Evaluation of Different MODIS AOD Retrieval Algorithms for PM$_{2.5}$ Estimation in the Western, Midwestern and Southeastern United States with Implications for Public Health

Mohammad Al-Hamdan$^1$, William Crosson$^1$, Erica Burrows$^2$, Shane Coffield$^3$, Breanna Crane$^4$

$^1$Universities Space Research Association at NASA/MSFC, $^2$San Jose State University, $^3$University of Chicago, $^4$University of Alabama in Huntsville

Email: mohammad.alhamdan@nasa.gov

Abstract

This study was part of the research activities of the Center for Applied Atmospheric Research and Education (CAARE) funded by the NASA MUREP Institutional Research Opportunity (MIRO) Program. Satellite measurements of Aerosol Optical Depth (AOD) have been shown to be correlated with ground measurements of fine particulate matter less than 2.5 microns (PM$_{2.5}$), which in turn has been linked to respiratory and heart diseases. The strength of the correlation between PM$_{2.5}$ and AOD varies for different AOD retrieval algorithms and geographic regions. We evaluated several Modern Resolution Imaging Spectrometer (MODIS) AOD products from different satellites (Aqua vs. Terra), retrieval algorithms (Dark Target vs. Deep Blue), Collection 5.1 vs. 6 and spatial resolutions (10 km vs. 3 km) for cities in the Western, Midwestern and Southeastern U.S. We developed and validated PM$_{2.5}$ prediction models using remotely-sensed AOD data, which were improved by incorporating meteorological variables (temperature, relative humidity, precipitation, wind speed, and wind direction) from the North American Land Data Assimilation System Phase 2 (NLDAS-2). Adding these meteorological data significantly improved the predictive power of all of the PM$_{2.5}$ models, especially in the Western U.S. Temperature, relative humidity, and wind speed were the most significant meteorological variables throughout the year in the Western U.S. Wind speed was the most significant meteorological variable for the cold season while temperature was the most significant variable for the warm season in the Midwestern and Southeastern U.S. Our study re-establishes the connection between PM$_{2.5}$ and public health concerns including respiratory and cardiovascular diseases (asthma, high blood pressure, coronary heart disease, heart attack, and stroke). Using PM$_{2.5}$ data and health data from the Centers for Disease Control and Prevention (CDC)'s Behavioral Risk Factor Surveillance System (BRFSS), our statistical analysis showed that heart attack and stroke occurrences had the strongest correlations with PM$_{2.5}$.

Objectives

1. Evaluate different MODIS Aerosol Optical Depth retrieval algorithms for PM$_{2.5}$ estimation
2. Use the Center for Disease Control (CDC) data to find the effects of PM$_{2.5}$ on respiratory and cardiovascular diseases

Methodology

We developed a linear regression model from PM$_{2.5}$ concentrations against remotely-sensed aerosol optical depth (AOD) data for 2010 through 2012. For the PM$_{2.5}$ concentrations, we used EPA Air Quality Systems (AQS) data 24 hour average data. For AOD, we used NASA MODIS satellite data for the following combinations: Aqua and Terra Satellites, Collection 5 and 6, 10 km and 3 km spatial resolutions, and the Deep Blue and Dark Target algorithms. The models were validated using 2013 AOD data to derive the PM$_{2.5}$ concentrations. The robustness of the model was measured using the root mean square error. The model was improved by incorporating North American Land Data Assimilation System (NLDAS) meteorological data (relative humidity, peak gust speed, precipitation, direction, temperature and precipitation). The cold season (October-March), warm season (April-September), and all year data were utilized to verify the seasonal variation with PM$_{2.5}$. The second part of the study was to use Center for Disease Control (CDC) data to determine the correlation between PM$_{2.5}$ concentrations and the following public health outcomes: stroke, heart attack, quality of health, asthma, high blood pressure, and coronary heart diseases.

PM$_{2.5}$ Model Results

Single Variable Linear Regression Models (PM$_{2.5}$ vs. AOD)

Validation of Single Variable Model

Atlanta Chicago Huntsville Sacramento

Table: PM$_{2.5}$ Model Results

<table>
<thead>
<tr>
<th>City</th>
<th>Average PM$_{2.5}$ Concentrations across the U.S.</th>
<th>Health Concern R Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor Health</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>Asthma</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>High Blood Pressure</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Heart Attack</td>
<td>0.461</td>
<td></td>
</tr>
<tr>
<td>Coronary Heart Disease</td>
<td>0.348</td>
<td></td>
</tr>
</tbody>
</table>

Implications for Public Health

Conclusions

We confirmed that there is a seasonal variability in PM$_{2.5}$ concentration, as found in Al-Hamdan et al. (2009). With the incorporation of meteorological variables, we successfully developed and robust PM$_{2.5}$ models for each region, especially in the West. The most frequently statistically significant meteorological variables depended both on season and region. For example, only in the West was relative humidity repeatedly significantly in predicting PM$_{2.5}$ concentrations. Also, in the West, seasonal humidity and gust were always more significant than AOD. For every region, peak gust speed was also more significant than the cold season than in the warm season.

We determined that the most useful MODIS product in each case varies by region. In the Midwest and Southeast, the Dark Target algorithm yielded stronger models than Deep Blue, as measured by the correlation coefficient. In the West and Midwest, the Collection 6.1 km resolution yielded more improvements in the single and multivariable models than did the 10 km spatial resolution. These findings promote the role of remotely-sensed AOD data, which can be applied with broader coverage than ground stations for data-sparse areas at PM$_{2.5}$ concentrations.

We established the connection between PM$_{2.5}$ and respiratory and cardiovascular diseases, as found by other studies including Al-Hamdan et al. (2014). Heart attack and stroke occurrence showed the highest correlations with PM$_{2.5}$, and all of the other health outcomes analyzed also illustrated positive correlations.

Future Work

We hope to build generalized regional models, using satellite data to better understand PM$_{2.5}$ concentrations on a broader scale without the need for ground stations and to confirm the discovery made about NLDAS-2 enhancement with meteorological variables. Future work will also continue improving these models for metropolitan cities across the globe and to investigate potential causal relationships between AOD, PM$_{2.5}$, and public health.

Acknowledgements

We would like to thank the NSF/C, Center for Applied Atmospheric Research and Education (CAARE) Program, NASA Marshall Space Flight Center (MSFC), Universities Space Research Association (USRA), and Dr. Sen-Chao from San Jose State University. Support was provided by NASA Office of Education’s Minority Research and Education Project Contract Number NNX14AQ02A.

References


