Documentation for the Global Annual Average PM2.5 Grids from MODIS and MISR Aerosol Optical Depth (AOD), 2001–2010

Data Set Disseminated by the NASA Socioeconomic Data and Applications Center (SEDAC)
http://sedac.ciesin.columbia.edu/data/set/sdei-global-annual-avg-pm2-5-2001-2010

Data Set Motivation and Methods

This data set was inspired by work by van Donkelaar et al. (2010), who generated a global, satellite-derived, annual average $PM_{2.5}$ surface for the years 2001-2006 based on level 2 (L2), daily Moderate Resolution Imaging Spectroradiometer (MODIS) and Multi-angle Imaging SpectroRadiometer (MISR) satellite instrument Aerosol Optical Depth (AOD) (Figure 1). The geographic coverage of the van Donkelaar et al. (2010) dataset is nearly global with a horizontal resolution of 0.1° x 0.1°. Coincident aerosol vertical profiles from the GEOS-Chem chemical transport model, validated with CALIPSO space-borne lidar vertical profiles, were used to calculate daily conversion factors that account for the relationship between satellite column AOD and surface $PM_{2.5}$ concentrations. The AOD-$PM_{2.5}$ relationship varies spatially and temporally due to global and seasonal variations in aerosol size, aerosol type, relative humidity, and boundary layer height. The conversion factors were applied by van Donkelaar et al. (2010) to the MODIS/MISR AOD data to estimate surface-level $PM_{2.5}$ concentrations, measured in micro-grams per cubic meter ($\mu g/m^3$).

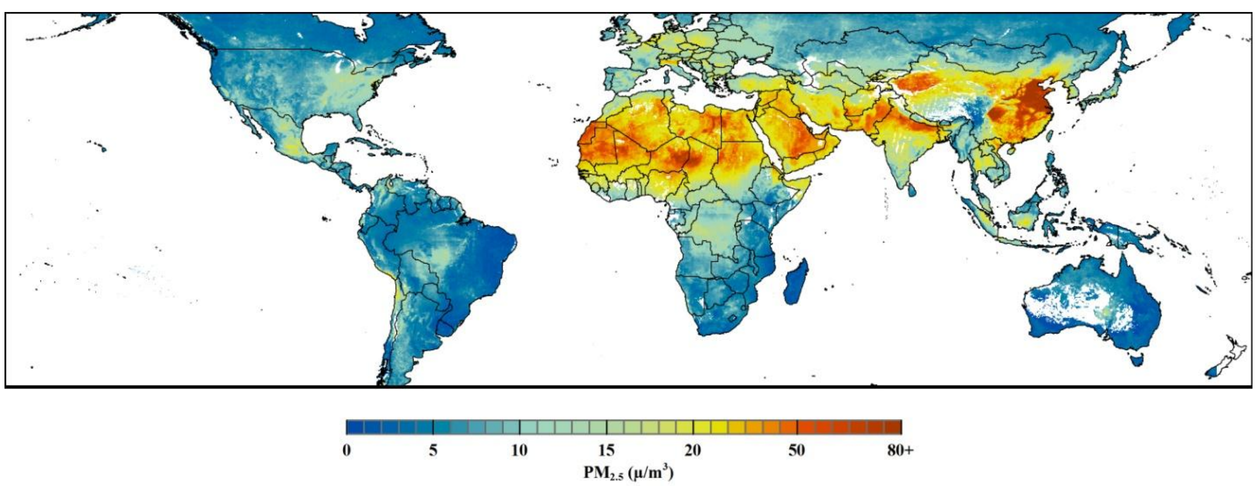

Figure 1. Satellite-derived annual average surface-level $PM_{2.5}$ concentrations, 2001–2006, from Method 1 (van Donkelaar et al. 2010).

While contributing significantly to applied research on satellite-based estimates of $PM_{2.5}$ worldwide, van Donkelaar's methodology is computationally expensive. To reduce the computational burden and overcome the barrier of difficulty in using satellite data regular monitoring, researchers Erica Zell and Stephanie Weber of Battelle Memorial Institute developed a method to leverage the AOD/$PM_{2.5}$ surface level conversion factors calculated by van Donkelaar et al. (2010) and apply them to gridded, monthly AOD data from MODIS and MISR from 2001 to 2010. This method requires comparatively little processing, based on continually updated satellite observations of AOD with higher degrees of processing (so-called level 3 data), with the goal of better tracking temporal trends in PM2.5 concentrations.

Several processing steps were required to apply the AOD/$PM_{2.5}$ surface level conversion factors to the MODIS and MISR data. The MODIS level 3 (L3) monthly data were re-mapped from 1° x 1° to a 0.5° x 0.5° grid to match the native resolution of the MISR L3 monthly data. MODIS and MISR data were then excluded from grid cell locations within a given surface-albedo class that had an anticipated bias greater than the larger of ± (0.1 or 20%) for a month, based on comparison with Aerosol Robotic Network (AERONET; Holben et al. 1998) sun photometer measurements of AOD as conducted by van Donkelaar et al. (2010). The AOD within a grid cell was excluded only if all of the 0.1° x 0.1° bias filter grid cells that fell within the 0.5° x 0.5° AOD cell met the exclusion criteria. This filter was generated separately for MODIS and MISR because these instruments have independent spatial and temporal biases based on instrument mechanisms and processing algorithms. The remaining data were averaged for each month across three year rolling periods from 2001 to 2010 (i.e., 2001 through 2003, 2002 through 2004, etc.). For each of these three year periods, an annual-average, estimated $PM_{2.5}$ concentration, E, for each grid cell, i, was calculated by multiplying the MODIS and MISR mean AOD for each month, $\overline{AOD}_{i,m}$, by the monthly conversion factor, $\eta_{i,m}$, as in Equation 1.

$$E_i = \frac{\sum_{m=1}^{12} \overline{AOD}_{i,m} * \eta_{i,m}}{12} \quad \text{(Equation 1)}$$

Figure 2 shows an example of the estimated $PM_{2.5}$ surface for the years 2001–2003.

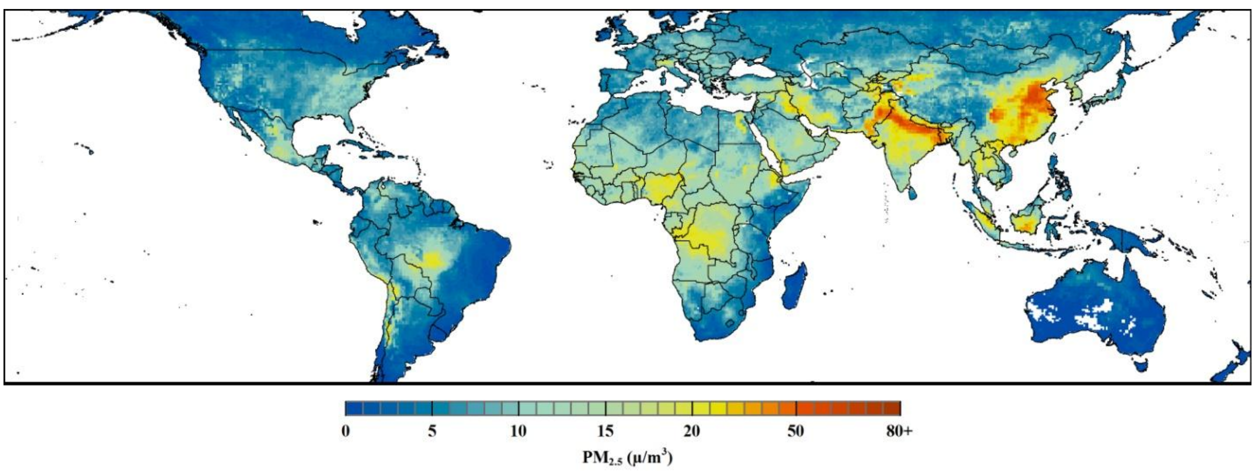

Figure 2. Global, satellite-derived $PM_{2.5}$ based on MODIS L3 monthly means averaged over 2001–2003.

The bias filter and the conversion factors applied in this method were based on data from 2001–2006 (van Donkelaar et al. 2010), but were treated as constants over 2001–2010 in order to reduce computational complexity. These conversion factors could be updated as new analyses are generated, but since these factors largely depend on land surface type and monthly-averaged meteorological parameters, it is not anticipated that these factors would change much over short time periods. For the purposes of this study, the conversion factors that were use were based on relative humidity of 50%. Three-year rolling averages (within 2001 to 2010) were utilized in order to emphasize lasting changes in $PM_{2.5}$ concentrations likely reflective of emissions changes (which is of policy interest), rather than using annual averages that may be heavily influenced by annual weather variability (e.g., a particularly strong El Nino year).

Note that comparisons of population-weighted country-level estimates of $PM_{2.5}$ concentrations based on grids produced by van Donkelaar et al. and those developed for this project (Battelle/CIESIN) suggest a systematic bias over certain regions. For countries in the Sahel, North Africa, and the Arabian Peninsula (largely arid and semi-arid countries with large desert areas), the population-weighted estimates of PM2.5

concentrations from van Donkelaar et al.'s data set were consistently higher than for those by Battelle/CIESIN. For India, results from Battelle/CIESIN were higher than those for van Donkelaar et al. The reasons for these differences are unclear. There are a number of possible explanations, including the difficulties in MODIS AOD retrievals over sandy surfaces (which, however, should affect both estimates), or differences between Level 2 and Level 3 data in combined AOD values, or the application of conversion factors on a daily basis vs. monthly, which would mean that the Battelle/CIESIN data set may be missing peaks in $PM_{2.5}$ concentration.

Acknowledgments

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References

van Donkelaar, A., R. V. Martin, M. Brauer, R. Kahn, R. Levy, C. Verduzco, and P. J. Villeneuve. 2010. Global Estimates of Exposure to Fine Particulate Matter Concentrations from Satellite-based Aerosol Optical Depth. *Environmental Health Perspectives* 118(6): 847–588. doi:10.1289/ehp.0901623.

Technical Annex

File Information

Each file contains integer values for a global, 0.5° x 0.5° grid of estimated $PM_{2.5}$ concentrations.

- Scale Factor: In order to avoid values to the right of the decimal place, all $PM_{2.5}$ concentrations in micrograms per cubic meter are multiplied by 1,000

- ASCII Raster Header Information:
  ncols 720
  nrows 360
  xllcorner -180
  yllcorner -90
  cellsize 0.5
  NODATA_value -9999

Satellite Data Sources

- MODIS AOD
  - Product: MOD08 – Level 3 Global Monthly Mean Aerosol Optical Depth
    - Satellite: Terra
    - SDS: "Optical_Depth_Land_And_Ocean_Mean_Mean"
    - Version: 5.1
    - Resolution: 1° x 1°
    - Years: 2001 – 2010
    - Source: NASA LAADS (http://ladsweb.nascom.nasa.gov/)

- MISR AOD
  - Product: MIL3AE – Level 3 Global Monthly Mean Aerosol Optical Depth
    - Satellite: Terra
    - SDS: "Optical depth average"
    - Version: F15_0031
    - Resolution: 0.5° x 0.5°
    - Years: 2001 – 2010
    - Source: NASA Langley ASDC (http://eosweb.larc.nasa.gov/)

Summary Methods

Global, monthly-mean MODIS and MISR AOD data for the years 2001–2010 were acquired from the sources listed above. The MODIS data were disaggregated from 1° resolution to 0.5° resolution to match the resolution of the MISR AOD data. AOD for both instruments that were anticipated to have a bias of greater than ±(0.1 or 20%) as compared to ground-based AERONET AOD due to high surface albedos or other persistent factors were removed from the analysis (see supplemental material for van Donkelaar et al., 2010). The filtered MODIS and MISR data were then combined by taking the mean of each grid cell for each month of the year.

Ground-level concentrations of dry 24 h PM2.5 (in μg/m^3) were estimated from the satellite observations of total-column AOD by applying a conversion factor that accounts for the spatial and temporal relationship between the two. This conversion factor is a function of aerosol size, aerosol type, diurnal variation, relative humidity and the vertical structure of aerosol extinction, which were derived from a global 3-D chemical transport model (GEOS-Chem) and assumes a relative humidity of 50% (see supplemental material for van Donkelaar et al., 2010). The satellite AOD data were multiplied by monthly-mean conversion factors (calculated as a climatological mean over 2001–2006) for each grid cell.

Finally, an annual-average estimated surface PM2.5 concentration was estimated by taking the mean of the monthly estimates over each year.