**NASA DEVELOP National Program**

**California – Ames**

*Project Summary – Spring 2018*

**California Health & Air Quality**

*Measuring California Air Quality through the Use of NASA Earth Observations to Identify Spatial, Temporal, and Social Disparities in Particulate Matter Pollution*

**VPS Title:** Breathing in New Perspectives: Using Remote Sensing to Examine Air Quality in California

**Project Team**

***Project Team*:**

Amanda Wasserman (Project Lead), [awasserman@csumb.edu](mailto:awasserman@csumb.edu)

Megan Seeley

Ariana Nickmeyer

***Advisors & Mentors*:**

Dr. Juan Torres-Pérez (Bay Area Environmental Research Institute, NASA Ames Research Center)

***Past or Other Contributors*:**

Jenna Williams

John Dilger

**Project Overview**

***Project Synopsis*:** California has some of the most polluted air in the United States, which may be attributed to the state’s geography, large cities, and growing population. Particulate matter 2.5 µm or smaller (PM2.5) is an important metric to measure air pollutants that can cause a myriad of serious health problems, contribute to climate forcing, and induce negative site-specific effects on ecosystems. Analyses of PM2.5 derived from remotely-sensed imagery offer a better understanding of air quality, the efficacy of air quality policy, and the socioeconomic distribution of air pollution throughout California.

***Abstract*:**

Thirty-five million California residents live in counties where they are more susceptible to contracting an air quality-related health ailment. Particulate matter less than 2.5 µm in size (PM2.5) is an important metric of air quality and can cause significant health problems. Despite California’s policies targeted at reducing PM2.5 and other air pollutants, three major cities experienced increasing levels of PM2.5 from 2013 to 2015. California’s rapid population growth compounds these air quality problems and stresses the need for air pollution reduction policies. Current air quality remediation and regulations are based off *in situ* air quality monitors; however, these methods do not provide optimal spatial coverage. The NASA DEVELOP project team investigated the advantages of using PM2.5 data derived from remote sensing imagery taken from Moderate Resolution Imaging Spectroradiometer (MODIS), Multi-angle Imaging Spectroradiometer (MISR), Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO), and Sea-Viewing Wide Field-of-View Sensor (SeaWiFS), to study PM2.5 in California from 1998 to 2016. We analyzed trends in PM2.5 concentrations over time as well as the spatial distribution of PM2.5 relative to socioeconomic factors. With the results of these analyses, the California Air Resources Board (CARB) will gain a clearer understanding of the spatial and temporal distribution of particulate matter pollution in the state, and which communities are more likely to face heightened health risks from air pollution.

**Keywords:**

PM2.5, remote sensing, MODIS, MISR, SeaWiFS, CALIPSO, environmental justice

***National Application Area Addressed:*** Health & Air Quality

***Study Location:*** California

***Study Period:*** 1998 – 2016

***Community Concern:***

* Poor air quality leads to a number of serious health concerns for 35 million California residents, including increased rates of asthma, respiratory illnesses, and heart-related complications.
* Disadvantaged communities in California are especially vulnerable to air pollution and less-equipped to deal with its effects on their own.
* High concentrations of particulate matter emissions from anthropogenic activities exacerbate the changing global climate and its associated environmental impacts.
* While policies target air pollution reduction, air quality continues to worsen in California.

***Project Objectives:***

* Determine the feasibility of using a satellite-derived dataset to represent PM2.5 in California
* Examine statewide spatial and temporal trends in PM2.5 concentration
* Evaluate the correlation between satellite-derived PM2.5 and socioeconomic factors

**Partner Overview**

***Partner Organizations:***

|  |  |  |  |
| --- | --- | --- | --- |
| **Organization** | **POC (Name, Position/Title)** | **Partner Type** | **Boundary Org?** |
| **California Air Resources Board** | Hyung Joo Lee, Research Division, Health & Air Exposure Assessment Branch | End User | No |
| **University of California, Los Angeles, Institute of Transportation Studies** | Madeline Brozen, Associate Director | Collaborator | Yes |

***Decision Making Practices & Policies***:

CARB tracks PM2.5 through *in situ* PM2.5 monitors and the California Emissions Inventory Development and Reporting System (CEIDARS), a compilation of self-reported air pollution emissions. CARB also uses CalEnviroScreen data, which compile 20 indicators (12 pollution indicators and 8 population indicators) to characterize pollution-burdened populations throughout California. These data rely on the *in situ* monitors and *post hoc* spatial interpolation, a method that cannot reliably predict at-risk areas.

***Project Benefit to End User***:

Data collected with CARB’s ground-based monitors are both spatially and temporally inconsistent. As a result, CalEnviroScreen data, which attempt to predict at-risk areas using these monitors and *post hoc* spatial interpolation, may be unreliable. CEIDARS data, in addition to relying on industries to accurately report their emissions, are also measured in units that are impractical when considering human health.  Maps of satellite-derived, statewide PM2.5 concentrations used in this project provide a consistent, reliable method to examine particulate matter pollution and its spatial distribution relative to socioeconomic factors in California. Further, satellite-derived PM2.5 data are of relatively high spatial resolution and are calculated in a manner that is useful for evaluating implications on human health. This project’s landscape-level approach will allow CARB to gain a better understanding of air pollution patterns throughout the state.

**Earth Observations & End Products Overview**

***Earth Observations:***

|  |  |  |
| --- | --- | --- |
| **Platform & Sensor** | **Parameters** | **Use\*** |
| **Terra MODIS** | Aerosol Optical Depth (AOD) | Dark Target, Deep Blue, and MAIAC (Multi-Angle Implementation of Atmospheric Correction) AOD retrieval algorithms were applied to the Collection 6 product at 10 km (1 km for MAIAC, where available). AOD was used in a Geographically Weighted Regression (GWR) model to estimate PM2.5 concentrations. |
| **Terra MISR** | Aerosol Optical Depth | The multiangular algorithm applied to MISR at 17.6 km resolution used multiple aerosol models to accommodate for differences in particle size, shape, and refractive index for AOD retrieval, to be included in the GWR to estimate PM2.5. |
| **Aqua MODIS** | Aerosol Optical Depth | Dark Target, Deep Blue, and MAIAC (Multi-Angle Implementation of Atmospheric Correction) AOD retrieval algorithms were applied to the Collection 6 product at 10 km (1 km for MAIAC, where available). AOD was used in the GWR to estimate PM2.5. |
| **CALIPSO CALIOP** | Aerosol Extinction Profiles | CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) aerosol extinction vertical profiles were used to correct the GEOS-Chem (Goddard Earth Observation System) chemical transport model aerosol simulation, which was applied to the GWR to estimate PM2.5. |
| **SeaStar SeaWiFS** | Aerosol Optical Depth | The Deep Blue AOD retrieval algorithm was applied to SeaWiFS at 13.5 km resolution to include in the GWR to estimate PM2.5 values. |

\* All data processing and model calculations were conducted by the Dalhousie University Atmospheric Composition Analysis Group (ACAG). The NASA DEVELOP California Health & Air Quality Team did not perform these steps.

***Ancillary Datasets:***

Dalhousie University ACAG global PM2.5 dataset – Analyze trends in PM2.5 across California at a 1 km spatial scale from the years 1998 to 2016. Annual averages of PM2.5 concentrations were derived by ACAG by applying a GWR to information from multiple satellite sources, the GEOS-Chem chemical transport model, and Aerosol Robotic Network (AERONET) ground-based observations.

California Department of Transportation Monthly Vehicle Miles of Travel report – Examine trends in

vehicle miles traveled on the California State Highway System with PM2.5 concentration.

CARB Aerometric Data Analysis and Management (iADAM) air quality statistics – Compare CARB’s state

annual averages of PM2.5 at each monitoring site with satellite-derived PM2.5.

CARB Pollution Mapping Tool – Compare satellite-derived PM2.5 to self-reported facility emissions (CEIDARS); CARB currently uses these data to develop air quality management plans.

PRISM Climate Data – Statewide precipitation means analyzed in conjunction with PM2.5 means

TIGER 2010 – Analyze relationship between PM2.5 and socioeconomic factors.

***Software & Scripting:***

Esri ArcGIS -- Visualization and spatial analysis of demographic, CEIDARS, and satellite-derived PM2.5 data

R -- Statistical analysis of demographic, CEIDARS, and satellite-derived PM2.5 data

***End Products:***

|  |  |  |  |
| --- | --- | --- | --- |
| **End Products** | **Earth Observations Used** | **Partner Benefit & Use** | **Software Release Category** |
| **PM2.5 Time Series Analysis** | Terra MODIS, Terra MISR, Aqua MODIS, CALIPSO CALIOP, SeaStar SeaWiFS | This comparison of remotely sensed PM2.5 data and data interpolated from *in situ* PM2.5 monitors will allow partners to determine whether current methods are adequate for evaluating air quality in California and provide an alternative. | I |
| **PM2.5 Ground-Truthing Analysis** | Terra MODIS, Terra MISR, Aqua MODIS, CALIPSO CALIOP, SeaStar SeaWiFS | This validation of satellite-derived PM2.5 data with data from *in situ* PM2.5 monitors investigates the accuracy of satellite data and concurrently examines the reliability of monitors. Partners can determine whether current methods are adequate for evaluating air quality in California and, if not, be provided with an alternative. | I |
| **Pollution Disparity Analysis** | Terra MODIS, Terra MISR, Aqua MODIS, CALIPSO CALIOP, SeaStar SeaWiFS | This product assesses the relationship between PM2.5 concentration and various socioeconomic factors (e.g., poverty, race and ethnicity, education) to help partners identify pollution disparities in California and work towards environmental justice for all state residents. | I |

**Project Handoff Package**

**Transition Plan:**

The DEVELOP team will disseminate end products and deliverables to its partner organizations during the final week of the term. The project will be presented to any attending partners at the end-of-term closeout and to those unable to attend in person through a WebEx teleconference. A handoff package with all end products and deliverables will be sent via NASA’s Large File Transfer (LFT) to CARB.

**Team POC:** Amanda Wasserman, [awasserman@csumb.edu](mailto:awasserman@csumb.edu)

**Partner POC:** Hyung Joo Lee, [HyungJoo.Lee@arb.ca.gov](mailto:HyungJoo.Lee@arb.ca.gov)

**Handoff Package:**

* Presentation
* Technical Paper
* Poster
* Project Video
* Map/Figure Package
* PM2.5 Time Series Analysis
* PM2.5 Ground-Truthing Analysis
* Pollution Disparity Analysis

**References:**

American Lung Association. (2017). State of the air 2017. Retrieved from

<http://www.lung.org/assets/documents/healthy-air/state-of-the-air/state-of-the-air-2017.pdf>

Burnett, R. T., Pope III, C. A., Ezzati, M., Olives, C., Lim, S. S., Mehta, S., ... & Anderson, H. R. (2014). An

integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure. *Environmental Health Perspectives*, *122*(4), 397–403.

Collantes, G., & Sperling, D. (2008). The origin of California’s zero emission vehicle mandate. *Transportation*

*Research Part A: Policy and Practice*, *42*(10), 1302–1313.

Cushing, L. J., Wander, M., Morello-Frosch, R., Pastor, M., Zhu, A., & Sadd, J. (2016). *A*

*preliminary environmental equity assessment of California’s cap-and-trade program* (Research brief). Retrieved from <https://dornsife.usc.edu/PERE/enviro-equity-CA-cap-trade>

Crouse, D. L., Peters, P. A., Hystad, P., Brook, J. R., van Donkelaar, A., Martin, R. V., ... & Brauer, M. (2015).

Ambient PM2.5, O3, and NO2 exposures and associations with mortality over 16 years of follow-up in the Canadian Census Health and Environment Cohort (CanCHEC). *Environmental Health Perspectives, 123*(11), 1180–1186.

Environmental Protection Agency. (2017). *History of reducing air pollution from transportation in the*

*United States (U.S.).* Retrieved from <https://www.epa.gov/air-pollution-transportation/accomplishments-and-success-air-pollution-transportation>

Fisher, J. B., Kelly, M., & Romm, J. (2006). Scales of environmental justice: Combining GIS and spatial

analysis for air toxics in West Oakland, California. *Health & Place*, *12*(4), 701–714.

Grantz, D. A., Garner, J. H. B., & Johnson, D. W. (2003). Ecological effects of particulate matter. *Environment*

*International*, *29*(2-3), 213–239.

Kaufman, Y. J., Tanré, D., Gordon, H. R., Nakajima, T., Lenoble, J., Frouin, R., ... & Teillet, P. M. (1997).

Passive remote sensing of tropospheric aerosol and atmospheric correction for the aerosol effect. *Journal of Geophysical Research: Atmospheres*, *102*(D14), 16815–16830.

Kioumourtzoglou, M. A., Schwartz, J., James, P., Dominici, F., & Zanobetti, A. (2016). PM2.5 and mortality

in 207 US cities: Modification by temperature and city characteristics. *Epidemiology*, *27*(2), 221–227.

Jerrett, M., Turner, M. C., Beckerman, B. S., Pope III, C. A., van Donkelaar, A., Martin, R. V., ... & Diver, W.

R. (2017). Comparing the health effects of ambient particulate matter estimated using ground-based versus remote sensing exposure estimates. *Environmental Health Perspectives*, *125*(4), 552–559.

Lee, H. J., Chatfield, R. B., & Strawa, A. W. (2016). Enhancing the applicability of satellite remote sensing for

PM2.5 estimation using MODIS deep blue AOD and land use regression in California, United States. *Environmental Science & Technology*, *50*(12), 6546–6555.

Levy, R. C., Remer, L. A., Kleidman, R. G., Mattoo, S., Ichoku, C., Kahn, R., & Eck, T. F. (2010). Global

evaluation of the Collection 5 MODIS dark-target aerosol products over land. *Atmospheric Chemistry and Physics,* *10*(21), 10399–10420.

Raz, R., Roberts, A. L., Lyall, K., Hart, J. E., Just, A. C., Laden, F., & Weisskopf, M. G. (2015). Autism

spectrum disorder and particulate matter air pollution before, during, and after pregnancy: A nested case-control analysis within the Nurses’ Health Study II cohort. *Environmental Health Perspectives, 123*(3), 264–270.

Remer, L. A., Kaufman, Y. J., Tanré, D., Mattoo, S., Chu, D. A., Martins, J. V., ... & Eck, T.

F. (2005). The MODIS aerosol algorithm, products, and validation. *Journal of the Atmospheric Sciences*, *62*(4), 947–973.

Van Donkelaar, A., Martin, R. V., Brauer, M., Hsu, N. C., Kahn, R. A., Levy, R. C., ... & Winker, D. M.

(2016). Global estimates of fine particulate matter using a combined geophysical-statistical method with information from satellites, models, and monitors. *Environmental science & technology*, *50*(7), 3762-3772.

Van Donkelaar, A., Martin, R. V., & Park, R. J. (2006). Estimating ground‐level PM2.5 using aerosol optical

depth determined from satellite remote sensing. *Journal of Geophysical Research: Atmospheres*, *111*(D21201), 1–10.

Wang, J., & Christopher, S. A. (2003). Intercomparison between satellite-derived aerosol optical thickness and

PM2.5 mass: Implications for air quality studies. *Geophysical Research Letters, 30*(21), ASC 4-1–ASC 4-2.

West, J. J., Cohen, A., Dentener, F., Brunekreef, B., Zhu, T., Armstrong, B., & Dockery, D. W. (2016).

What we breathe impacts our health: Improving understanding of the link between air pollution and health. Retrieved from <https://pubs.acs.org/doi/pdf/10.1021/acs.est.5b03827>