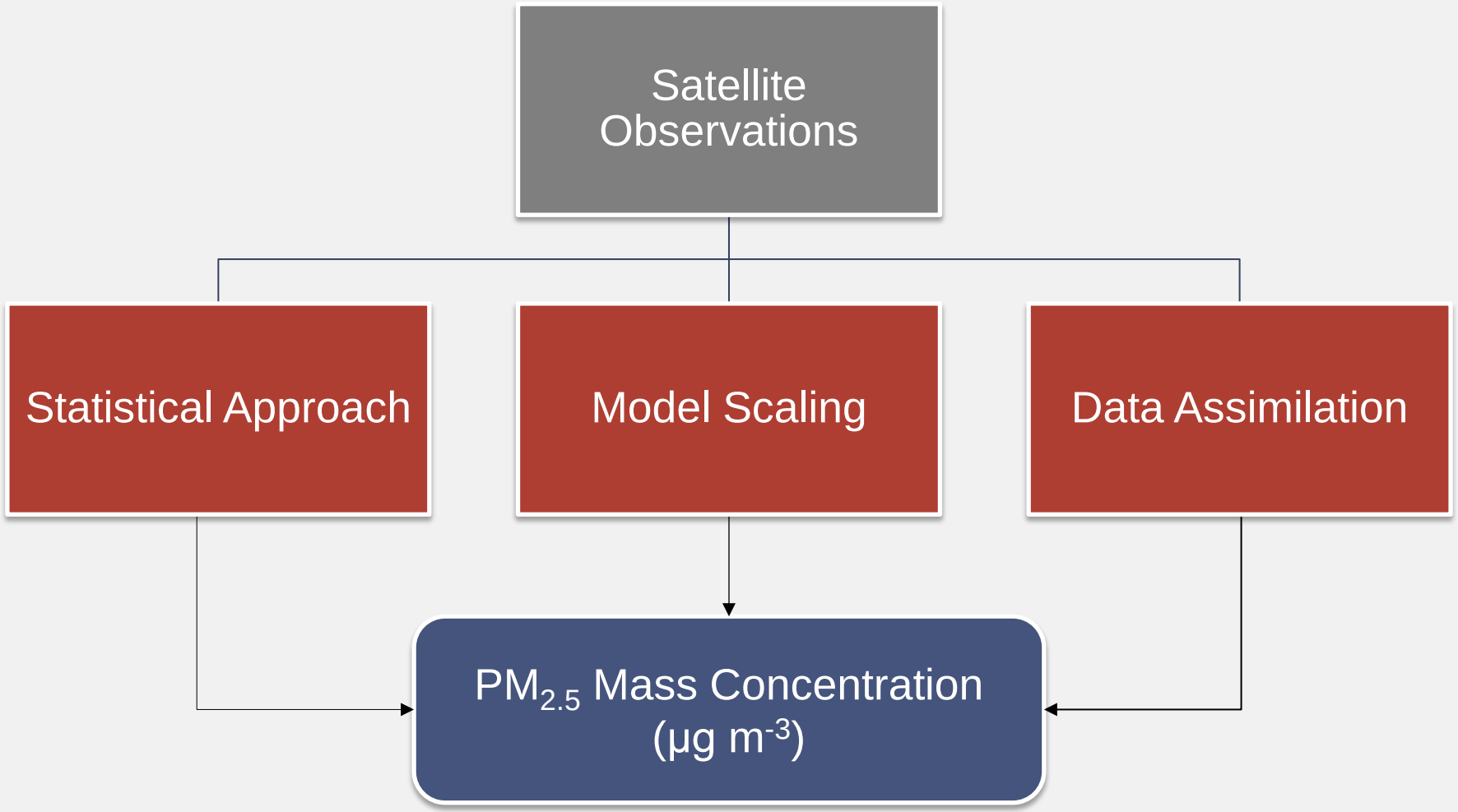
Assuming cloud-free skies, a well mixed boundary layer with no overhead aerosols, and aerosols that have similar optical properties*, AOD and $PM_{2.5}$ can be related by the following equation:

$$PM_{2.5} = \frac{4\rho r_{eff}}{3QHP_{BLf}(RH)} \; x \; AOD$$

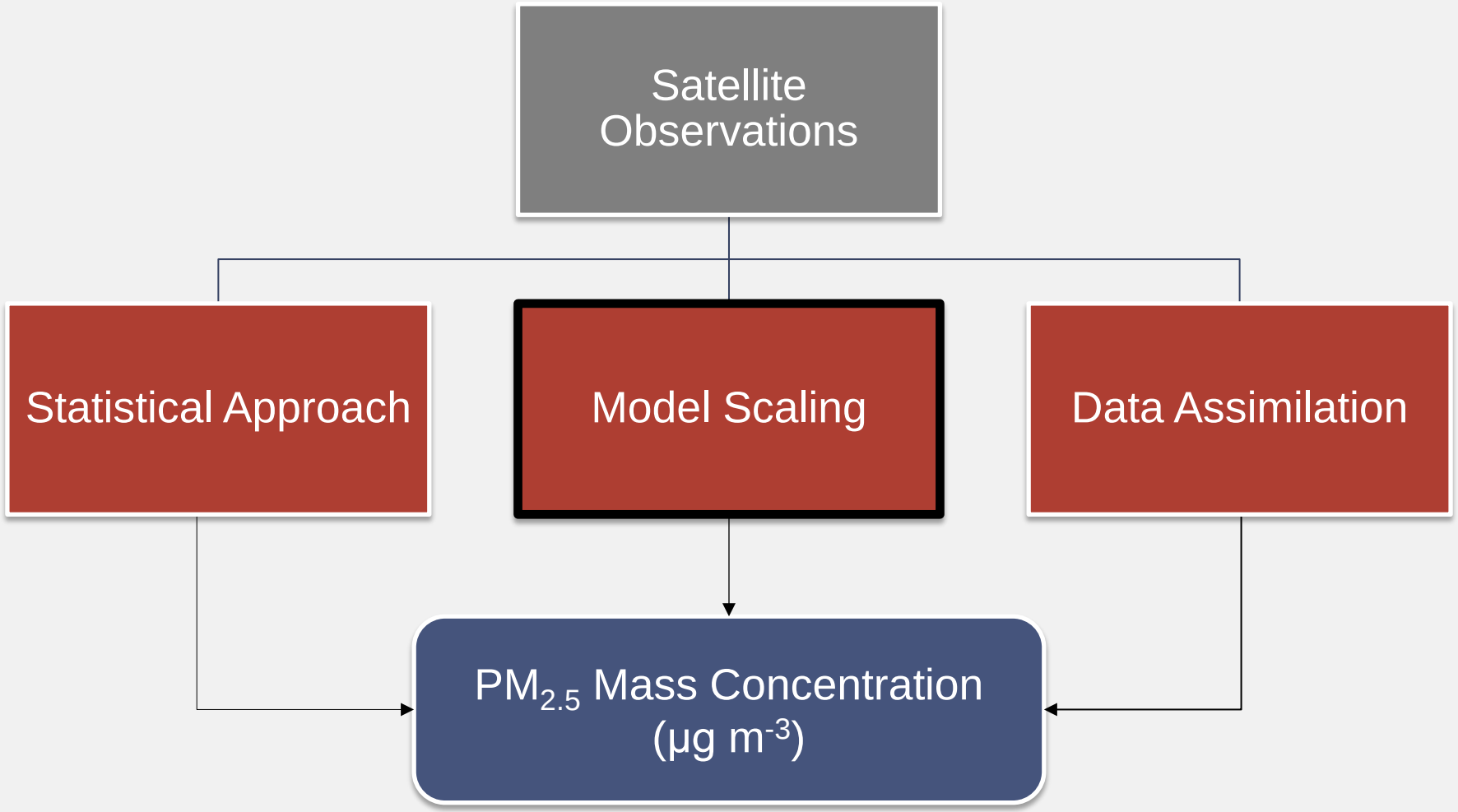
- ρ: aerosol mass density
- r_{eff}: particle effective radius
- Q: extinction coefficient
- H_{PBL}: mixing height
- *f (RH)*: how aerosol scattering changes with changing relative humidity

*Hoff, R. & Christopher, S., 2009, J. Air and Waste Manage.Assoc., doi:10.3155/1047-3289.59.6.645

Satellite Remote Sensing of $PM_{2.5}$: Summary



Satellite Remote Sensing of $PM_{2.5}$: Summary

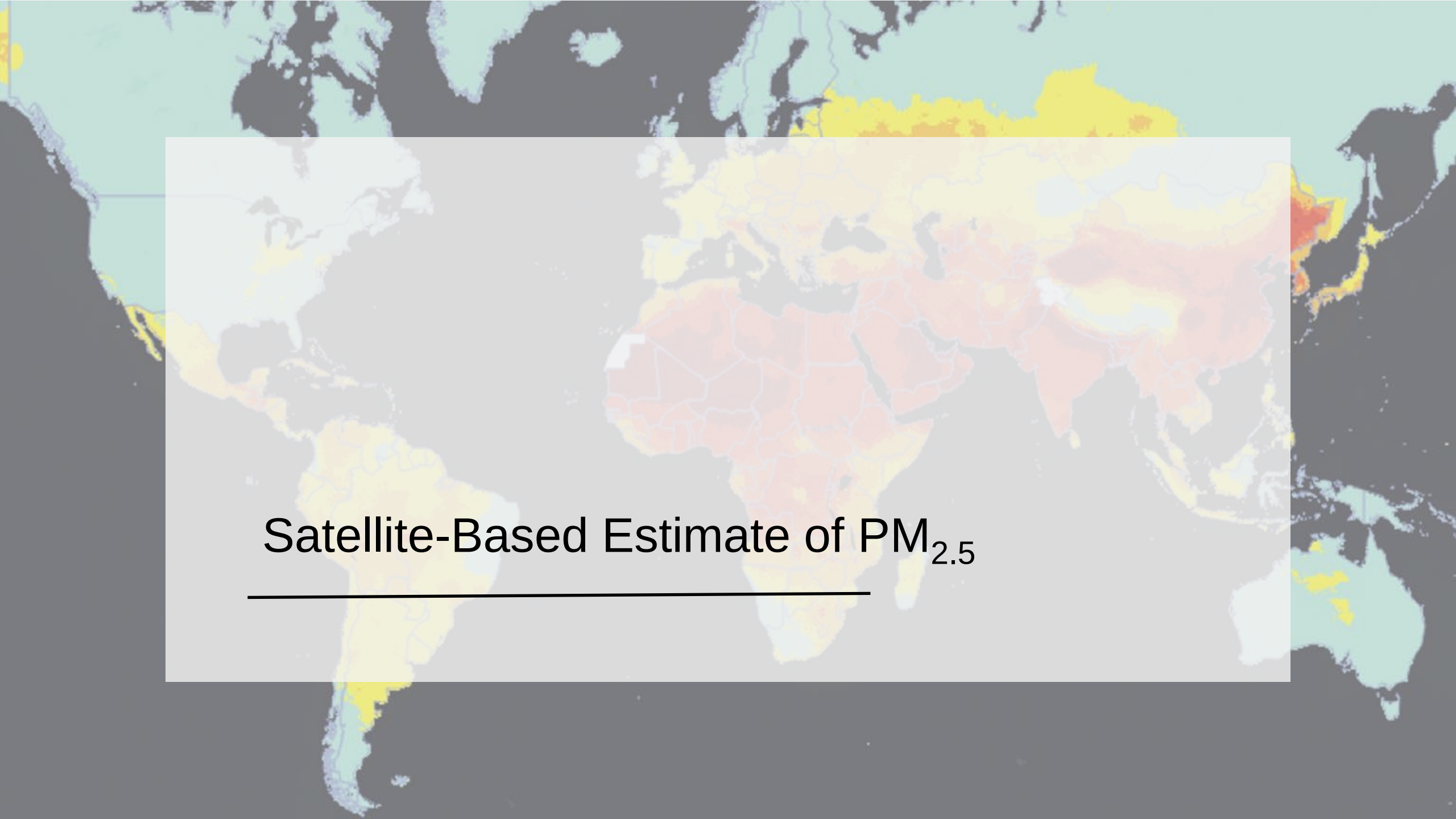


Model Scaling Approach

Let an atmospheric chemistry model decide the conversion from AOD to $PM_{2.5}$

$$\text{Satellite-Derived } PM_{2.5} = \left(\frac{PM_{2.5}}{AOD} \right)_{\text{Model}} \times AOD_{\text{Satellite}}$$

Source: Liu et al., 2006

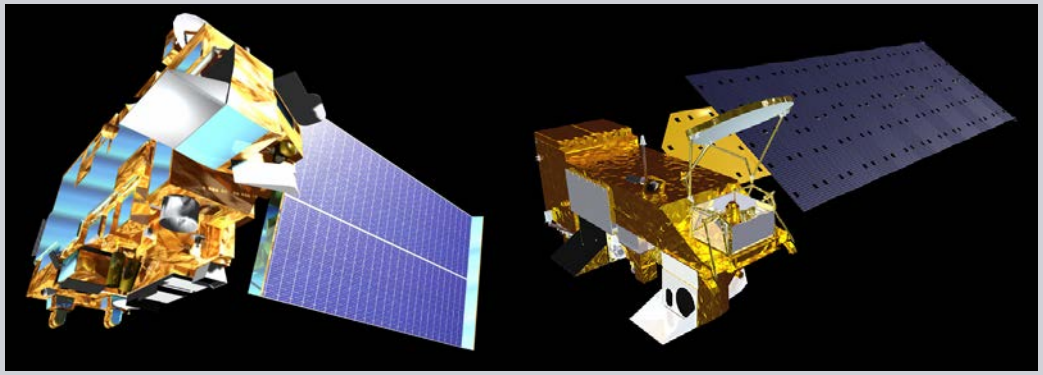
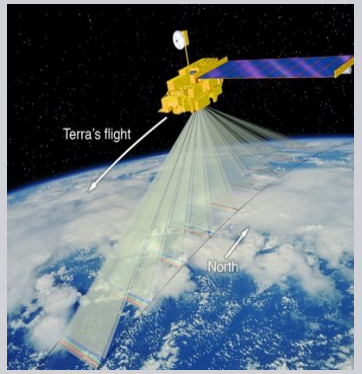


Satellite-Based Estimate of $PM_{2.5}$

Satellite-Based Estimate (Van Donkelaar et al., 2016, doi:10.1021/acs.est.5b05833)

AOD From Satellites

Eight retrievals of AOD from four different instruments

Instrument	MODIS: Terra/Aqua			MISR	SeaWiFS
					
Retrieval Algorithm	Deep Blue	Dark Target	MAIAC	MISR	Deep Blue
Horizontal Resolution	10 km	10 km	1 km	17.6 km	13.5 km

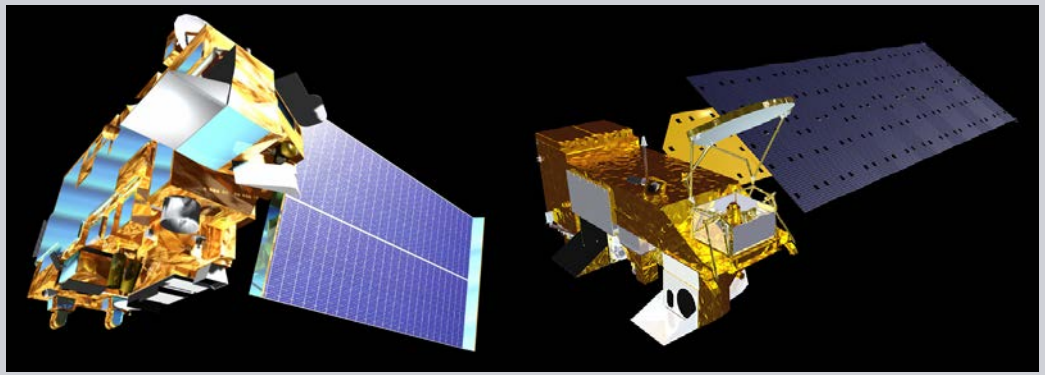
Van Donkelaar et al., 2016, doi:10.1021/acs.est.5b05833.
The Van Donkelaar product is available at: http://sedac.ciesin.columbia.edu/data/set/sdei-global-annual-avg-pm2-5-modis-misr-seawifs-aod-1998-2012

MODIS

MODerate resolution Imaging Spectrometer

- The MODIS instrument flies aboard both the Terra and Aqua satellites
  - Terra: morning overpass time
  - Aqua: afternoon overpass time
- 36 spectral bands covering from 0.405 µm (or 405 nm) to 14.385 µm

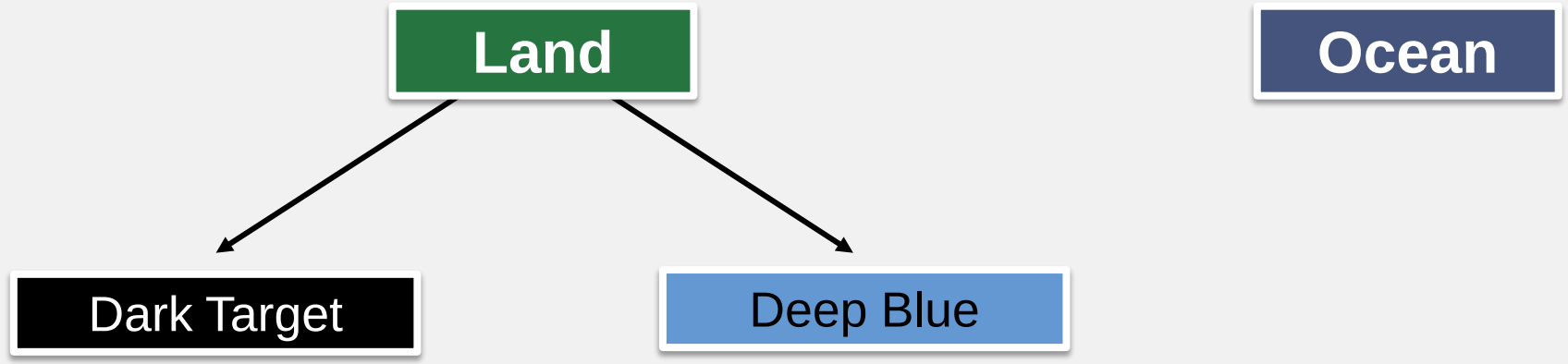
MODIS: Terra/Aqua



Deep Blue	Dark Target	MAIAC
10 km	10 km 3 km	1 km

MODIS Aerosol Products

Three Separate Algorithms



- used over dark, low reflectance surfaces

- used over bright land surfaces
- Also used for SeaWiFS retrievals

- The dark target and deep blue products are separate and when both are available, the user must select which to use
- In collection 6, there is a joint product that uses an automated procedure to select the appropriate product

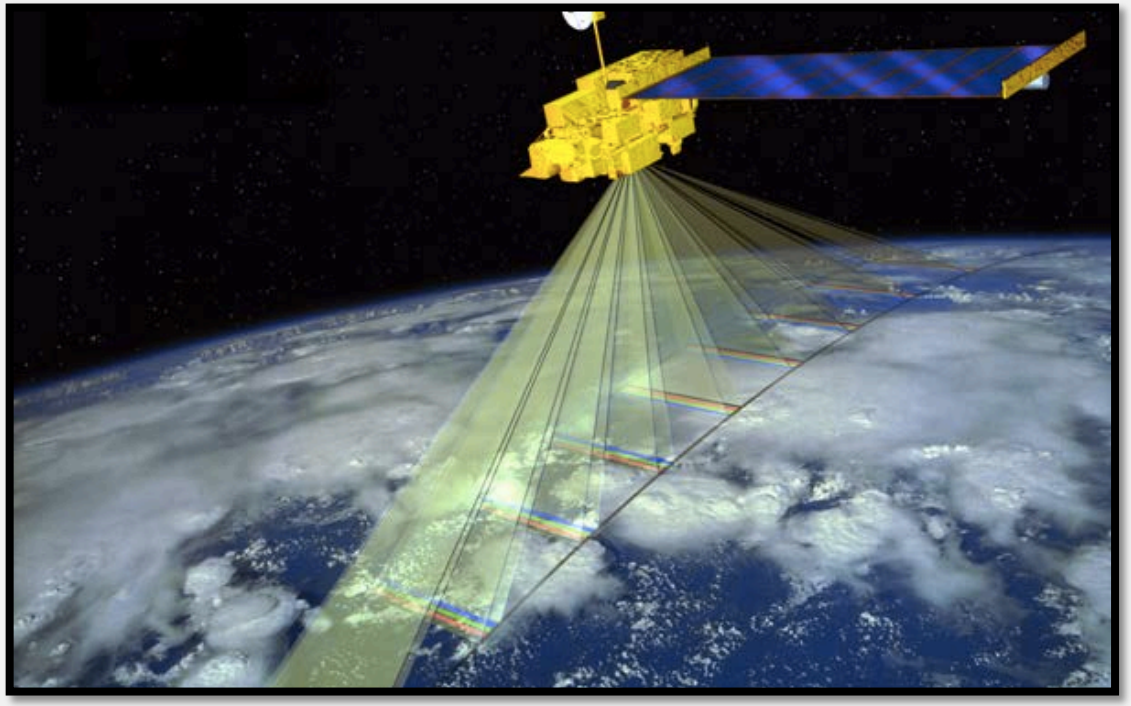
MODIS

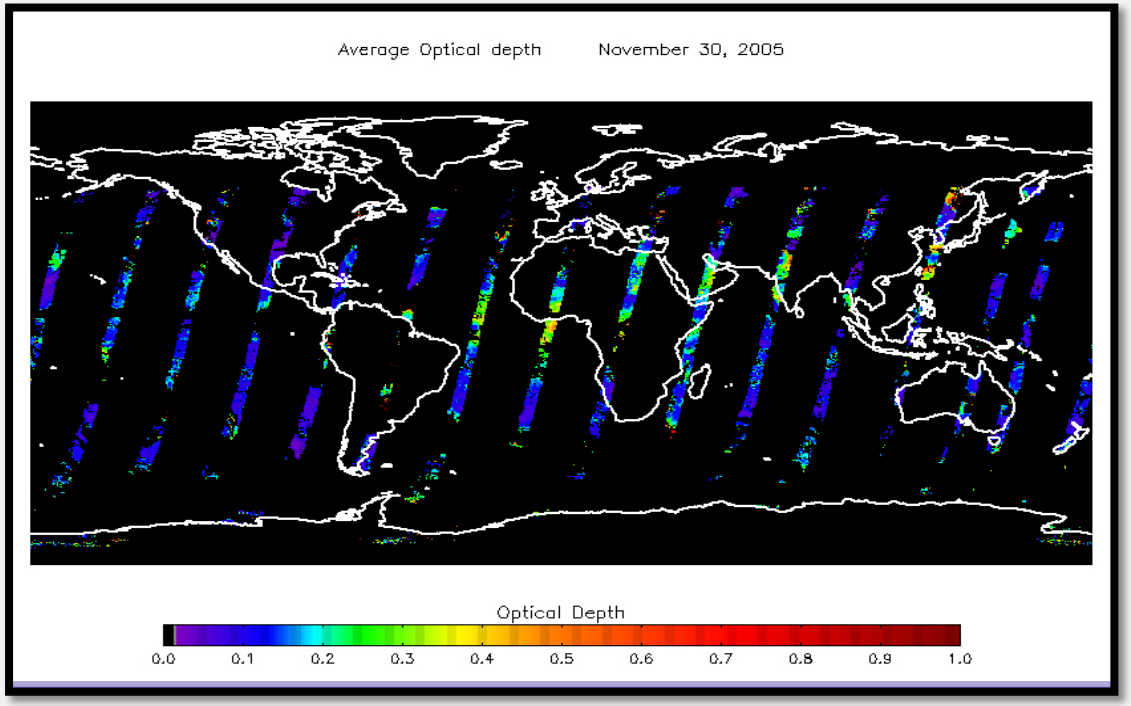
An additional algorithm – Not operational yet

- MAIAC: Multi-Angle Implementation of Atmospheric Correction
- Higher resolution (1 km) than Dark Target or Deep Blue (10 km)
- Based on time series and spatial analysis
- Can be used over areas with low reflectance and bright surfaces
- Also provides aerosol type (background / smoke / dust)

MISR

Multi-angle Imaging SpectroRadiometer

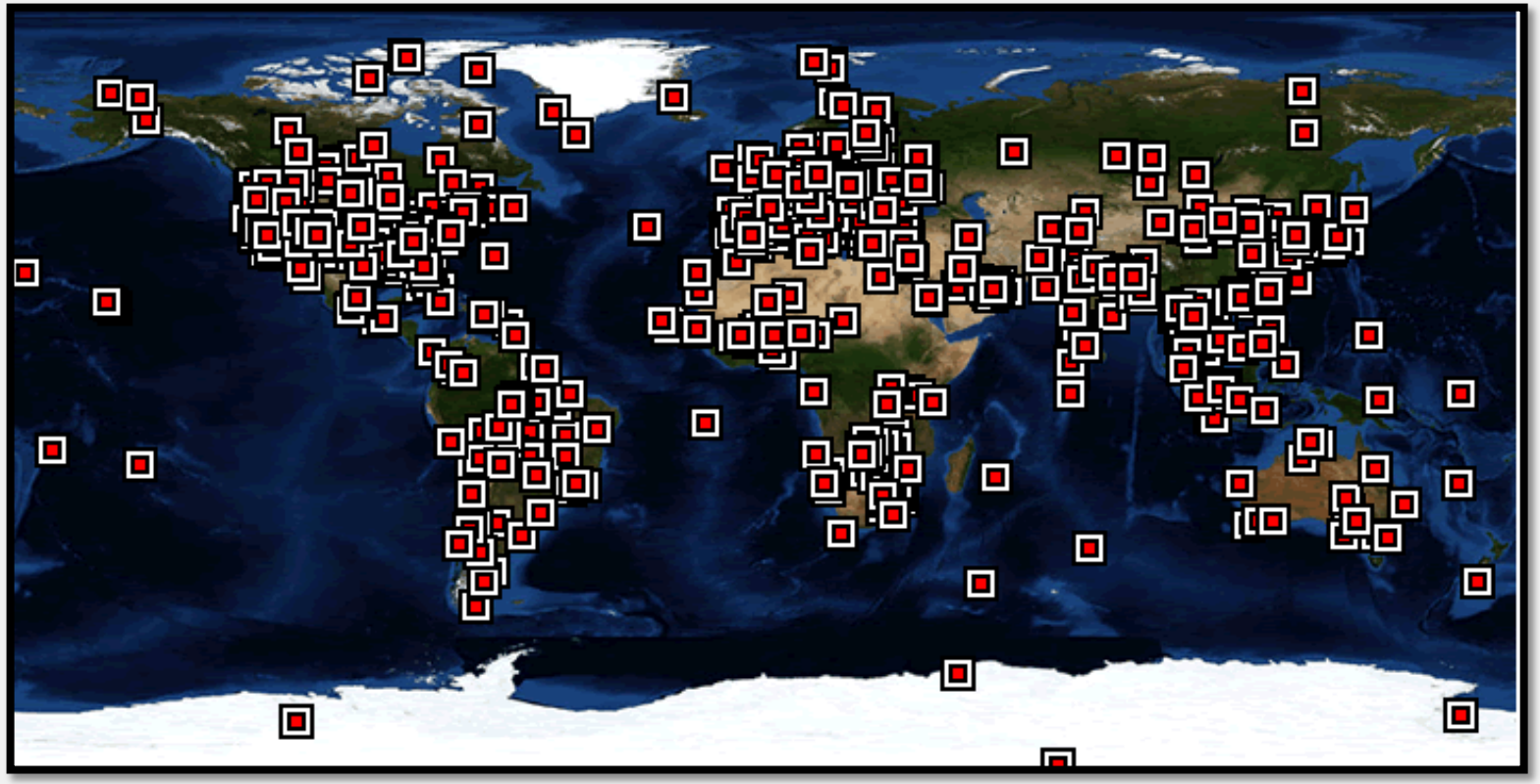




AERONET

AEROsol Robotic Network

- The AERONET network is a network of ground-based sun photometers
- They provide continuous cloud-screened observations of AOD

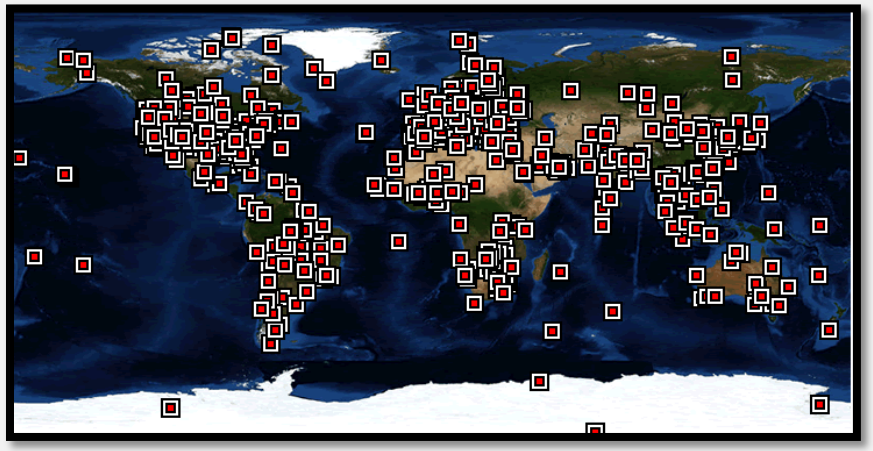


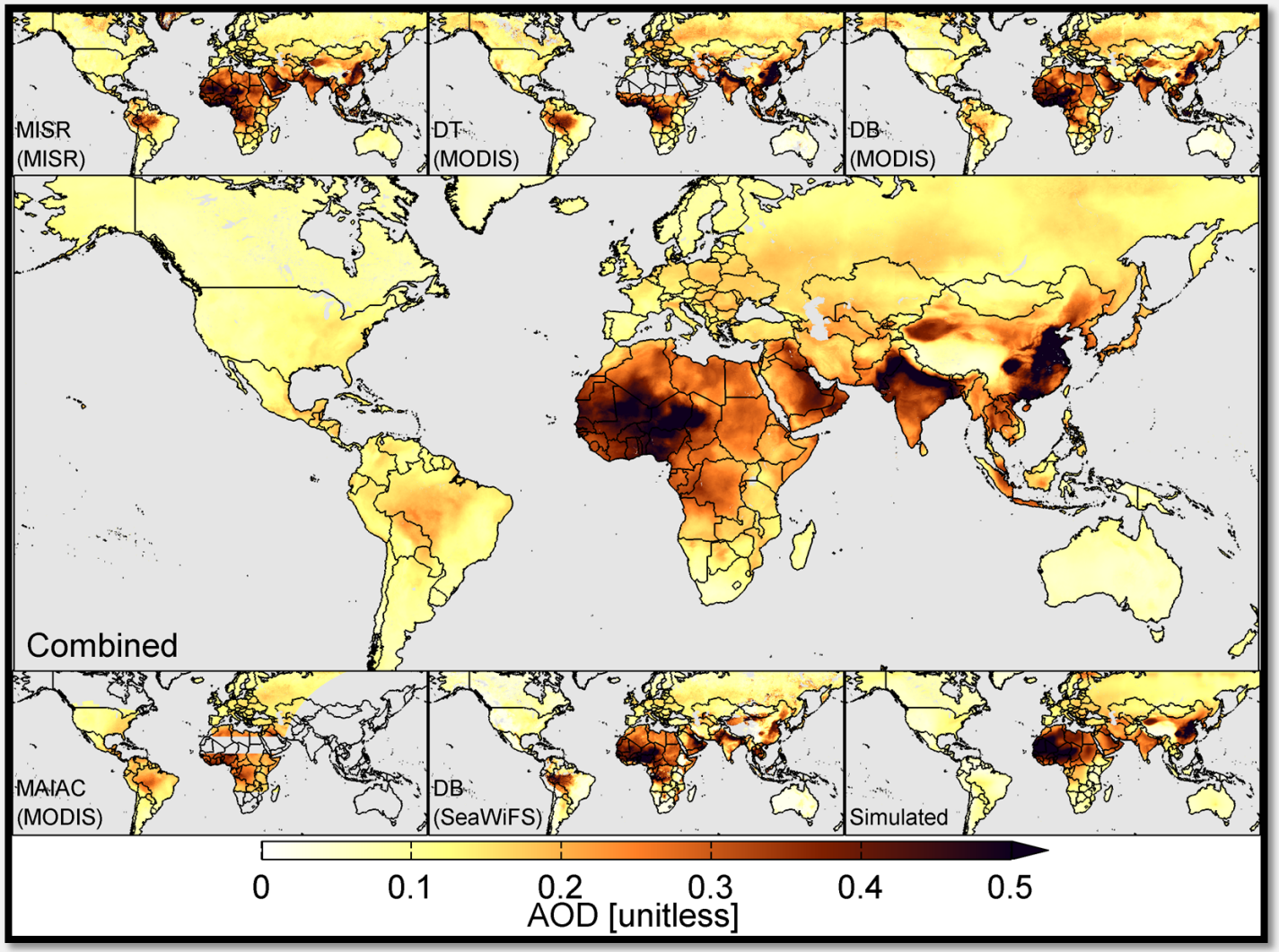
https://aeronet.gsfc.nasa.gov/

Satellite-Based Estimate

Combine AOD estimates

- AERONET is used to determine the accuracy of each AOD source
- All AOD sources are combined





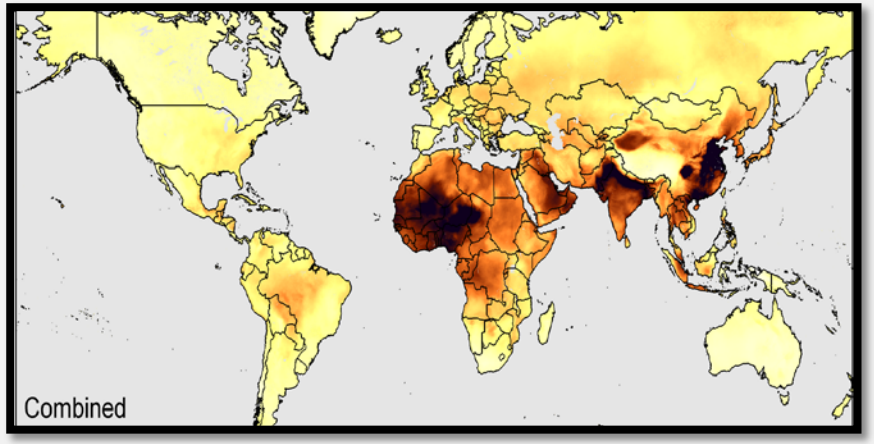
- The Van Donkelaar product is available at: http://sedac.ciesin.columbia.edu/data/set/sdei-global-annual-avg-pm2-5-modis-misr-seawifs-aod-1998-2012

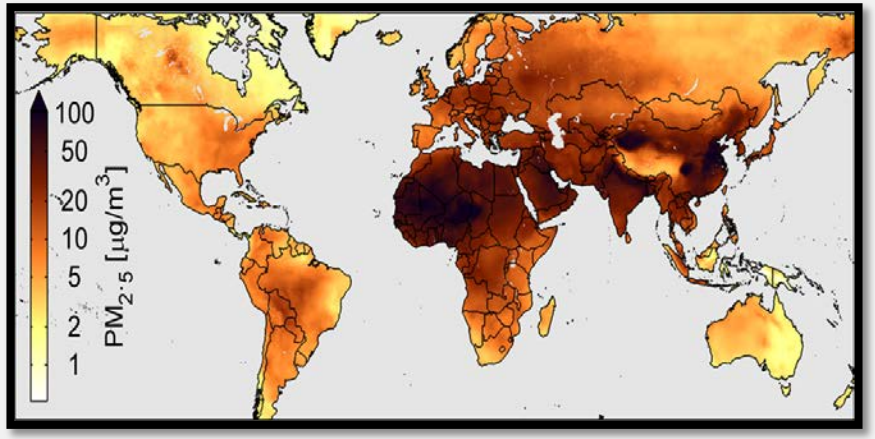
- Image Credit: Van Donkelaar et al., 2016, Figure 1 (MODIS-Average of Terra and Aqua shown)

Satellite-Based Estimate

AOD → $PM_{2.5}$

$$AOD_{Satellite} \times \left(\frac{PM_{2.5}}{AOD} \right)_{Model} = \text{Satellite-Derived } PM_{2.5}$$



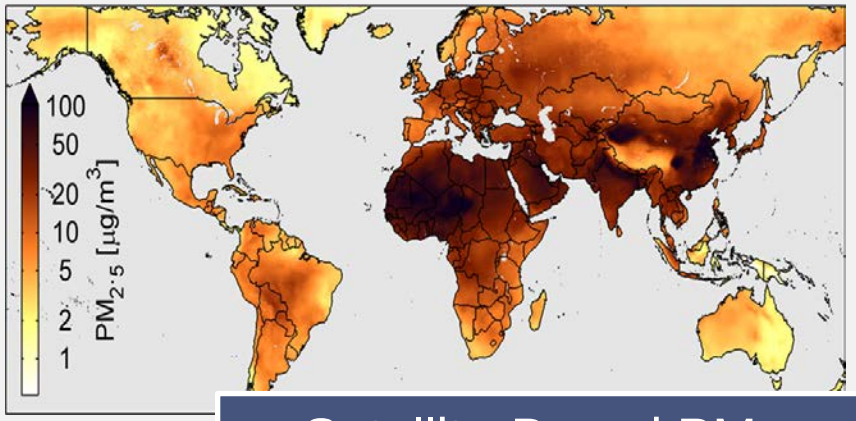


The Van Donkelaar product is available at: http://sedac.ciesin.columbia.edu/data/set/sdei-global-annual-avg-pm2-5-modis-misr-seawifs-aod-1998-2012. Left Image: Van Donkelaar et al., 2016, Figure 1. Right Image: Van Donkelaar et al., 2016, Figure 3

Satellite-Based Estimate

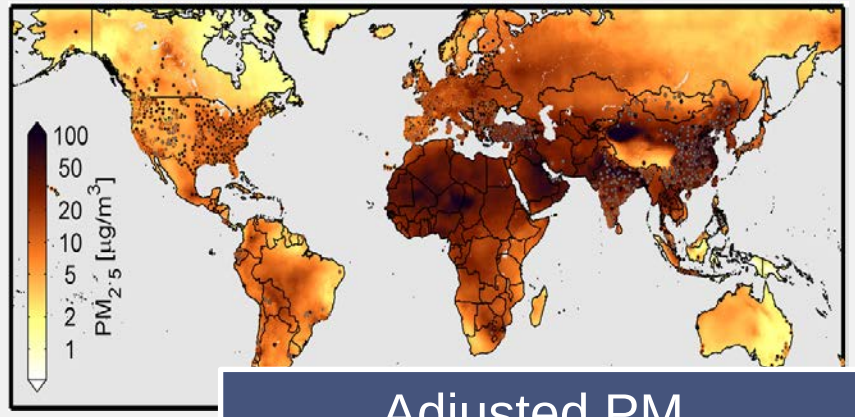
Geographic Weighted Regression (GWR)

GWR corrects the satellite estimate using the relationship between $PM_{2.5}$ from ground monitors and variables such as model aerosol composition, elevation data, and land use indicators



Satellite-Based $PM_{2.5}$

GWR



Adjusted $PM_{2.5}$

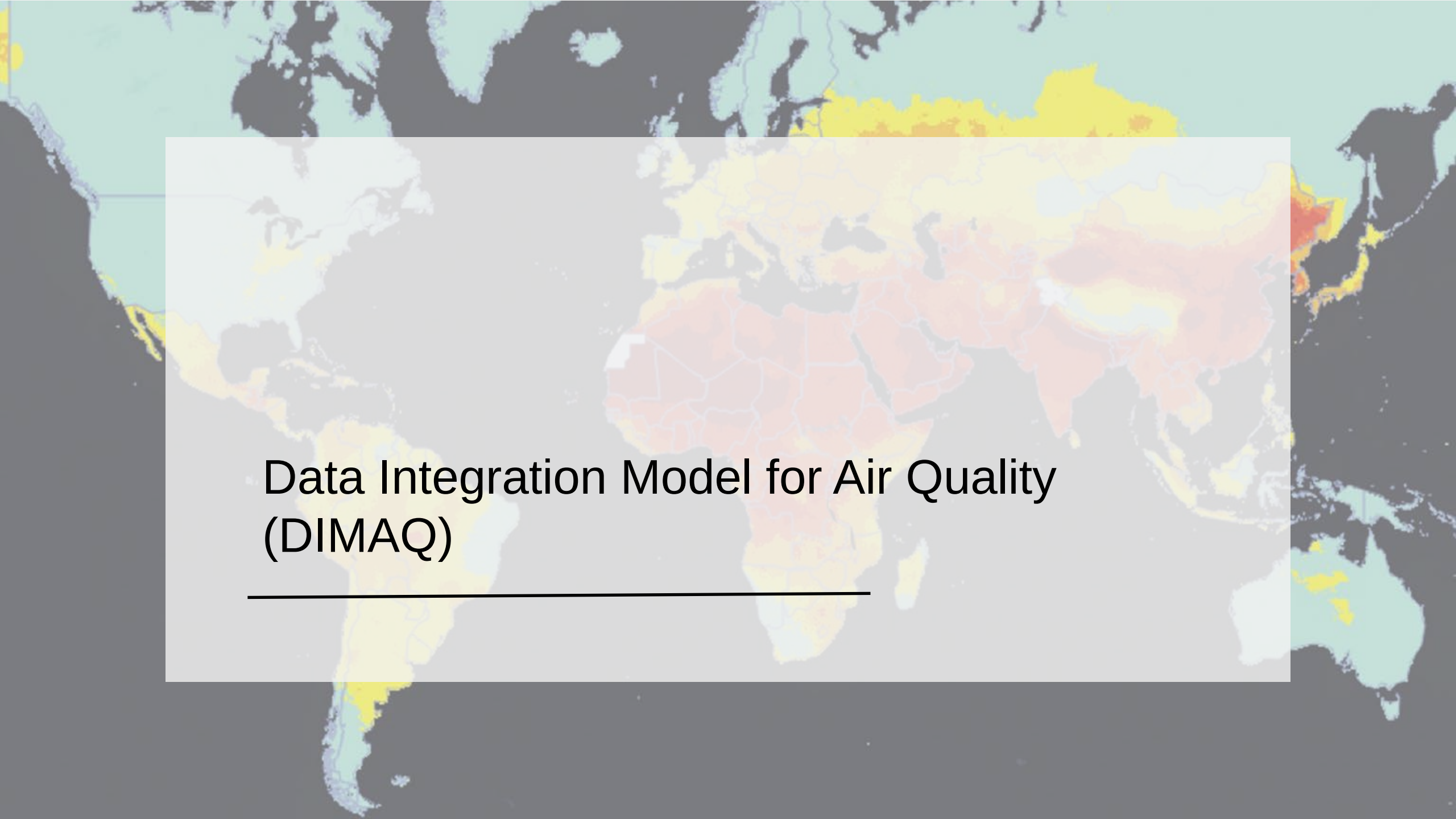
The Van Donkelaar product is available at: http://sedac.ciesin.columbia.edu/data/set/sdei-global-annual-avg-pm2-5-modis-misr-seawifs-aod-1998-2012. Left Image: Van Donkelaar et al., 2016, Figure 3. Right Image: Van Donkelaar et al., 2016, Figure 5

Satellite-Based Estimate

Access and Limitations

- The Van Donkelaar estimate provides annual mean estimates of $PM_{2.5}$
- It can be found at the following two locations:
  - http://sedac.ciesin.columbia.edu/data/set/sdei-global-annual-avg-pm2-5-modis-misr-seawifs-aod-1998-2012
  - http://fizz.phys.dal.ca/~atmos/martin/?page_id=140

- However, this and other estimates do not provide an analysis of uncertainties
- The WHO and the University of Bath have led the development of the Data Integration Model for Air Quality (DIMAQ)
  - This model estimates $PM_{2.5}$ along with their associated measures of uncertainty



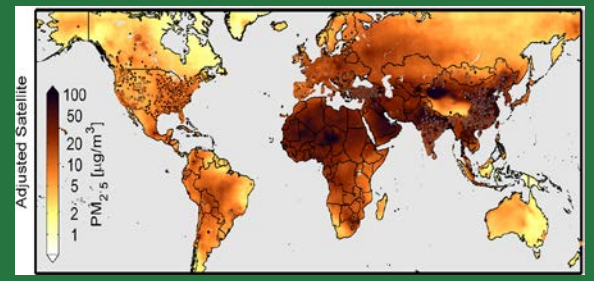
Data Integration Model for Air Quality (DIMAQ)

Data Integration Model for Air Quality (DIMAQ)

Population Data

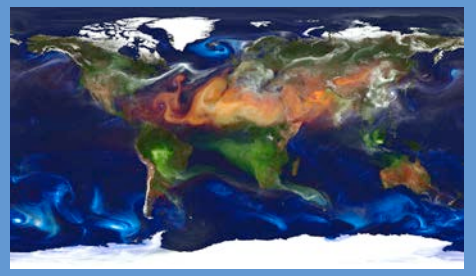
Gridded and Country-Level Estimates of $PM_{2.5}$

Satellite-Based Estimates



Ground Monitors and Information on Local Monitoring Networks

Simulated Aerosols



Topography & Land Use

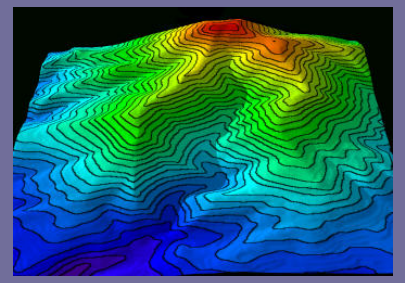


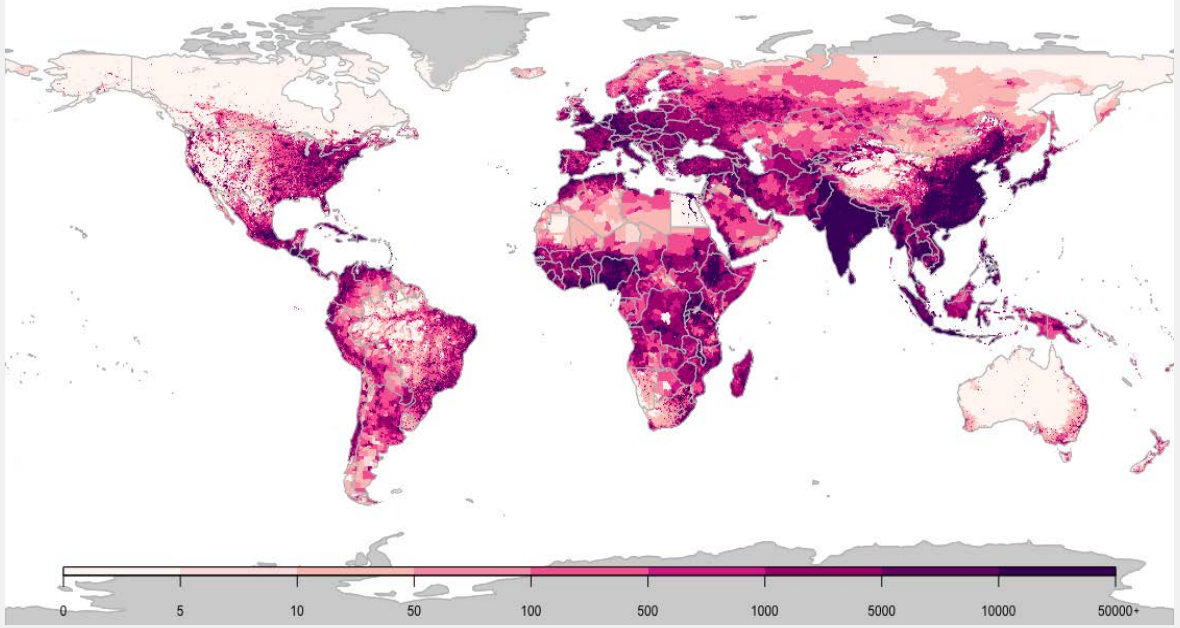
Image Credits: Population: Financial Tribune; Ground Monitor: EPA; Topography: Stephen Reynolds, Arizona State University

Population Data

Gridded Population of the World (GPW)

- Data provided at 0.0417° x 0. 0417° resolution and aggregated to 0.1° x 0.1°
- Data can be found at: http://beta.sedac.ciesin.columbia.edu/data/collection/gpw-v4

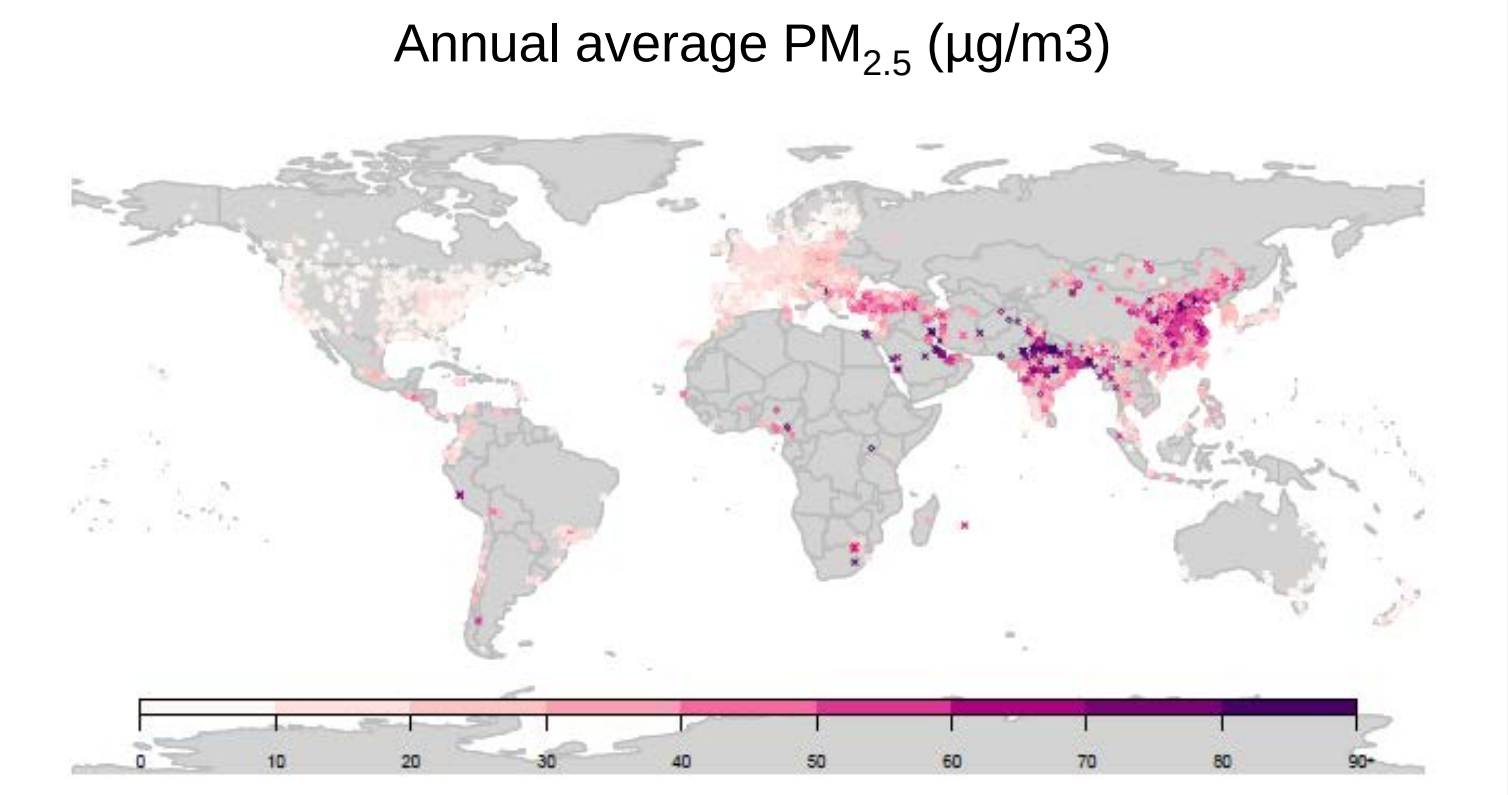
Population Estimates for 2014



Credit: Shaddick et al., 2016, submitted, Figure 4

Ground Measurements

- Measurements of PM_{10} and $PM_{2.5}$ from 6,003 ground monitors were used
- Locations and annual average $PM_{2.5}$ (or $PM_{2.5}$ converted from PM_{10}) are shown
- Monitor data are from 2014 (46% of monitors), 2013 (36%), 2012 (9%), and 2006-2011, 2015 (9%)
- Where only PM_{10} data were available, observations were converted to $PM_{2.5}$

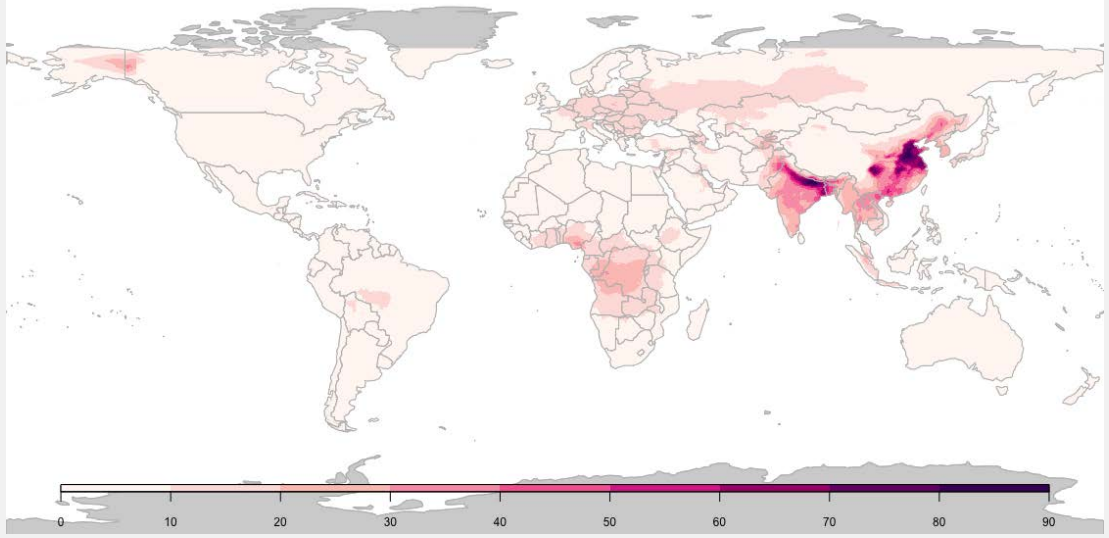


Shaddick et al., 2016, submitted, Figure 1

Simulated Aerosols

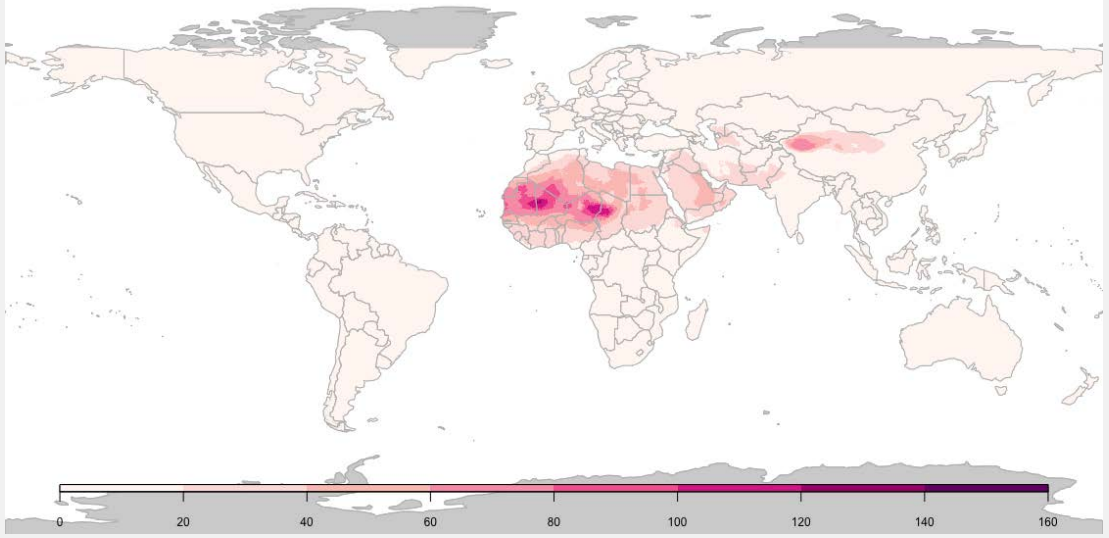
- GEOS-Chem is a atmospheric chemical transport model: http://acmg.seas.harvard.edu/geos/
- Modeled estimates of the sum of different aerosol types (sulfate, nitrate, ammonium, and organic carbon - SNAOC) along with mineral dust were also inputs

GEOS-Chem SNAOC for 2014



Shaddick et al., 2016, submitted, Figure 3b

GEOS-Chem Dust for 2014



Shaddick et al., 2016, submitted, Figure 3c

Topography and Land Use

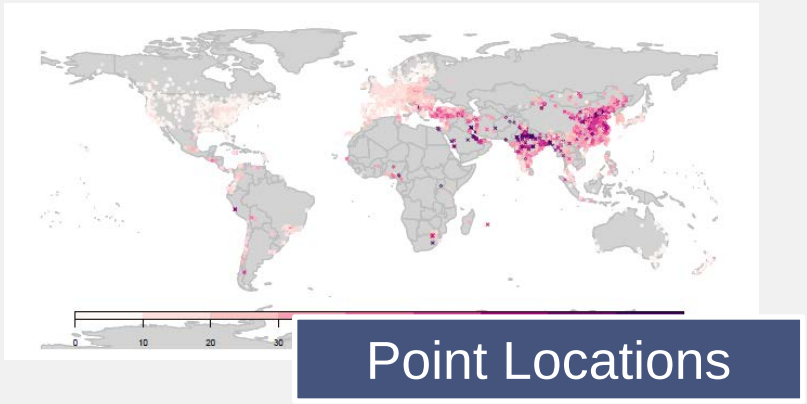
ED

Difference in elevation between a ground monitor and the surrounding grid cells

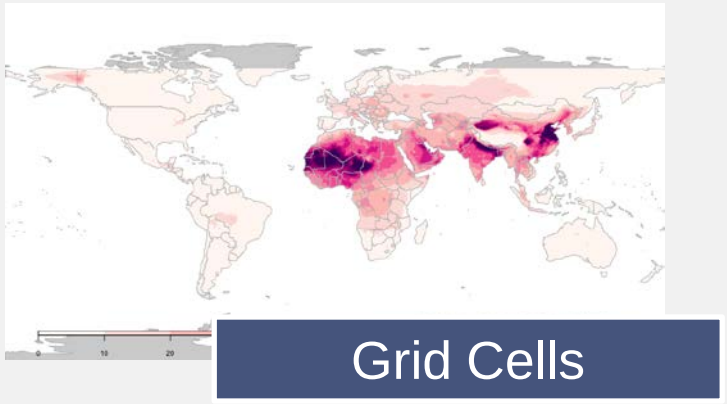
DU

Distance to the nearest urban land surface

Data Integration Model for Air Quality (DIMAQ)

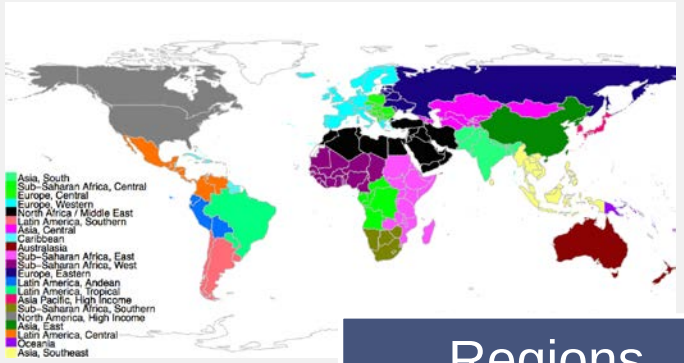


Point Locations



Grid Cells

Countries



Regions

Super-Regions

Image credits: Shaddick et al. 2016, submitted, Figures 1 and 2; prinatble-maps.blogspot.com; Shaddick et al. 2016, submitted, Figures 5a and b.

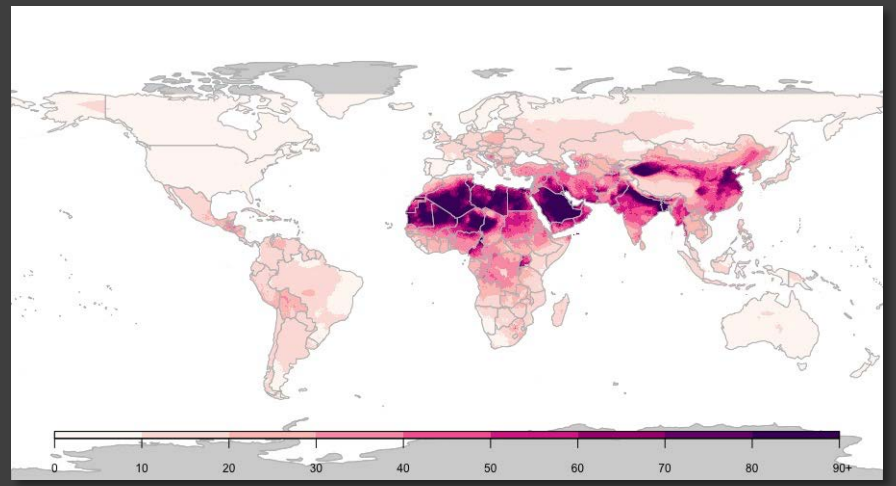
Data Integration Model for Air Quality (DIMAQ)

- Population Data
- Ground Monitor Information & Data
- Satellite-Based Estimate
- Simulated Aerosols
- Topography & Land Use

Bayesian Hierarchical Framework

Estimates $PM_{2.5}$ as well as measures of uncertainty

Annual Average $PM_{2.5}$ for 2014



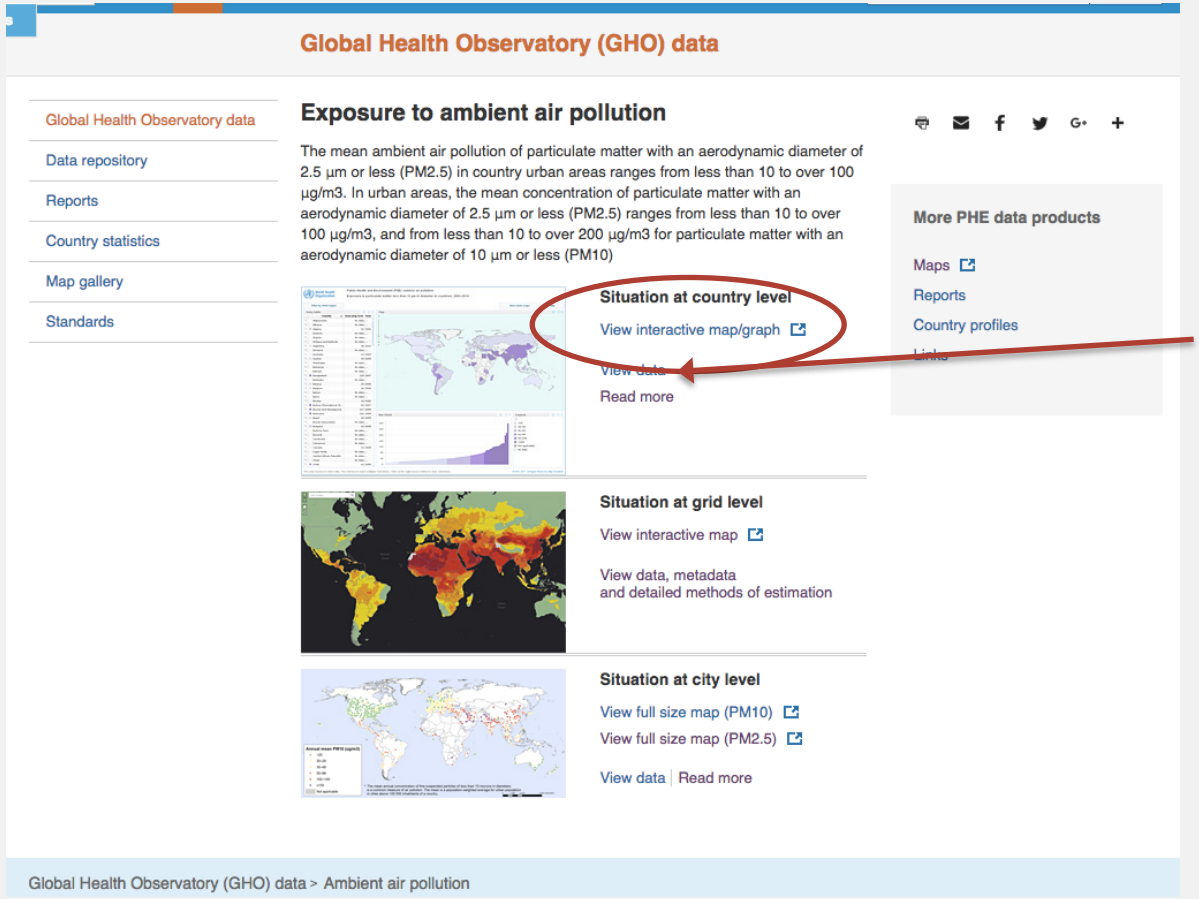
Estimates on a 0.1° x 0.1° grid

Shaddick et al. 2016, submitted, Figure 7 (top)

Available World Health Organization (WHO) Tools

Where to Find and View the Data

WHO Website – Country Level



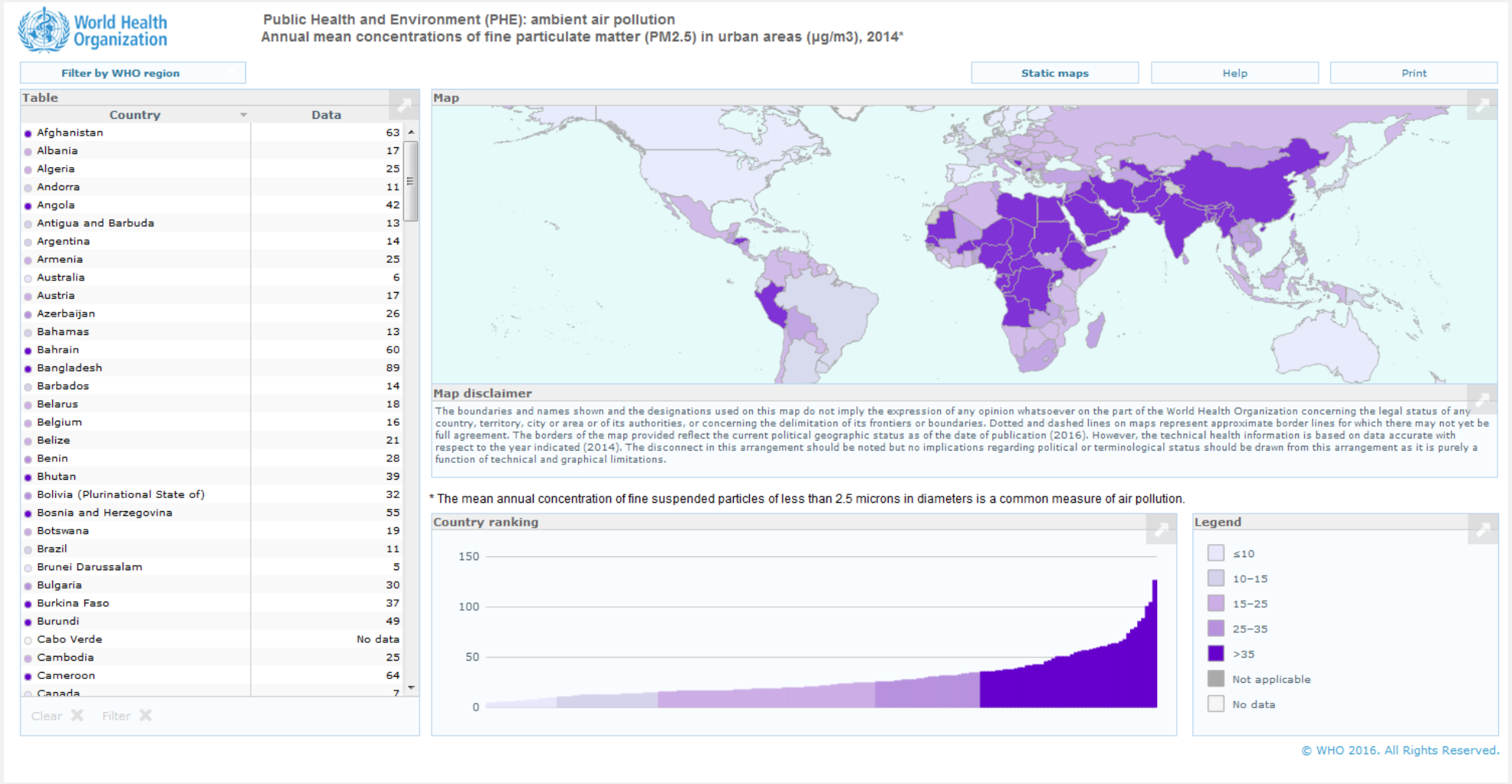
http://www.who.int/gho/phe/outdoor_air_pollution/exposure/en/

Follow this link to download 2014 country level data:

- Formats: csv, Excel, html, XML, etc.
- Can also filter by country and download

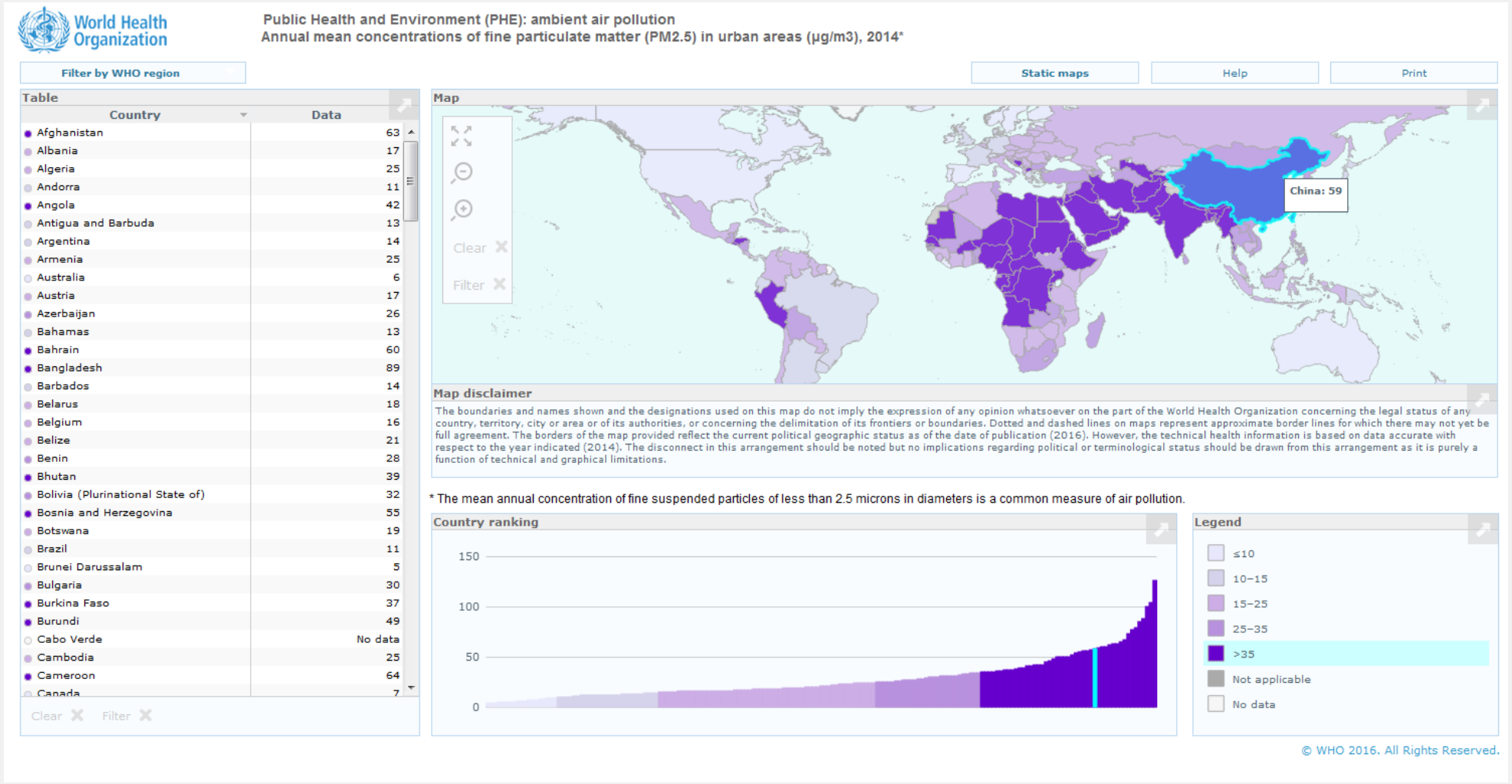
$PM_{2.5}$ at Country Level

http://gamapserver.who.int/gho/interactive_charts/phe/oap_exposure/atlas.html



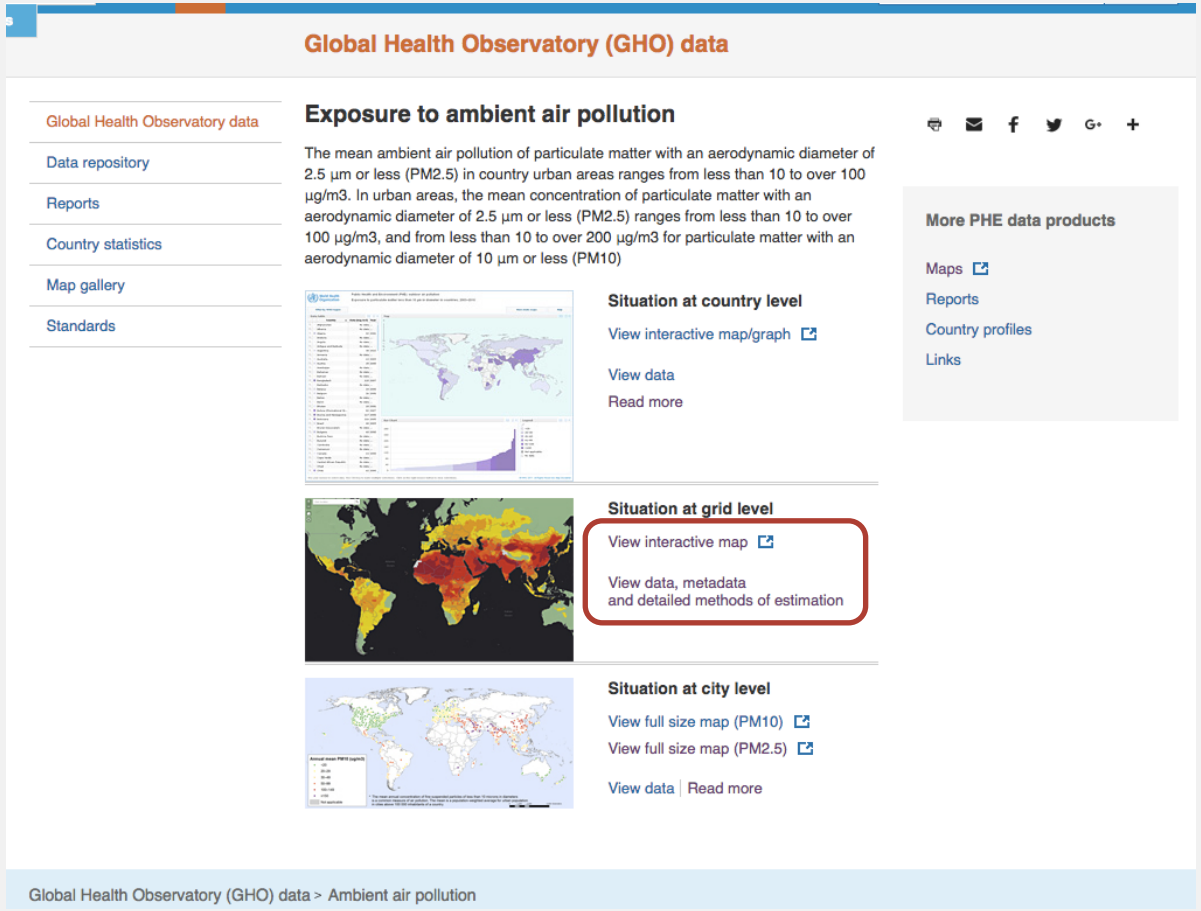
$PM_{2.5}$ at Country Level

http://gamapserver.who.int/gho/interactive_charts/phe/oap_exposure/atlas.html



Where to Find and View the Data

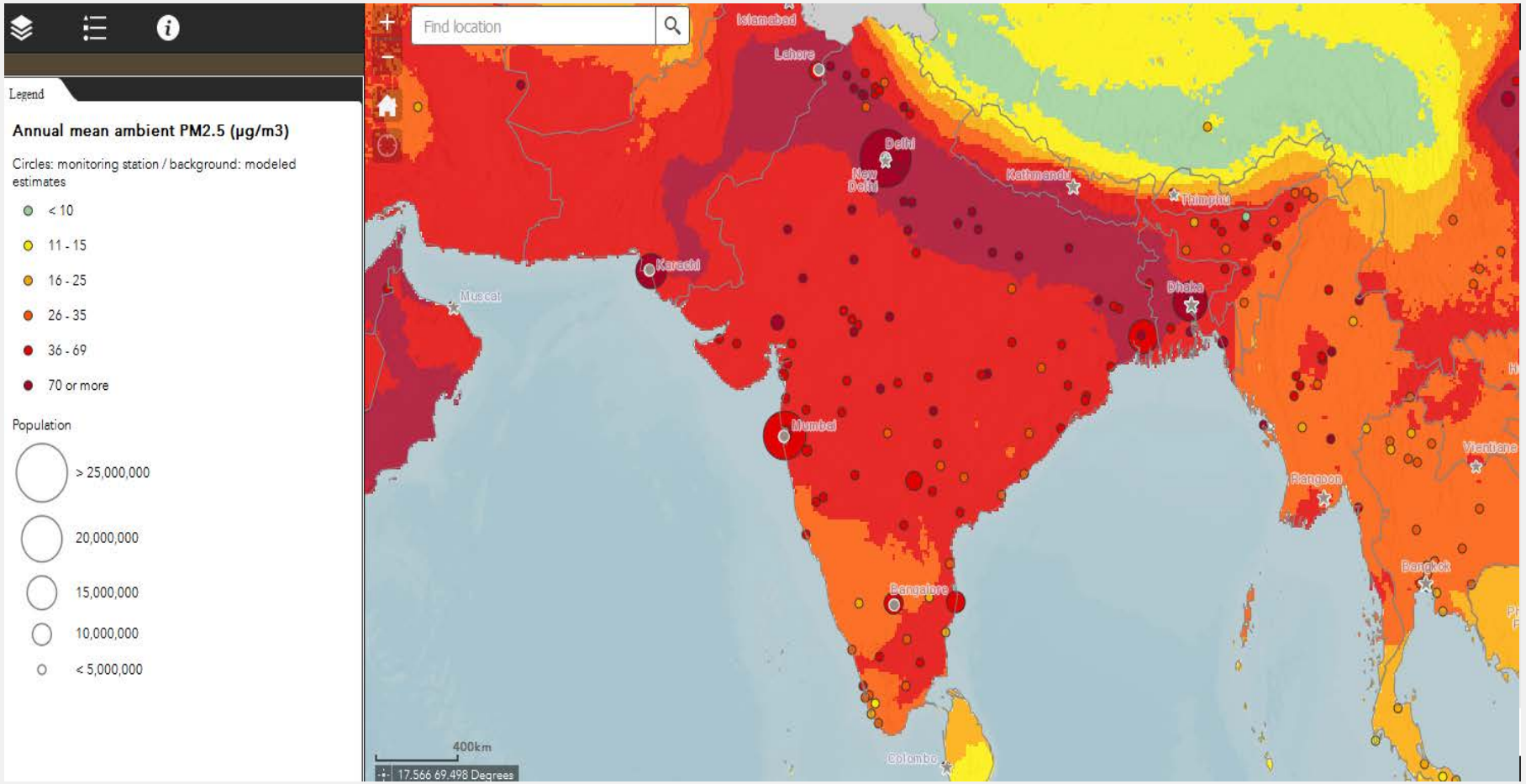
WHO Website – Grid Level



http://www.who.int/gho/phe/outdoor_air_pollution/exposure/en/

$PM_{2.5}$ at Grid Level

http://maps.who.int/airpollution/



Zooming in shows circles indicating monitoring stations

$PM_{2.5}$ at Grid Level

http://www.who.int/phe/health_topics/outdoorair/databases/modelled-estimates/en/

Public health, environmental and social determinants of health (PHE)

Public health, environmental and social determinants of health
About us
News and events
Health topics
Publications

Modelled Global Ambient Air Pollution estimates

Estimation of global health risks from exposure to ambient air pollution requires a comprehensive set of air pollution exposure data covering all inhabited areas. The recently developed Data Integration Model for Air Quality (DIMAQ) has produced estimates based on data from ground measurements together with information from other sources including data from satellite retrievals of aerosol optical depth and chemical transport models. It provides estimates of annual exposures of PM2.5 levels at high spatial resolution (0.1° × 0.1°, which equates to approximately 11x11km at the equator) globally.

The sources of data include: Ground measurements from 6 003 monitoring locations around the world, satellite remote sensing; population estimates; topography; and information on local monitoring networks and measures of specific contributors of air pollution from chemical transport models. The DIMAQ model calibrates data from these sources with ground measurements. This model has provided produced estimates of air quality, expressed in terms of median concentrations of PM2.5, for all regions of the world, including areas in which PM2.5 monitoring is not available.

This model has been developed by an international group of experts, and led by the University of Bath and WHO.

- Global ambient air pollution map
  Global map containing both modelled and monitored annual mean PM2.5 levels.
- DIMAQ database, 2014 data
  csv, 51.33Mb
  Contains the following rows: longitude, latitude, country code, PM2.5 (annual average PM2.5 in µg/m3, for 2014)
- Detailed methods for DIMAQ
  Data Integration Model for Air Quality: A Hierarchical Approach to the Global Estimation of Exposures to Ambient Air Pollution
- Meta-data file for DIMAQ
  xlsx, 156kb

Related links

Ambient air pollution: A global assessment of exposure and burden of disease

More on ambient air pollution

← Map from previous slide

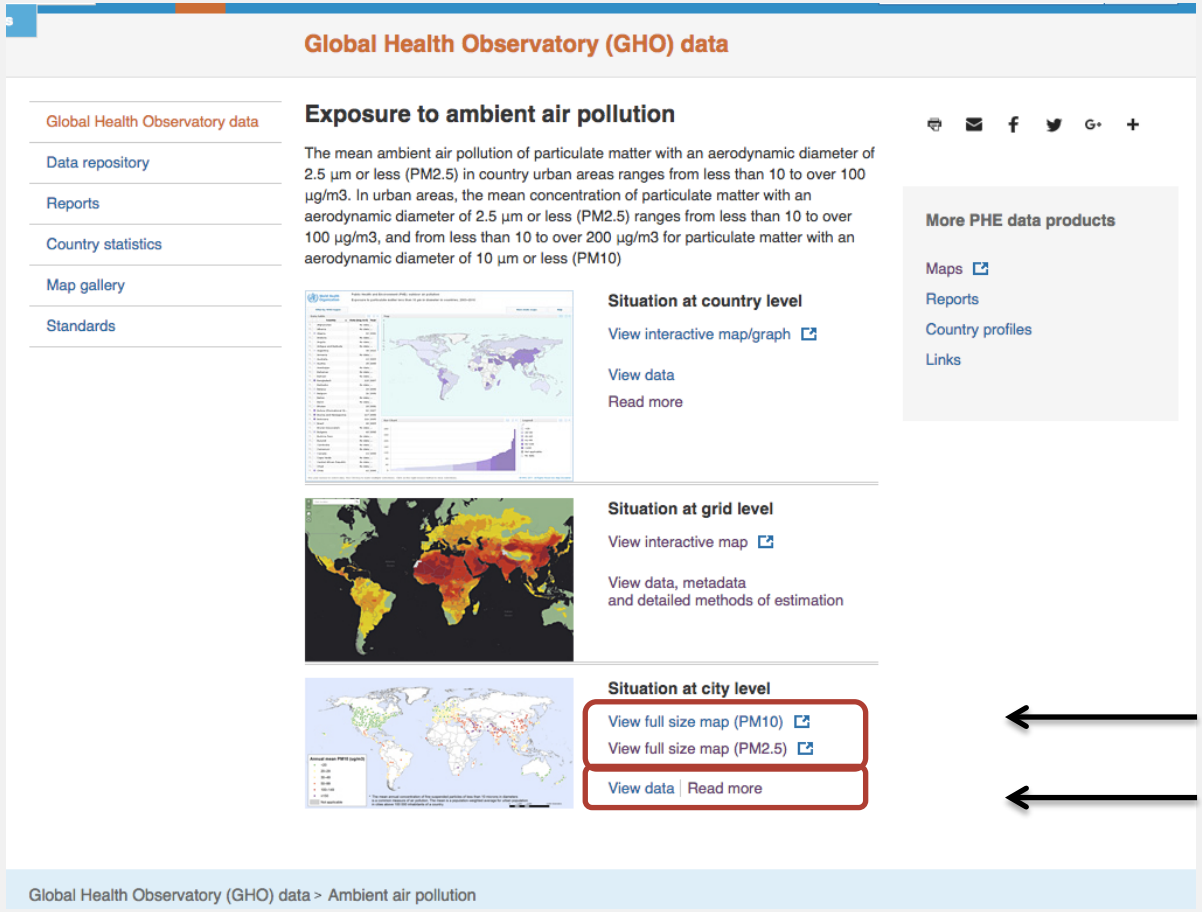
← .csv file with gridded $PM_{2.5}$ estimates

← Link to Shaddick et al. 2016 paper

← Meta-data for $PM_{2.5}$ estimates

Where to Find and View the Data

WHO Website – City Level



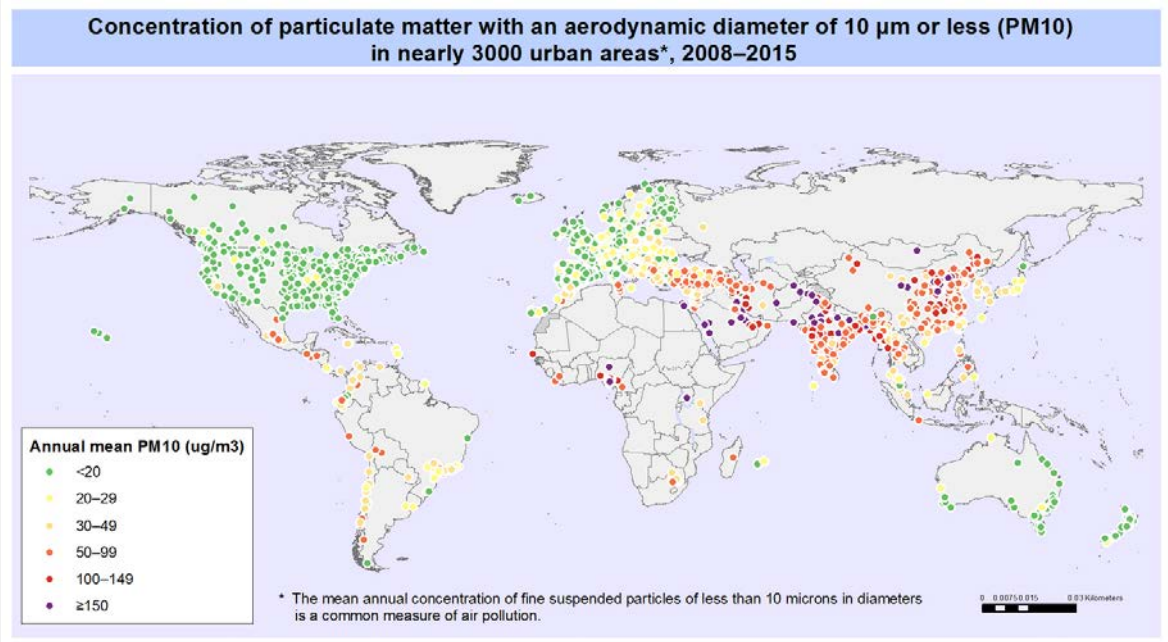
http://www.who.int/gho/phe/outdoor_air_pollution/exposure/en/

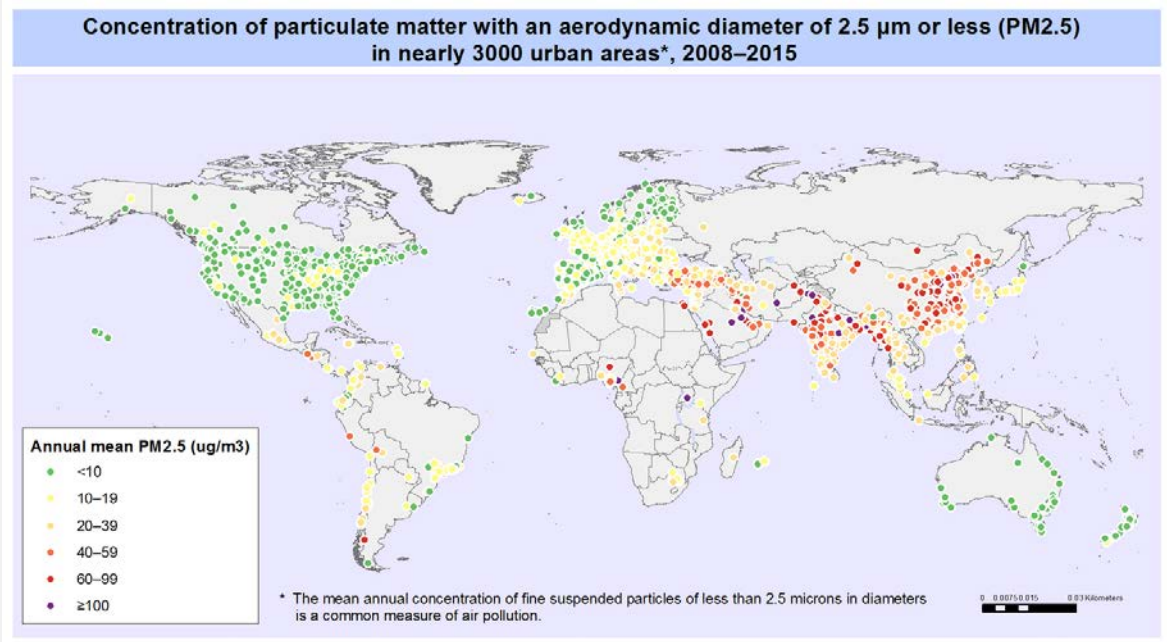
← Maps of city level PM_{10} and $PM_{2.5}$

← .csv file with city level annual means

$PM_{2.5}$ at City Level

http://www.who.int/gho/phe/outdoor_air_pollution/exposure/en/





Where to Find the Data

NASA Aura Validation Data Center

- Dr. Pawan Gupta has subsetted the DIMAQ gridded data by country
- The individual country .csv files are available at:
  - http://avdc.gsfc.nasa.gov/pub/tmp/WHO_PM25_2014_COUNTRY_DATA/
- There is also a readme.txt file

Home Work – Due March 28, 2017

English: http://goo.gl/forms/Xzoz8BD6S9VxnCTv2
Spanish: http://goo.gl/forms/EeHbZxArdecnvajd2

- All the material will be available at:

https://arset.gsfc.nasa.gov/airquality/webinars/AQ-SDG-17

Next Week: Case Study Analysis

- Before next week's session each registrant must:
  - Download the .csv files by country: http://avdc.gsfc.nasa.gov/pub/tmp/WHO_PM25_2014_COUNTRY_DATA/
  - Download any finer resolution county/city shapefiles beyond what is provided
  - Install the QGIS software: http://www.qgis.org/en/site/forusers/download.html
- Using the available gridded 2014 WHO data set and the QGIS software, each user will:
- Map the gridded $PM_{2.5}$ indicator data for a country
- Change the color scale
- Explore a variety of ways to subset the data
- Extract a subset of data
- Compute basic statistics of the country gridded data or a user-chosen subset