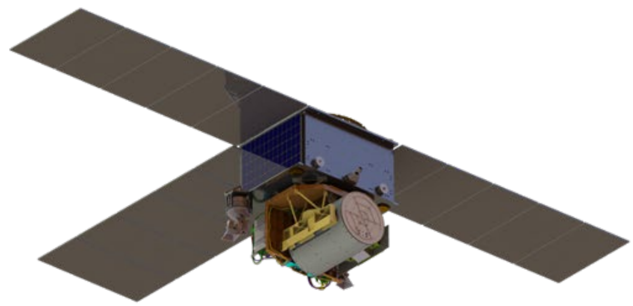
May 2020 MAIA-TEMPO Early Adopters Workshop Report

Complete virtual workshop, May 18-19, 2020



General Atomics

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1. Introduction

The Multi-Angle Imager for Aerosols (MAIA) and the Tropospheric Emissions: Monitoring of Pollution (TEMPO) projects are two competitively selected NASA instrument investigations focused on the study of air quality and societal benefit. Both projects are part of NASA's Earth Venture Instrument program and will be hosted by commercial spacecraft, with separate launches scheduled in 2022. MAIA and TEMPO are complementary missions, with MAIA focusing on particulate air pollution and TEMPO on trace gas pollutants including ozone and nitrogen dioxide. MAIA's host will be launched into a polar, sun-synchronous low-Earth orbit, while TEMPO's host will be in geostationary orbit stationed over North America. MAIA's data products will have higher spatial resolution and will be generated over discrete locations distributed around the globe, while TEMPO's data products will have higher temporal resolution and will provide complete coverage of North America.

A MAIA-TEMPO Early Adopters Workshop was held on May 18-19, 2020, in a virtual format. The objectives of this workshop, held approximately two years before MAIA's and TEMPO's planned launch dates, were to:

1. Inform new MAIA and TEMPO Early Adopters about the MAIA and TEMPO missions, target areas, and data products.
2. Inform workshop participants of progress and updates on the MAIA and TEMPO projects since their respective previous workshops.
3. Hear from a selection of Early Adopters about their interest in various applications of MAIA and TEMPO data and their insight into how MAIA and TEMPO can best address their needs.
4. Review the currently-in-development versions of the MAIA and TEMPO data products and gather feedback that can be used to make improvements during the finalization of the pre-launch data production software.

The two-day event was roughly split into one day per project, with MAIA material occupying the majority of May 18 and TEMPO the majority of May 19, followed by a session on synergy between the two projects. The full agenda for the workshop is included here in Appendix A. 171 people participated in the workshop, including epidemiologists, environmental health researchers, air quality managers, environmental advocates, and others. The full list of attendees is included in Appendix B.

The workshop was originally planned to take place in Atlanta, but because of the ongoing COVID-19 pandemic, the coordinators decided to hold a completely virtual workshop instead. To reduce teleconference fatigue, the agenda was compressed and introductory material about the projects was migrated to slides made available to participants in advance of the workshop. The workshop was presented via Webex teleconference and an online tool called Mentimeter (https://www.mentimeter.com) was employed to allow all participants to ask questions and provide feedback in real time. Activities included some initial questions before the workshop began to gauge the attendees' previous knowledge, as well as quizzes to ensure that the teams had successfully communicated the most salient points about the projects.

1.1 Introduction to the NASA Multi-Angle Imager for Aerosols (MAIA) Early Adopters Program

MAIA's primary science objective is to study the effects of various compositional makeups of particulate matter (PM) air pollution on human health. Exposure to PM air pollution is recognized as the largest worldwide environmental risk factor, as opposed to personal risk factors like heredity and behavior, for premature death. MAIA will use a combination of spaceborne technologies to collect multispectral, multi-angle, and polarimetric observations, which provide information about the size, shape, and composition of the particles that comprise PM air pollution. The data collected from the instrument will be combined with measurements from air pollution monitors on the ground and outputs from a chemical transport model to calculate the concentrations of various PM types over a globally distributed set of Primary Target Areas. Epidemiologists on the MAIA team will conduct studies on the health impacts of the derived PM compositions.

From the beginning, MAIA has included a diverse team of co-investigators along with collaborators from the Environmental Protection Agency (EPA), National Institutes of Health (NIH), the Centers for Disease Control and Prevention (CDC), and the National Oceanic and Atmospheric Administration (NOAA). This unique team will help ensure that MAIA data products and science advancements are able to make a material impact on those managing public health air quality issues. More recently, collaborations with the South Coast Air Quality Management District (SCAQMD), the US Agency for International Development (USAID), and the US Department of State have been established, and a cadre of researchers who will assist in surface monitor operations and epidemiological studies has been identified. In addition, the NASA Applied Sciences Program (ASP) is committed to developing and implementing a broad-reaching applications program to reach additional potential users of the MAIA data. Lawrence Friedl, the NASA ASP Director, and John Haynes, ASP Health and Air Quality Program Manager, oversee the applications efforts associated with various missions. ASP funds the MAIA Deputy Program Applications (DPA) Lead, who acts on behalf of the ASP specifically for MAIA.

The primary goal of the MAIA Applications Program is to maximize the benefit of the NASA Earth Science Directorate (ESD) investment by enhancing the applications value and overall societal benefits of the project. The keystone of the MAIA applications effort is the Early Adopters Program, through which interested potential users will have the opportunity to avail themselves of regular updates from the science team, take advantage of resources including simulated data products prior to launch, and offer feedback to the project on potential product improvements. The Early Adopters program is intended to entrain potential users outside the MAIA science team prior to launch and provide resources to ensure the MAIA project is meeting their individual needs to the greatest possible extent. MAIA Early Adopters, who numbered 136 individuals at the time of this workshop, will have the opportunity to offer feedback on MAIA's planned data products through workshops, experiment with test versions of the products pre-launch, and take advantage of the expertise of the MAIA science team. More details about the Early Adopters program and other MAIA activities related to reaching data users, including a link to sign up for the MAIA Early Adopters mailing list, are available on the applications page of the MAIA website (https://maia.jpl.nasa.gov/resources/data-and-applications/).

1.2 Introduction to the NASA Tropospheric Emissions: Monitoring of Pollution (TEMPO) Early Adopters Program

The TEMPO spectrometer will observe trace gases and aerosols at unprecedented temporal (hourly daytime) and spatial resolution (~2.0 x 4.75 km^2) over a Field of Regard (FOR) covering Greater North America. By measuring radiances in the ultraviolet (290-490 nm) and visible (540-740 nm) spectrums, TEMPO will be capable of distinguishing between boundary layer and free tropospheric ozone throughout the daytime diurnal cycle. These new measurement capabilities from space will greatly enhance the monitoring of emission sources and transport pathways of trace gases and aerosols in the troposphere to improve air quality forecasting and address the societal and climatic impacts of air pollution, which are key objectives of the TEMPO mission.

The TEMPO mission is part of an international geostationary constellation of spectrometers that will enable hourly monitoring of air pollution over North America, Europe, and Asia. The Korean-led Geostationary Environment Monitoring Spectrometer (GEMS) mission, recently launched in February 2020, is currently providing observations over Asia with data products planned for release in early 2021, which will provide an early understanding of potential capabilities and limitations of TEMPO data over North America. Operational data products and visualizations from GEMS are expected to help engage users of future TEMPO data over North America for strengthening and expanding the TEMPO Early Adopters Program. GEMS data is of particular interest to the TEMPO user community, since transport of trace gases and aerosols from Asia frequently contributes to pollutant concentrations over North America. The European Space Agency (ESA) Sentinel-4 mission will complete the geostationary air quality constellation after the planned launch over Europe in 2023.

As a dedicated air quality mission, a key partner of TEMPO from the early planning stages has been the Environmental Protection Agency. The TEMPO science team is committed to developing high-quality retrieval algorithms and data products that are crucial to the mission success. The Environmental Protection Agency aims to help build an appropriate infrastructure of surface air quality sites to enable robust validation of TEMPO data products after launch, which can lead to more accurate data products for use in research and applications. Other early collaborations with TEMPO include researchers from the National Oceanic and Atmospheric Administration, National Center for Atmospheric Research, and a number of universities. With support from the ASP, the DPA Lead for the TEMPO mission is committed to expanding the knowledge and use of TEMPO data by engaging a broad spectrum of users, especially in the health and air quality communities.

The overarching goal of TEMPO Applications Program is to maximize the value and application benefits of operational TEMPO data for societal benefit. Success of the TEMPO Applications Program hinges on the pre-launch activities of the Early Adopters Program, which fosters interactions between users and the TEMPO science team with the DPA Lead acting as a common interface between the science and user community. The primary objectives of the TEMPO Early Adopters program are to prepare users for operational TEMPO data, identify current gaps between the science data and user needs, and better align TEMPO products and data interfaces to meet these needs. An important application component of the TEMPO mission are the non-standard operational scans with time resolution of 10 minutes or less and reduced spatial coverage over the FOR, which can consume up to 25% of the observing time of TEMPO. Additional planning and preparation for these irregular scans will be required to promote effective use of the high-time data; therefore, this will be a focus area of the TEMPO Applications and Early Adopters Program during the pre-launch phase of the mission. To effectively interact with users on TEMPO products, the DPA Lead is coordinating with the science team on distributing synthetic data products that emulate the expected TEMPO products after launch. At the time of the workshop, the Early Adopters Program consisted of approximately 110 users from a broad range of organizations across the TEMPO FOR, including additional state and local air quality agencies, universities, non-governmental organizations, several private companies, and health organizations. More details on the TEMPO Early Adopter activities along with synthetic data visualizations and distribution can be found on the applications site (https://weather.msfc.nasa.gov/tempo/). Registration to join the early adopter team is also available on this site.

2. Summary of MAIA section – May 18, 2020

A summary of the material presented by the MAIA team is provided here for the benefit of those who were not able to attend the workshop and other interested parties.

2.1 MAIA project updates

2.1.1 MAIA project and target area update (presenter: David Diner, JPL)

The workshop began with a welcome from John Haynes, NASA ASP Health and Air Quality Program Manager, and an introduction to the TEMPO and MAIA Early Adopters programs and their respective leads, Aaron Naeger and Abigail Nastan. After this, MAIA's principal investigator David Diner offered an introduction to the project, including an update on current status of the instrument, surface monitor deployments, target areas, and data products. Three new members recently joined the MAIA science team from JPL, the US Department of State, and USAID. MAIA's launch is currently scheduled for the period May-October 2022, and NASA has selected General Atomics-Electromagnetic Systems Group to build the spacecraft that will host the MAIA instrument. The MAIA instrument (see Figure 1) has been completely designed and many of the parts have been fabricated. Integration and testing of the instrument has been impacted by the COVID-19 pandemic, but work is starting to resume as of June 2020.

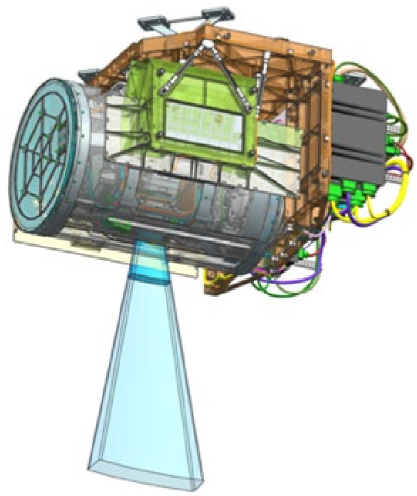

Figure 1. A CAD model of the MAIA instrument as of May 2020. The camera is represented as pointing downward and the large, circular drum contains the two-axis gimbal that allows pointing. Instrument electronics are housed in the boxes on the far right of the figure.

For brevity, the full technical description of the instrument is omitted here. For more details, consult the MAIA website https://maia.jpl.nasa.gov and the publications listed therein. The instrument will collect multi-angular views of each target (see Figure 2) and produce radiance and polarization information, from which aerosol optical properties will be retrieved. The approach to produce speciated PM concentrations is geostatistical regression modeling, which will take the MAIA aerosol product and geospatial and spatiotemporal predictors, including PM surface monitor data, as inputs. A daily-averaged, gap-filled PM concentration product will be produced using a chemical transport model as input to cover areas and days that have no MAIA aerosol retrievals. The full details of the MAIA aerosol and PM retrieval approach and validation will be detailed in several Algorithm Theoretical Basis Documents and a Science Validation Plan, which will be available online and accessible from the MAIA website once published.

The latest list of candidate MAIA target areas (Figure 2) was presented. The MAIA Primary Target Areas, wherein epidemiologists on the MAIA Science Team will conduct health studies, are mostly finalized with a list of 12 identified targets. Deployments of Surface PARTiculate mAtter Network (SPARTAN) and Aerosol Mass and Optical Depth (AMOD) filter-based samplers, AethLabs aethelometers, PurpleAir low-cost sensors, and AERONET sunphotometers to supplement surface monitors already present in the Primary Target Areas are underway in several of these areas to ensure sufficient surface-based measurements to complement the satellite data acquisitions. The MAIA Secondary Target Areas include cities with major PM pollution, aerosol source regions, climatically important cloud regimes, or other locations of scientific interest. As of May 2020, the MAIA team has identified 25 potential Secondary Target Areas based on team and Early Adopter input, though finalization is still underway. Calibration/Validation

Target areas will be primarily used for instrument radiometric, polarimetric, and geometric calibration while in flight.

Figure 2. The MAIA candidate target areas (current as of May 2020).

2.1.2 MAIA data product development update (presenter: Scott Gluck, JPL)

The MAIA Science Data System will generate the various MAIA data products, archive them, and provide them to the public, free of charge. The public data products will include:

1. Level 1 radiance/polarization product: this will include calibrated and georectified radiance data for MAIA's fourteen spectral bands and Stokes parameters describing linear polarization for the three polarimetric bands. This product will be produced for every angle of MAIA step-and-stare observations, at 250 meter spatial resolution.
2. Level 2 aerosol product: this product is the output of the aerosol retrieval algorithm, and will include total and fractional aerosol optical depths along with other optical and microphysical particle properties. Ancillary variables such as surface albedo, light scattering dataset properties, bidirectional reflectance factors, and solar and view angle information will also be included. The aerosol

optical depths will have associated uncertainties. One file will be produced per set of MAIA observations of a target, at 1-kilometer spatial resolution.

3. Level 2 PM product: This product will include daily-averaged total particulate matter with aerodynamic diameter less than 2.5 micrometers ($PM_{2.5}$) and particulate matter with aerodynamic diameter less than 10 micrometers (PM_{10}) concentrations, as well as concentrations of $PM_{2.5}$ sulfate, nitrate, organic carbon, elemental carbon, and dust components on the days of satellite overpass. One file will be produced per set of MAIA observations of a target, at 1-kilometer spatial resolution.
4. Level 4 PM product: This product will include the same variables and be produced at the same resolution as the level 2 PM product, but will be produced every day, whether MAIA observations were taken on that day or not, and will be gap-filled using chemical transport model PM estimates, corrected for biases using surface monitor measurements and the geostatistical regression model approach.

All of these products will be generated in each Primary Target Area, but the situation is different among the Secondary Target Areas and Calibration/Validation Target Areas. For each MAIA Secondary Target Area located on land, at a minimum the Level 1 imagery and Level 2 aerosol products will be produced. The resources and ancillary data needed to produce the Level 2 and 4 PM products in the Secondary Target Areas are still being evaluated. For the Secondary Target Areas intended to study clouds over the ocean and for the Calibration/Validation Target Areas, only Level 1 imagery will be produced.

MAIA's data products will be provided in Network Common Data Form (NetCDF) format, which is commonly used by NASA, NOAA, NSIDC, and others. There are many software tools available to read and visualize NetCDF files, including the free NASA Panoply software (https://www.giss.nasa.gov/tools/panoply/), and it is compatible with geographic information systems (GIS) including ArcGIS and QGIS. After launch, the MAIA data products will be publicly available from the NASA Langley Atmospheric Science Data Center (ASDC).

The development of the software to generate the MAIA data products is well underway, and as of May 2020, the radiometric correction, production of map-projected imagery, aerosol data product production, and chemical transport model processing elements are complete and undergoing testing. The cloud detection, integration of surface monitor data, geostatistical regression model processing, and PM data product production elements are currently being developed.

2.1.3 Special topic: COVID-19 and particulate air pollution (presenters: Sina Hasheminassab, South Coast Air Quality Management District, and Michael Garay, JPL)

The impact of lockdowns, stay-at-home orders, and other changes in human activities due to COVID-19 on air quality was a hot topic in the news as of May 2020. Most news stories focused on the "silver lining" of improved air quality during this traumatic period, but is it possible to definitively identify COVID-19 mitigation strategies as the cause, are decreases observed for all pollutants, and was improvement seen everywhere? Sina Hasheminassab, Air Quality Specialist at the South Coast Air Quality Management District and MAIA Science Team member, first covered the evidence from ground monitors in several metropolitan areas around the world. He found statistically significant decreases in $PM_{2.5}$ levels during the COVID lockdown compared to the averages observed during the same period in 2015-2019 in Los Angeles, New York, New Delhi, and Beijing, while no significant trend was found in the Emilia-Romagna region of Italy, and a statistically significant increase was observed in Houston, which had not undergone a lockdown to this point in time. However, a closer look at meteorology in Los Angeles, in particular, showed that the observed changes could be heavily influenced by precipitation. Los Angeles and several other areas had higher than usual precipitation over the same period as the COVID-19 mitigation strategies were in place. It is important to note that emissions changes due to the COVID-19 lockdown do not necessarily translate into concentration changes in atmospheric pollutants and, due to the complex interaction of emissions and meteorology, detangling the two signals is difficult.

Michael Garay of JPL, another MAIA Science Team member, followed this presentation with satellite data analysis from the NASA Multi-angle Imaging SpectroRadiometer (MISR) instrument, which has a twenty-plus year data record and which also demonstrates some of the observational and data processing techniques to be used by MAIA. Similar to the surface monitor measurements, significant decreases in aerosol optical depth (AOD) were observed in Los Angeles, New York, New Delhi, and Beijing, while Houston had a significant increase over the same time period compared to the 2015-2019 average. Differing from the surface monitor data, a decrease in AOD was also observed in the Emilia-Romagna region of Italy. In order to investigate whether these changes were truly exceptional, the AOD percent change in 2020 relative to the 2015-2019 average was compared for each year relative to the previous five years in the MISR dataset going back to 2005. This result shows that for almost all locations, while the 2020 percent change in AOD may appear to be large, 2020 typically does not represent the largest annual drop in AOD observed over the period the MISR data record covers. This leads to a conclusion that it's very difficult to isolate the effects of the lockdown from the effects of meteorology and other factors for aerosol pollutants.

2.2 MAIA applications examples

The second portion of the MAIA section consisted of presentations by Early Adopters who have worked with members of the MAIA team previously. They shared a sampling of previous work with other satellite datasets and their thoughts on how MAIA data might benefit their particular use case.

2.2.1 Health studies in Atlanta (presenter: Matt Strickland, University of Nevada-Reno)

Matt Strickland, Associate Professor at the School of Community Health Sciences, University of Nevada-Reno, presented a summary of two proposed health studies for the Atlanta Primary Target Area. The first is a case-crossover study of emergency room (ER) visits to hospitals belonging to the Georgia Hospital Association. The US Environmental Protection Agency (EPA) has determined that exposure to elevated levels of $PM_{2.5}$ over short periods can cause cardiovascular problems and likely causes respiratory effects that can lead to increased ER visits in the day or two following exposure. This study would use ICD-10 codes from ER records to investigate links between PM exposure and a variety of health outcomes. The second proposed study is a case-control investigation of pregnancy outcomes using data from the Georgia Department of Public Health. The links between PM exposure during pregnancy and birthweight and gestational age of the infants would be studied. Since the EPA has not yet determined that PM exposure definitively causes premature birth and low birth weight, this study will contribute more findings to this area.

2.2.2 Satellite applications for operational air quality forecasting (presenter: Daniel Tong, NOAA National Air Quality Laboratory and George Mason University)

Daniel Tong, a member of the NOAA Air Quality Forecast Capability team, Research Professor at the Center for Spatial Science and Systems at George Mason University, and a member of the NASA Health and Air Quality Applied Science Team, presented on the use of satellite data for air quality forecasting. Since 2004, the National Weather Service and NOAA have produced several operational air quality forecasting systems for ozone, dust, $PM_{2.5}$, and smoke covering various regions of the US and the globe and at various spatial resolutions. Satellite observations have been used in both emission data assimilation to reduce emissions uncertainties and in chemical data assimilation to improve initial concentrations of the models. For example, NASA's Ozone Monitoring Instrument (OMI) NO_2 data have been used in rapid refresh of NO_x forecast models, and NASA Moderate Resolution Imaging Spectroradiometer (MODIS) albedo climatologies have been used to generate monthly maps of dust sources that can be used in dust forecast models. In the future, MAIA and TEMPO aerosol and trace gas data can be used for chemical data assimilation, and they can also contribute to emission data assimilation by providing current information on anthropogenic and natural sources of pollutants. In addition, both can also provide valuable data for model evaluation and diagnostics of weather, emissions, and chemistry.

2.2.3 Applications of Satellite Data at CDC's Environmental Health Tracking (presenter: Ying Zhou, Centers for Disease Control)

Ying Zhou, of the Environmental Health Tracking Section of the National Center for Environmental Health, presented an overview of the Environmental Health Tracking program, founded in 2002, and a current example of the use of satellite data to tracking estimate skin cancer vulnerability. Twenty-five states and New York City participate in the tracking program, which partners with other CDC programs, federal agencies, and national organizations to increase the number of data-driven environmental public health actions and decisions by providing information from a nationwide network of standardized, integrated health and environmental data. One example of satellite data used in the program is OMI UV irradiance and daily dose data, which are used to assign a UV exposure to every census tractcounty in the United States. These data have been validated against 32 ground sites in the UV-B Monitoring and Research Program by U.S. Department of Agriculture (USDA) and have been used to demonstrate a statistically significant increase in UV exposure from 2005 to 2015. The CDC has used this data to encourage show that the most impactedsome states with high surface UV irradiance do not currently haveto pass laws allowing children to use sunscreen at school to prevent future skin cancer. In the future, the Environmental Health Tracking program would like to include other sources of timely, accurate, and accessible satellite data, including air pollution data.

2.3 MAIA data product feedback

The third portion of the MAIA section consisted of discussion exercises focused on the MAIA data products, conducted using the Mentimeter online tool. Workshop participants were provided with “preview” versions of the MAIA Level 2 aerosol and MAIA Level 2/4 PM products, based on current progress of the development of the product generation software. Abigail Nastan conducted a virtual tutorial on how to examine the products using the free NASA Panoply software, and then participants were asked to provide feedback on the preview products that will help guide the finalization of the software, scheduled to be complete by the end of 2020. The changes recommended in this report, based on the feedback provided, will be incorporated into the MAIA Simulated Data Products that will be available to Early Adopters before launch.

2.3.1 General data discussion exercise

The first discussion exercise was designed to gather general information about participants’ intended use of MAIA data products. The audience was fairly evenly split between those who used NASA data routinely and those who had only tried it a few times or had never tried to use it. Attendees were asked which tools they use most frequently to analyze data, in order to provide information to the Atmospheric Science Data Center on what conversion tools and data compatibilities are most important for likely users of MAIA data. Experienced NASA data users mostly used programming languages, especially Python and R, and GIS tools to examine data. Those newer to NASA data were more likely to use Excel and GIS tools in their usual work. Converting MAIA’s NetCDF files to Excel-readable CSV data is a challenge, but may be important to empower new users. Meanwhile, data recipes in R and Jupyter notebooks such as those ASDC has already provided for other projects would be an excellent resource. NetCDF files are natively readable by ArcGIS and QGIS, so this important need will be accommodated.

Participants were also asked which task(s) in their usual or aspirational workflow for which they would like to use MAIA data. The most frequent individual responses were calculating human and environmental (including cultural object) exposure to PM and conducting studies on health outcomes. However, tasks associated with air quality management and characterization (day-to-day air quality tracking, exceptional event demonstrations, air quality and smoke forecasting, source attribution, and identifying air pollution hotspots) outnumbered exposure/epidemiology in aggregate. Participants also said model input, model evaluation, and fusion with other satellite and ground monitor data were tasks for which they would consider applying MAIA data. These responses demonstrate how the MAIA Early Adopters program has grown beyond the initial core team of epidemiologists on the MAIA Science Team to encompass external epidemiologists, air quality managers and advocates, and aerosol modelers, among others.

2.3.2 Aerosol product discussion exercise

The next portion of the discussion focused on obtaining feedback on the “preview” MAIA L2 aerosol file. Early in MAIA’s development, the team recognized that the MAIA aerosol product had two major, and rather different, use cases:

1. Constructing “custom” PM models: Many of the MAIA epidemiologists stated early in project development that they would prefer to use the MAIA L2 aerosol product to construct their own PM models, rather than using the MAIA L2/L4 PM products. An experienced exposure scientist or epidemiologist may theorize based on previous work that different model inputs or a different model design (e.g., machine learning versus MAIA’s geostatistical regression model approach) may improve performance in a particular area. Additionally, the MAIA team may not have the resources to produce PM products in some or all of the Secondary Target Areas. If a user requires PM concentrations in those areas, they may need to construct their own model using the MAIA L2 aerosol product as input.
2. “Traditional” aerosol applications: MAIA represents continuity for many of the technologies and data products from previous and in-flight instruments including MISR, MODIS, and AVHRR, as well as a bridge to in-formulation projects such as the Aerosols and Cloud Convective Processes Decadal Observable mission. As such, many who have used NASA aerosol products in the past for tasks such as aerosol model evaluation, constructing aerosol climatologies, and studying cloud-aerosol interactions and aerosol effects on climate will wish to use the MAIA L2 aerosol product for similar tasks.

This poses a distinct challenge for the design of the aerosol product, since these two use cases represent communities with needs for different sets of output parameters from the MAIA aerosol retrieval, and importantly, different expectations, data and workflow conventions, and technical language. The potential aerosol product users at the workshop were asked to identify their own use case: 39% were interested in making their own PM models, 33% were interested in non-PM usage, and the remaining 28% were interested in both.

Prior to the workshop, the MAIA team had noted the naming convention for the size distributions of MAIAs bimodal aerosol retrieval as a potential point of confusion. They were originally called “small mode” and “large mode.” Therefore, participants of the

Early Adopters workshop were asked to give their own definitions of “small mode” and “large mode” to evaluate the potential confusion. As expected, definitions varied widely, and responses confirmed that the terms were conflated with specific concepts for certain communities, most prevalently the $PM_{2.5}$ and PM_{10} (or PM_{coarse}, which is PM_{10} – $PM_{2.5}$) size bins for the air quality community, as well as nucleation mode/accumulation mode/coarse mode among atmospheric chemists.

Because the two size distributions are not meant to represent $PM_{2.5}$/PM_{10} or specific modes in atmospheric chemistry, and the actual particle sizes represented by the two distributions will vary from retrieval to retrieval, this exercise at the Early Adopters workshop confirmed the MAIA team’s suspicion that these modes should be renamed. Addressing this confusion is critical, as it contributed to a larger confusion, especially among the participants less familiar with MAIA, about the difference between the L2 Aerosol and L2 PM products, and what was the proper use for each. The MAIA team should consider what other changes and/or supporting material (documentation, tutorials, etc.) can help to easily guide new users to the correct product for their intended use. (See section 4.1 for the data product changes that the MAIA team has agreed upon based on findings from this workshop.)

To assist with improving the product organization, the participants were asked two questions about what parameters were most useful to them. Fortunately for efforts to make the product intuitive for both PM modelers and “traditional” aerosol users, the ranking of parameters was similar for both groups, though non-PM users were most interested in total aerosol optical depth (AOD) and PM modelers were most interested in the fractional AODs partitioned by particle size, sphericity, and absorption. Single scattering albedo (SSA) was of least interest to all groups, with aerosol optical properties and surface properties falling in the middle.

All potential aerosol product users gave the “preview” aerosol data files relatively high marks on statements evaluating the product’s ease-of-use, with most scores above 3 on a scale of 0 – 5. Users said the product had “clearer layout than many NetCDF files” and had “pretty straightforward naming and parameters”; they also appreciated that the file already contained geolocation fields that allow parameters to be easily mapped to any desired projection with common plotting tools (demonstrated in the Panoply software). However, ease-of-use scores were lower among both the most and least experienced users (Figure 3), and the majority of the users indicated they would need a comprehensive user guide, perhaps including sample code, or an in-person workshop in order to feel ready to start using the product. This indicates there is definitely room for improvement. Participants suggested including more complete descriptions of the individual parameters within the product files themselves. (Traditionally, parameter descriptions for NASA products have been described in a separate document called the Data Product Specification, but new users may not know such a document exists or how to find it.)

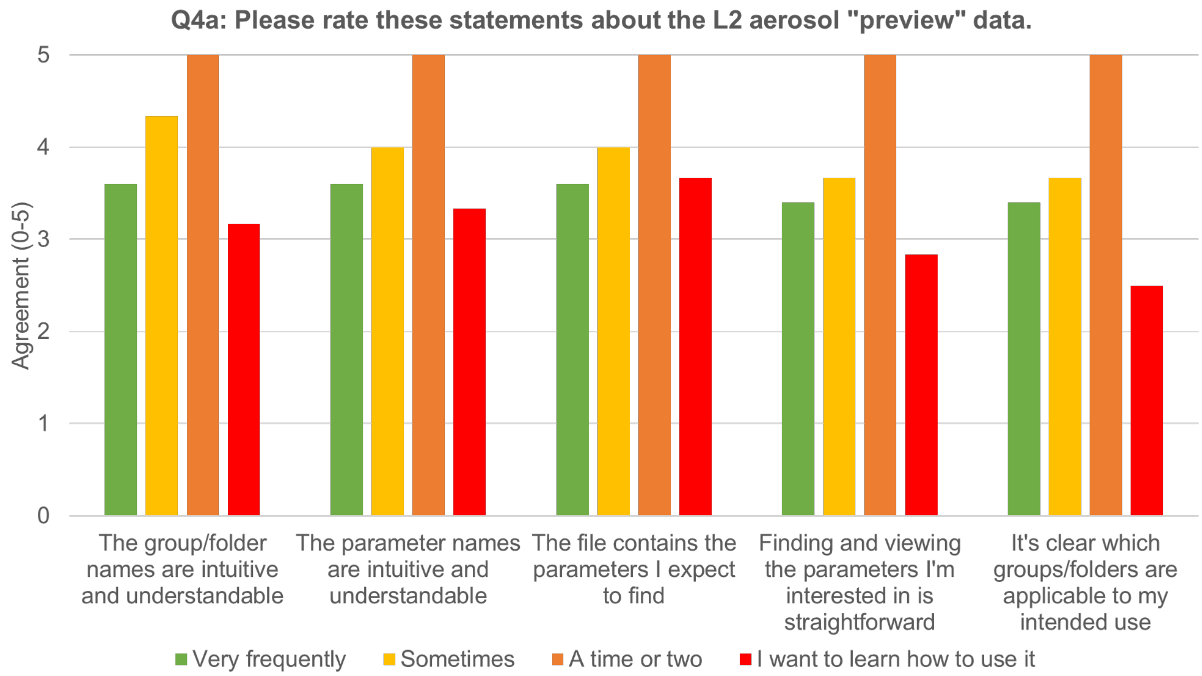

Figure 3. Participant ratings of the ease-of-use of the "preview" MAIA Level 2 Aerosol product, broken out by their response to the question, "Have you used any other NASA datasets in your work previously?"

2.3.3 PM product discussion exercise

MAIA's Level 2 and Level 4 PM products were discussed together since they will have identical format. The difference between the two products is that the Level 2 PM product is only produced for a target on the days that the MAIA instrument captured observations of that target, and will only contain results for the pixels within the target area for which the MAIA aerosol algorithm successfully retrieved results (in other words, there will be holes in the MAIA L2 PM product where there are clouds, shallow water bodies, particularly complex terrain, etc.). The Level 4 PM product, in contrast, will use the bias-corrected chemical transport model running within MAIA's geostatistical regression model to produce a PM file for each of MAIA's Primary Target Areas every day, and any gaps in the MAIA observations will be filled.

The MAIA PM maps are the key products of the project and represent the major advancement of the MAIA investigation over previous NASA projects; NASA does not currently distribute any operational PM products. However, MAIA's PM products will also be relatively straightforward: they simply contain concentrations of total PM_{10} and $PM_{2.5}$, as well as the concentrations of sulfate, nitrate, elemental carbon, organic carbon, and dust $PM_{2.5}$, as well as per-pixel uncertainties for all these parameters. The great majority of the potential PM product users present at the workshop had not constructed their own PM models or previously used any of the satellite-derived PM datasets (such as the global total $PM_{2.5}$ dataset available through NASA Socioeconomic Data and Applications Center (SEDAC) at https://sedac.ciesin.columbia.edu/); this was their first exposure to such data products.

The potential PM product users present said they were more likely to use the Level 4 PM product than the Level 2 PM product, and this preference was most marked among the new users of satellite-derived PM data. All user groups (those who had made their own models, those who had used satellite-derived PM data before, and new users) agreed that MAIA's total $PM_{2.5}$ information and speciated $PM_{2.5}$ information were the most important parameters in the product, with modelers and new users expressing that total $PM_{2.5}$ was slightly more important. Following these were the per-pixel uncertainties, and total PM_{10} was least important to participants. Of the MAIA $PM_{2.5}$ species, elemental carbon was rated of most interest, followed by nitrate, organic carbon, sulfate, and then dust. However, there was a fair amount of variation from individual to individual on this question, as would be expected since the species of most importance will vary depending on the important air pollutants in the user's geographic area of interest.

Participants were also asked to think about their requirements for latency of the PM products in regards to the reprocessing schedule for the MAIA geostatistical regression models. When the PM products are first released after completion of post-launch testing, they will be "beta" products that use a geostatistical regression model (GRM) trained in each applicable target area before launch with available surface monitor data and chemical transport modeling. After the MAIA instrument has collected observations of the target areas for a certain period (likely a year), the GRM will be re-trained with MAIA observations and surface monitor data available up to that point, and the PM products will be reprocessed. This process will be repeated periodically throughout the MAIA mission until the final reprocessing, which will take place after the MAIA instrument has been taken offline at the end of the active mission, which is nominally three years. This means that the quality of the MAIA PM products will increase with each reprocessing as more MAIA data and surface monitor observations are included. Fifty percent of participants said they would wait until after the first reprocessing to begin using MAIA PM data, while 21% said they'd wait for the second reprocessing, and 14% each said they would either wait for the final reprocessing or would begin using the beta version of the MAIA PM data before the first reprocessing. This spread of answers was expected due to the different latency needs of various user communities, but does emphasize the need for the MAIA team to provide clear information about the relative product quality with each reprocessing.

Overall, the potential PM users gave the PM products higher scores for ease-of-use than the aerosol product received (Figure 4), though the group of users new to satellite-derived PM products gave slightly lower ratings. Additionally, only one potential user responded that they thought they'd need an in-person workshop to help them get started using the data, with the majority of participants stating that they already felt confident enough or that a document in line with a NASA Data Product Specification would provide the information they needed to get started. Several participants stated that they liked that the product was intuitive and straightforward and that per-pixel uncertainties were included for every parameter. One participant who had previously made PM models simply responded that they liked "Everything!" Users suggested that some example literature on using satellite PM data, similar to the background slides sent to participants before the workshop, would be helpful to include with the products.

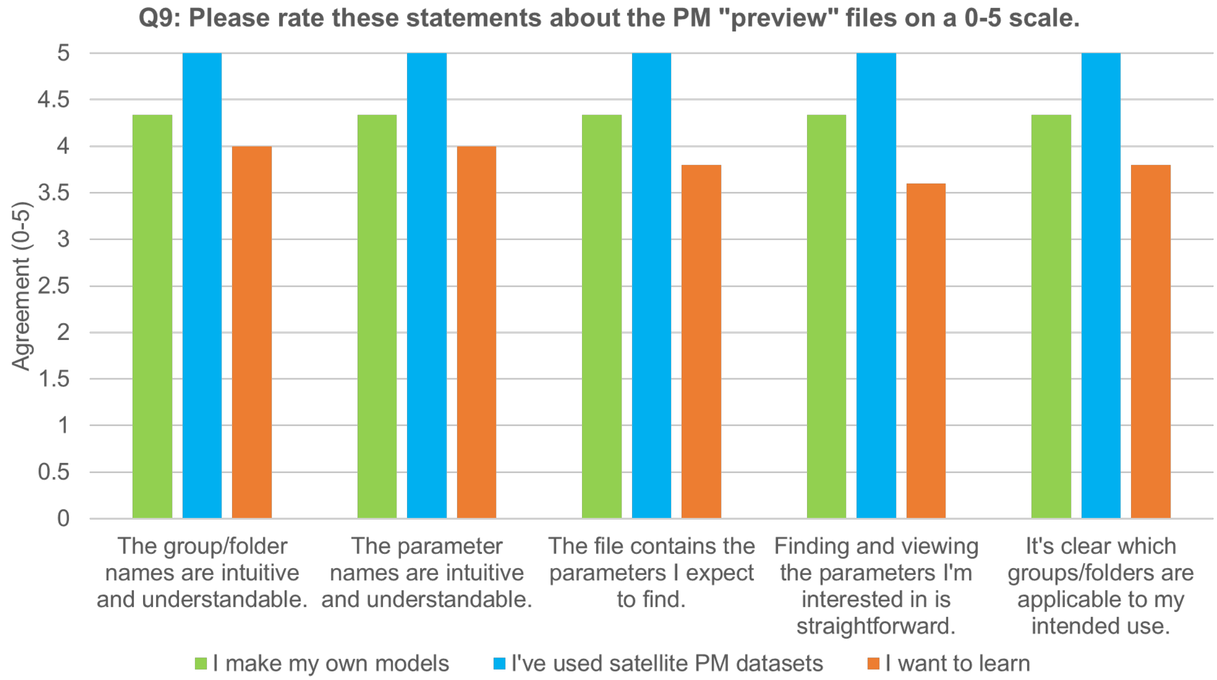

Figure 4. Participant ratings of the ease-of-use of the "preview" MAIA Level 2/Level 4 PM products, broken out by their response to the question, "Have you ever used PM datasets based on satellite data before?"

Participants also expressed a desire for brown carbon, particulate matter with aerodynamic diameter less than 1 micrometer (PM_1), radiative properties of speciated PM, and near-surface particle counts. While the MAIA team recognizes that these are quantities of importance to the study of air pollution, the team must focus first on meeting the science objectives agreed on with NASA. The team hopes that Early Adopters may be interested in investigating the utility of MAIA data for deriving these quantities in addition to the PM species that the MAIA products are currently planned to produce operationally.

3. Summary of TEMPO section – May 19, 2020

3.1 TEMPO mission updates

Recent updates on the TEMPO mission was the focus of this session. Complete details on the TEMPO mission and data products were provided to workshop attendees through pre-workshop slides. The TEMPO team also maintains an archive of past presentations that provide detailed information on the mission (http://tempo.si.edu/presentations.html).

Although the COVID-19 pandemic has led to increased risk of delays in mission progress, Kelly Chance, Principal Investigator of the TEMPO mission, noted that the TEMPO launch date is still expected in mid-2022. TEMPO will now be hosted on

Intelsat 40e at 91°W, which is a slight change from the previous position at 92.85°W. Minor updates to the specifications of the TEMPO FOR scans were also provided in this presentation including a spatial resolution of 2.0 x 4.75 km^2 at the center of the FOR.

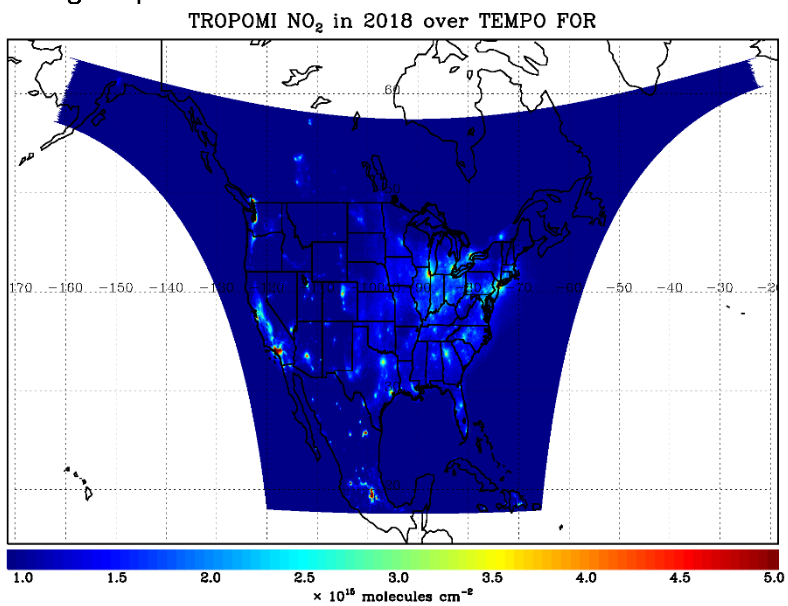

Figure 5. TROPOMI nitrogen dioxide product oversampled to the TEMPO grid. Image courtesy of Kang Sun on TEMPO team.

Tropospheric nitrogen dioxide data from the Tropospheric Monitoring Instrument (TROPOMI) aboard the ESA Sentinel-5P satellite were oversampled across the TEMPO FOR to highlight the TEMPO scan coverage (Figure 5). The sub-urban pixel resolution of TEMPO over Los Angeles and Puerto Rico was also shown in this presentation.

Xiong Liu, Deputy Principal Investigator of the TEMPO mission, discussed some important updates to trace gas retrieval algorithms and data products that directly impact early adopter activities. Aerosols products, including AOD, single scatter albedo, and aerosol absorbing index, along with sulfur dioxide and glyoxal were previously removed as baseline product requirements of the mission, but the science team plans to reintroduce these products after completing the version 2 algorithms by late summer or early fall 2020. Accuracy of the trace gas retrievals depend on cloud fraction and cloud pressure from the cloud retrieval algorithm. A complete list of data products expected for operational processing are shown in Table 1. Key outputs of trace gas products consist of slant column densities (SCD), total column and tropospheric vertical column densities (VCD), errors, quality flags, and cloud fraction and pressure. The ozone product also provides 0-2 km layer information, which will be critical to the early adopter activities and health and air quality applications of the TEMPO mission.

The current version 1 data products are limited to nitrogen dioxide and formaldehyde products. Version 2 release will include the ozone profile product with 0-2 km ozone (above surface) along with updates to the formaldehyde, nitrogen dioxide, and cloud products. Once complete, the version 2 synthetic TEMPO data products will be

Table 1. Specifications of expected data products from TEMPO. Cloud algorithm (OMCLDRR) may be changed to algorithm developed by NASA Goddard Space Flight Center.

Level	Product	Algorithm	Major Outputs	Res km[2] **	Freq/Size
L1-b	irradiance	SAO L0-1	Calibrated & quality flags		daily
	radiance	SAO L0-1	Geolocated,calibrated, viewing,geolocation&quality flags	2.0 x 4.75	Hourly, granule
L2	Cloud	OMCLDRR*	Cloud fraction, cloud pressure	2.0 x 4.75	Hourly, granule
	O_3 profile	SAO O3 profile	O3 profile, total/strat/trop/0-2 km O3 column, errors, a priori, AKs	8.0 x 4.75	Hourly, granule
	Total O_3	TOMS V8.5	Total O3, AI, cloud fraction	2.0 x 4.75	Hourly, granule
	NO_2	SAO trace gas, BU strat/trop sep.	SCD, strat./trop. VCD, error, shape factor, scattering weights	2.0 x 4.75	Hourly, granule
	H_2CO	SAO trace gas	SCD, VCD, error, shape factor, scattering weights	2.0 x 4.75	Hourly, granule
	$C_2H_2O_2$	SAO trace gas		2.0 x 4.75	Hourly, granule
	H_2O	SAO trace gas		2.0 x 4.75	Hourly, granule
	BrO	SAO trace gas		2.0 x 4.75	Hourly, granule
	SO_2	OMSO2 PCA	SCD, VCD (PBL,TRL,TRM,TRU,STL)	2.0 x 4.75	Hourly, granule
	Aerosol	OMAERUV	AAI, AOD, SSA	8.0 x 4.75	Hourly, granule
L3	Gridded L2	SAO L2-3	Same as L2	TBD	Hourly, scan
L4	UVB	OM UVB	UV irradiance, erythemal irradiance, UVI	TBD	Hourly, scan
	AQ Index	EPA, Washington U. St. Louis	Air quality index	TBD	Hourly, scan

distributed to early adopters to aid pre-launch activities of the program. Development of a version 3 product for operational processing is also planned, which will be based on trace gas climatology from the NASA GEOS Composition Forecasting (GEOS-CF). Both near real-time (NRT) and offline trace gas products are being considered by the TEMPO team, with expected NRT data latency of 2-3 hours. Synthetic level 2 products for early adopter activities will consist of a fast and operational version. The fast version of the nitrogen dioxide, formaldehyde, and ozone products will be completed by late summer or early fall 2020 (version 2 release). Actual operational retrievals are not performed for generating the fast products, instead trace gas fields from chemistry transport models are used to bypass the computationally expensive radiance calculations. The operational synthetic products are currently being developed by the science team, but data production is extremely slow due to radiance calculations.

Planned aerosol retrievals and products were also discussed. Phase 1 aerosol products of AOD and single scatter albedo using 354 and 388 nm measurements from TEMPO will be ready by the launch date. These products utilize the heritage algorithms from the NASA Ozone Monitoring Instrument (OMI). Phase 2 aerosol products of aerosol layer height and AOD (688 nm) using a newer algorithm that employs the 680 and 688 nm measurements are planned for the future.

3.2 TEMPO Data Distribution

In this session, ASDC and NASA Short-term Prediction and Research Transition (SPoRT) Center provided details on their data distribution activities and plans for the NASA TEMPO mission.

ASDC will be the primary distribution center of level 1 to level 3 products from the TEMPO mission. TEMPO data files will be indexed by variable, date, scan, and granule, and archived in Netcdf4 format with their respective metadata record. ASDC provides tools and services including NASA Earthdata search, NASA Worldview, HTTPS data access, and example scripts. A new ASDC website (https://asdc.larc.nasa.gov/) has been developed with filters by discipline and tools, keyword search bars, new stories, and outreach activities. ASDC data can also be accessed from the direct data download section of new website, which will soon have a landing page for the TEMPO mission. ASDC science outreach and support activities include development of data user guides, GIS tools, Esri ArcGIS story maps, and tools for data analytics. TEMPO data will also be available through the EPA Remote Sensing Information Gateway (https://www.epa.gov/hesc/remote-sensing-information-gateway).

The NASA SPoRT Center at the Marshall Space Flight Center collocated with the University of Alabama in Huntsville plans to supplement the TEMPO data distribution activities. The SPoRT Center employs a unique research-to-operations / operations-to-research (R2O/O2R) paradigm that builds and maintains interactive partnerships with users, integrates data in user decision support tools, creates applications-based training material, and performs targeted product assessments. This R2O/O2R approach aims to ensure the sustained use of TEMPO data in operations, which will enhance the value of the data products in the user community. The TEMPO DPA Lead is affiliated with the NASA SPoRT Center; therefore, researchers at the center have been key partners in the TEMPO Early Adopters Program. During the pre-launch phase of the mission, the TEMPO DPA Lead and NASA SPoRT Center have developed early visualizations of synthetic TEMPO products (Figure 6) that can be accessed through the data page of the TEMPO applications site (https://weather.msfc.nasa.gov/tempo/data.html). SPoRT Center will begin distributing synthetic level 2 products to early adopters after the science team completes the version 2 fast products in late summer or early fall 2020.

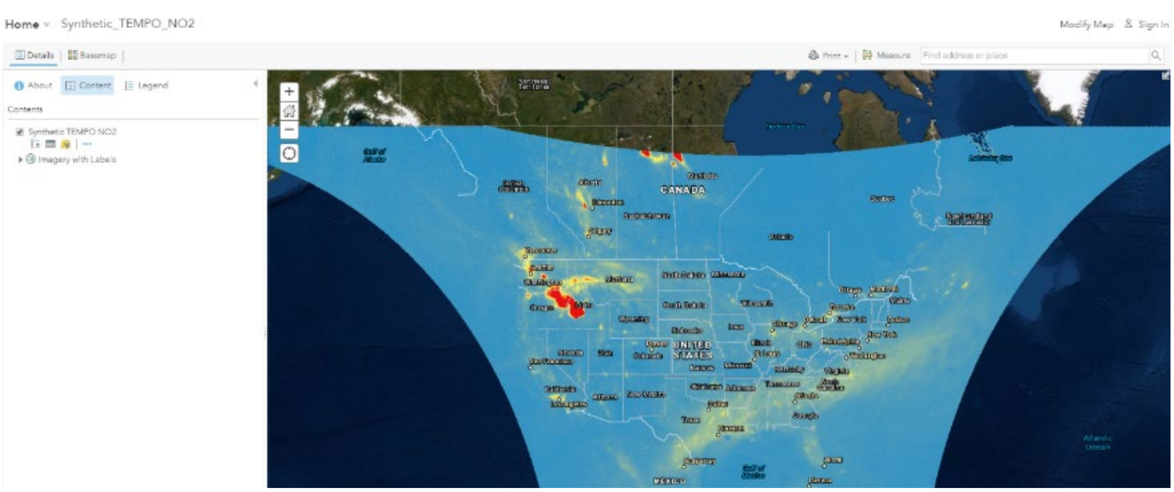

Figure 6. ArcGIS visualization of tropospheric nitrogen dioxide from synthetic TEMPO products at NASA SPoRT.

Future versions of synthetic TEMPO products will also be distributed by the center. The synthetic products will enable successful interactions with users to identify preferred data interfaces, file formats, and products in an effort to promote effective and immediate use of operational TEMPO data. Post-launch plans of the SPoRT Center include distributing TEMPO NRT Level 3 and 4 products depending on user needs, providing visualization tools, and developing training material and product assessments. Due to the added complexities of the non-standard operational scans of TEMPO, the SPoRT Center also plans to help manage the high-time data products to users.

3.3 TEMPO Applications: Planning and Assessment

Potential benefits of TEMPO data for air quality management decisions have been a focus area of previous TEMPO Early Adopter workshops. Based on previous workshop outcomes and follow-up discussions, the TEMPO DPA Lead selected several key early adopters to present their perspective on application benefits of future TEMPO data in air quality planning and assessment activities.

Tom Moore from the Western States Air Resources (WESTAR) Council and Western Regional Air Partnership (WRAP) air quality program focused on the application of TEMPO data in the western region. Regional haze rule planning for state implementation plans is a mandate under the Clean Air Act, which requires an extensive effort and collaboration between 15 western states (Figure 7). The impacts of mobile, international, and smoke emissions are areas of concern for regional haze rule planning and air quality health standards in the western region. Remote sensing data are not regularly applied in these air quality management and planning decisions, since routine regulatory analyses are not integrated with the data in a manner that typical agencies can access them. This current gap between remote sensing science data and air quality regulatory agencies will continue to grow due to the rapidly increasing complexity and size of new (e.g., GOES-16/17 Advanced Baseline Imager (ABI), TROPOMI) and future (e.g., TEMPO, MAIA, GeoCarb) remote sensing datasets. To ensure the enhanced capabilities of new remote sensing instruments are effectively utilized by air quality regulatory agencies, the presenter addressed the need to integrate agencies' data with

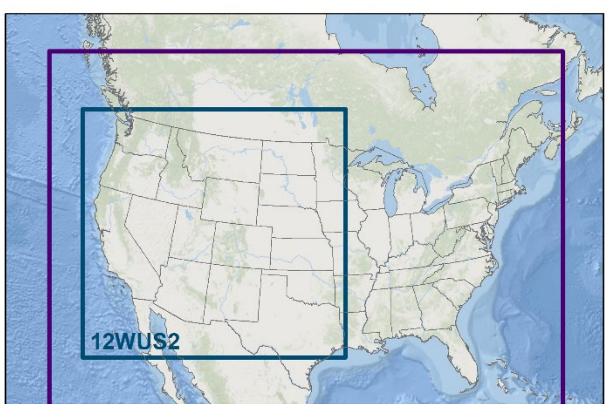

Figure 7. Grid configuration used in the WESTAR-WRAP Regional Haze modeling platform with outer domain at 36-km resolution (purple) and inner nest at 12-km resolution (green).

remote sensing data in usable formats and resolution and to better engage these agencies on the new satellite products, especially for TEMPO. The Weight of Evidence (WoE) was also discussed, which is a necessary and critically important component of ozone and particulate matter attainment demonstration for air quality planning. TEMPO will fit perfectly into the WoE as the unprecedented data products will support modeled attainment demonstrations by improving modeling and trend analyses in ambient concentrations and emissions.

In preparation for the TEMPO mission, the EPA Office of Research and Development discussed their surface air quality monitoring plans in the Photochemical Assessment Monitoring Stations (PAMS) program. This program requires state-of-the-art regulatory grade measurements of nitrogen oxides, formaldehyde, carbon monoxide, and speciated volatile organic compounds, along with meteorology and hourly boundary layer or mixed layer height measurements. The Enhanced Monitoring Plan (EMP) element of the PAMS program is intended to provide air quality agencies flexibility to implement monitoring to address data gaps in their particular areas. As part of the validation team of the TEMPO mission, the EPA, in collaboration with the NASA Pandora Project, is implementing a subset of surface air quality sites to host Pandora spectrometer instruments that will contribute to the larger Pandonia Global Network. Deployment of Pandora instruments at up to 40 sites is possible by October 2021, which includes placement at EPA-operated Clean Air Status and Trends Network (CASTNET) sites. The deployment of Pandora instruments will provide necessary validation data to make air quality management decisions in a defensible manner. The EPA showed excellent agreement between tropospheric nitrogen dioxide measurements from the new-generation TROPOMI and Pandora, which highlighted the ability of the TROPOMI and future TEMPO data to provide forecasters relevant information on nitrogen dioxide plume movement, especially when combined with other relevant measurements. The importance of planetary boundary layer monitoring in understanding the connection between surface air quality and column integrated measurements was also stressed. Ceilometers offer a low cost and reliable option for continuous measurements of the planetary boundary layer that can provide critical supplementary information for the high spatiotemporal scale data from TEMPO.

Detailed measurements of ozone and aerosol structures throughout the troposphere from the Tropospheric Ozone Lidar Network (TOLNet) are another key source of validation data for the TEMPO mission. TOLNet has shown that trace gas and aerosol structures exhibit substantial spatiotemporal variability in a few locations over the TEMPO FOR. Synergy of space-borne with ground-based (and aircraft) lidars and other sensors offer the best approach to measure and diagnose important air-quality structures and processes in a modeling framework. The integration and application of these measurements will be key to achieving the objectives of the TEMPO mission.

The Colorado Department of Public Health and Environment (CDPHE) discussed the potential benefits of applying TEMPO data in their operations. Use of the high spatiotemporal data from TEMPO can be particularly beneficial in the serious non-attainment area for ozone in the Colorado northern Front Range where an insufficient coverage of ground-based monitoring instruments exist. An ozone exceedance event across northern Colorado in April 2020 was discussed. Post-event analysis of TOLNet and ozonesonde data at Boulder, CO confirmed that the enhanced total column ozone measurements from the Ozone Mapping Profiler Suite (OMPS) were related to a stratospheric intrusion (Figure 8). The CDPHE noted that high spatiotemporal information from operational TEMPO data will be critical for monitoring the evolution of these exceedance events as they occur. Discrimination of low-level (0-2 km) and tropospheric ozone will add confidence in forecasts where stratospheric influence/exchange is suspected and support documentation of events that exceed National Ambient Air Quality Standards. Lastly, CDPHE highlighted that the additional trace gas and aerosol measurements from TEMPO will add value for source identification and pollutant forecasting and monitoring activities.

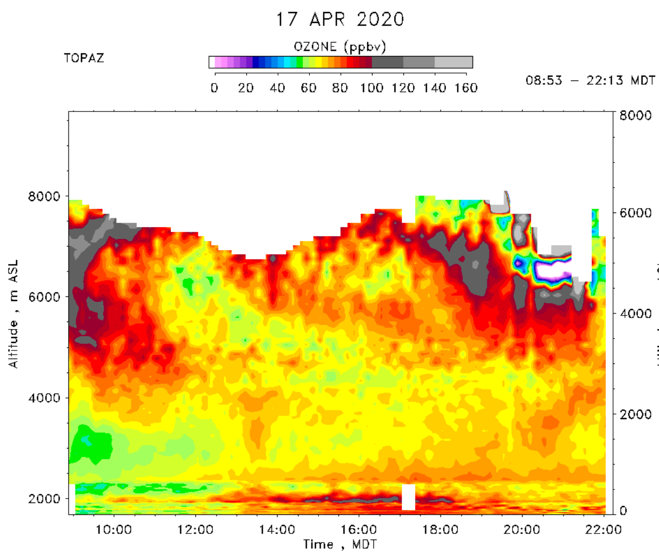

Figure 8. TOPAZ lidar ozone measurements from TOLNet site at Boulder, CO showing presence of higher ozone concentrations in elevated layers on April 17, 2020. Courtesy of Andrew Langford at NOAA Earth System Research Laboratories and presented by Dan Welsh at CDPHE.

3.4 TEMPO Applications: Air Quality Forecasting and Health

This session featured presentations focused on air quality forecasting and health applications from several key early adopters. These applications have been recognized as important elements of the TEMPO mission in previous Early Adopter workshops. The presentations in this workshop aim to expand on this application area.

Initial work on assimilating trace gas retrievals from TEMPO with the Weather Research and Forecasting model coupled with Chemistry (WRF-Chem) / Data Assimilation Research Testbed (DART) was discussed. This project is preparing for hourly trace gas data from TEMPO by building an effective assimilation system using synthetic products during the pre-launch phase of the mission, with a particular emphasis on the unprecedented ozone profiles (0-2 km) from TEMPO. New versions of synthetic TEMPO products will be utilized by this project to ensure the assimilation system is fully operable for real TEMPO data.

NOAA highlighted their current capabilities and future plans in air quality forecasting. Their National Air Quality Forecast Capability currently provides 48-hour predictions of ozone, $PM_{2.5}$, smoke, and dust over the CONUS from the Global Ensemble Forecast System (GEFS) – Aerosol member, with plans to develop assimilation of AOD and improved representation of biomass burning emissions. NOAA is also currently testing and evaluating the Global Forecast System (GFS) and Community Multiscale Air Quality (CMAQ) model, which will extend ozone and PM2.5 predictions to 72 hours. TEMPO will provide valuable trace gas and aerosol data that can further advance this operational air quality system.

NOAA also discussed synergistic opportunities using ABI and TEMPO measurements for $PM_{2.5}$ applications in this session. People do not breathe 24-hour average $PM_{2.5}$; therefore, it is important to understand the diurnal variability of PM2.5 using the high temporal data from geostationary instruments. However, many factors influence the scaling of AOD to surface $PM_{2.5}$. Deriving a suite of aerosol products synergistically from collocated satellite systems may bring new insights to addressing this problem. The utility of combining imager and spectrometer measurements to derive aerosol type using Visible Infrared Imaging Radiometer Suite and TROPOMI was demonstrated in this presentation. This work could be extended to operate with the geostationary satellite constellation including ABI and TEMPO over North America.

The Department of Environmental Medicine and Public Health at Icahn School of Medicine at Mount Sinai echoed the message from NOAA that no one breathes 24-hour averaged air when discussing NRT public health applications from TEMPO products in New York City and Mexico City. Past studies have focused mostly on investigating the role of daily averaged exposures of individual air pollutants on public health. Advanced studies on the role of sub-daily mixtures of air pollutants could help understand disease etiology and potential mitigation strategies. This could be accomplished by integrating NRT TEMPO products and syndromic surveillance / electronic health records in New York City for ongoing monitoring of exposure and health. TEMPO could also leverage the dense ground-based monitoring network across Greater Mexico City (Figure 9), which provides hourly averages from continuous measurements of key trace gases and

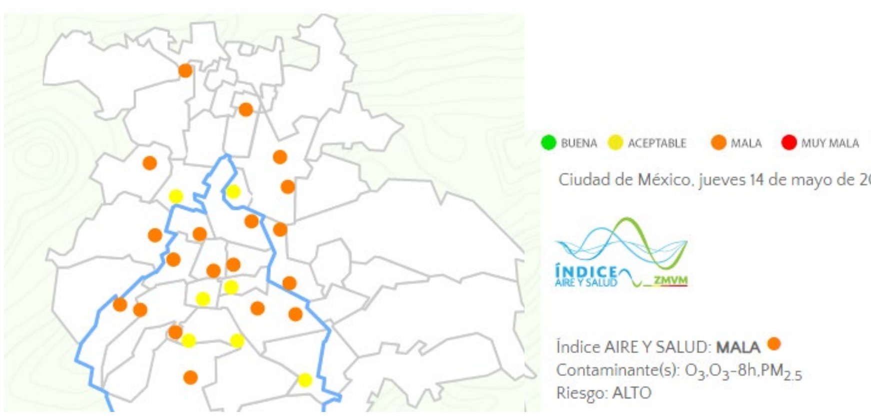

Figure 9. Daily Mexican Air Quality Index at ground stations across Greater Mexico City showing acceptable and bad air quality in the region.

PM, to construct an empirical Air Quality Index for the region. Since New York City and Mexico City reside within MAIA target areas, MAIA aerosol products could be integrated with TEMPO products to further aid air quality and health studies in these cities.

3.4 Demonstration of Synthetic TEMPO Data

For this session, the TEMPO DPA provided information on new and future versions of synthetic TEMPO products along with file size and naming conventions. The location and time of individual data granules across the TEMPO FOR were also shown to workshop participants, as many users will not require data over the entire FOR. The TEMPO DPA also highlighted the application of hourly TEMPO data for monitoring rapidly evolving nitrogen dioxide within smoke plumes (Figure 10) and conducting source attribution studies of mobile and stationary emissions.

A brief demonstration of the version 1 fast synthetic TEMPO nitrogen dioxide and formaldehyde products along with a sample operational file was also provided to workshop participants. Participants were instructed on how to browse and visualize the fast synthetic data files in NetCDF-4/HDF5 format using the NASA Panoply tool. The TEMPO DPA Lead discussed the different groups and variables within the fast synthetic files, and showed how to plot and visualize the total column and tropospheric VCD product variables in the files using Panoply. Other important variables including quality flags and cloud pressure and cloud fraction were discussed. Differences between the fast and operational synthetic data files were also shown to workshop participants. Lastly, a demonstration on how to display the fast synthetic TEMPO products using the ArcGIS portal developed by the TEMPO DPA Lead and the NASA SPoRT Center was provided in this session.

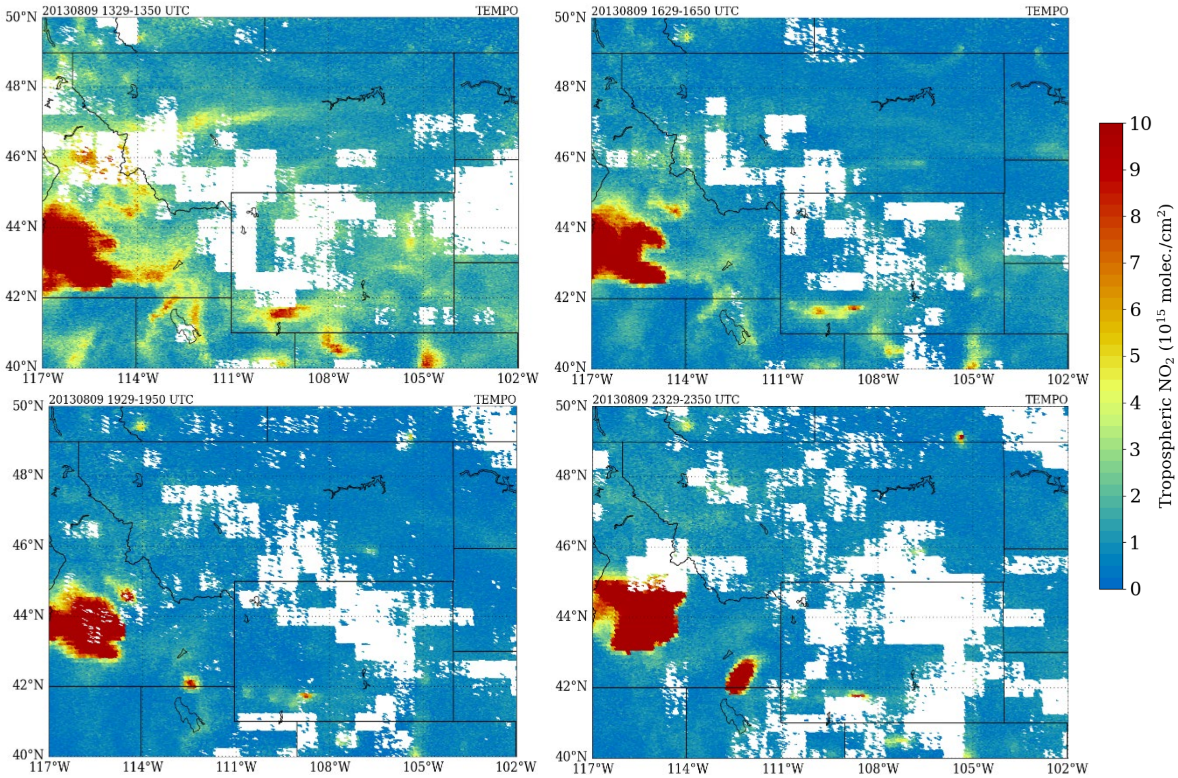

Figure 10. Synthetic TEMPO tropospheric nitrogen dioxide VCDs for a large fire event on August 9, 2013. Hourly TEMPO scans during early morning (top left), mid-morning (top right), early afternoon (bottom left), and evening (bottom right) are shown.

3.5 TEMPO and MAIA Synergy

The workshop concluded with a couple presentations from early adopters involved with both the TEMPO and MAIA missions. First, the synergistic use of MAIA and TEMPO data for urban air quality management was discussed. This presentation used OMI and TROPOMI data as proxies for TEMPO and MODIS and MISR as proxies for MAIA to construct a top-down synergistic approach to update bottom-up emissions with a focus on China. OMI sulfur dioxide measurements successfully constrained sulfur dioxide emissions in China using an inverse modeling approach with observational constraints, which led to improved air quality forecasts in the region. Improved air quality simulations using a joint inversion of sulfur dioxide and nitrogen oxide emissions from OMPS were also highlighted. Interestingly, this presentation showed very similar results on sulfur dioxide emissions when applying different top-down constraints using MODIS AOD and OMI sulfur dioxide measurements. Overall, these results have important implications for constraining and downscaling emissions using future TEMPO and MAIA data. Synthetic data products generated from WRF-Chem simulations, which are used by the MAIA algorithm, are in development in an effort to produce synthetic data for both MAIA and TEMPO for early adopters in three MAIA PTAs. The effort in producing TEMPO synthetic data from WRF-Chem model output is being done in collaboration with the TEMPO DPA Lead.

The next presentation focused on the synergistic application of MAIA and TEMPO for environmental health research. Similar to previous presentations, it was stressed that people are exposed to mixtures of air pollutants instead of individual ones. The synergy between MAIA and TEMPO could provide integrated multipollutant datasets to support epidemiological studies that systematically investigate a range of pollutants and their potential independent, synergistic, and antagonistic effects. There are numerous potential health effects from different exposures (acute, chronic, short-term) to both PM2.5 and ozone, and the synergistic application of MAIA and TEMPO data could help better understand these health effects. It was also noted that the impacts of nitrogen dioxide on health is an emerging focus area with recent research showing independent effects. Lastly, MAIA and TEMPO data could be used to study the impacts of air pollution mixtures on health.

This session concluded with a brief discussion on the potential of using crowdsourcing to create an algorithm to predict surface-level concentrations of air pollutants for a point in time and space. Crowdsourcing algorithms could benefit the development of data products for both the MAIA and TEMPO missions. The potential of this approach was highlighted in a challenge included in the 2019 NASA SpaceApps crowdsourcing event, which was designed by Ethan McMahon of the EPA, and Caroline D'Angelo, John Kerekes, and Stephanie Meredith of the U.S. Department of State, in collaboration with Abbey Nastan of MAIA. Ninety-one teams from all over the world participated in the challenge, and while most developed visualization tools rather than algorithms, it was a clear demonstration of the great public interest in better access to air quality information.

4. Conclusions and recommendations

Attendees rated the workshop highly, giving a response of 4.4 out of 5 to the statement "I learned what I wanted to get out of the workshop" on May 18 and 4.2 out of 5 to the same statement on May 19. Additionally, attendees rated the statement "I enjoyed participating in the workshop" at 4.5 on May 18 and 4.2 on May 19. Overall, the workshop was effective at conveying information; attendees' average rating of the statement "I know how to get involved with MAIA" increased from 2.9 to 4.3 and "I know how to get involved with TEMPO" increased from 3.2 to 4.2. This indicates that, while some compromises were necessary in order to accommodate the limitations of a completely virtual workshop due to COVID-19, the workshop was an overall success and did accomplish the objectives stated in the introduction of this report. Some attendees even preferred the online format: One anonymous response stated, "Great workshop, learned a lot! As a bonus, I was able to hear a lot more than I usually can during in-person meetings. The text-based chat was excellent."

A note about the 100% virtual format: Given the likelihood that virtual events will be necessary for quite a while longer due to COVID-19, we will include some thoughts on this workshop's virtual format and how to mitigate the downsides of this workshop style. Participants were polled on their personal pet peeves for online workshops beforehand, and their largest dislikes were lack of interaction and networking, telecon woes including unmuted lines and trouble logging in, and not enough breaks. Therefore, our recommendations for online workshops are the following:

- The use of an online feedback tool like Mentimeter is critical to increase the interactivity of the workshop and lend an element of fun. Mentimeter has several advantages for this type of event, including that: feedback is anonymous; it can be used on any internet-connected device (computer, phone, etc.) and is free to participants; it offers live results for real-time analysis; it can also be used to obtain feedback offline at participants' leisure; it supports many question types and has quiz capabilities for knowledge checks; and it provides data export for later analysis.
- In addition to as much interaction as possible through Mentimeter, having shorter talks, longer breaks, and keeping the schedule to half-days is critical to allow participants to stay focused and accommodate multiple time zones in North America. Recording the workshop was also helpful to those on other continents or with additional obligations.
- Having a second person solely tasked with managing the telecon software (Webex in this instance), in addition to the meeting host/presenter, is critical to ensure lines are muted and chat questions and virtual hands raised are addressed in a timely fashion.
- To offer networking opportunities for those who wanted them, we set up a forum page on the workshop wiki space and encouraged interested people to post their contact information and discussion topics on the forum during the longer breaks. However, this activity was strictly optional since we knew some attendees would prefer to use this time to step away from their computer or complete some work tasks.

4.1 Recommendations to the MAIA team and actions taken

The MAIA portion of the workshop highlighted the fact that MAIA's Level 2 aerosol product needs to not only serve the more traditional user community of remote sensing aerosol products, but also provide the most effective inputs to allow users to generate their own PM prediction models in Secondary Target Areas where the MAIA team does not have resources to produce our own PM products (see section 2.3.2). Moreover, the product must accomplish both these tasks in a format that provides as much clarity and organization as possible to users.

Based on the feedback provided by the participants of this workshop, the MAIA team undertook a detailed review of the parameter naming and organization in the Level 2 Aerosol product. The adopted changes are too numerous to detail here individually, but in general, many parameters names were edited to reduce potentially confusing abbreviations and to replace ambiguous parameter names with more specific ones, while simultaneously employing NetCDF long names to provide more information to users and make creating ready-to-publish plots and tables simple for the many at the workshop who indicated that they would use the NASA Panoply software or similar to visualize MAIA data. For example, the version of the product shown at this workshop had two parameters simply called "total," one each within the AerosolOpticalDepth and

SingleScatteringAlbedo groups. These parameters were renamed to “Total_AOD” and “Total_SSA,” while adding the long names “Total Aerosol Optical Depth” and “Total Single Scattering Albedo.” The team also decided to change the parameter naming convention to “title snake case,” both to improve readability and to match the convention established with the latest versions of the MISR aerosol product.

The names for the two size distributions of MAIA’s aerosol retrieval, previously called “coarse mode” and “fine mode,” have been renamed to “Mode 1” and “Mode 2” to avoid any associations with particular size descriptors used in the air quality or atmospheric chemistry communities. The Mode 1 distribution will have a smaller characteristic particle size than Mode 2.

In general, the workshop participants were very satisfied with the planned MAIA PM products, so no specific naming or organizational changes will be made at this time. However, the MAIA team will continue to note the requests made by workshop participants for parameter descriptions that are as complete and clear as possible as the team continues development of the product and parameter metadata for both the aerosol and PM products.

All of the changes described here will be reflected in the MAIA Simulated Data that will be available to Early Adopters in 2021. These pre-launch data products will be the result of the end-to-end software tests performed on the MAIA data production software after development is completed this year. The data products will reflect the complete file format (including metadata) that the operational MAIA data products will have, and will contain simulated results using Landsat and available PM surface monitor data as inputs. They are not intended for scientific or operational use, but to allow users to prepare to incorporate the operational MAIA data into their workflows after launch by providing a realistic picture of what the true data products will be like. Early Adopters will have the opportunity to provide further feedback on the updated Simulated Data at future Early Adopter workshops, and any further changes can be incorporated into the operational MAIA data products in future software updates.

4.2 Recommendations to the TEMPO team and actions taken

Workshop participants expressed a strong interest in the synthetic TEMPO products during the data demonstration session of the workshop. Distributing synthetic products to users will help grow interest in the TEMPO mission while expanding the Early Adopters and Applications Program. However, it is important that the synthetic data files are as close in structure to the expected operational files as possible. Several workshop participants expressed concern that the groups and variables in the version 1 fast synthetic files did not match the operational synthetic file. Furthermore, some participants were unsure on how to apply the cloud variables in the synthetic files. Current capabilities are in place to generate fast synthetic products for the period from July 2013 – June 2014, but generation of more recent products would help facilitate interactions with potential users of TEMPO data and ultimately grow the Early Adopters Program.

To resolve concerns of the workshop participants, the TEMPO team restructured the fast synthetic data files to better match the expected operational files. During this process, the TEMPO team found numerous other discrepancies in variable names, dimensions, and attributes between the synthetic and operational files. All issues have been corrected in the synthetic code. The TEMPO DPA Lead is now generating the updated fast synthetic products on the NASA SPoRT cluster, with plans to distribute to early adopters by late summer or early fall in 2020. The TEMPO team is also preparing short user guides and python scripts to help early adopters effectively process and display the synthetic TEMPO products. Finally, the TEMPO team is currently updating scripts to produce synthetic TEMPO products for more recent time periods, with capabilities now in place to generate synthetic products using GEOS-5 Nature runs from March – June 2016. Progress has also been made on producing synthetic products from GEOS-CF and high-resolution WRF-Chem simulations. High performance computing time on the NASA Center for Climate Simulation (NCCS) Discover platform has been requested by the TEMPO team to significantly speed up production of the operational synthetic TEMPO products.

Appendix A: Agenda

MAIA-TEMPO Early Adopters Workshop
Remote Meeting

Monday, 18 May 2020

UTC time | **Duration**

Welcome and introductions

UTC time	Session	Presenter	Duration
15:40	Webex setup and icebreaker questions	All	20
16:00	Introduction from NASA Applied Sciences Program	John Haynes	10
16:10	Introduction and welcome from TEMPO	Aaron Naeger	10
16:20	Introduction and welcome from MAIA	Abbey Nastan	10

MAIA: Recent project updates

UTC time	Session	Presenter	Duration
16:30	Pop quiz: Introductory MAIA material	All	10
16:40	Questions about MAIA introductory material	All	15
16:55	Update on the MAIA project and target areas	David Diner	15
17:10	Update on MAIA data product development	Scott Gluck	10
17:20	Special topic: Aerosol air pollution and COVID-19	Mike Garay/Sina Hasheminassab	10
17:30	Questions and discussion	All	10
17:40	Break		45

Example applications of MAIA data

UTC time	Session	Presenter	Duration
18:25	Health studies in Atlanta	Matt Strickland	10
18:35	Satellite applications for operational forecasts of emissions and air quality	Daniel Tong	10
18:45	Applications of Satellite Data at CDC's Environmental Health Tracking	Ying Zhou/ Fuyuen Yip	10
18:55	Questions/Discussion	All	10
19:05	Break	All	10

First look at MAIA data products

UTC time	Session	Presenter	Duration
19:15	MAIA product file walkthrough	Abbey Nastan	20
19:35	Discussion activity: Data file content	All	45
20:20	Questions/Summarization	All	30
20:50	Wrap-up and summary of future plans	Abbey Nastan	10
21:00	Adjourn		

MAIA-TEMPO Early Adopters Workshop
Remote Meeting

Tuesday, 19 May 2020

UTC time **Duration**

Welcome and introductions

16:00	TEMPO status	Kelly Chance	5
16:05	TEMPO Trace Gas Products	Xiong Liu	10
16:15	TEMPO Aerosol Products	Omar Torres	10
16:25	Questions and discussion	All	5

TEMPO Data Distribution

16:30	ASDC	Tim Larson	10
16:40	MSFC / SPoRT	Aaron Naeger	10

TEMPO Applications: Planning & Assessment

16:50	Application of TEMPO in air quality and planning studies	Tom Moore	15
17:05	Ground-based remote sensing capabilities at existing AQ monitoring sites	Luke Valin	10
17:15	TEMPO & MAIA - TOLNet Synergies: What Lidars bring to the Table	Mike Newchurch	10
17:25	The Benefits of Use of TEMPO Data for Air Quality Forecasting and Event Analysis	Dan Welsh	10
17:35	Questions and discussion	All	10
17:45	Break		35

TEMPO Applications: Air Quality Forecasting & Health

18:20	Assimilating TEMPO O3 and NO2 retrievals with WRF-Chem/DART: A first look at TEMPO O3 CPSR properties	Arthur Mizzi	10
18:30	NOAA's National Air Quality Forecast Capability	Ivanka Stajner	10
18:40	GOES-R/TEMPO synergy for PM2.5 applications	Shobha Kondragunta	10
18:50	Near real time public health applications from TEMPO products: syndromic surveillance in NYC and Mexico City's AQI	Allan Just	10
19:00	Special Topic: Trace gas pollution and COVID-19	Susan Alexander	10
19:10	Questions/Discussion	All	10
19:20	Break		10

Demonstration of Synthetic TEMPO Data

19:30	Synthetic TEMPO data products and use cases	Aaron Naeger	30

TEMPO & MAIA Synergy

20:00	Synergistic application of MAIA and TEMPO for urban air quality forecast and management	Jun Wang	15
20:15	Synergistic application of MAIA and TEMPO for air pollution and health effects	Yang Liu	15
20:30	Discussion and wrap-up / Future plans	All	30
21:00	Adjourn		

Appendix B: Attendees

Name	Affiliation	Country
Aaron Naeger	University of Alabama-Huntsville	United States
Abdullah Mahmud	California Air Resources Board	United States
Abigail Nastan	NASA/JPL	United States
Alex Kotsakis	NASA GSFC	United States
Allan Just	Icahn School of Medicine at Mount Sinai	United States
Allison Patton	Health Effects Institute	United States
Arlene Fiore	Columbia University	United States
Armistead Russell	Georgia Institute of Technology	United States
Arthur Mizzi	National Center for Atmospheric Research	United States
Austin Madden	Unknown	Unknown
Barry Lefer	NASA HQ	United States
Beth Huffer	Lingua Logica	United States
Betsy Farris	Ball Aerospace	United States
Bill Murphey	Georgia Department of Natural Resources	United States
Brian Himes	Idaho Department of Environmental Quality	United States
Brian Tisdale	NASA ASDC	United States
Carol Bohnenkamp	EPA	United States
Caroline Nowlan	Harvard University	United States
Charles Davidson	Sunflower Alliance	United States
Chris Howard	NASA LaRC	United States
Chris Hurt	NASA LaRC	United States
Christian Pelayo	California State University Los Angeles	United States
Claudia Rivera	UNAM-Center for Atmospheric Sciences	Mexico
Cui Ge	South Coast Air Quality Management District	United States
Dan Goldberg	George Washington University	United States
Dan Lindsey	NOAA	United States
Dan Welsh	State of Colorado	United States
Dan Westervelt	Columbia University	United States
Daniel Carrión	Icahn Scool of Medicine at Mount Sinai	United States
Daniel Dix	Minnesota Pollution Control Agency	United States
Daniel Tong	George Washington University	United States
Danielle Groenen	NASA ASDC	United States
Dave Westenbarger	Texas Commission on Environmental Quality	United States
David Broday	Technion - Israel Institute of Technology	Israel
David Diner	NASA/JPL	United States
David Edwards	National Center for Atmospheric Research	United States
David Flittner	NASA LaRC	United States
David Krask	Maryland Department of the Environment	United States
David Williams	EPA	United States

Ebba Malmqvist	Lund University	Sweden
Eloise Marais	University of Leicester	United Kingdom
Emily Prezzato	Centers for Disease Control and Prevention	United States
Erin Urquhart	NASA GSFC	United States
Ethan McMahon	EPA	United States
Fernando Santos	University of Maryland, College Park	United States
Gary Arcemont	San Luis Obispo Air Pollution Control District	United States
Greg Carmichael	University of Iowa	United States
Greg Frost	NOAA	United States
Greg Stover	NASA LaRC	United States
Guanyu Huang	Spelman College	United States
Hao Zhou	Arizona Department of Environmental Quality	United States
Haofei Yu	University of Central Florida	United States
Helen Wang	Harvard University	United States
Helena Chapman	NASA HQ	United States
Henian Zhang	Georgia Department of Natural Resources	United States
Holli Wecht	Bureau of Ocean Energy Management	United States
Huanxin Zhang	University of Iowa	United States
Hyung Joo Lee	California Air Resources Board	United States
Idit Belachsen	Technion - Israel Institute of Technology	Israel
Ivan Gutierrez-Avila	Instituto Nacional de Salud Pública	Mexico
Ivanka Stajner	NOAA	United States
Jacob Wolf	Idaho Department of Environmental Quality	United States
James Flynn	University of Houston	United States
James McDuffie	NASA/JPL	United States
James Podolske	NASA ARC	United States
Javier Martinez-Santos	University of Wisconsin-Madison	United States
Jay Al-Saadi	NASA LaRC	United States
Jeanne Holm	City of Los Angeles	United States
Jeff Walter	NASA ASDC	United States
Jennifer Lee	Ball Aerospace	United States
Jeremiah Johnson	Ramboll	United States
Jesse N Marquez	Coalition for a Safe Environment	United States
Jie Ban	China Center for Disease Control and Prevention	China
Jim Kelly	EPA	United States
Jin Xu	California Air Resources Board	United States
Joe Koch	NASA LaRC	United States
Joel Dreessen	Maryland Department of the Environment	United States
Joel Scott	NASA GSFC	United States
John Haynes	NASA HQ	United States
John Kerekes	Rochester Institute of Technology	United States
Jose Hernandez	Bureau of Ocean Energy Management	United States

Joshua Kalfas	Oklahoma Department of Environmental Quality	United States
Joshua Uebelherr	Maricopa County Air Quality Department	United States
Jun Wang	University of Iowa	United States
K Kirwa	University of Washington	United States
Kai Chen	Yale University	United States
Karin Ardon-Dryer	Texas Tech University	United States
Kelly Chance	Smithsonian Astrophysical Observatory	United States
Kembra Howdeshell	National Institutes of Health	United States
Ken Mooney	NOAA	United States
Kevin Briggs	State of Colorado	United States
Kristoffer Mattisson	Lund University	Sweden
Laura Judd	NASA LaRC	United States
Laura Rivers	The Getty Museum	United States
Le Kuai	NASA/JPL	United States
Leif Paulson	Wyoming Department of Environmental Quality	United States
Lixu Jin	University of Montana	United States
Lotta Mayana	South African Air Quality Information System	South Africa
Lu Hu	University of Montana	United States
Lukas Fehr	University of Saskatchewan	Canada
Luke Valin	EPA	United States
Madankui Tao	Columbia University	United States
Madeline Corona	The Getty Museum	United States
Madison Broddle	NASA ASDC	United States
Makhan Virdi	NASA ASDC	United States
Marc Carreras Sospedra	South Coast Air Quality Management District	United States
Marcin Kawka	Warsaw University of Technology	Poland
Maria Tzortziou	Columbia University	United States
Matt Strickland	University of Nevada-Reno	United States
Matthew Densberger	California Air Resources Board	United States
Matthew Johnson	NASA	United States
Melissa Lowe	University of Colorado Anschutz	United States
Mian Chin	NASA GSFC	United States
Michael Garay	NASA/JPL	United States
Michael Woodman	Maryland Department of the Environment	United States
Mike He	Columbia University	United States
Mike Newchurch	University of Alabama-Huntsville	United States
Mike Veto	Ball Aerospace	United States
Minghui Diao	San Jose State University	United States
Miriam Marlier	University of California Los Angeles	United States
Monika Kopacz	NOAA	United States
Myungje Choi	NASA/JPL	United States
Nash Skipper	Georgia Institute of Technology	United States

Nathan Janechek	University of Iowa	United States
Nathan Pavlovic	Sonoma Technology, Inc.	United States
Nick Witcraft	Minnesota Pollution Control Agency	United States
Nyasha Dunkley	Georgia Department of Natural Resources	United States
Olga Kalashnikova	NASA/JPL	United States
Omar Torres	NASA GSFC	United States
Peter Peterson	Whittier College	United States
Priyanka deSouza	Massachusets Institute of Technology	United States
Pubu Ciren	NOAA	United States
Raj Nadkarni	Texas Commission on Environmental Quality	United States
Randall Martin	Washington University in St. Louis	United States
Rebecca Buchholz	National Center for Atmospheric Research	United States
Richard Eckman	NASA HQ	United States
Rick Saylor	NOAA	United States
Rima Habre	University of Southern California	United States
Ronald Pope	Maricopa County Air Quality Department	United States
Rong Li	Idaho Department of Environmental Quality	United States
Rui Zhang	South Coast Air Quality Management District	United States
Sang-Mi Lee	South Coast Air Quality Management District	United States
Sanjana Paul	NASA LaRC	United States
Sara Strachan	Idaho Department of Environmental Quality	United States
Scott Gluck	NASA/JPL	United States
Sean Coogan	NASA LaRC	United States
Shobha Kondragunta	NOAA	United States
Sina Hasheminassab	South Coast Air Quality Management District	United States
Stephanie Shirley	Texas Commission on Environmental Quality	United States
Steve Hall	NASA	United States
Sue Chen	California Air Resources Board	United States
Sue Estes	University of Alabama-Huntsville	United States
Sujung Go	Yonsei University	South Korea
Susan Alexander	University of Alabama-Huntsville	United States
Susan Anenberg	George Washington University	United States
Terry Keating	EPA	United States
Timothy Larson	NASA ASDC	United States
Tom Moore	Western States Air Resources Council	United States
Vanessa Escobar	NOAA	United States
Vincent Beltran	The Getty Museum	United States
Vishal Bagadia	NASA LaRC	United States
Xi Chen	University of Iowa	United States
Xiong Liu	Harvard University	United States
Yanelli Nunez	Columbia University	United States
Yang Liu	Emory University	United States
Yaoxian Huang	Wayne State University	United States

Yeonjin Jung	Harvard University	United States
Ying Zhou	Centers for Disease Control and Prevention	United States
Yuanyuan Liu	Unknown	China
yzhoubj@gmail.com	Unknown	Unknown
Zhu Huanhuan	University of Michigan	United States