Eyeing Visibility from Space

The Upcoming Multi-Angle Imager for Aerosols (MAIA) Investigation

by Abigail Nastan

An upcoming NASA satellite mission will produce data of interest to the study of regional visibility.

NASA's Multi-Angle Imager for Aerosols (MAIA) project aims to improve our understanding of the associations between speciated particulate matter (PM) air pollution and human health. While the United States supports systems of ground monitors that report PM species concentrations, notably the Chemical Speciation Network (CSN) (https://www.epa.gov/amtic/chemical-speciation-network-csn) and the Interagency Monitoring of Protected Visibility Environments (IMPROVE) (http://vista.cira.colostate.edu/Improve/) network, maintenance of speciated monitors and analysis of the filters involve substantial costs and limit the total number of monitors in the network. Many other countries do not enjoy networks as robust as those in the United States.

Data from a satellite instrument like MAIA (https://maia.jpl.nasa.gov/) can provide a geographically continuous view of speciated PM over wide regions and therefore provide coverage in areas where ground monitors are scarce. The MAIA instrument will collect multispectral, multiangular, and polarimetric imagery that can be used to retrieve aerosol optical depth (AOD, a measure of vertical extinction), size, shape, absorption, and other optical particle information.[1] The MAIA project will use these data to generate products, including column-integrated aerosol properties and daily-averaged near-surface PM concentrations at 1-km resolution for PM_{10}, $PM_{2.5}$, and sulfate, nitrate, dust, elemental carbon, and organic carbon $PM_{2.5}$ in a selected set of target areas. The MAIA satellite instrument (see Figure 1) is being built at the NASA Jet Propulsion Laboratory (JPL), and NASA and JPL will identify a host satellite, with launch currently expected circa 2024 for a three-year baseline mission with a possibility for extension.

While the efforts of the MAIA science team focus mainly on a set of Primary Target Areas, MAIA data products can be helpful to other user communities, including air quality management agencies. To support all possible end users, the NASA Applied Sciences Program partners with the MAIA project on the MAIA Early Adopters Program. This effort actively engages epidemiologic, environmental health, aerosol research, air quality management, environmental justice, and other communities to understand their needs and to help users incorporate MAIA data into their workflow.

This article focuses on the applicability of MAIA data to management of visibility impairment due to regional haze in the United States, especially in connection with the U.S. Environmental Protection Agency (EPA) Regional Haze Rule and U.S. Clean Air Act Section 169A.

MAIA Data in the United States

Due to several practical considerations—including the observing strategy of the MAIA instrument, which involves pivoting the camera on a gimbal to capture multiangular views of each target to support aerosol property retrievals—MAIA will target specific regions rather than the entire globe. There are two main target types: Primary Target Areas (PTAs) and Secondary Target Areas (STAs). The MAIA team will conduct at least one epidemiologic study in each PTA, where the project is committed to generating the full suite of data products. The STAs, by contrast, are intended to provide data of interest to the project's Early Adopter community. The project's capacity to process the full suite of products in any given STA is dependent on the associated observational objectives and availability of resources.

In the United States, the MAIA team has identified three PTAs and five STAs, in addition to a sixth STA that spans both the United States and Canada. (There are eight more PTAs and 23 additional STAs in other countries; the latest target map is available on the MAIA website https://maia.jpl.nasa.gov/investigation/#target_areas.) The PTAs will be observed at least three times per week and the STAs will likely receive roughly twice-weekly observations. The target areas are referred to by their principal city of interest: Los Angeles, Boston, and Atlanta for the PTAs; and Hilo, San

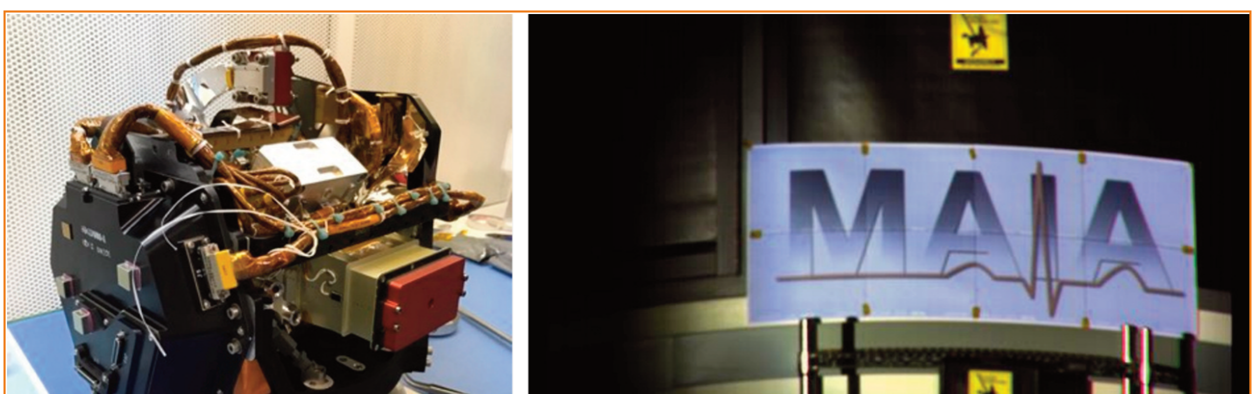

Figure 1. The assembled MAIA camera (left) and a test image taken by the camera in the assembly lab (right). The image is slightly out of focus because the MAIA camera is focused to infinity, rather than a few feet away as this target was.

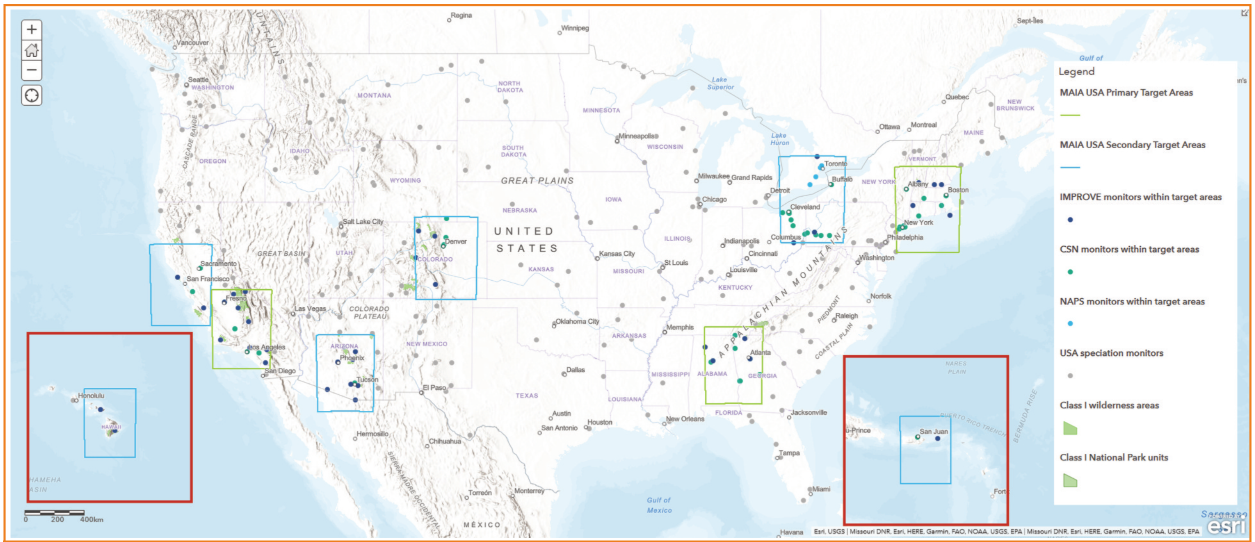

Figure 2. The MAIA target areas in the United States, with surface monitors measuring speciated PM and Class I areas within the target areas overlaid. Surface monitors are colored as follows: gray—U.S. speciation monitors outside of target areas; teal—CSN monitors within target areas; navy—IMPROVE monitors within target areas, including IMPROVE protocol sites; and aqua—NAPS monitors in Toronto target area. The blue target areas are Primary Target Areas, and the green are Secondary Target Areas. *Note:* The online ArcMap from which Figure 2 is available as an embedded interactive figure. Go to https://arcg.is/101Orq to zoom in to areas of interest and check the Class I areas and monitors nearby.

Francisco, Phoenix, Denver, Toronto, and San Juan for the STAs (see Figure 2). However, each target area covers a substantial region, 480 km (~300 miles) north–south and 360 km (~225 miles) east–west, so a single target has roughly the same surface area as the state of Florida and covers both urban and rural regions. Additionally, because the position of each target bounding box is optimized to capture the greatest population and minimize observing conflicts with nearby targets, the principal city is not necessarily at the center of the target area.

EPA's Regional Haze Rule focuses on improving visibility in 156 national parks and wilderness areas across the country where the most pristine visibility conditions are desired, called Class I Areas. MAIA's three U.S. PTAs cover all or part of 16 Class I Areas in California, Georgia, New Jersey, North Carolina, Tennessee, and Vermont. The STAs cover an additional 23 in Arizona, Colorado, Hawaii, and the U.S. Virgin Islands.

Most Class I areas feature an IMPROVE monitor site. The IMPROVE network was established in 1985 to provide data in support of visibility improvement in national parks and wilderness areas and now operates 154 monitoring sites across the country. The IMPROVE samplers collect particles on filters for a 24-hour period every three days, and the filters are analyzed in the laboratory to determine the concentrations of various $PM_{2.5}$ species and total PM_{10} and $PM_{2.5}$ mass.

Not only will MAIA data complement IMPROVE data within the target areas, but the IMPROVE data are also essential to MAIA's PM retrieval approach. This is because MAIA is a passive remote sensor (i.e., it observes sunlight reflected from the Earth rather than actively probing with, say, a laser) from which aerosol properties integrated over the entire atmospheric column, such as AOD, are derived. Furthermore, MAIA is sensitive to aerosol physical and optical properties, which are indirectly related to particle chemistry. However, since health-based PM standards specifically address air pollution at ground level where people breathe, ground-based measurements are needed to calibrate the MAIA retrievals of PM composition. In the United States, IMPROVE and its sister network CSN will provide the required data to train MAIA's geostatistical regression models for each U.S. target area (see Table 1 for more details). Other data sources will be used in the other countries MAIA will be observing.

MAIA, Visibility, and the Regional Haze Rule

The Regional Haze Rule, promulgated in 1999 by EPA, requires state and federal agencies to develop and implement plans to improve visibility in the 156 Class I Areas across the country, with the goal of achieving natural visibility conditions by 2064. To date, EPA has required agencies to submit two rounds of State Implementation Plans (SIPs) for the Regional Haze Rule, due in 2007 and 2021, respectively.

In each regional haze SIP, the submitting agency is required to evaluate the trends in visibility and PM composition in the Class I areas in their state (as well as Class I areas in other states that are affected by their state's emissions) since the date of the previous plan. Agencies are also required to use air quality modeling to evaluate the visibility conditions expected at the time of the next plan due. These modeled

Table 1. Traceability of MAIA parameters of interest to Regional Haze Rule analysis to the surface monitor data source used to train the relevant geostatistical regression model (with specific EPA Air Quality System (AQS) parameters noted), where applicable, and method of determining MAIA data performance.

MAIA parameter of interest	Surface monitor data used for model training (U.S. targets)[1]	Evaluation method
Aerosol Optical Depth (vertical extinction)	N/A[2]	Comparison with AERONET[3] sunphotometer network
Total PM_{10}	EPA FRM/FEM monitors (AQS PM_{10} Total 0-10μm STP)	Cross-validation/leave-one-out validation against surface monitor data
Total $PM_{2.5}$	EPA FRM/FEM monitors (AQS $PM_{2.5}$ - Local Conditions and Acceptable $PM_{2.5}$ AQI and Speciation Mass)	Cross-validation/leave-one-out validation against surface monitor data
Sulfate $PM_{2.5}$	CSN/IMPROVE (AQS Sulfate $PM_{2.5}$ LC)	Cross-validation/leave-one-out validation against surface monitor data
Nitrate $PM_{2.5}$	CSN/IMPROVE (AQS Total Nitrate $PM_{2.5}$ LC)	Cross-validation/leave-one-out validation against surface monitor data
Elemental carbon $PM_{2.5}$	CSN/IMPROVE (AQS EC $PM_{2.5}$ LC TOR)	Cross-validation/leave-one-out validation against surface monitor data
Black carbon $PM_{2.5}$	CSN/IMPROVE (AQS Black Carbon) monitor data	Cross-validation/leave-one-out validation against surface
Organic carbon $PM_{2.5}$	CSN/IMPROVE (AQS OC $PM_{2.5}$ LC TOR)	Cross-validation/leave-one-out validation against surface monitor data
Dust $PM_{2.5}$	CSN/IMPROVE (AQS Aluminum $PM_{2.5}$ LC + Calcium $PM_{2.5}$ LC + Iron $PM_{2.5}$ LC + Silicon $PM_{2.5}$ LC + Titanium $PM_{2.5}$ LC)	Cross-validation/leave-one-out validation against surface monitor data

[1]The geostatistical regression models used to generate MAIA's PM concentration products will be trained separately in each target area. Outside the United States, other data sources will be used.

[2]Unlike the other parameters in this table, AOD is derived directly from MAIA reflectance and polarimetric observations; therefore, no training data are required.

[3]Aerosol Robotic Network (AERONET) (https://aeronet.gsfc.nasa.gov/).

visibility conditions establish reasonable progress goals. Monitored trends are evaluated against these goals and the overall progress from baseline (2000–2004) visibility toward the 2064 goal is tracked. The agency also analyzes the effectiveness of existing emission control programs for sources of visibility-impairing PM and precursor pollutants and outlines the future emission control measures it plans to take (or ask contributing states to take) to ensure that reasonable progress will be achieved.

The metrics required for state regional haze SIP preparation are calculated using IMPROVE data, as outlined in EPA guidance. In addition, state, tribal, and other air agencies participate in one of the five Regional Planning Organizations (https://www.epa.gov/visibility/visibility-regional-planning-organizations), which support the preparation of regional haze SIPs with additional analysis including transport modeling, trends in emissions, and back-trajectory analysis, used to help determine the origins of transported pollution in Class I areas and inform the emissions control strategies undertaken in each state. MAIA data could potentially augment these analyses for the Class I areas covered by MAIA target areas for the third round of Regional Haze Rule SIPs for 2029–2038, anticipated to be due in 2028.

The species mapped by MAIA's PM data are well suited to provide insight into current trends. For example, the eastern United States and especially the MANE-VU Class I areas in the Northeast experienced a significant drop in sulfur dioxide emissions and sulfate PM over the period covered in the 2021 SIP. As sulfate decreased, nitrogen oxides emissions and nitrate PM became proportionally more important, especially in the winter.[2] MAIA's sulfate and nitrate data will allow greater spatial inquiry into this trend. Additionally, MAIA's elemental and organic carbon data can provide information on wildfire emissions, which can be widespread, and woodsmoke, which can be highly localized. MAIA's coverage in the United States, especially if used in conjunction with data from NASA's complementary TEMPO (https://eospso.nasa.gov/missions/tropospheric-emissions-monitoring-pollution-evi-1) project (which will launch in 2023 and focus on gaseous pollutants over North America), can inform analysis of inter-state and long-range transport of pollution. In addition, it is possible to relate satellite-derived AOD to the deciview haze index for tracking visibility trends.[3]

MAIA Early Adopter Program

Establishment of collaborations between the MAIA team, A&WMA, and state, tribal, local, and regional air quality organizations is needed to further efforts to provide useful data for Regional Haze Rule analysis. The MAIA team would like to recognize the representatives from such organizations who have already provided valuable input to the project and invite anyone interested to become a MAIA Early Adopter by contacting Abbey Nastan at bigail.m.nastan@jpl.nasa.gov. **em**

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