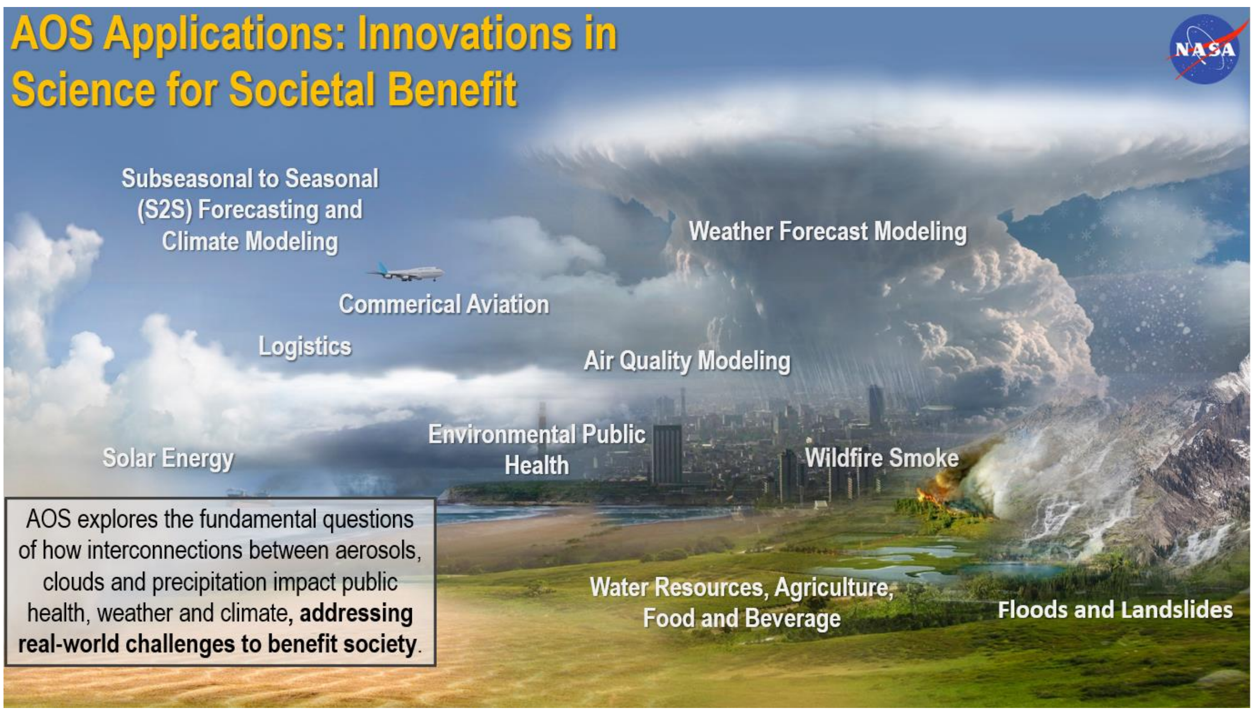
Atmosphere Observing System (AOS) Community Assessment Report (CAR)

April 2022

The objective of this Community Assessment Report (CAR) is to provide an overview of key stakeholder communities and their needs relevant to the Atmosphere Observing System (AOS) in terms of their current use and potential application of data products for decision making. This report is based solidly on input from stakeholders and serves as a reference to articulate stakeholder needs as well as provide guidelines for how to optimize the applications benefit to communities of practice and communities of potential that may use the suite of AOS products.



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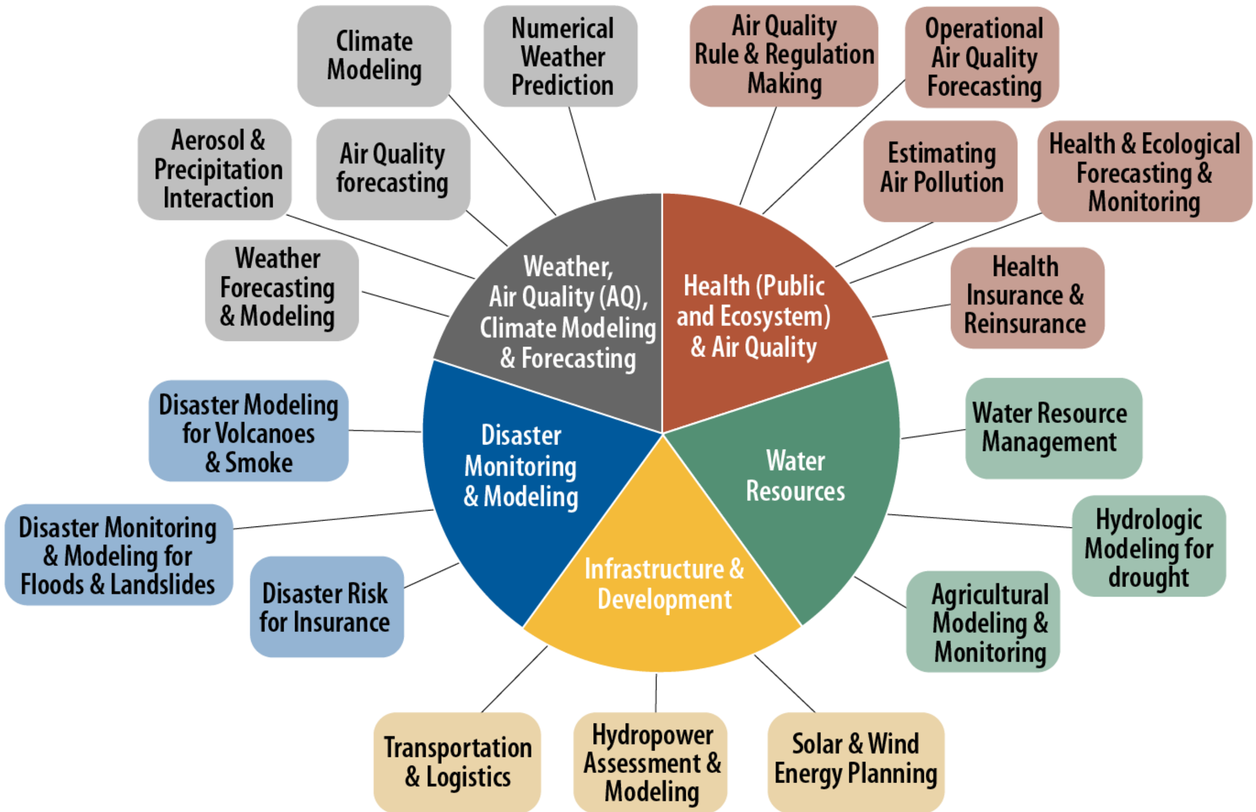
EXECUTIVE SUMMARY

The goal of this Community Assessment Report (CAR) is to distill input from stakeholders that will inform the Atmospheric Observing System (AOS) architecture options, design considerations, algorithm needs, data latency, and data product generation. During the mission study phase, referred to as the Aerosols, Clouds, Convection and Precipitation (ACCP) Study, we, the Applications Impact Team (AIT), solicited feedback from user communities (*both communities of practice* [those that routinely use satellite remote sensing data] and *potential* [those that do not yet use satellite remote sensing data]) that may benefit from data products developed from the proposed observations and instrument suite. The main findings of our community assessment are summarized in this CAR, which will be maintained as a living document throughout the mission lifecycle. From this community feedback, we provided a summary of key findings and suggested recommendations in a complementary report entitled, *AOS CAR Findings and Recommendations*, for the AOS team to enhance the applications value throughout the AOS mission life cycle. The AIT solicited feedback from the AOS team on this complementary report, and there was wide agreement across the team that this separate *AOS CAR Findings and Recommendations* document was an effective way to communicate applications desires and NASA opportunities to enhance applications. The CAR, along with the complementary report, will support the development of the Project Applications Plan, formation of an Early Adopters program, and creation of illustrative use cases to characterize and articulate stakeholder's decision makings.

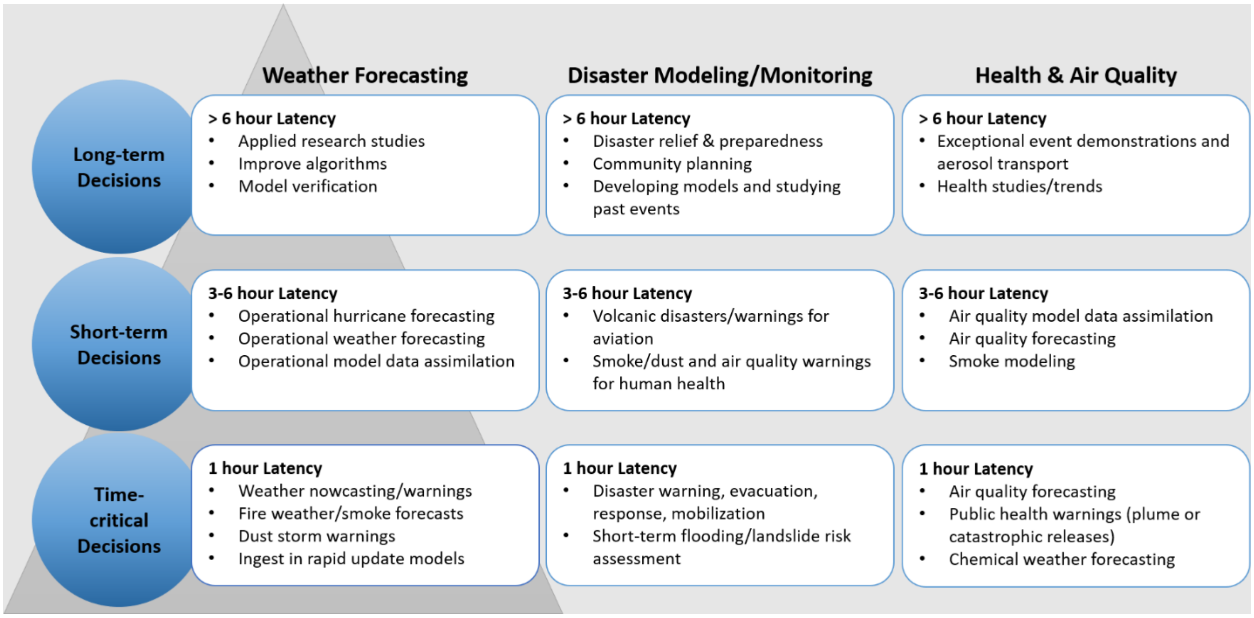
In our assessment of stakeholder communities, we leveraged our existing contacts, including those from relatively nascent communities (e.g., human health, environmental justice), through NASA and partner missions (e.g., Terra Multi-angle Imaging SpectroRadiometer [MISR], Global Precipitation Measurement [GPM]), NASA Applied Sciences programs (e.g., Health and Air Quality Applied Sciences Team [HAQAST], Applied Remote Sensing Training Program [ARSET]), and mission early adopter programs (e.g., Tropospheric Emissions: Monitoring of Pollution [TEMPO], Multi-Angle Imager for Aerosols [MAIA], Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats [TROPICS], and Plankton, Aerosol, Cloud, ocean Ecosystem [PACE]). Through these stakeholder engagements, we identified approximately 70 potential applications that may benefit from AOS data (Applications Traceability Matrix) and organized them into 19 high-level categories of enabled applications that could benefit from future AOS observations. NASA also contracted Research Triangle Institute (RTI) International to help identify and assess new communities that could benefit from these observations. For the CAR purposes, we down selected to 10 user communities. The focus on 10 communities for this version of the CAR is to go in more depth and highlight examples and opportunities within each community to use mission data. We will increase the number of communities characterized in future versions of the CAR as additional engagement and information from these communities evolves. Lastly, we stress that the AOS architecture system is still under development and changes in the architecture could impact application opportunities across communities.



***AOS enabled applications** divided into five core areas that roughly align with NASA Applied Sciences programs.*

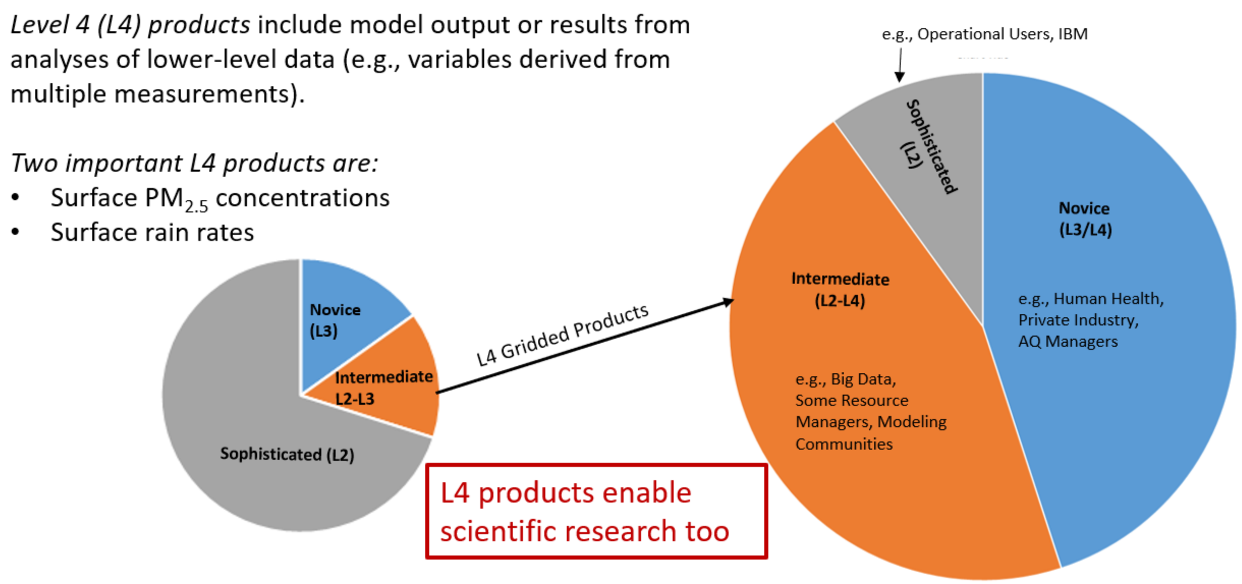
In our assessment of stakeholder communities for each of the enabled applications, we found the following *common features and requirements* among most or all of the communities:

Diverse Needs of Stakeholders, including within a Given Community: We found that several communities have distinct requirements to integrate AOS satellite data into their operating procedures and that these requirements often vary widely within subcommunities of a given community. For example, satellite data latency is critical for subcommunities tasked with making time-critical decisions, such as for issuing weather and disaster warnings, and longer latencies are acceptable, for example, for model development and validation. Other distinct requirements include continuity of data with the Program of Record (POR) and complete spatio-temporal coverage of satellite data products.



***Desired stakeholder latencies** for Weather Forecasting, Disasters, and Health and Air Quality that are common AOS applications.*

Wide Range of Organizational Resources and Capacity: We found that majority of stakeholders agencies (i.e., both communities of practice and potential) do not have the financial resources to devote to hiring satellite data experts to download and process satellite data. That is, building the necessary capacity is simply not an option. Therefore, many stakeholders cited the need for NASA investment to facilitate the ease-of-access to AOS satellite data (e.g., via webtools that subset and process data, APIs) and, most importantly, the development of Level 3 (L3) and Level 4 (L4) data products (i.e., surface gridded rain rates and particulate matter 2.5 [$PM_{2.5}$]). *It should be noted here that the AOS mission will not likely provide the necessary data alone to support the generation of these L3/L4 data products. Consequently, NASA investment is necessary for the generation of these multi-mission L3/L4 data products.* However, providing easily accessed gridded datasets for desired observables, like precipitation and $PM_{2.5}$, is the single most impactful opportunity that NASA could take; the potential end users of gridded datasets is far-ranging, and the decisions made from these datasets is often critical to human health, infrastructure, and environmental resilience.



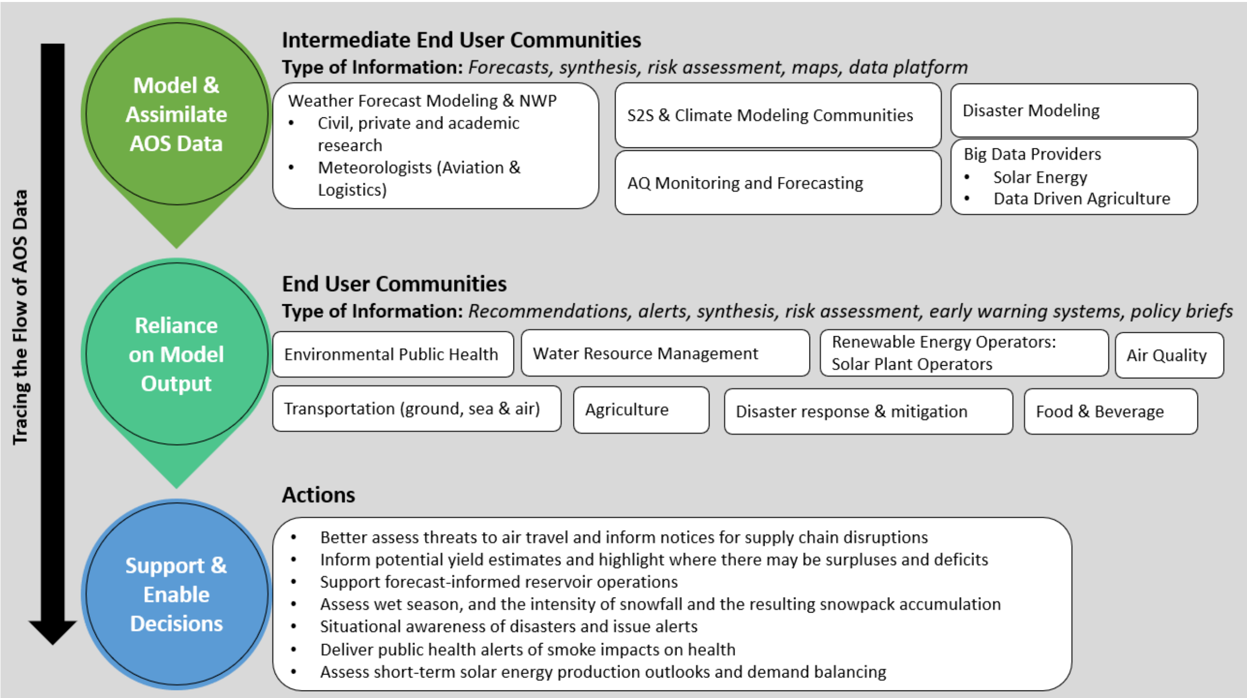
***The creation of L4 products** is an <u>untapped potential</u> that could significantly enable a range of stakeholders from communities of practice and communities of potential.*

Spectrum of Stakeholder Expertise with Satellite Data: We found a range of levels of expertise and comfort downloading and processing satellite data among the communities, but, more importantly, within a given community's subcommunities. For example, the human health community is largely a community of potential while numerical weather prediction (NWP) community is primarily a community of practice. However, the air quality community spans a wide range from communities of practice (e.g., California Air Resources Board [CARB], Texas Commission on Environmental Quality [TCEQ]) to communities of potential (e.g., more than half of U.S. state air quality agencies). In this sense, most communities should be viewed as communities of potential.

Hesitancy of the Accuracy of Satellite Data: We found that the majority of stakeholders were hesitant to incorporate satellite data into their operating procedures. These stakeholders cited a number of concerns, including the lack of characterization of data uncertainties, data products not being in quantities that they are familiar with, and poor validation of the satellite data with their *in situ* observations.

Reliance of Certain Stakeholder Communities on Intermediary Data Product Providers: *Many of the stakeholder communities do not work with satellite data themselves by choice, and, instead, rely on intermediaries or vendors to provide the L3/L4 data products that they require for their decision-making.* For instance, many communities rely on data products (e.g., forecasts) produced by the NOAA NWS or private companies such as Accuweather, and their decision-making is constrained based on the regions, resolutions, and temporal resolutions of data provided by intermediaries.

Reliance on Improved Models – Analysis of the Earth Observation (EO) Data User Value Chain: We found that most communities and sub-communities rely on or benefit from model output from a core group of communities of practice, primarily those who make time-critical decisions (i.e., weather, disaster, and air quality forecasters). Therefore, AOS satellite data that may be used to improve the representation of model processes, used to create improved data assimilation products, or improve model forecasts would benefit many more stakeholders than those who make time-critical decisions. For example, the improvement and development of air quality forecasts would significantly benefit the public health, transportation (including air, sea and ground-based), agriculture and solar energy communities as many of them rely on model output data and information to make decisions.



EO Value Chain for AOS Data. *Many communities would benefit from improved forecasts. Intermediate End User Communities represent communities that access data and translate information to support downstream users. End Users Communities most often rely on and receive much of their information from intermediaries so that they can make decisions and provide recommendations and alerts that directly impact society. Engaging with communities that directly access EO data for modeling and assimilation activities would significantly enable applications, and therefore decision-making, across several communities downstream. As such, details about an organization's characteristics, preferences, and perceptions towards directly or indirectly using AOS data helps target creative solutions and prioritize methods to maximize the benefit of AOS data for society.*

As we move forward through the AOS project life cycle, the AIT will continue to update and assess these findings in order to articulate key NASA opportunities that could enhance applications across several communities from pre-Phase A and beyond mission launch. As a result, the AIT will remain active in updating the CAR at the beginning of each mission life cycle phase, based on findings and experience working with end user communities, focus groups, panel discussions, and other activities as necessary. This includes continue assessment of the characterization and data technical needs of each community. As we, the AIT, will strive to update the CAR during each mission life cycle phase, we stress that the AOS architecture system is still under development and changes in the architecture could impact application opportunities. Therefore, we will also revisit the CAR after significant architecture developments to reflect the impact towards applications and discuss how new developments will meet the needs and/or desirements across communities.

1 INTRODUCTION

The goal of this Community Assessment Report (CAR) is to distill input from stakeholders that will inform the Atmospheric Observing System (AOS) architecture options, design considerations, algorithm needs, data latency, and data product generation. During the mission study phase, referred to as the Aerosols, Clouds, Convection and Precipitation (ACCP) Study, we, the Applications Impact Team (AIT), solicited feedback from user communities (*both communities of practice* [those that routinely use satellite remote sensing data] and *potential* [those that do not yet use satellite remote sensing data]) that may benefit from data products developed from the proposed observations and instrument suite. The main findings of our community assessment are summarized in this CAR, which will be maintained as a living document throughout the mission lifecycle. These findings will also support the development of the Project Applications Plan, formation of an Early Adopters program, and creation of illustrative use cases to characterize and articulate stakeholder's decision makings.

In our assessment of stakeholder communities, we leveraged our existing contacts, including those from relatively nascent communities (e.g., human health, environmental justice), through NASA and partner missions (e.g., Terra MISR, GPM), NASA Applied Sciences programs (e.g., HAQAST, ARSET), and mission Early Adopter programs (e.g., TEMPO, MAIA, TROPICS, and PACE). Through these stakeholder engagements, we identified approximately 70 applications (Applications Traceability Matrix) and organized them into 19 high-level categories of enabled applications (Figure 1.1) that would likely benefit from future AOS observations.

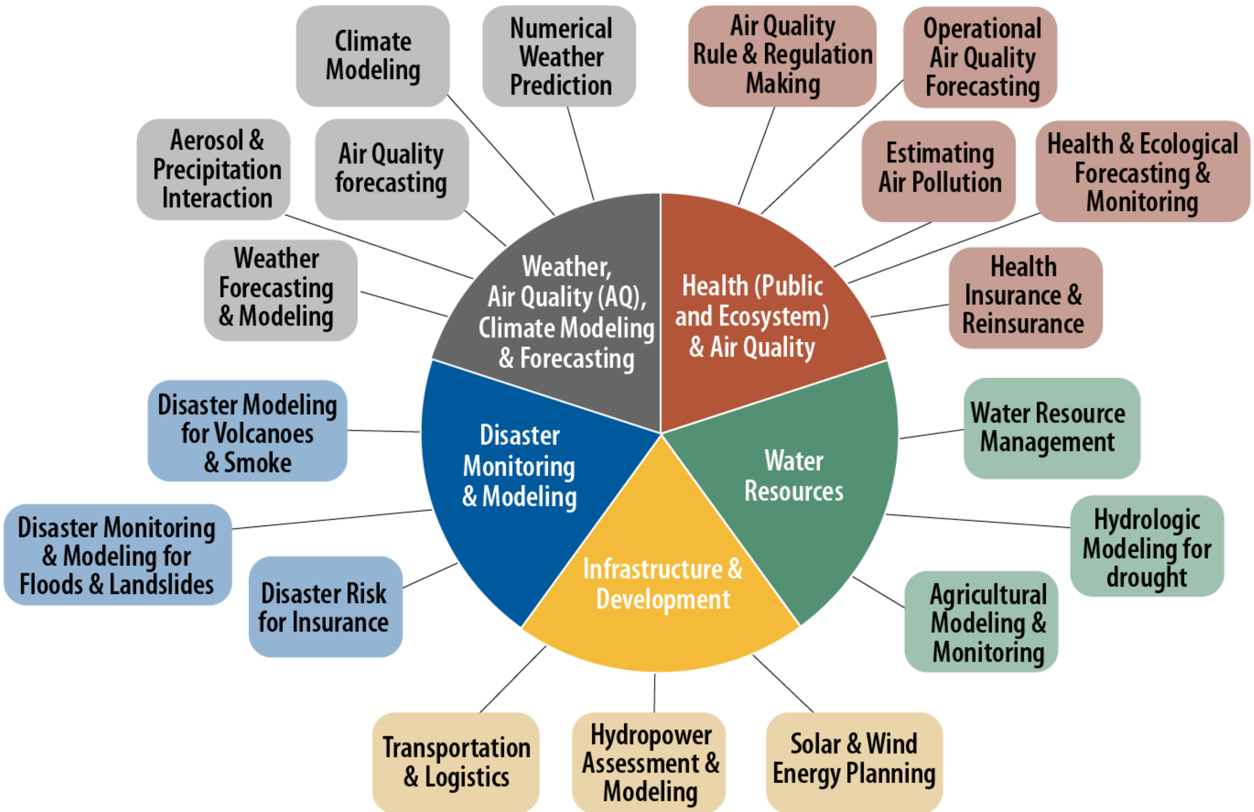


Figure 1.1. AOS enabled applications divided into five core areas that roughly align with NASA Applied Sciences programs.

Our outreach activities, to both new and familiar stakeholders, included several AOS (then referred to as ACCP) applications workshops, engagement during scientific conferences, information solicited through GPM trainings and surveys, and small focus groups. Several prominent outreach events led, co-led or attended by AIT members include:

- ACCP Weather & Air Quality Forecasting Applications Workshop (July 2019)
- AIT Transportation Logistics Workshop (November 2020)
- 2020 ACCP Modeling & Assimilation Virtual Workshop (November 2020)
- NASA ACCP Air Quality Workshop (March 2021)
- HAQAST Spring 2021 Discussion Groups (Spring 2021)

NASA also contracted RTI International (an independent, nonprofit research institute dedicated to improving the human condition) to identify new communities of potential or sub-communities within communities of practice (Figure 1.2), with the goal to explore non-traditional stakeholders' interests and requirements for using AOS data products in their decision-making. RTI's findings are summarized in a report entitled, "Nontraditional User Needs for Aerosols, Clouds, Convection, and Precipitation (ACCP)".

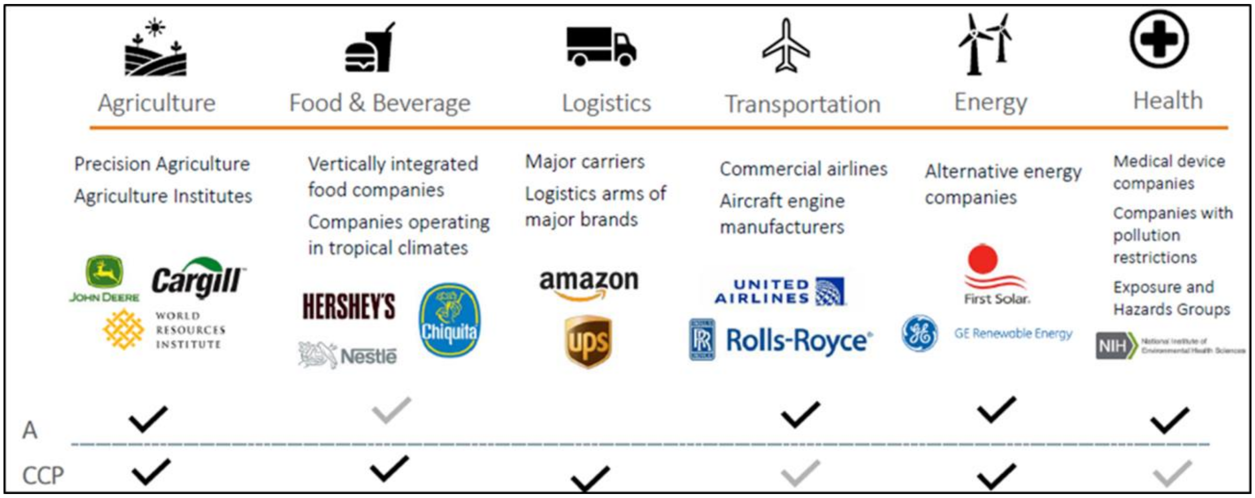


Figure 1.2. RTI engaged six specific communities that the AIT identified as communities of potential for using AOS data. Below each community heading, RTI selected specific sub-communities to engage. The logos show examples of who RTI engaged and their potential use of aerosols (A) or clouds, convection, and precipitation (CCP) data (indicated by checkmarks).

For the CAR purposes, we down-selected to 10 user communities, from both AIT and RTI's assessment of potential enabled applications, that could take full advantage of AOS measurements and would have high and immediate impact in the community (Figure 1.3). The focus on 10 communities for this version of the CAR is to go in more depth and highlight examples and opportunities within each community to use mission data. We will increase the number of communities characterized in future versions of the CAR as additional engagement and information from these communities evolves. Stakeholders from these communities range from federal, state, non-profit and commercial/private organizations. We integrated select findings of the RTI report into this CAR; therefore, the reader is referred to the RTI report for the full presentation of RTI's findings.

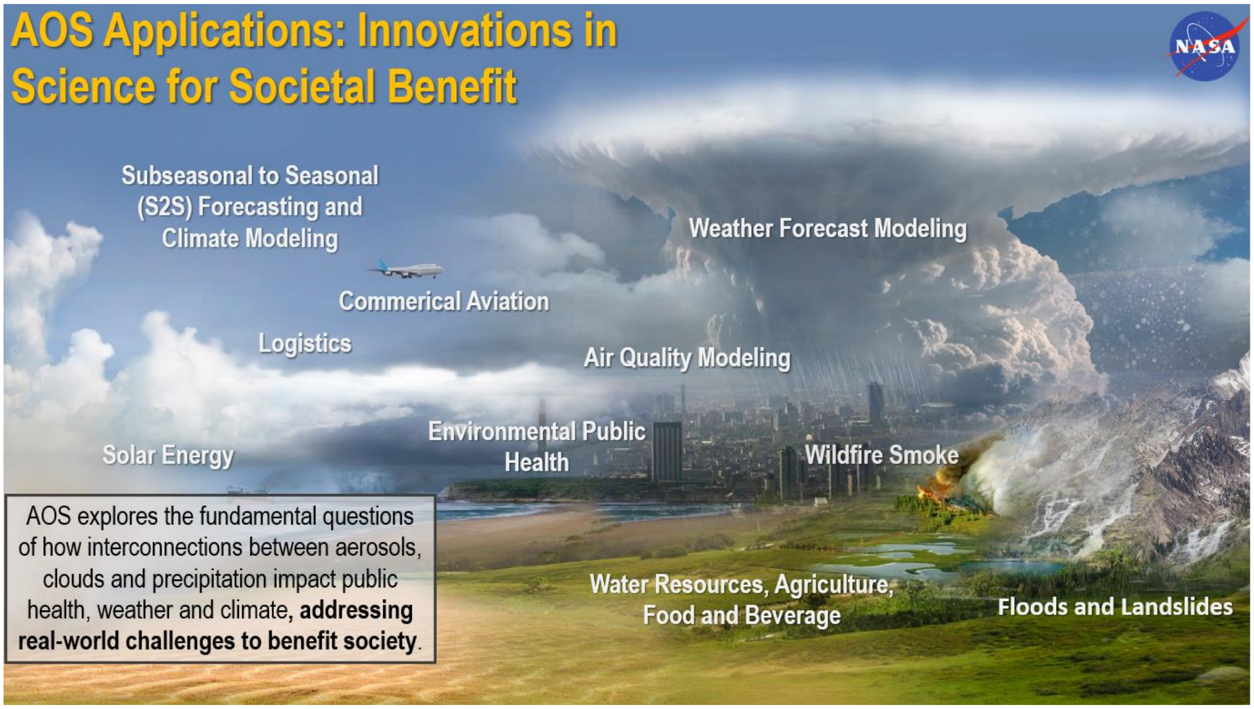


Figure 1.3. Ten thematic application categories explored within the CAR.

The CAR is organized in the following way:

Section 2: We discuss the aspects of the AOS program and proposed architecture that will continue key data products from the Program of Record (POR) and promise novel capabilities that could "raise the bar"* for the applications of stakeholder communities.

Section 3: We articulate and summarize the unique requirements of specific stakeholder communities, which will broaden stakeholder use of AOS data products by both communities of practice and potential.

Section 4: We summarize the commonalities, differences, and variations in organizational characteristics and technical aspects across the communities presented in Section 3.

Section 5: We conclude this report with a high-level summary of key findings and implications from the assessment activities and analyses.

***NOTE:** In this context, "raise the bar" refers to enhancing applications for these communities.

2 PROPOSED ATMOSPHERE OBSERVING SYSTEM: NOVEL ASPECTS FOR APPLICATIONS

This is a high-level overview of the AOS Observing System and a description of how it could advance science and "raise the bar" for the applications of stakeholder communities. The ACCP Science Narrative report contains more details.

NOTE: The AIT will continually work with the Science Impact Team (SIT) to identify exactly how AOS will raise the bar for applications. **We stress that this section is under development and will continue to evolve as the architecture system is redefined. Information included is based on the current, proposed architecture system relative to the POR. As the architecture develops, the AIT will revisit two questions during each project life cycle phase, "how exactly is the AOS architecture meeting both minimum and enhanced DS science goals" and "how exactly is this AOS architecture benefiting applications". The former will be addressed more broadly while the latter will be addressed more specifically. As a result, the AIT will update this section 2 to address any impacts, such as changes in latency, towards applications and will be also reflected in analysis and findings in each community in Sections 3 through 5.**

2.1 Decadal Survey

Understanding the processes that move, transform and cycle particle suspensions throughout the atmosphere plays an integral part in understanding the Earth system. These processes profoundly affect both weather and climate, impacting our environment and human health. The NASA AOS mission was designed to quantify the consequences of particle-transforming processes across spatiotemporal scales, ranging from seconds to minutes on sub-km scales, hours to days on meso-to near synoptic scales, and sub-seasonal to seasonal and beyond on a global scale. AOS data will provide answers to basic questions and applications about weather, air quality, climate and our environment that were specifically called out in the 2017 Decadal Survey (DS) report, "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observations from Space". Three "most-important" DS questions serve as the underpinning science questions for AOS and are the basis of five fundamental science goals and eight specific science objectives (Figure 2.1). The DS also motivates the selection of enabled applications identified for AOS. The three questions are:

i. Why do convective storms, heavy precipitation, and clouds occur exactly when and where they do?
ii. What processes determine the spatio-temporal structure of important air pollutants and their concomitant adverse impacts on human health, agriculture, and ecosystems?
iii. How can we reduce the uncertainty in the amount of future warming of the Earth as a function of fossil fuel emissions, improve our ability to predict local and regional climate response to natural and anthropogenic forcings, and reduce the uncertainty in global climate sensitivity that drives uncertainty in future economic impacts and mitigation/adaptation strategies?

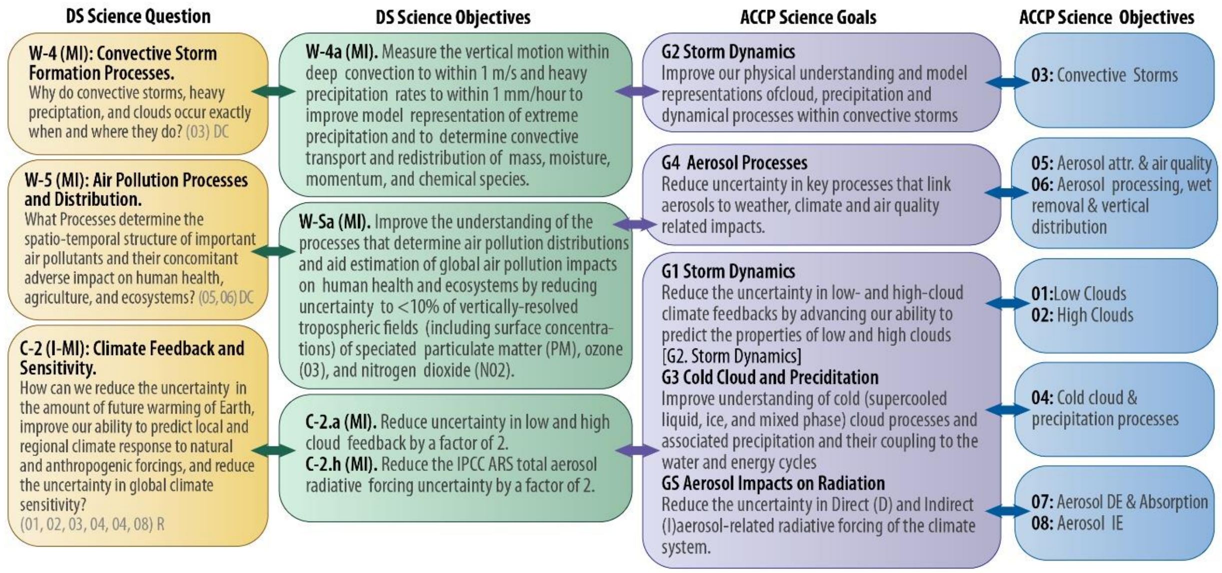


Figure 2.1. Schematic diagram of AOS science goals and objectives related to the three fundamental DS science questions. The DS questions and its subsequent DS science objectives propose "an achievable plan of space-based observations to monitor and understand our planet over the next decade, without sacrificing pursuit of ambitious goals" (2018 Decadal Survey report). See more at https://aos.gsfc.nasa.gov/at-a-glance.htm.

These DS questions and the subsequent DS science objectives propose "an achievable plan of space-based observations to monitor and understand our planet over the next decade, without sacrificing pursuit of ambitious goals" (2018 Decadal Survey report).

2.2 AOS Science Motivation

AOS will focus on processes and proposes the first-ever space-based global measurements of vertical air motion occurring in convective clouds combined with the first direct measurement of aerosol properties, including vertical profiles of aerosol type, absorption and extinction, and vertical profiles of cloud and precipitation characteristics in the surrounding environment. Understanding how air rises and sinks in clouds will improve our knowledge of processes that create convection and clouds, result in extreme weather, severe storms, and precipitation processes. Very importantly, the novel AOS observations will help understand how water, clouds, and aerosols cycle through the atmosphere throughout the day (called the diurnal cycle). Accurate modeling of the diurnal cycle is still an evasive goal. AOS observations will provide better understanding of the complex interaction between the dynamical and thermodynamical environment, the convective processes, and the aerosol loading of the atmosphere. As such, the novel process-oriented AOS observations will lead to improved predictions of air quality, weather and climate. AOS will also advance our knowledge of aerosols, the degree to which they interact with and are impacted by clouds and precipitation (and vice versa, e.g., how clouds and precipitation interact with aerosols), and their contributions to air quality events that adversely impact human health, agriculture, and ecosystems. Finally, the combined global cloud, precipitation, and aerosol measurements of AOS will provide critical information linking clouds and aerosols to radiation in the Earth's atmosphere, a key to understanding Earth system feedbacks, Earth's climate and climate change, and the linkages between the energy and water cycles of the Earth system, all of which will help reduce uncertainties and advance climate models.

2.3 Architecture: Addressing Science and Applications

The proposed AOS architecture and the subsequent evaluation of it flowed down from the set of science objectives that quantitatively link to the three DS questions shown above (Figure 2.1). These objectives revolve around the topics of low and high cloud climate feedbacks, convective storm dynamics and storm initiation, cold cloud and precipitation processes, aerosol attribution and air quality, aerosol processing, wet removal and vertical redistribution, and aerosol direct and indirect effects (Figure 2.2).

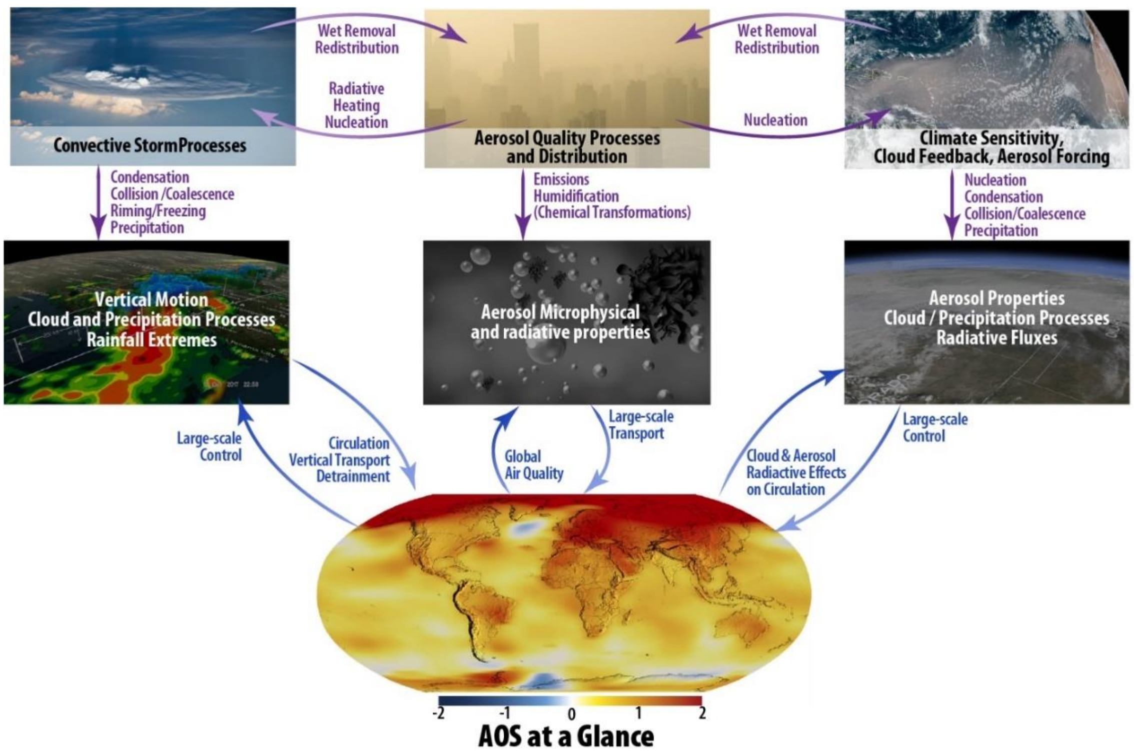


Figure 2.2. ACCP Science at a glance. See HERE for more information

Figure 2.3. AOS architecture recommendation during the ACCP Study.

These objectives then led to a set of minimum- and enhanced-capability geophysical variables that traced to a set of measurements and requirements, which can be referenced within the AOS Science and Applications Traceability Matrix.

The final architecture recommendation from the ACCP Study is graphically portrayed in Figure 2.3. The AOS dual orbit architecture consists of two stages, an earlier launch of the inclined orbit to enable early science and characterize diurnal variability, and a later launch in polar orbit with a suite of instruments that meet the threshold objectives of AOS. Tables 2.1-2.3 provide details on the proposed set of instruments that will enable new science and enhance applications (note this depiction does not include international instrument contributions that are in development). The spaced-based architecture is augmented by the AOS Suborbital (SUB) Program, which provides SUB observations with the necessary data accuracy and sampling resolution to support the AOS science objectives, as well as provide data for space-based retrievals and for calibration/validation.

NOTE: We stress again that this architecture is still in development and the summaries provided here represent the outcome from the ACCP Study but **do not necessarily** describe what will be the final AOS mission architecture. **This document will be updated as the architecture and instruments are confirmed and will include how the current architecture system will meet both minimum and enhances DS science goals as well as benefit applications.**

The AOS inclined orbit has the potential to provide crucial information on diurnally-varying processes associated with deep convection and aerosol emissions and transport.

Table 2.1. AOS Inclined orbit instrument description and enabled science.

Instrument	Potential Enabled Science
Dual Doppler Radars	will provide improved measurements of vertical profiling of clouds and precipitation while Doppler capability will enable the first-ever measurements of vertical air motion in convective clouds
Radiometer	will provide constraints on cloud ice properties, precipitation, and horizontal context
Backscatter Lidar	will provide vertical profiles of aerosol and cloud properties
Polarimeter	will provide multi-angle, multi-frequency observations of enhanced aerosol and cloud properties

Tandem Stereo Cameras	will provide the first-ever measurements of low cloud and aerosol plume dynamics

The AOS polar orbit has the potential to provide critical information on cloud-aerosol-radiation processes that contribute to uncertainty in our changing climate.

Table 2.2. AOS polar orbit instrument description and potential enabled science.

Instrument	Potential Enabled Science
Dual Doppler Radars	will provide vertical profiling of clouds and light-to-moderate precipitation and in-cloud vertical air motions with a focus on measuring these properties to very near the surface, a limitation of previous space-based radars
High Spectral Resolution Lidar (HSRL)	will provide enhanced profiling of aerosol properties (type, microphysical, microphysics, optical) and cloud properties
Microwave Radiometer	complementing other sensors, these instruments will help provide first ever collocated measurements of cloud dynamics, cloud and precipitation microphysical properties, aerosol properties, and cloud-scale radiation measurements
Polarimeter	
Spectrometers	will provide information on how clouds and aerosol interact with solar and terrestrial radiation

2.4 AOS Enabled Applications Summary

The AOS mission has the potential to advance scientific research and directly impact societal applications. Table 2.3 summarizes these enabled applications and highlights opportunities for AOS to advance research and applications within these areas.

Table 2.3. The proposed AOS architecture system has the potential to enhance a range of applications that could directly benefit society.

Enabled Applications	Opportunity for AOS to Advance Application
Severe Weather	Novel observations from AOS will cover the diurnal cycle, which will help to better understand timing, intensity and severity of storms leading to improved forecasting skill over high-risk areas.
Climate Modeling	AOS observations will support improvement of parameterizations that are used by climate and weather numerical prediction models, leading to improved forecasting on a variety of spatial and temporal scales.
Water Resources, Agriculture, and Drought	AOS will contribute to the POR to continue and advance a long record of global precipitation vital for monitoring the variability of terrestrial water that is fundamental for a wide range of stakeholder to support activities including agricultural modeling to inform crop yields and water resource allocation.
Disasters Monitoring and Forecasting	AOS will raise the bar for disaster-related applications by providing timely data products with unprecedented accuracy of volcanic ash, dust, and wildland, agricultural, and prescription fire smoke, supporting activities such as aviation safety. Leveraging the POR, AOS will contribute to improve characterization of extreme precipitation from convective events and

	continue gridded global estimates of precipitation important for disaster modeling.
Public Health	AOS will provide enhanced information on aerosol characterization, improving the ability to discern aerosol subtypes to inform public health activities.
Air Quality Modeling and Monitoring	AOS will provide the first-ever diurnal observations of the characterizations and vertical structure of aerosols, along with high-quality information on aerosol intensive properties, aerosol radiative effects and aerosol-cloud interactions, leading to improved model representation of emissions, transport, and composition.
Infrastructure and Development	AOS data, through value added service providers, may ultimately improve accurate predictions of precipitation that may impact supplier and customer access, disruptive air quality events, and seasonal weather that could affect supplier availability and pricing.
Energy	AOS will provide opportunities to directly support key decisions or analyses within the energy sector, providing information on aerosols, extreme precipitation, and cloud cover.

3 USER COMMUNITIES

In this section, we characterize several specific communities and highlight the unique needs of each stakeholder community (Figure 1.3) for AOS data products, calling out how AOS data products can 'raise the bar' or enhance applications for these communities. Each section on a specific user community includes three main sections:

1. ***Community Overview***: Characterizing the community, including who it includes (e.g., organizations), familiarity with NASA data and relevance of aerosols, clouds, convection, and precipitation data within this community.
2. ***Sub-Community Overview***: A deeper dive of the community, defining sub-groups and decisions that are being made with aerosols, clouds, convection, and precipitation data. This section provides details of organizational (e.g., types of decisions, risk tolerance) and technical aspects (e.g., familiarity and depth of experience with Earth observation data*, remote sensing, and modeling, and key desirements for observations), data challenges and needs with respect to satellite data and the use of and opportunities with NASA data within each sub-community.
    a. While this section helps articulate critical needs and key desirements expressed by each sub-community, we note that technical and organization aspects and needs covered (e.g., latency, data coverage, resolution, etc.) vary across the communities due to how stakeholders articulate their key desirements to the AIT or RTI groups. Therefore, some attributes may not be highlighted within a given sub-community due to their lower priority within the application area. As community engagement evolves, we will be able to capture additional information regarding the details of community interest in specific mission aspects.
3. ***Community Analysis and Findings***: A description of potential opportunities to use aerosols, clouds, convection, and precipitation data collected from AOS for applications and how to effectively engage the community to make use of future AOS data.

***NOTE:** NASA's Earth Observing System Data and Information System (EOSDIS) data products are processed at various levels ranging from Level 0 to Level 4. Throughout this section, we reference data products level needs for the communities below. Please see NASA's Data Processing Levels for a description of data product levels.

3.0 PREFACE: SUMMARY OF FINDINGS OF ALL STAKEHOLDER COMMUNITIES

In our assessment of stakeholder communities for each of the enabled applications (Figure 1.3), we found common features and requirements among most or all of the communities. Therefore, we preface the discussions below of each of the communities with a summary of our primary, high-level findings of our AOS community assessment.

Finding	Description
Diverse Needs of Stakeholders, including within a Given Community	Several communities have distinct requirements to integrate AOS satellite data into their operating procedures and that these requirements often vary widely within subcommunities of a given community (e.g., latency, continuity of data, spatio-temporal coverage).
Wide Range of Organizational Resources and Capacity	Majority of stakeholders agencies do not have the financial resources to devote to hiring satellite data experts to download and process satellite data. Therefore, many stakeholders cited the need for NASA investment to facilitate the ease-of-access to AOS satellite data and the development oflevel data products, L3/L4 (i.e., surface gridded rain rates and $PM_{2.5}$).
Spectrum of Stakeholder Expertise with Satellite Data	Range of levels of expertise and comfort downloading and processing satellite data among the communities, but, more importantly, within a given community's subcommunities.
Hesitancy of the Accuracy of Satellite Data	Majority of stakeholders were hesitant to incorporate satellite data into their operating procedures. These stakeholders cited a number of concerns, including the lack of characterization of data uncertainties, data products not being in quantities that they are familiar with, and poor validation of the satellite data with their in situ observations.
Reliance of Certain Stakeholder Communities on Intermediary Data Product Providers	Many of the stakeholder communities do not work with satellite data themselves by choice, and, instead, rely on intermediaries or vendors to provide the L3/L4 data products that they require for their decision-making.
Reliance on Improved Models	Most communities rely on or benefit from model output from a core group of communities of practice, primarily those who make time-critical decisions (i.e., weather, disaster, and air quality forecasters).

3.1 WEATHER FORECAST MODELING, INCLUDING NUMERICAL WEATHER PREDICTION

Community Overview

Weather forecast modeling, which includes Numerical Weather Prediction (NWP), benefits scientists and non-scientists, businesses from virtually every industry, and civil organizations of all types. Downstream use of weather forecasts is ubiquitous in modern societies and sought after in most Low- and Moderate-Income Countries (LMIC). Improved weather forecasts will benefit a number of stakeholder communities, including logistics (e.g., predicting severe weather that impact supply chain activities), disasters (e.g., predicting hurricane activity), and agriculture/ food and beverage (e.g., predicting crop yield and irrigation needs).

For simplicity, we will define the primary communities of practice as those communities that directly retrieve the observational data, develop the models, and produce forecasts of various types. We divide this sector further into slightly different sets of stakeholders. Civil modeling and development, like NOAA, NASA, and European Centre for Medium-Range Weather Forecasts (ECMWF), are tasked with producing various weather forecast models at a variety of valid times (days to seasonal (i.e., S2S; Section 3.2)) and geographic areas (hemispheric to regional), for downstream users ranging from civil aviation to the ordinary person. These forecasts also serve as input to value-added products offered by private sector weather services. Research organizations, such as universities, develop models and assimilate observations to answer specific questions and to see how changes in certain parameters might improve the forecast. In the private sector, forecast models and value-added products are developed to target specific end users and time frames, such as agricultural forecasts for anticipating freeze and frost, aviation forecasts help pilots plan their routes and avoid specific unfavorable conditions, or even forecasts provided to television stations that show forecast data in broadcast-friendly formats.

All of these communities use observations available to develop their models and forecasts. Good quality observations can be used for model initialization, to validate and improve model forecasts, or develop parameterizations. As computational resources become simultaneously cheaper and more sophisticated, the amount and type of data that can be incorporated into models will only increase. Loss of a type of data, or continuity of a data record, can drastically lesson forecast skill in specific areas. Likewise, short-term data from field experiments or short missions may be used to help validate data or experimentally assimilate new observations, but the time and skill required to assimilate and test observations into models means that end users are choosy about incorporating a new data source, and have difficulty incorporating completely new observations. Additionally, the anticipated use or end users for a model will dictate the community's tolerance for latency. For example, a deep layer soil moisture model that uses precipitation data will not require low latency data, but a short-term regional weather forecast model certainly will.

In the following subsections, we will describe the modeling sub-communities in more detail, including their challenges and current and future needs, and provide a summary of their preferred requirements and thoughts on how to move forward with this community.

Weather Forecast Modeling Sub-Communities

A) Civil Forecasting

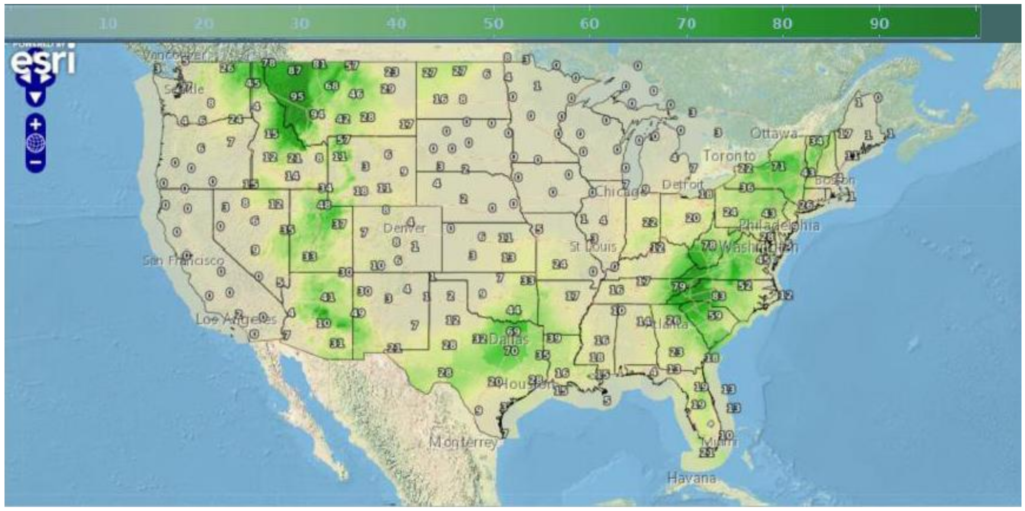


Figure 3.1.1. Experimental Precipitation Potential Index from NOAA NWS, a new short-term forecast product that relies on high resolution, low latency weather observations. Satellite observations provide data in traditionally data-sparse regions, like the intermountain west, and can be used in products like this for detailed, communication of high impact weather events. Credit: https://nws.weather.gov/products/viewItem.php?selrow=258

Civil forecasting models are the backbone of operational weather forecasting worldwide. For example, in the US, NOAA Environmental Modeling Center produces more than 20 different NWP models that are used across National Centers for Environmental Prediction (NCEP) and the National Weather Service (NWS) for severe weather, hydrology, aviation weather, marine weather, etc. NASA's Global Modeling and Assimilation Office (GMAO) similarly uses their model forecasts to support field campaigns, test new assimilation strategies, including those for aerosols and trace gases, reanalysis, and to simulate observational datasets. The ECMWF serves a similar function, providing model forecasts globally for forecasting centers in the European Union as well as other international partners, including the US.

In the civil forecasting realm, most users are highly proficient at using existing datasets, acquiring them from NASA's near-space network including direct broadcast sites or the global telecommunications system (GTS) and integrating familiar data from new sources into their processes. Observational datasets from Earth observing satellites are used by this community, including precipitation, temperature, humidity, wind, soil moisture, and atmospheric ozone. Longer range forecast models (e.g., Global Forecast System [GFS]) are able to utilize data within about a 6-hour period prior to model run; however, finer scale short term models (e.g., Rapid Refresh [RAP]) are unable to effectively utilize a large percentage of existing data because their runs are more frequent and the window for useable observations is shorter. In either case, data latency of an hour or less is optimal for assimilation into these forecast models.

In the future, we expect that for civil forecasting, data will continue to be acquired through satellite observations. While it is a challenge for these larger modeling entities to incorporate completely new datasets (e.g., sub-millimeter passive microwave observations), we expect that if those observations have potential value in addressing forecast questions, and if those datasets will be well-calibrated and available for long periods of time, civil forecasting will be able to devote the time and resources needed and pivot toward their use for operational forecasting within 2 to 5 years.

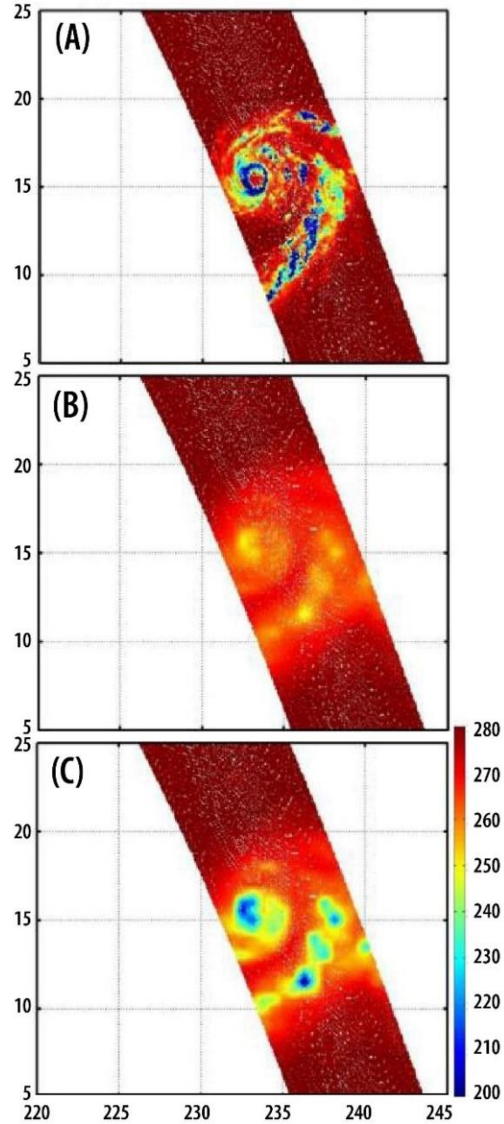


Figure 3.1.2. Observed and simulated GPM Microwave Imager brightness temperatures using different scattering assumptions; an example of data assimilation in NASA Goddard Earth Observing System (GEOS) model (Kim et al. 2020), which benefits from improved microphysical retrievals to constrain initial conditions in the presence of clouds and precipitation.

B) Modeling Research

Modeling researchers (e.g., universities, co-operative institutes) work to either address specific questions in constrained environments or locations or they work to assimilate new observations into existing model frameworks to improve forecasting skill. These end users are highly technically proficient and often acquire data through DAACs and other repositories of archived data, if the use is experimental and retrospective, and occasionally from real-time data streams if the readiness level of the model assimilation is high and experimental operational use is being evaluated. They often collaborate with civil agencies through the Joint Center for Satellite Data Assimilation to develop new techniques to assimilate novel observations with transition to operations in mind. These end users often look for new and interesting datasets to attempt to answer compelling questions, and may be considerably more willing to use novel observations (e.g., GPM Dual-frequency Precipitation Radar, vertical velocity, sub- millimeter passive microwave) in an attempt to further research objectives. Shorter lifespans of missions are still acceptable to these end users (e.g., Pathfinder style missions) and can often help researchers expose the need for future missions by proving the impact of specific datasets or observations. Latency likewise is less of a factor because the objective for these end users is often not to produce a real-time forecast. The bigger challenge for these end users is the ability to find large datasets and interpret what is within them.

In the future, there may be increased interest in third-party data providers if the dataset is novel; however, the expectation is that these end users will be able to continue free, unfettered access to NOAA and NASA observations via NOAA and NASA archives.

C) Private Sector NWP and Forecasting

Private sector NWP and modeling communities develop proprietary models and forecast products that address challenges for specific downstream end users. For example, a private sector company (e.g., IBM, Accuweather, Baron Services, DTN˚) might develop a propriety model and display of precipitation and surface analysis for a news station, using satellite and other datasets available from NASA and NOAA. Another company might provide pinpoint agricultural forecasts for temperature and precipitation using their own NWP or model. These models are often very high resolution and regionally specific. Depending on the use case, these end users may often have latency needs similar to civil NWP and modeling entities' short-range, high-resolution models (i.e., an hour or less), and for other applications, they may be more tolerant (e.g., precipitation data up to 12 hours latency for a soil moisture model). But they may not have access to near-real time data sources like direct broadcast sites, and they may have considerable difficulty sourcing the data they want in a timeframe that is effective to their operations. They may also prefer specific data types that work well with their framework. In short, while private sector end users will likely be just as technically savvy as other end users, they typically have more tightly constrained needs and are often not "NASA insiders" with the ability or the knowledge to freely access near-real time data from the available data sources.

D) Analysis and Findings for NWP Community

For each of these end-user groups, there exists an opportunity to expand the role of EOS data and potential AOS data in their activities. Novel measurements like vertical profile information and sub-millimeter passive microwave observations stand to benefit the research community immediately, and with assistance, those advances can be implemented in civil NWP. Private sector companies may choose to utilize new measurements for specific end users, as well. For all these communities, continuity of observations helps model development and validation. Civil NWP is especially sensitive to changes or loss in POR datasets, and due to the time and effort required to assimilate and test new data, they are the least likely to implement data from a short-term mission with no follow-on. This is the impetus for the AIT's insistence that certain observations be prioritized in the upcoming proposed mission. Targeted early adopter activities and access to proxy data would help assist in the pivot toward assimilating novel observations well before launch.

Private sector NWP development using AOS and other EOS data is hindered primarily by their inability to access data in near-real time and in formats that are preferred. Continuing this dialogue with private sector end users will find them willing to utilize cutting-edge NASA data in unique and impactful ways, and will help NASA understand what their technical requirements are regarding data access.

3.2 SUBSEASONAL-TO-SEASONAL (S2S) AND CLIMATE MODELING

Community Overview

Societal and environmental impacts from accelerated changes in Earth's climate have become increasingly visible, including wildfires and more intense precipitation (Figure 3.2.1). Improved forecasting of subseasonal-to-seasonal (S2S) weather and climate will enable the development of successful climate change mitigation strategies and will benefit a number of stakeholder communities, including disasters (e.g., predicting hurricane activity), public health (e.g., anticipating areas with water-borne disease outbreaks and wildfire smoke), agriculture (e.g., predicting growing locations, crop yield, and irrigation needs), and water resources (e.g., predicting snow pack, drought, and seasonal precipitation patterns).

Figure 3.2.1. Potential future effects of climate change include more frequent wildfires, longer drought periods, an increase in number, duration, and intensity of tropical storms. Credit: Left - Mellimage/Shutterstock.com, center - Montree Hanlue/Shutterstock.com, and taken from climate.nasa.gov/effects/.

A) S2S and Climate Modeling Communities

The S2S modeling community, which includes NOAA, NASA, and European Centre for Medium-Range Weather Forecasts (ECMWF), provides actionable forecasting for a number of business communities on two timescales: 14 days to 3 months and extended seasonal, 3 months to 2 years. Many in this community use the NASA GMAO Modern-Era Retrospective analysis for Research and Applications (MERRA) gridded analyses (a Level 4 product) because of the ease-of-use. However, there are also some very mature users that use a variety of satellite observations. For instance, the community uses observations of clouds and precipitation from the GPM constellation (both retrievals and radiometer observations) for model initialization and validation, with a particular focus on the model representation of the diurnal signal. Another example is the use of aerosol observations for model initialization. Hence, the S2S and climate modeling community represents experienced users of NASA data, that is familiar with the NASA data formats and standards and is comfortable using Levels 2 - 4 data. The communities have expressed the importance of Level 3 products (e.g. of surface precipitation and $PM_{2.5}$) which could be used to validate models and improve parameterizations.

Some of the key challenges and needs for S2S precipitation forecasting are the accurate representations of the diurnal signal, different precipitation types (pointing to the need for improved parameterizations of shallow and deep convection), mixed phase clouds and stratocumulus clouds, seasonal accumulation of precipitation (Fig. 3.2.2), and global propagation of global cycles (e.g., the Madden-Julian Oscillation and El Niño Southern Oscillation forecasts). Additionally, long records of consistent/homogeneous and accurate observations are strongly desired in order to provide the basis for model validation and improvement. Overall, continuity and uncertainty quantification are of greatest importance to this community, while coverage is of somewhat lower importance and short latency is not important. Addressing these needs would help improve S2S forecasts and significantly benefit communities spanning the humanitarian, public heath, disasters, energy, water, and agricultural sectors that strongly depend on these forecasts.

As for technological needs, this includes developing “flexible” datasets that consider end-user needs. For example, enabling the user to pull a time series of particular data (e.g., precipitation) over a certain domain, and certain period (for example, 60 days) without requiring them to manually pull 60 days’ worth of all the data into their systems.

The modeling community is more hesitant about using "one-of-a kind" data (e.g., *field campaign data*) that are new in terms of data types, quality, coverage. However, these communities are willing and eager to work with NASA to understand the nature of new *satellite* observations and to use them for model validation and for improvement of parameterizations. The incorporation and use of new data types requires time and effort to translate new observations in the context of the existing long records of clouds, precipitation, and aerosols observations to support model development activities.

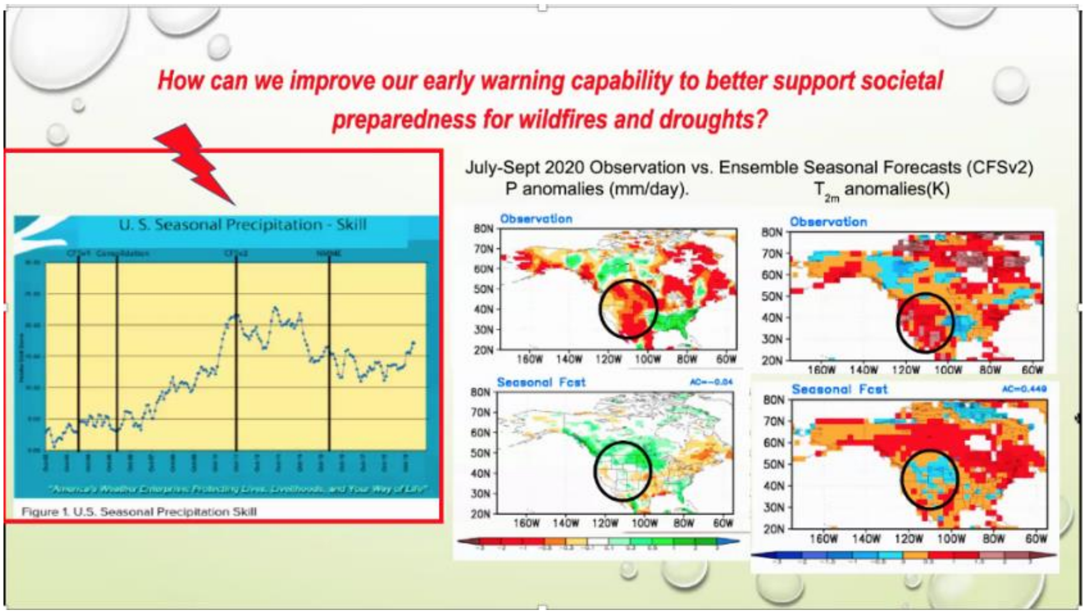


Figure 3.2.2. The S2S forecasting challenges and implications for the community of S2S forecast applications. Can we accurately forecast seasonal precipitation accumulation? This is an issue that strongly impacts water and agriculture management activities. Credit: CPC/NCEP/NWS/NOAA

AOS data products have the potential to benefit the S2S community in the following ways:

- The diurnal signal is a key characteristic of the precipitating systems. However, it is currently not represented accurately in models. Observations provided by instruments in the inclined AOS orbit will provide critically important information to help understand and accurately forecast the diurnal signal.
- A very important challenge in the NWP modeling is the proper representation of different types of precipitation including microphysical properties and vertical profiles of water mass and its phases. Novel AOS operations will help improve microphysical parameterizations and reduce uncertainties in model forecasts.
- Time-differenced observations would also be very important, if provided by AOS, to give information on how the clouds are evolving on very small timescales (i.e., the time-change, or tendency, that is the critical component computed by the models as part of the numerical integration in time). With multi-frequency time-differenced observations, the AOS observations should provide enough information to help tease out processes (e.g., changes in the particle size distributions, changes in the mass of the condensate, or changes due to advection). These are the terms that determine the change in time of the total condensate, as computed by the models. Providing any observations will directly help in the improvements of the model parameterizations.
- There is also a great need to know the storm type. This includes information on the morphology of the storms – isolated convection versus mesoscale convective complexes versus synoptic type systems - and the types of the storms that have been observed – convective versus stratiform. This information is also very important for improving the model parameterizations. The AOS radiometer observations will provide the wide-swath coverage that is needed to understand the storm organization and morphology.

- The S2S community expressed a strong need of a long, continuous record (~30 years) of observations that are homogeneous. Thus, consistency between AOS observations and those from the POR is important. Hence, early efforts by the AOS team need to focus on connecting the new observations to CloudSAT, GPM, and Passive Microwave (PMW) observations in general.

B) Users of S2S and Climate Forecast

There is a large, and growing community of users of the S2S and climate forecasts. Such forecasts have wide applications in: i) Water Resource Management (dam operations; snow pack forecasts and water allocations; mitigations from prolonged draughts); ii) Disaster Preparedness (e.g. potential for flooding and landslides as related to landfalling hurricanes and atmospheric rivers); iii) Forecasts of seasonal and decadal hurricane activity to help develop mitigation plans related to the electrical infrastructure, storm surge protections, and even urban development along coastlines; and iv) Data-driven Agriculture. Many of these users are familiar with L2 and L3 data products, however L4 products are strongly desired. Overall, these users of the S2S forecasts are willing and eager to use any new source of data that provides actionable information to support their decision making. Of greatest importance to these users are: coverage and resolution; accuracy and latency of the data; ease of data access and the use of format standards. Of secondary importance is the existence of long data records. These users are also willing to work with NASA to establish data format standards and protocols for data access. This includes the willingness and eagerness to engage in the development of APIs that target the needs of the users of S2S forecasts. More information on these users of S2S and climate forecasts can be found in Sections 3.7 through 3.10 and Section 4.

C) Analysis and Findings for S2S and Climate Modeling Communities

The S2S and climate modeling communities outlined in Section 3.2.A routinely use satellite observations for model initialization and validation. AOS promises a suite of novel measurements, such as representation of the diurnal signal, the vertical structure of clouds and precipitation, in cloud vertical velocity profiles, and vertical aerosol information, which could greatly improve model parameterizations and thus model performance.

The incorporation and use of new data types requires time and effort to translate new observations in the context of the existing long records of clouds, precipitation, and aerosols observations to support model development activities. Hence going forward, the AOS community should begin early work on integration of the new observations with the POR. A critically important parallel effort to support the integration of the new data into the models should be the development of new and fast instrument simulators that provide the connection between the model parameters and the satellite observables. These instrument simulators could be used early on to create synthetic satellite-like data to help modelers gain familiarity with the upcoming new observations, and to develop ways to integrate the observations in their models, once the actual observations become available.

Additionally, the S2S communities would benefit from improved data documentation and storage to support machine learning and artificial intelligence techniques, improved discoverability and accessibility of data (e.g., development of APIs and consistent data formats), and access to suborbital data to improve model forecasts including forecasting the sub-grid variability. Continued engagement with these communities will further inform preferred data formats, methods of data access (e.g. through the cloud, with established protocols), and opportunities for evaluation of model performance. These activities could increase the likelihood that these groups incorporate AOS observations into their applications at the time of AOS program launch date.

The end result of the collaboration between the AOS and the modeling community will assist in several S2S and climate model activities including: model validation, diagnostics of miss-representation of processes, improvement of parameterizations, increased forecast accuracy through data assimilation, and the development of new 4-dimensional products through the integrations of models and observations.

As for enabling applications among users of S2S and climate forecasts, a collaborative engagement between the S2S modeling communities and the AOS teams would lead to the development of new Level 4 products and would significantly benefit these end users. These Level 4 products would optimally incorporate the novel AOS observations with S2S and climate models to produce high-resolution estimates with global coverage of the parameters that are of very high value to downstream users of the S2S community (e.g. data driven agriculture, water management, disasters response and mitigation, etc.).

3.3 COMMERCIAL AVIATION

Community Overview

The U.S. commercial aviation sector is extensive and complex. Before the COVID-19 global pandemic, a typical day in 2019 would find 45,000 flights shuttling 2.9 million passengers to approximately 5,000 public airports across the country. The economic impact of this sector is estimated at $488 billion annually, constituting over 5% of the gross domestic product. Most commercial airlines also fly to international locations, which greatly expands the scope of geography, time, flight crew availability, and weather conditions for which they must plan.

The commercial aviation user community is already highly dependent on weather data on a daily and hourly basis for safe and reliable transportation of passengers and crew. This includes relying on model forecasts from agencies, such as NOAA, to conduct meteorological assessments for aviation operational decisions. This community is also actively experimenting with a variety of data sources and reporting measures and is eager to collaborate with NASA or anyone else who can provide improved data or data products. The need to understand air quality (AQ)/aerosol-related conditions is increasing but is not at a similar level of critical need as weather conditions. Each flight represents a series of planning steps and decisions that must be made.

Decisions that airlines make that incorporate weather and AQ data include:

Planning—Weather data are used to inform decisions at national scale and regional scale (meaning a multiple-state area) on alterations to flight schedules and flight paths. Forecasts are used to determine if flights will need to be canceled, delayed, or rerouted—preferably far enough in advance (24–36 hours) to minimize the effects on passengers and crews.

Dispatch—Each airport terminal has to make decisions about whether a flight can depart on time, arrive, or be rerouted. Local weather and AQ conditions play a major factor in this decision-making.

En route—While en route, pilots rely on ground-based radar, satellite-based data, and sensors on nearby aircraft to understand the weather and AQ conditions in which they are flying. Course corrections to fly above storms and route around turbulent areas have effects on timely arrival and fuel consumption.

Aviation Sub-Communities

A) Airline Meteorologist

Airline meteorologists are intermediate end users who use and analyze weather data and observations in order to communicate risks to their stakeholders. They are employed by airlines and may provide forecasts to flight planners, flight dispatchers, ground crews and pilots. Meteorological data used by airline meteorologists comes from satellite, ground-based radars, aircraft instrumentation, and other observations and is analyzed often in proprietary software for customizable mapping capabilities.

Figure 3.3.1. Example image from the Aviation Weather Center's Significant Meteorological Information (SIGMET) map, showing large regions of turbulence and convection, primarily on CONUS. Credit: https://www.aviationweather.gov/sigmet

Airline meteorologists are very comfortable using weather and AQ datasets, with most Level 1 and Level 2 satellite products portraying cloud characteristics (e.g., brightness temperature, cloud top height) and Level 3 products used for easy ingestion into systems, and are often able to use this data in proprietary models for specific forecast needs. Weather phenomena of the highest impact to airline operations (and needed within forecasts products) include convective storms, precipitation, wind and turbulence, lightning, and fog. Storms affecting flight routes and storms within 60 miles of airports are two areas of focus.

The quality, quantity, and fidelity of these types of data greatly decrease outside of North America, specifically over oceans and in other countries. This is a big concern and area of opportunity with this community. Airline meteorologists want more and better data to predict convective storms and turbulence, including improved spatial resolution of wind components and turbulent conditions in and around urban environments. Incorporation of AOS observations may lead to more coverage and provide observations in data sparse regions where this community operates. While air quality products are less of a priority, monitoring smoke plumes and the transport of hazardous volcanic ash are two areas that continue to be challenging. Data formats that are compatible with their graphical displays and models that arrive with low latency (< 3 hours) are also a need. Near real-time lidar data from the AOS mission could raise the bar for applications in this sector, as the lidars in the polar and inclined orbits will increase the coverage of vertical resolved observations of smoke aerosols and better inform flight planning and decision-making.

Many aviation meteorological services, especially those in the commercial sector, are actively trying to develop new products. As such, product development is often a significant part of their investments, especially the larger companies (e.g., The Weather Company) and meteorologists are very familiar to the infusion of new products that have the potential to improve their performance. Although this community is familiar with testing new data, the aviation meteorological services are not engaged with NASA because NASA satellite products are not tailored enough for their applications. As a result, they are more likely to invest in new products targeted for specific applications (e.g., weather hazards around high traffic airports). These products need to be reliable and accurate.

Key organizations within this sub-community to engage and enhance the application of AOS data include science and product development leads at government and commercial weather services (e.g., NOAA's Aviation Weather Center, The Weather Company) since they serve as in-house data advocates. Additionally, the FAA develops products for use by aviation meteorologist. Therefore, partnering with the FAA on product development is one way to reach this community.

B) Commercial Airline Pilots

Pilots receive guidance from meteorological service providers (e.g., meteorologists), from in situ observations and from airplane instrumentation, and from other pilots; they represent an end user of weather data and information, having to act on these disparate lines of information in the air. As such, they are more often considered as end users that rely on intermediaries and could be a community of potential. Pilots, in conjunction with air traffic controllers, make decisions on how to best avoid hazards in route, primarily related to changing route or altitude to avoid convection, turbulence, or icing. Most commercial pilots are primarily trained to interpret geographical maps of weather radar and satellite observations of clouds. They receive gridded, high level weather data in the cockpit, but are not meteorologists themselves, and they often respond to very quickly changing weather conditions without the aid of a meteorologist. Therefore, they value accurate, high resolution, high level data with low latency that is easily available.

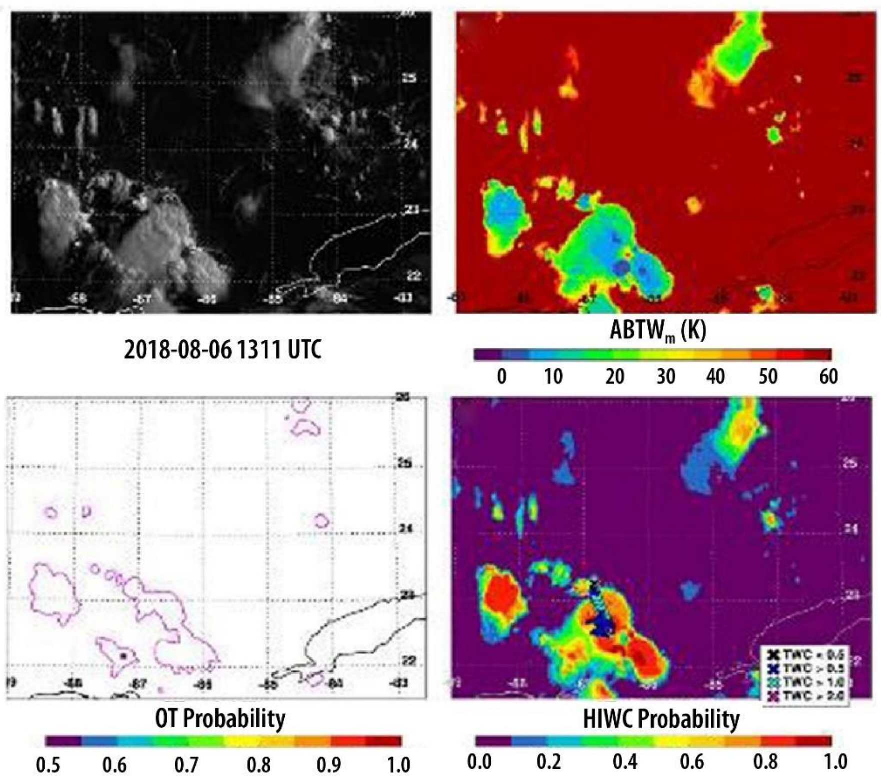


Figure 3.3.2. Adapted from Bedka et al. 2019, showing satellite imagery and Bedka's experimental product that identifies the presence of high ice water content which leads to in-flight icing.

Airline pilots desire more localized guidance for turbulence, which causes considerable discomfort to passengers on flights, and fog, which reduces visibility in take-off and landing. Additionally, small file sizes of data that can be accommodated by the displays available in the cockpit are desired. A further need is data over generally data-sparse regions, like oceans.

We note that the ingestion of new data into their systems is limited as pilots have neither the time nor the funds to incorporate new data into their operations. Pilots will use new data *if* it is made readily available in their flight system, it is easy to interpret and will support their decisions (e.g., maps of low clouds and fog). As a result, pilots are less likely to embrace change in operations since they are the final decision-makers on flight safety. The information will have to be very reliable and highly accurate if they are going to incorporate new data into their systems and processes.

C) Airport Chief Operations Officer

Airport operations is distinct from airline operations; the primary decision made by airport operations is ground-delays when lightning is observed within three miles of the airport. In the event of strong winds from tropical storms and hurricanes, airport operations pivot toward securing or moving vehicles. They receive data and information for making this decision from entities like National Weather Service and the Weather Channel. Many airport operations rely on or are familiar with higher-level data products.

Airport operations personnel desire better localized forecasting for wind, thunderstorms, fog, and snow events. Models or tools that would help reduce operational delays are highly desired.

As many airport operations rely on weather information from meteorological services, they are more unlikely to directly engage with NASA. However, it is also important to note that while most airport operations officers don't have time to ingest and test new data, they do have the funds to improve their operations.

D) Analysis and Findings for Aviation Community

For commercial aviation, one specific need for users is low latency (<1 hour is ideal but 3-6 hours is acceptable), high resolution, and localized data (airport level). Key observations would reduce the risk of flying through hazards over data sparse regions, like oceans, and hazards to takeoff and landing operations, such as fog, icing and thunderstorms. AOS observations will likely include data that addresses these operational needs, such as increased coverage and providing observations in data sparse regions, and delivering the data in near-real time will facilitate the use of the datasets in the aviation sector. Additionally, it is encouraged that these data products be relevant and targeted to users (e.g., fog/cloud bases at high traffic airports) and in formats compatible with popular dissemination tools (e.g., WSI Fusion).

While the commercial aviation industry is large and consists of many different organizations and stakeholders, convening bodies like A4A (Airlines For America) can help facilitate training and communicating opportunities in anticipation of new data from AOS. The FAA is also a key organization to engage as they develop new products for the aviation community. Additionally, partnering with a company that develops widely used applications for flight planning and operations, especially one focused on weather (e.g., The Weather Company, Tomorrow.io) would be beneficial to the aviation sector.

3.4 LOGISTICS

Community Overview

The transportation of goods and services around the world are carried out by logistics firms and carriers, which include the likes of United Parcel Service (UPS) and Federal Express (FedEx). Major companies like these rely on a combination of air-, sea-, and land-based transportation in their operations. With global parcel business exceeding $300 billion in 2018 alone and the U.S. contributing more than a third of that (Statista, 2019), delays to their operations can disrupt the supply chain resulting in significant financial losses. Hence, timely and accurate depiction and prediction of weather affecting these transportation modes are vital to their success. Furthermore, as unmanned aircraft vehicle (UAV) technology and regulations evolve, these companies are looking to UAVs as an approach to parcel delivery. Many of these parcel carriers, especially major ones with continental or global operations, invest in weather decision support to reduce their risk to adverse weather. Although the major companies utilize satellite data, they are largely accustomed to observations provided by operational geostationary satellites, such as Geostationary Operational Environmental Satellites (GOES) R. They do rely on guidance provided by numerical weather prediction (NWP) models and hence may indirectly utilize NASA satellite information (via assimilation into NWP models).

Additionally, major retail brands, such as Walmart, Amazon, and Kroger, bring products (e.g., clothes, grocery items, electronics, etc.) to consumers around the world. Grocery stores, which contributed $634 billion to the U.S. gross domestic product in 2019 (USDA, 2021), are especially vulnerable to regional and local weather hazards since their operations often involve delivery and quality of perishable items. This community largely relies on third-party data services, which include both government agencies and commercial vendors, to obtain value-added weather information relevant to their operations.

Logistics Sub-Communities

A) Air-based Logistics (Mainly Meteorologists)

Meteorologists at logistics companies, especially ones that include vast air cargo operations, such as UPS and FedEx, play a vital role helping the company achieve efficient operations and timely deliveries. This sub-community consist of technical users of weather data that are able to interpret lower-level products (e.g., level 2 or 3) and communicate relevant hazards to decision-makers. They also employ data through ports that are commonly used by the aviation industry, such as NWS data, NOAAPort, outputs from NOAA's Automated Surface Observing Systems (ASOS), and Terminal Aerodrome Forecasts (TAF) that are provided by NOAA in coordination with the FAA. For example, a logistical meteorologist will provide convective hazard forecasts that cargo pilots use to plan efficient and safe flight routes. They monitor fog forecasts and conditions at key air cargo hubs (e.g., San Francisco) and recommend canceling or delaying flight operations if the fog does not dissipate by 1 am the morning of the flight (many air cargo flights occur overnight so they can reach their destination in time for deliveries required that day). Hence, this sub-community is primarily interested in high-resolution (airport scale) and low latency weather products with 4 hours of lead time to react to weather for domestic flights, 12 to 14 hours for international flights, and 2 to 3 days before large natural disaster events.

Additionally, the use of UAVs has garnered much interest by major carriers and brands in the logistics community. Their adoption of UAVs hinges on their ability to fly safely and reliably. Winds and precipitation significantly affect the range, routes, and safety of UAVs. In anticipation of this future need, weather companies are utilizing data scientists that are highly familiar with Earth observing satellite datasets and can provide value-added products tailored for UAV operations in the logistics sector. Like the aviation community, this UAV-focused sub-community is primarily interested in visibility, winds, and thunderstorm hazards in the lowest part of the atmosphere. Hence, they need easily discoverable, timely (<6-hour latency), very high vertical resolution data products that include measurements of winds and moisture within about 500 feet off the ground to access hazards to the efficient operation of UAVs.

Many meteorologists at logistics companies are not actively engaging with NASA as many NASA data products are not tailored to specific applications. They need to know that the data are accurate and reliable enough to ensure crew safety and delivery of goods. Meteorologists in this field have expressed eagerness to increase engagement with NASA to communicate data format needs and understand capabilities of new observations in order to promote early testing and integration of data into their systems. The time for understanding, evaluating, and incorporating new data in the current workflows could be an adoption barrier and needs to be considered with new Earth-observation technology developments. Key organizations to engage include cargo companies such as FedEx and UPS as they are familiar with satellite data, have the resources to test new data, and can become local pivots of dissemination within their organization.

B) Ground-based Logistics

Major *logistical brands* —including Walmart, Amazon, FedEx, and UPS— that service ground-based transportation and supply chain activities rely on weather information to strategically allocate resources for business continuity, and monitor supply chain disruptions from their partners. Many of these private and public companies and organizations need data products within 24–48 hours of an event to alert their transportation service providers of the probability of heavy rain, snowfall, and fog. Three- to seven-day weather forecasts are also valuable for identifying large storm systems, such as hurricanes. They also need high-resolution data, city block level, to understand the impacts of weather on the surrounding facilities and roads. For these groups, most data come from third-party platforms and vendors, such as StormGeo or AccuWeather, that have meteorologists on staff to advise managers, to monitor multiple locations. These third-party entities enable easy and direct access to specific thresholds (e.g., snow amounts through gridded products) and identification of risks that may influence transport routes and delivery of goods. Currently, these stakeholder needs for satellite data accessed directly from NASA or other federal partners are low. However, some logistical organizations have expressed desire to understand the full range of data to understand current capabilities, limitations, and opportunities for use of new NASA data to enhance operational decision- making.

C) Sea-based Logistics

Federal agencies (e.g., NOAA, U.S. Army Corps of Engineers, U.S. Coast Guard), private companies (e.g., Fathom Science), and international organizations heavily rely on satellite data for maritime services and operations and thus are considered more sophisticated users of satellite data. This sub-community caters to a wide range of users including fisheries, military organizations, shipping companies, energy services, port authorities, and disaster response organizations. The use of level 2 and level 3 near-real-time and historical data products are delivered downstream through technology platforms or web portals to provide value-added, high-resolution meteorological and physical oceanographic information on demand to their users. Satellite observations of precipitation, clouds, and water vapor are often used as input to constrain and validate models within a maritime service provider's system.

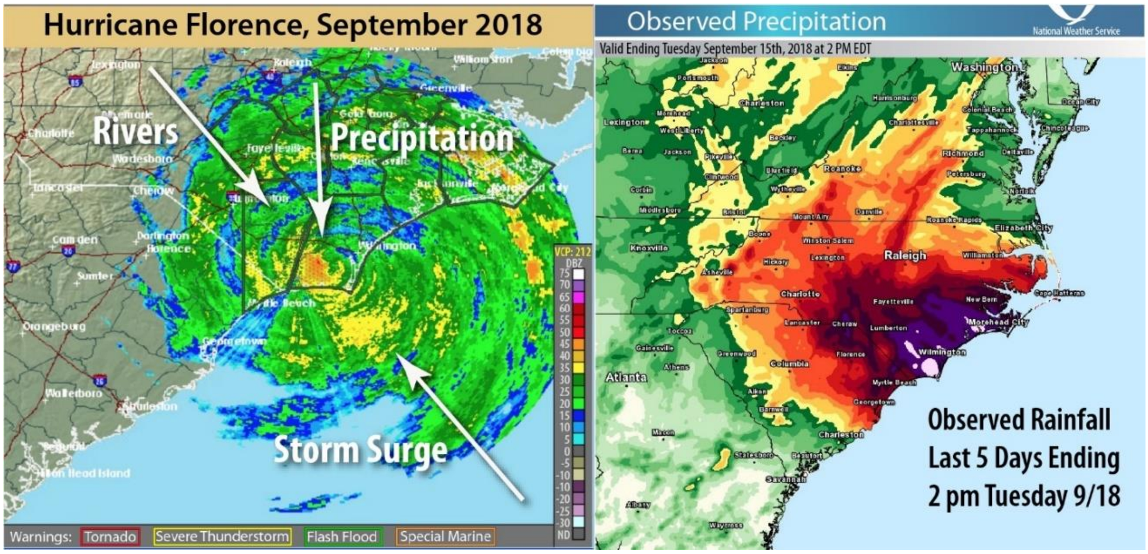


Figure 3.4.1. Fathom Science, a participant at the NASA GPM-ACCP Transportation Workshop in November 2020, presented a case study using GPM data within their system to model the arrival of Hurricane Florence and forecast compound flooding in North Carolina, U.S. in September 2018. The left image shows the area most at risk for compound flooding. The image on the right shows observed precipitation using GPM data. This forecast was then disseminated through Fathom's web portal. Credit: Fathom Science

Maritime service providers have expressed specific meteorological needs that are important for operations. These include more-frequent and higher-resolution vertical profiles of temperature, moisture, and wind; the need for both local and global coverage; and spatiotemporal continuity of data. Stakeholders expressed interest in instruments that would enhance monitoring of hazardous storms over lakes. While there are interests to be a part of the conversation to understand current capabilities, limitations, and opportunities for use of NASA data, stakeholders have emphasized that incorporating new data within their systems needs to be strategic and planned, as ingesting new data into systems and models takes time; cost need to be considered; and training on data utilization is important. As such, directly engaging with the private sector including companies like Fathom Science and agencies like NOAA will help facilitate the use of AOS data and decision-making for their downstream users. This includes coordinating workshops and trainings with these organizations as well as encourage participation in the Early Adopter program.

D) Analysis and Findings for Logistics Community

The main hazards that concern logistical operations includes fog, convection, precipitation, and volcanic ash. Fog occurrence at airports, especially at those that do not meet standard visibility minimums required for landing/taxiing/takeoff, can cause major delays. Similarly, significant winter precipitation (e.g., >1-2 inches per hour) is a major concern for aircraft operations. Hence, additional coverage of higher latitudes can provide more frequent observations that will assist this community with these two concerns, especially at its northern hubs. Tropical convective hazards (e.g., hurricanes) are another concern for two reasons—1) they may significantly disrupt regional operations for an extended period of time and 2) they complicate efficient air- and sea-based cargo operations, which often have to navigate large distances around these hazards (requiring more fuel and can introduce delays). Also, volcanic ash is another hazard that can disrupt major air routes. Hence, AOS observables including aerosol types, their vertical distributions, low clouds (and fog), precipitation and convective hazards are valuable to this community for efficient operations and planning.

Logistical companies with global operations, especially those with an air cargo fleet, such as UPS and FedEx, rely heavily on Earth observing satellite information. Although most are familiar with that provided by operational geostationary weather satellites, they also rely on global NWP models, most of which assimilate microwave observations from low-Earth orbiting (LEO) satellites, and would benefit from improved NWP (Section 3.1). These users also share similar needs to the commercial aviation users (Section 3.3) (e.g., convective storms, volcanic ash and smoke data, vertically resolved fog cloud layers above 12,000 feet), and work closely with aviation users, and may have more current bandwidth and resources to commit to working with NASA than their passenger transportation counterparts.

Therefore, working directly with third-party platform providers, the aviation sector, such as A4A, and NWP community would strongly enable this community on a larger scale.

3.5 ENVIRONMENTAL PUBLIC HEALTH

Community Overview

Outdoor air pollution is estimated to cause over 4 million premature deaths annually around the world (WHO, 2016), with most being attributed to particulate matter < 2.5 µm in size ($PM_{2.5}$), and costs more than $5 trillion in lost labor income and welfare losses annually (World Bank, 2016). A recent study increased the premature mortality associated with $PM_{2.5}$ to 8.7 million (Vohra et al., 2021). People living in Low and Middle Income Countries (LMICs) are disproportionately (91%) burdened with the mortality associated with outdoor air pollution (WHO, 2016) and the annual number of deaths are projected to more than double by 2060 (OECD, 2016). de Sherbinin et al. (2014) note that most of the world's population have little or no information on the health risks of air pollution. In the United States, roughly $65 billion is spent annually on mitigating air pollution, resulting in $2 trillion in benefits, including over 160,000 cases of reduced infant and adult premature mortality (U.S. EPA, 2011). By 2060, 6 to 9 million premature deaths worldwide are expected in association with poor AQ, with the associated annual global welfare costs projected to rise from U.S. $3 trillion in 2015 to U.S. $18 to $25 trillion in 2060 (OECD, 2016).

Within the last decade, environmental public health professionals (e.g., World Health Organization [WHO], Centers for Disease Control and Prevention [CDC], Global Burden of Disease, U.S. Environmental Protection Agency [EPA], United Nations Environmental Programme, numerous non-governmental organizations [NGO]), who are a large and diverse community with a wide range of specialties, have begun using satellite data for their applications, especially given the poor spatio-temporal coverage of speciated particulate matter data. However, *the environmental public health community largely remains a community of potential* as most health professionals do not currently use satellite data or only use it sparingly. Using the number of scientific publications as a metric (e.g., Brauer et al., 2015; Cohen et al., 2017; Bowe et al., 2021;

Shin et al., 2021), arguably the most successful use of satellite data of aerosols (e.g., aerosol optical depth [AOD]) for human health applications has been a global surface $PM_{2.5}$ data product, which was inferred from multi-instrument, long-term satellite data of aerosols and an atmospheric model (van Donkelaar et al., 2010); the L4 data product, which was developed by an intermediary – a university professor and team in this case, is available via NASA Socioeconomic Data and Applications Center (SEDAC) and has been used in numerous health studies. *Given the considerable expertise required (as well as time and financial resources) to develop a surface gridded $PM_{2.5}$ data product, the vast majority of this community of potential will likely continue to rely on a handful of experts to generate the product for them. That is, capacity building is not an option for most potential stakeholders within this community.*

Environmental Public Health Sub-Communities

Here we discuss current and potential uses of satellite data by several sub-communities of environmental public health professionals. While these sub-communities share similar aerosol data needs, they also have distinct requirements. For instance, various sub-communities have spatio-temporal coverage requirements, such as to monitor and assess the impact of acute, sub-chronic, and chronic exposures. However, they all benefit from 1) the primary advantage (i.e., spatio-temporal coverage) of satellite data over surface AQ monitors, including where there are no monitors, and 2) the availability of multi-instrument, long-term L4 data products of $PM_{2.5}$, such as produced by intermediaries as discussed above. In fact, several stakeholders mentioned that they value spatial continuity and long-term, consistent datasets of surface $PM_{2.5}$ to such a degree that they will tolerate data with relatively large uncertainties within reason, of course. While data product latency is generally not a priority of this community, the sub-community that relies on AQ forecasts do indeed value low latency data.

A) Burden of Disease Researchers

A Community of Potential and Practice

This sub-community of public health professionals are concerned with all aspects of the natural and built environment, including air pollution, that may affect human health and disease. Environmental public health researchers represent a diverse field that includes epidemiology – the study of the causes of health outcomes and diseases in populations. Within the last decade, some epidemiologists began using satellite data in their studies (e.g., Shin et al., 2021; Zhang et al., 2021 to name a few recent ones) and were enabled by publicly-available surface $PM_{2.5}$ estimates inferred from satellite and ground observations with atmospheric models. However, this sub-community is considered to be of both practice and potential as not all of these stakeholders use satellite data in their applications.

The Global Burden of Disease (GBD) study, led by the Institute for Health Metrics and Evaluation (IHME), is the most comprehensive worldwide observational epidemiological study to date that quantifies death and loss of health due to diseases, injuries and risk factors, including exposure to air pollution, for all regions of the world. Disease burdens are estimated using the global data of surface $PM_{2.5}$, which are publicly-available through the State of Global Air report and interactive website, and updated annually by the Health Effects Institute and IHME. The gridded ($0.1 \times 0.1°$) estimate of surface $PM_{2.5}$ concentrations was created by integrating AOD observations from multiple satellites with global chemical transport models and ground observations (van Donkelaar et al., 2016; Shaddick et al., 2018).

While global estimates of surface $PM_{2.5}$ have transformed environmental health surveillance capabilities in many respects, environmental public health researchers would benefit from better spatio-temporal information on the components of aerosol mixtures (e.g., wildfire smoke, dust, sea salt), which is critical for understanding toxicity. In addition, consistent, long-term satellite data records are important for exposure models.

B) Environmental Justice Advocates

A Community of Potential

Environmental justice (EJ) advocates work toward the fair treatment of all people, regardless of race, color, national origin, or income, with respect to the development, implementation and enforcement of environmental laws, regulations and policies, including for air pollution. A number of federal agencies, such as US EPA and the U.S. Dept. of Health and Human Services, as well as non-governmental organizations (NGOs) work to address EJ issues. The Biden Administration issued an Executive Order in January 2021 that calls for a national scale EJ screening tool, which will require spatially complete information about environmental risk factors, including air pollutants. The EJ sub-community would benefit from very fine spatio-temporal resolutions of surface $PM_{2.5}$ and concentration gradients as they identify patterns of air pollution down to the neighborhood level (e.g., Southerland et al., 2021; Castillo et al., 2021). Additionally, they would benefit from pollution source identification and attribution, which is discussed in the section on environmental public health mitigation and policy planners.

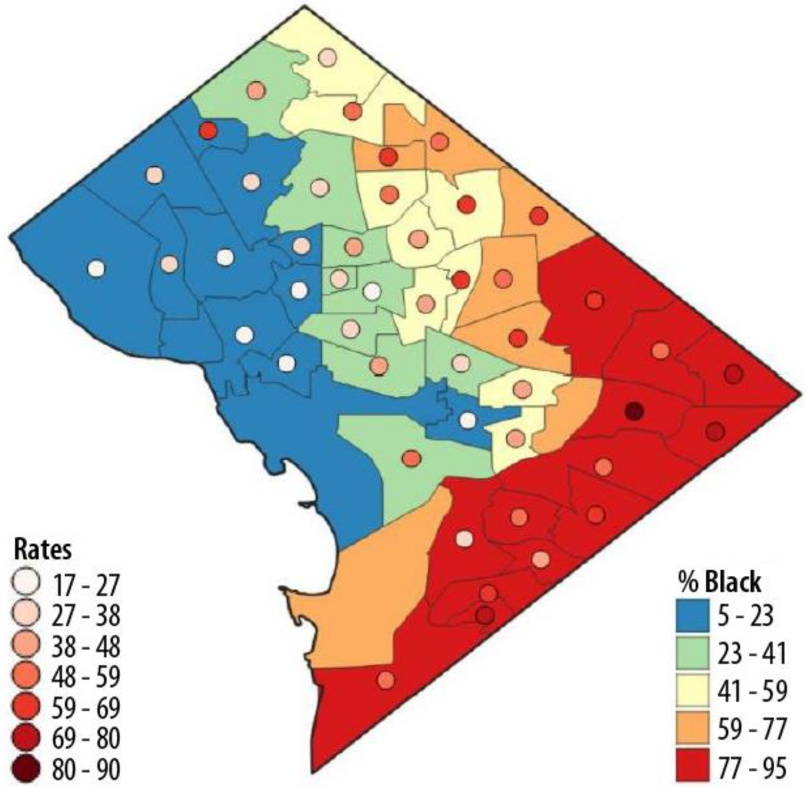


Figure 3.5.1. The relatively high-spatial resolution of a Level-4 $PM_{2.5}$ data product, which was derived from various satellite AOD datasets (van Donkelaar et al., 2019), allowed for the calculation of $PM_{2.5}$-attributable mortality rates (per 100,000 people) for all-cause mortality and percent (%) Black distribution by neighborhood across Washington, DC. Data represent equal intervals and 2011-2015 means. Figure from Castillo et al., 2021.

C) Environmental Public Health Mitigation and Policy Planners

A Community of Potential

Environmental public health mitigation and policy planners, which work in almost all world city and federal governments (e.g., U.S. National Institutes of Health [NIH], CDC), have the goal to protect communities from a variety of environmental hazards, including air pollution. For example, some cities around the world have developed "urban dashboards" that bring together many sources of data (e.g., on air quality, transportation, population, health) to inform environmental public health mitigation and policy making efforts. They could use satellite data to track air pollution plumes (e.g., from wildfires), quantify emission sources, monitor long-term air pollution trends, and to verify the efficacy of air pollution control efforts. This sub-community would benefit from satellite-based estimates of surface $PM_{2.5}$ and satellite data that may be used for source identification and attribution as well as exposure estimates. Aerosols can be directly emitted from, for example, fires, combustion engines, and soil disturbance, but also can form in the atmosphere as gaseous pollutants undergo a chemical process called gas-to-particle conversation. These gaseous pollutants include sulfur dioxide (SO_2), ammonia (NH_3), and nitrogen dioxide (NO_2), all of which are observable from satellite instruments. Aerosol precursor emissions source estimation could include both large point sources (e.g., power plants) as well as areas sources (e.g., cities). Therefore, source identification and attribution for mitigation planning would include both satellite observations of speciated aerosol and aerosol precursor trace gases.

D) Air Pollution Real-Time Avoidance Behavior

A Community of Potential, see Sections 3.6-3.7 for more information.

For the world's roughly 339 million asthma patients and 251 million chronic obstructive pulmonary disease (COPD) patients, exposure to PM may trigger an acute respiratory event, which could be life-threatening. Health care professionals (e.g., general practitioners) require *near-real-time, speciated surface $PM_{2.5}$ and PM_1 data* to link exposure to particulates and other co-located environmental factors (e.g., weather) to specific health outcomes. This knowledge allows the health care professional to manage care for individuals afflicted by these respiratory diseases. In addition, AQ forecasts (e.g., from US NOAA), including alerts when unhealthy levels of pollution are occurring or expected, allow sensitive populations time to take action to protect their own health as well as the health of others that they care for.

E) Analysis and Findings for Environmental Public Health Community

The environmental public health community is likely the largest community of potential for satellite data of aerosols. As discussed above, *a Level 4 (L4) gridded surface $PM_{2.5}$ data product has the greatest potential to enable this community on a large scale.* The creation of such a hybrid satellite data-model product (i.e., a "Level 4 data product" in NASA terminology) requires considerable remote sensing and geoscientific data expertise as well as financial and computational resources, which is simply not feasible for the vast majority of health professionals (e.g., Anenberg et al., 2020; Duncan et al., 2021). Therefore, the further development of Level 4 data products by AOS satellite retrieval experts, in consultation with health professionals, is necessary to enable more health professionals to use satellite data in their applications. As discussed at the beginning of Section 3, AOS data will not likely be sufficient on its own to support the generation of a L4 data product. Thus, AOS satellite retrieval experts would need to closely work with retrieval experts of other POR instruments and data assimilation experts to generate a multi-instrument L4 data product.

In addition, better knowledge of the global vertical distributions of aerosols and inferred speciated $PM_{2.5}$ and PM_1 (i.e., ultrafine particles) that are expected to be derived from the AOS mission will help, for instance, to provide new information to aid the design of more efficient air pollution mitigation strategies to protect human health as well as the assessment of the impact of air pollution on human health. However, along with better estimates of speciated, surface $PM_{2.5}$ and PM_1, this community requires confidence in the surface concentrations, which may only be obtained through comprehensive validation with suborbital observations.

3.6 AIR QUALITY MODELING

Community Overview

Poor air quality (AQ) is a significant environmental risk to human health. Each year, millions of premature deaths are attributed to ambient (outdoor) air pollution and 91% of the world's population live in places where the World Health Organization (WHO) AQ guidelines are not met (WHO, 2016). The vast majority of negative health impacts is caused by exposure to fine aerosols (or particulate matter).

Models that simulate the emission and transport of pollutants are essential tools for AQ modelers to forecast AQ, mitigate the negative impacts of air pollution on the population, and design strategies to improve AQ. Agencies, such as NASA, NOAA, Naval Research Laboratory (NRL), and ECMWF, produce AQ forecasts for a variety of spatial (e.g., regional, global) and temporal (e.g., days, seasonal) scales. Agencies, such as the EPA along with state or regional agencies, are tasked with ensuring their region is in compliance with National Ambient Air Quality Standards (NAAQS). In the research sector, universities and civil agencies, such as EPA, NASA and NOAA, develop and improve models through comparisons with observations.

A lot of stakeholders in this user community currently use satellite observations, so most could be considered communities of practice. Uses of satellite observations include assimilation of observations to improve model forecast initialization, monitoring of AQ events, model verification, and model evaluation and development.

AQ Modeling Sub-Communities

A) AQ Forecasting

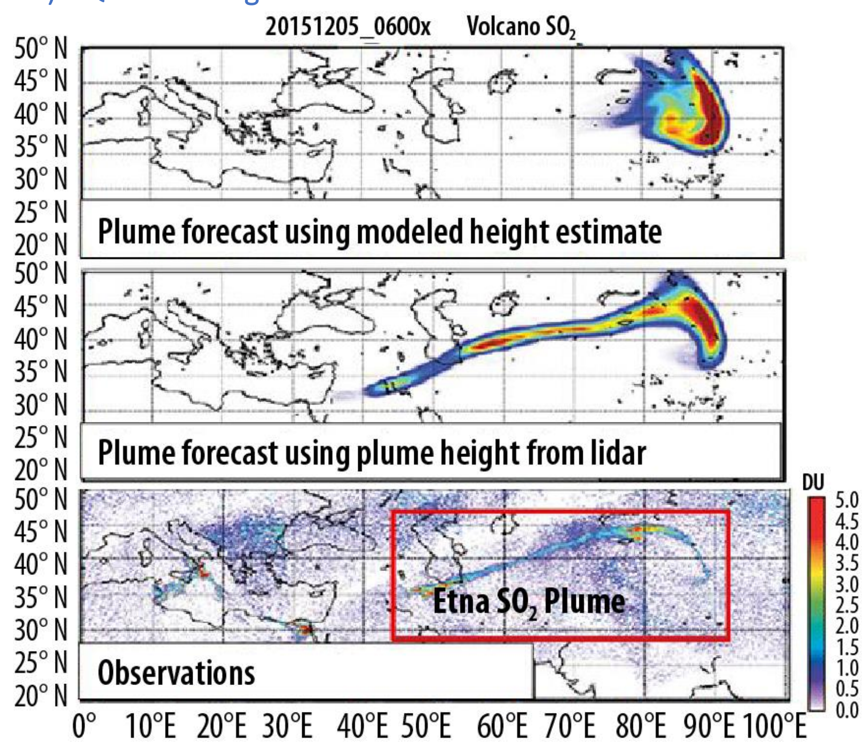


Figure 3.6.1. Low latency observations of the vertical profile of aerosols, such as from lidar, are critical to providing accurate forecasts of plume transport. Figure adapted from Hughes et al. (2016).

Operational AQ forecasts are used to provide the public with health alerts, supplement existing emission control programs through identification of scenarios that could benefit from temporary emission reductions, provide regional haze advisories for private and commercial aviation, and inform emergency response. Research AQ forecasts, such as from NASA Goddard Earth Observing System (GEOS), are used to support field campaigns, provide a testbed for modeling and assimilation techniques, and provide boundary conditions for regional models. Most stakeholders are proficient in using existing satellite data and have means of obtaining them directly from data sources. This community uses all levels (L1-L4) of satellite data in a variety of formats (HDF5, NetCDF, text) and a variety of ways, including hazardous plume monitoring (e.g., volcanic ash), forecast initialization, and model evaluation and verification. For these applications, observations at the spatial resolution of the model or finer is best. Additionally, increasing the number of observations increases the value for applications, so maximum spatial coverage (e.g., through wider-swath passive instruments and the dual-orbit architecture) is desired. Knowledge of uncertainties is a high priority for this community across all applications.

Assimilation or incorporation of satellite observations increases the accuracy of short-term (~1-10 day) operational weather, AQ, and plume forecasts. Aerosol or AQ forecast models such as the NASA GEOS, NRL Aerosol Analysis and Prediction System (NAAPS), and ECMWF Copernicus Atmosphere Monitoring Service (CAMS) models, currently assimilate satellite observations of aerosol optical depth (AOD). This capability is also being developed for the NOAA Global Ensemble Forecast System (GEFS). This application typically requires a latency of less than 6 hours, but latency on the order of one hour or less is optimal for plume monitoring and forecasting. Due to the operational nature of this application, data should be available on public-facing platforms that can be automatically accessed. While these agencies welcome new observations to improve forecast accuracy, it is both time (e.g., years) and resource consuming to incorporate new sensors into their assimilation systems, particularly when the observations are novel (e.g., lidar data). Therefore, for this application, continuity is a priority and engagement with this community early in a mission life cycle is strongly advised. Civil agencies such as these are currently engaged and working with NASA to incorporate AOS observations.

Satellite observations are also used for model evaluation and verification. For these applications, novel and/or short-term observations are welcomed, and low latency is not typically required.

B) AQ modeling for regulatory science and research

EPA, along with state and regional environmental agencies, use AQ modeling to determine the impacts of different pollution scenarios to inform AQ policy, design strategies to reduce harmful pollutants, and inform decision making. These agencies typically use variations of the high-resolution Community Multiscale Air Quality Modeling System (CMAQ), a regional chemical model. These stakeholders have a range of experience with using satellite observations. Typical uses of satellite data include model evaluation, inclusion as 'weight of evidence' in exceptional event analysis, and long-term trend analysis. Newer applications for this community are the use of satellite observations in the estimation of pollutant emissions and in model constraints through data assimilation.

Research arms of agencies, such as NASA, NOAA, National Center for Atmospheric Research (NCAR), and ECMWF, maintain and develop versions of their global models that are used for scientific analyses. Typical uses of satellite data include model evaluation and development, and assimilation into long-term reanalyses datasets. Users in this community are often eager to incorporate new observations to improve model process representation and will tolerate shorter lifespan missions or field campaigns if they further research questions.

These applications do not require low latency products. Level 2 data are used for quantitative analysis by experienced users. In other analyses, Level 3 or 4 data products are preferred. Acceptable data formats include HDF5, NetCDF, and text. Similar to the forecasting community, novel and/or short-term observations are welcomed, more spatial coverage is desired, and observations at the spatial resolution of the model or finer is best. Note, given that CMAQ is a regional model it is typically run at higher resolutions than global models. Characterization of data uncertainties is a high priority for this community. NASA is currently engaging directly with these stakeholders to facilitate the use of AOS observations for their applications.

C) Analysis and Findings for AQ Modeling Community

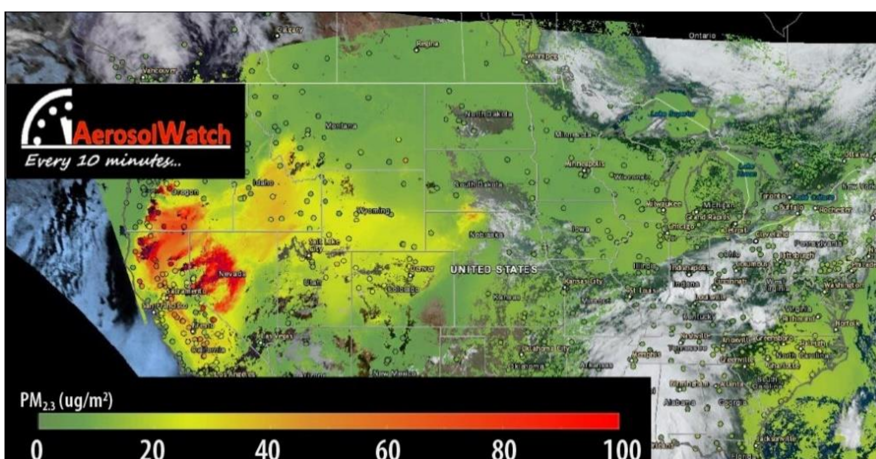
The two communities outlined here routinely use satellite observations for a variety of applications. AOS promises a suite of novel measurements, such as vertical aerosol information with co-located polarimeter observations, which could greatly benefit their applications. Agencies that produce operational AQ forecasts require time and resources to assimilate and test new observations. The creation of synthetic data products could assist in this effort and increase the likelihood that these groups incorporate AOS observations into their applications. For communities whose primary application is real time monitoring or forecast initialization, low latency (< 6 hour latency) is a key attribute in determining if observations will be useful. Key agencies to engage with include ECMWF, NOAA, and NRL, as these agencies are currently engaged and working with NASA to incorporate AOS observations.

For groups that do not require low latency for their application (e.g., regulatory science, model development and evaluation, and retrospective analyses) novel observations are encouraged, and short mission lifetimes are not a deterrent to incorporating new observations into these applications. The creation of gridded Level 3 and Level 4 products, consistent data formats, and opportunities for training would encourage AOS data use in these communities. Continued engagement with these communities will further inform preferred data formats and methods of data access. Key sectors for this application include federal regulatory agencies (e.g., EPA), regional and state regulatory agencies, civil agencies (e.g., ECMWF, NOAA, NRL, NCAR) and academia.

3.7 WILDFIRE SMOKE

Community Overview

As the frequency and size of wildfires continue to increase in the U.S. because of climate change (Balch et al., 2018; Williams et al., 2019), the resulting smoke emissions and transport of fine particulate matter ($PM_{2.5}$) and gaseous pollutants (e.g., NO_2, CO, O_3) are adversely impacting air quality (AQ) across the country



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Partnership (NPP) satellite. Regulatory-grade surface monitor sites from EPA AirNow network shown by colored circles. Aerosol retrievals from AOS will enable more accurate surface-level $PM_{2.5}$ products and improved air quality alerts to the public. Credit: NOAA Aerosol Watch.

(McClure and Jaffe, 2018). Public health is a major concern as large populations are exposed to the unhealthy to hazardous AQ conditions. The highly varying behavior of smoke emissions, particularly from wildfires, make it very difficult to monitor and predict downwind impacts on AQ and public health (Urbanski, 2014). During the summer of 2020, huge wildfires led to some of the highest levels of $PM_{2.5}$ concentrations ever observed in populated areas along the west coast of the United States (Liu et al., 2021). Costs for wildfire suppression have grown by a factor of four during the 30-year period from 1985-2018, exceeding 3 billion U.S. dollars in 2018 (Jaffe et al., 2020). Climate change projections indicate worsening economic and environmental outcomes due to further increases in fire activity in the future (Bowman et al., 2020). Smoke aerosols and gaseous constituents can in turn perturb weather and climate conditions via their effects on radiation and clouds in the atmosphere.

Although much smaller in scale compared to wildfires, agricultural and prescribed fires contribute to the amount of smoke in Earth's atmosphere. Smoke emissions from burning of agricultural fields throughout the globe can have local to regional impacts on AQ (Cusworth et al., 2018). Prescribed burning is a key wildfire management activity, but the resultant smoke particles can also degrade air quality in more localized areas (Haikerwal et al., 2015).

With the far-reaching impacts from fire smoke on AQ, environmental public health, weather, and climate, a large spectrum of user communities are active in this focus area, including AQ monitoring and forecasting, weather and climate, transportation, agriculture, energy, and health. Enhanced satellite data products from the AOS mission aim to provide improved monitoring and prediction capabilities of smoke emissions and transport, while enabling more accurate emission estimates from different smoke sources. *Key agencies to engage with include NOAA, EPA, NCAR, National Interagency Fire Center (NIFC), and the U.S. Forest Service.*

Wildfire Smoke Sub-Communities

A) AQ Monitoring and Forecasting

A Community of Practice, see section 3.6 for more information.

Universities and government agencies across the globe, including NASA, NOAA, NRL, Department of Energy (DOE), ECMWF, and Japan Meteorological Agency (JMA), are studying all facets of fire smoke impacts and AQ monitoring and forecasting capabilities. AQ modeling systems operated by NASA, NOAA, and ECMWF are capable of providing realistic AQ forecasts during fire smoke events. As such, these users are highly proficient at using existing NASA datasets. Assimilation of near real-time AOS observations, particularly lidar data, into these models will improve AQ forecasts and alerts to the public. Research efforts to improve model capabilities readily interface with novel remote sensing observations, in both near real time forecasts and for retrospective analysis. The EPA and state AQ agencies regularly monitor smoke and AQ during the fire season using satellite, surface monitoring stations, and model data for reporting daily AQ and issuing forecasts to the public. Monitoring of wildfire smoke is also critical in exceptional event demonstrations conducted by these agencies. An event is defined as exceptional if exceedances of the National Ambient Air Quality Standard (NAAQS) can be attributed to wildfires. Enhanced

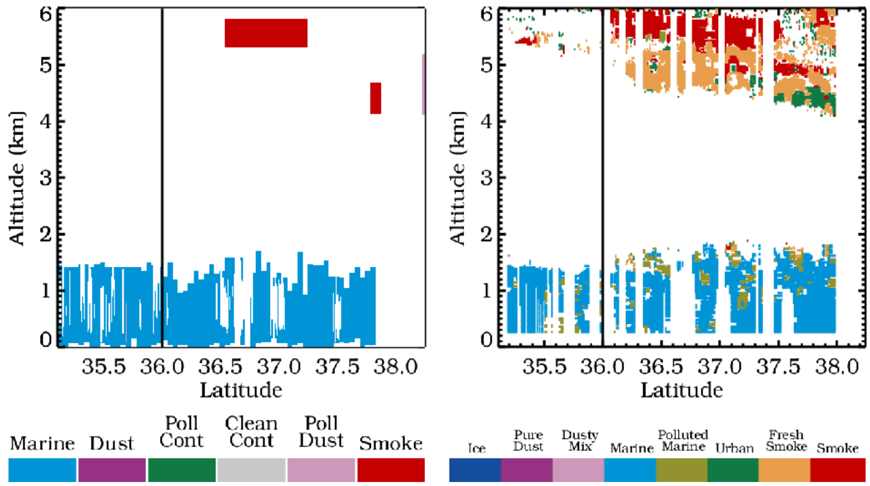


Figure 3.7.2. Aerosol classification masks from the NASA Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) on the CALIPSO satellite (left) and Langley Research Center (LaRC) airborne High Spectral Resolution Lidar (HSRL-1; right). Enhanced sensitivity of HSRL-1 to aerosol shape, size, and composition better distinguishes smoke layers in the atmosphere (Burton et al., 2013). HSRL from AOS mission will provide similar capabilities as HSRL-1. Figure from Burton et al. (2013).

observations and model forecasts from the AOS mission will provide valuable information on the influence of smoke transport on surface-level $PM_{2.5}$ concentrations, thereby enabling more informed decisions on exceptional event analyses and AQ planning. Accurate fire emissions estimates are crucial inputs to forecasts models of smoke and AQ but are highly uncertain due in part to a lack of observational data for verification. Observations from the AOS mission, particularly lidar data, are needed to validate fire emissions estimates and improve smoke forecasting capabilities. To support fire suppression efforts, national and local agencies such as the U.S. Forest Service and NIFC use near real-time satellite data to track fires and smoke plumes and dispersion models to predict smoke transport. Satellite data and dispersion model forecasts are also important for smoke management from prescribed burns. For more information on data needs and the risk tolerance of acquiring new data, we refer the reader to Section 3.6.

Near real-time application of AOS data at these agencies will offer improved tracking of smoke plume extent in the horizontal and vertical. While this community including civil forecasting organizations, NIFC, US Forest Service, and local agencies are eager to work with NASA, limited funding and mechanisms to implement research to operations can be an issue and should be noted.

B) Weather and Climate

Community of Practice, see sections 3.1-3.2 for more information.

Civil forecasting organizations (see section 3.1) such as NOAA and NCAR develop models and produce forecasts, advising the public on AQ and visibility issues. Most users in this sub-community are highly proficient at using existing datasets, acquiring them directly from NASA. Numerical weather prediction (NWP) models, such as the Rapid Refresh (RAP) model and High-Resolution Rapid Refresh (HRRR) from NOAA, and the Weather Research and Forecasting (WRF) model from NCAR, have started accounting for fire emitted aerosol feedbacks on cloud processes and radiative fluxes. As this community expands from prior sections, we refer the reader to learn more about data needs and risk tolerance of new data in Section 3.1 and 3.2.

Incorporation of AOS observations may lead to more accurate precipitation forecasts as a result of improved aerosol concentrations and layer heights in new-generation NWP models. High smoke concentrations during wildfire events are of particular importance for NWP models because of their pronounced effects on clouds and precipitation. With the increasing frequency and size of wildfires, there has been growing attention on the radiative effects of smoke in climate models. Improvements in the vertical representation of smoke aerosols in the climate models through use of lidar observations from AOS can reduce uncertainties and increase confidence levels in climate predictions. Working directly with modelers from NOAA and NCAR could increase the use of AOS data once the mission launches as these organizations are very willing to engage with NASA to implement new observations for model improvement.

C) Application Beneficiaries of Wildfire Smoke Data

AOS will help improve monitoring and prediction capabilities for smoke emissions and transport, offering an opportunity to enhance applications among several communities. Below are a few examples of beneficiaries from improved monitoring of wildfire smoke. We note here that most of these communities are eager to work with NASA, however many stakeholders expressed limited pathways (e.g., expertise, time and resources) to integrate new observations. We defer the reader to information below as well other sections of the CAR for more information.

- *Transportation (see Sections 3.3-3.4 for more information)*
  Interests in aerosol data for flight planning and en-route decision-making are increasing in the transportation community because of the impacts of volcanic ash, dust, and smoke aerosols on visibility and aircraft engines. In particular, thick smoke plumes pose the greatest risk to air travel and commercial flights have been detoured and suspended due to the presence of smoke. As a community of practice and potential, a number of users in the transportation sector, particularly for commercial flight planning (Federal Aviation Administration), apply aerosol data from satellites and models to aid decision-making activities. Near real-time lidar data from the AOS mission will raise the bar for applications in the transportation community, as the lidars in the polar and inclined orbits will increase the coverage of vertically resolved observations of smoke aerosols and better inform flight planning and decision-making. Incorporation of AOS observations into models will improve forecasts of smoke plume extent and aerosol concentrations in the atmosphere. An improved characterization of smoke plumes in new-generation weather models could also promote more accurate precipitation forecasts. Logistics carriers could also better assess threats to air travel and improve their delivery performance and reputation through application of AOS data. Furthermore, the enhanced $PM_{2.5}$ product from AOS will allow stakeholders to better characterize exceptional AQ events related to wildfire smoke for monitoring employee health and safety, an area of interest for logistics arms. Satellite data with low latency is critical to the transportation community, in addition to gridded Level 3 and 4 data because of the large community of potential in the logistics sector.

- *Agriculture (see Section 3.9 for more information)*
  The agriculture community, including national agencies such as the U.S. Department of Agriculture (USDA), has a high level of interest in using Earth observations for crop

management because of the better understanding of the relationship between air pollution and crop health in the community. However, AQ information is not currently used in the agricultural sector, a community of potential, but the research community is developing capabilities in preparation for future use of data in this user community as it has a medium to high risk tolerance of using new data. Smoke from fires and factories near farms are of particular interest in this community, as elevated levels of $PM_{2.5}$ and ozone from smoke can impact crop health and yield. Smoke aerosols can impact crop health by depositing onto fields and reducing photosynthesis activity. Surface-level $PM_{2.5}$ concentrations from AOS will be capable of improving farm management practices, such as closing greenhouses and covering plants to avoid deposition. In addition to wildfire smoke, the high-resolution $PM_{2.5}$ product will allow for improved characterization of local enhancements in smoke related to agricultural and prescribed burning activities, further enhancing farm management practices. Furthermore, the agriculture community can use satellite-informed AQ forecasts to apply the most effective procedures for crop management in advance of exceptional AQ events from wildfire smoke. Aerosol data from AOS could also aid planning strategies for planting vegetation in preferred city locations, where plants are often in direct contact with pollution. AOS observations will help fill the gap in AQ information in regions that are growing key commodities and impacted by biomass burning and smoke, such as tropical zones in Africa and Latin America. The agriculture community would benefit from near real-time (latency less than 3 hours) of column aerosol and surface-level $PM_{2.5}$ products. As a community of potential in terms of using AQ data, the production of gridded Level 3 and 4 products will be critical for the agriculture sector.

- *Energy (see Section 3.10 for more information)*
  Commercial users in the solar energy community regularly apply aerosol data from satellites for solar site development and operational optimization activities, since their production performance is highly dependent on the aerosol loading in the column and at the surface-level. Solar energy production can be particularly impacted by wildfire smoke events that produce high aerosol concentrations, which reduce the amount of solar irradiance reaching the panel. High smoke concentrations at the surface-level can lead to a significant deposit of ash on the solar panels, further reducing the production efficiency. Near real-time aerosol data from AOS can lead to more efficient solar energy production by providing more accurate information on column and surface-level aerosol amounts during smoke events. For example, solar plant operators will be able to turn on the plant when a lower amount of smoke exists over the local site during a wildfire outbreak. Assimilation of AOS observations into AQ models should permit more accurate 3- to 5-day forecasts, allowing solar plant operators to better assess short-term production outlooks and demand balancing. Enhanced spatial resolution products from AOS will provide information on fine-scale aerosol gradients around solar sites. As a community of practice, the solar energy sector has experience using level 2 products, but some users will benefit from gridded higher-level products. Aerosol data with low latency and high accuracy are both important to this community.

- *Health (see Section 3.5 for more information)*
  Enhanced levels of $PM_{2.5}$ from smoke related to wildfires and agricultural and prescribed burning can lead to poor health outcomes. Wildfires are of particular importance to the health community as the long-range smoke transport from wildfire outbreaks can lead to large population exposure to high levels of $PM_{2.5}$ concentrations. Lidar observations from AOS will enable a better understanding on the impacts of different aerosol particle types, such as smoke, on health outcomes. Enhanced surface-level $PM_{2.5}$ products from AOS during wildfire smoke outbreaks can inform exposure models and assessments of smoke impacts on health. Gridded level 4 data products are most important to this community.

D) Analysis and Findings for Wildfire Smoke Community

A myriad of users could benefit from enhanced aerosol observations of smoke from AOS, as smoke from wildfires and agricultural and prescribed burning activities are prevalent throughout the globe. Near real-time data is critically important for many of the applications and users in the fire smoke community. A large community of potential exists in this focus area, including the agriculture (e.g., USDA, National Corn Growers Association) and logistics (e.g., UPS, FedEx) communities, which stresses the need for gridded level 3 and 4 data products that are easily accessible to users in this community. AOS AIT should coordinate workshops focused on these communities of potential, especially the agriculture sector, to increase awareness of the AOS mission and better prepare data products, interfaces, and visualization tools that fulfill stakeholder needs. AOS applications for wildfire smoke will be fully realized by transforming the large community of potential into a community of practice by the time of AOS launch.

Synergistic aerosol products from the spectrometer, polarimeter, and lidar instruments planned for AOS could further aid in monitoring wildfire smoke transport and surface-level $PM_{2.5}$ concentrations. An Early Adopters Program will benefit many users in this community and ability of the users to understand AOS data products before launch will be key for successful application of operational data. Providing information on product uncertainties early in the mission lifecycle will also benefit adoption of data by users requiring highly accurate data.

3.8 FLOODS AND LANDSLIDES

Community Overview

Hydrometeorological disasters cause hundreds of deaths, thousands of injuries and cost billions of dollars each year in the U.S. alone. NOAA's National Center for Environmental Information estimates that in 2020 alone we experienced 22 separate billion-dollar weather and climate disasters, far surpassing the 16 events in 2011 and 2017, with combined $95 billion in damages (Figure 3.8.1). As the climate changes, it is imperative that resilience and adaptation are improved by understanding what environments are likely to produce severe hydrometerological events and what is the timing and longevity of these impacts.

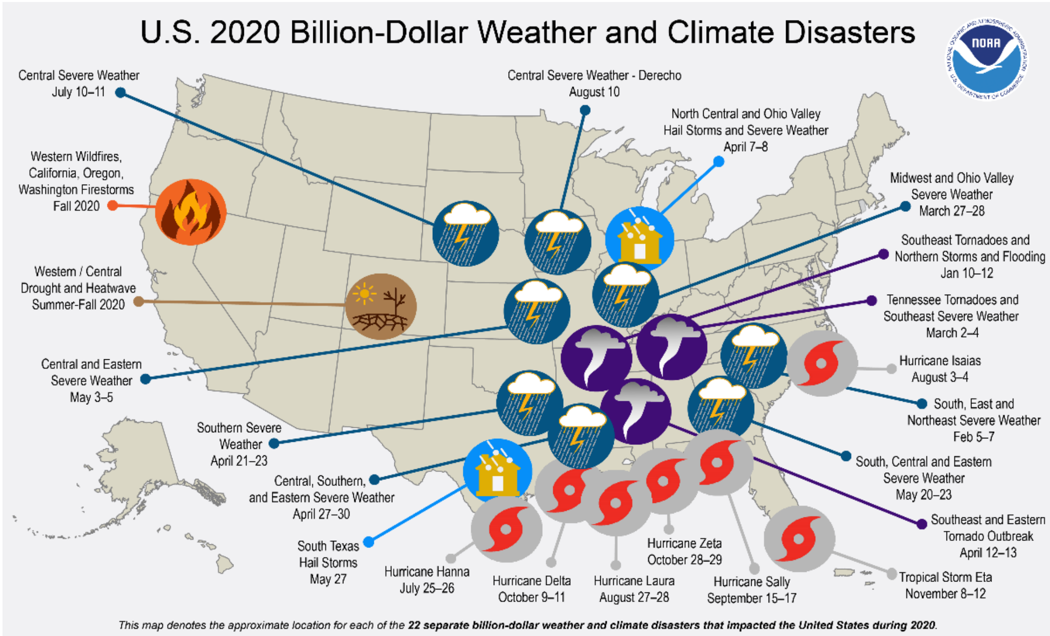


Figure 3.8.1. In 2020, the US experienced 22 billion-dollar weather and climate disasters, far surpassing the 16 in 2011 and 2017. AOS will advance severe storm forecasting by observing vertical air motions in storms and atmospheric parameters relevant for weather forecasting. Figure from https://www.climate.gov/news-features/blogs/beyond-data/2020-us-billion-dollar-weather-and-climate-disasters-historical.

Floods and Landslides Sub-Communities

A) Floods

Flooding is the number-one natural peril in the U.S. (Munich Re). The flood hazard assessment, response and mitigation community seeks to address these challenges at local to global scales, with remote sensing playing a critical role in advancing flood hazard assessment (Schumann et al. 2018). Global initiatives such as the Global Flood Partnership provides a cooperative framework that engages scientific organizations and flood disaster managers around the world to share and cultivate new strategies for flood observations and modelling infrastructure (https://gfp.jrc.ec.europa.eu/about-us). Participants affiliated with these international partnerships, modelers in the academic and government communities, and multi-national companies are often well-versed in the use of remotely sensed products including precipitation, topography, soil moisture and vegetation as well as mapping capabilities using high resolution commercial optical data and Synthetic Aperture Radar. However, stakeholders at more local scales, particularly in low-income countries often have fewer tools or less capacity to incorporate flood hazard models into actionable information over their areas of jurisdiction.

The flood modeling community largely relies on gridded satellite precipitation estimates for regional to global characterization of the rainfall intensities that may exacerbate flooding conditions. In concert with estimates of gridded soil moisture, elevation, topography, and land cover, the land surface modeling schemes primarily use satellite precipitation as an input to machine learning, physical or empirical models to characterize the location and depth of discharge. NASA is currently engaging directly with the flooding modeling community to understand the integration of L3/L4 products into their models.

A foundational need from the flood modeling and hazard assessment community is having sufficiently long records of precipitation and other hydrologic variables to train and test their models. As such, data continuity is a high priority. The flood modeling communities are diverse and are generally experienced in using gridded satellite precipitation information, representing a robust and knowledgeable community of practice. Flood modelers would be susceptible in bringing in new data into their systems even if the data does not exactly meet their needs as they have the time and resources available for data testing. However, ingesting new data with no continuous record is a deal breaker. Local to regional flood managers have a range of expertise and familiarity with remote sensing products depending on their location. This community is growing in their capacity to use remote sensing products and could be generally considered a community of potential. As such, there is room to explore options on how to engage with this community and increase awareness of and use of lower-level products.

Working directly with flood modelers within the academic community and federal partners (e.g., Federal Emergency Management Agency [FEMA] and NOAA) would help facilitate the use of AOS observations within the flood hazard assessment, response and mitigation community. It would further help to substantiate the tools and capabilities needed to fully exploit existing and new data products most effectively.

B) Landslides

Intense or prolonged rainfall is the most frequent trigger of landslides around the world. Landslide hazard assessment is often conducted locally to regionally, with hazard assessment systems focused on leveraging gauge and radar data to support rapid characterization of landslide hazard and risk based on rainfall thresholds, topographic characteristics, vegetation, infrastructure, and lithologic structures, among many other factors. There are some global initiatives, such as the LandAware network **(https://www.landaware.org)**, which is a multi-disciplinary network of individuals (e.g. managers, researchers, stakeholders) who are interested in cooperating for addressing and promoting issues related to Landslide Early Warning Systems (LEWS) (Calvello et al. 2020). The primary purpose of LandAware is to share experiences, needs and innovations among LEWS experts and to develop and promote guidelines and best practices for upcoming LEWS, including the use of remote sensing data to support regional to global scale LEWS activities.

There is an increasing use of remote sensing products to assess landslide triggers, including the use of L3, gridded GPM precipitation and Soil Moisture Active Passive (SMAP) mission soil moisture products. This user community is a relatively small community and is quite varied in expertise, with some companies, academic and government agencies, and international organizations (e.g. World Bank Global Facility for Disaster Reduction and Recovery (GFDRR)) leveraging remote sensing products to characterize landslide hazards; whereas other more local agencies (e.g. district disaster response organizations, NGOs) have less capacity and knowledge to use these data and tools. Overall, the communities rely on gridded satellite precipitation information to better understand the rainfall intensity thresholds that may trigger a landslide.

These hazard modeling efforts and early warning systems are used to make operational warnings at local to regional scales and increase situational awareness of potential hazardous areas at regional to global scales. One example of a near real-time application of satellite precipitation information within a landslide hazard framework is the Landslide Hazard Assessment for Situational Awareness (LHASA) model, which uses GPM Integrated Multi-satellitE Retrievals for GPM (IMERG) data to provide routine, global estimates of landslide hazard and exposure (Kirschbaum et al. 2018, Stanley et al. 2021). The landslide hazard assessment and modeling communities also require long records from which to evaluate model performance and characterize distributions of extreme rainfall that may influence landslide-triggering rainfall thresholds. This community would be interested in bringing in new data into their systems. However, like the flooding community, ingesting new data with no continuous record is a deal breaker as a long data archive is needed to parameterize landslide models. Even more limiting for this community in using new data is the availability of funding opportunities, as this community is relatively small and mostly made of academia. Working directly and providing opportunities to discuss data needs with persons in academia would encourage use of AOS observations.

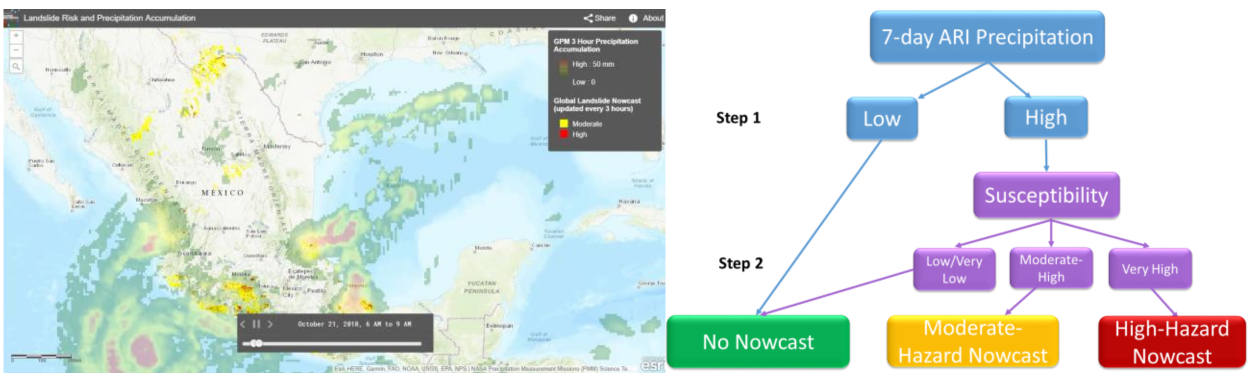


Figure 3.8.2. LHASA Version 1.1 model on left showing GPM IMERG data of Hurricane Willa about to make landfall in western Mexico with dynamic landslide hazard estimates shown in red and yellow. The system is updated routinely at https://landslides.nasa.gov. The right figure shows the decision tree-based model for LHASA Version 1.1 that leverages a 7-day antecedent rainfall index (ARI) using the 20-year IMERG record to identify extreme rainfall that exceeds the 95th percentile of this historic distribution (Kirschbaum et al. 2018).

C) Analysis and Findings for Floods and Landslides Communities

The suite of AOS products provide an opportunity to continue, extend and improve surface precipitation estimates and characterize extremes and anomalies that are vital to both the flood and landslide communities. Gridded precipitation products, such as the development of L3 and L4 products, with long records are foundational to both applications and provide the ability to leverage high resolution precipitation information to train and validate modeling efforts as well as characterize and relate extreme precipitation events to landslide and flood occurrence. Leveraging the POR to provide more comprehensive coverage of precipitation and better characterize extreme events will be critical and improved resolution of convective events will also advance modeling efforts to better identify the impacts of orographic impacts on hydrometeorological events, particularly for flash floods and landslides. These communities rely on low latency observations of extreme precipitation on standard grids (i.e. not swath data) to provide as inputs to their models. Improvements in more accurately resolving precipitation extremes in topographically complex regions remains an area of future research that the AOS suite of products may advance.

While these communities are made up of a diverse group of academic and government communities, and multi-national companies and some organizations, engagement at science conferences or thematically focus meetings with groups such as the Global Flood Partnership and other similar academic end users is ideal. These opportunities would enable continued dialogue and identification of new users and new opportunities.

3.9 WATER RESOURCES, AGRICULTURE, FOOD AND BEVERAGE

Community Overview

Growing human population, increased demand for water and energy, and a changing climate have contributed to concerns of how freshwater resources, food supply and production may be stressed. Both water resource managers and the agricultural community, which includes national and international agencies, non-profit organizations, and private companies, need to know the amount, distribution, timing and onset of seasonal rain and snow to prepare for freshwater shortages, determine crop growing locations, and forecast crop yields. Remotely-sensed gridded precipitation estimates play a key role in predicting changes in freshwater supply and agricultural yields/forecasting. Stakeholders from this community are viewed as a mixture of community of practice and community of potential, where stakeholders are direct users of EO data or act as intermediaries for application communities to assess water supply, crop yield and evaluate risks.

Water, Agriculture, Food and Beverage Sub-Communities

A) Water Resource Management

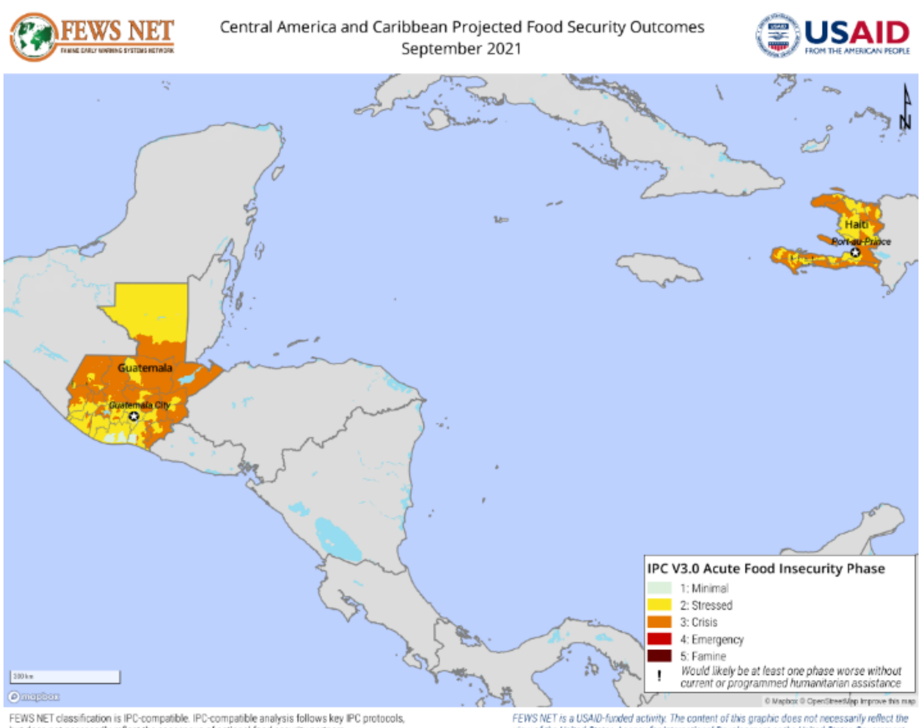
Only 3% of Earth's water is freshwater, and less than 1% is available for human use. The cyclical nature of freshwater moving around our world has led to the overarching science question that NASA is trying to answer about water on our world – where it is, in what supply, and in what condition. In addition, as the world warms because of climate change, NASA scientists are investigating how the world's water cycle is affected by and has effects on Earth's climate. Quantifying the variability of extreme flood or drought conditions is vital to understanding and forecasting the availability of freshwater resources worldwide. Water resource managers rely on accurate precipitation measurements to monitor freshwater resources necessary for human activities including public consumption, irrigation, sanitation, mining, livestock and powering industries. Gridded precipitation and other information is pulled into portals networks, such as the World Resources Institute Aquaduct "Water Risk Atlas" (https://www.wri.org/aqueduct), which is used by stakeholders around the world to characterize water supply and risks in different regions. As such, many stakeholders are viewed as mixture of sophisticated users and as novice users that rely on portal networks.

Managing the water supply often needs guidance on a variety of temporal scales:

- Short-term water resource management requires accurate weather forecasting for long-duration precipitation events in the upcoming 1-3 weeks (e.g., atmospheric rivers, semi-stationary mesoscale and large-scale systems, slow-moving hurricanes) to support forecast-informed reservoir operations to assure that a maximum amount of water will be captured in reservoirs while also preventing dam failures.
- Longer-term S2S water management requires more precise information on what the water year will be. Some particular examples of these needs are information on the beginning and duration of the wet season, and the intensity of snowfall and the resulting snowpack accumulation. Such information on the water budget would impact decisions on the water storage policies. All this has applications to both water and agriculture management.

Leveraging precipitation from both the POR and AOS, we will be able to continue the coverage and critical record of precipitation patterns and variability globally and help improve model parameters, which is important to a wide range of diverse stakeholder communities with various temporal scale needs. Many stakeholders are actively engaging with NASA to develop these portal networks and ingest L3 and L4 data products into these systems. As such, the incorporation of new data into networks and systems is welcomed. However, ingesting new data into systems and models takes time and training for water mangers on data utilization is important.

B) Data-driven Agriculture



Country-specific GIS shapefiles and images, starting from October 2020, are also available for download. The image shows near term (September 2021) food security outcomes and forward-looking analysis representing the most likely food security outcomes for medium term (October 2021 - January 2022) periods. Credit: https://fews.net/fews-data/333.

The data-driven agriculture community includes stakeholders that use big data to support on-farm precision agriculture. Remotely sensed precipitation estimates play a key role in monitoring and modeling efforts for these organizations and companies within this sector. As such, they are considered relatively proficient at using existing NASA datasets as well as act as key intermediaries of data to cater to their downstream users (e.g., mitigation and resource planners, farmers and commodity traders). In addition to the amount and distribution of seasonal rainfall, the timing of the onset of rainfall is an important variable for early estimation of growing season outcomes like crop yield. These communities primarily make use of gridded precipitation products to inform potential yield estimates and highlight where there may be surpluses and deficits. Remotely-sensed rainfall is a critical part of hydroclimate monitoring for organizations that track food and water security, like the Famine Early Warning Systems Network (FEWS NET; www.fews.net), particularly in areas where there is limited in-situ rainfall gauge information (Figure 3.9.1). Knowledge of both the amount and distribution of rainfall as well as the timing and onset of precipitation during the growing season are important metrics that can significantly influence estimation of fertilizer application, irrigation needs, and crop loss. The accuracy of crop yield metrics can have significant downstream effects on availability and pricing of food and beverage commodities, consumer goods, and more.

In high-income economies, growers often rely on third-party applications, developed by intermediaries (e.g., AccuWeather for short-term forecasts; a variety of companies for longer-term outlook). These intermediaries aggregate various data sources in platforms that create insights for a variety of end users. Growers (e.g., end users) are frequent users of farm and input management products. These tools help growers make decisions on planting and harvest time, pest and disease mitigation, types of seeds to plant, and which inputs (fertilizer, pesticides) to apply. However, data scientists may develop platforms that may help ingredient-sourcing leads and commodity traders anticipate supply chain disruptions and pricing changes across days or in an upcoming season. Weather conditions can help these end users understand where to invest their money, crop-wise and geographically, for the highest return. These data aggregators are actively using satellite-based weather data and a combination of publicly-available data products (including GPM IMERG data and Metop satellite products), long-range forecasting models, commercial weather products, and potentially on-ground inputs from weather stations and on-farm sensors.

Stakeholders have expressed a need for accurate observations of total precipitation (e.g., what type has fallen, how much has fallen, and at what intensity [farm-scale]) and duration at high temporal (~10 min) and spatial (<10km) scales. Intensity of precipitation can help understand immediate irrigation needs and where there may be crop damage due to hail, and accurate rainfall estimation over the past few weeks would impact soil moisture models and help guide irrigation needs.

Data driven agriculture is also of great need of accurate forecasts, on a variety of time scales. Of particular importance is the need of improved accuracy past the 5-day forecast, with an emphasis on the 7-day to 2-week forecast. “Users need to know whether in the next 7–14 days there may be potential disease conditions, therefore humidity, temperature, and leaf wetness are important in a mid-term forecast” to guide spray decisions (RTI report). Accurate precipitation forecast is also needed to guide irrigation planning decisions. Improved forecasts are also needed on the longer-term, especially on the S2S timeframe. From the RTI report, “For a seasonal forecast, users need a more accurate outlook of the next three months, with more information. For example, approximations of the first frost and distribution of rainfall across the season.” Rain forecast would be very valuable, especially with better hourly forecasts, also better hourly temperature and relative humidity forecasts.

Global coverage is needed. However, data and forecasts are especially needed in the "tropical regions in low and middle Income economies where there may be few on-ground data inputs" - from the RTI report, which further states: "To get an in-depth look of conditions across a field, users would require resolution under 10 km, ideally down to 1 x 1 km squares." Regarding forecasts, the desired temporal resolution is hourly.

Many users indicated that the data (and forecasts) are available but are not easy-to-get. As the intermediaries pointed out, "Incorporating data from multiple sources can be time consuming. Users mentioned a need for improved consistency and communication of formatting. Interviewees indicated that companies must dedicate a large amount of time and other resources to collecting and cleaning the data for their needs. Data scientists have indicated circumstances where databases have changed format and end users were not informed. This could lead to inaccurate data labels. Data users also emphasized the importance of "flexible" datasets that consider end-user needs. For example, enabling the user to pull a time series of data over a certain period (for example, 60 days) without requiring them to manually pull 60 days' worth of data into their systems" (RTI report).

A concerted effort should be made to leverage the coverage of precipitation from the POR and develop ways to more easily provide the data (both observations and forecasts). These efforts should include attention to maintaining formatting standards, as well as imposing and maintaining requirements on continuity of the data products, and requirements on the consistency in the accuracy, and in the types of data products that are provided. Discussions with the users of the data-driven agriculture revealed a very important need regarding the applications of the satellite observations of clouds and precipitation and the model weather forecast: namely the need of development of Application Programming Interface (APIs) that respond to the users need (i.e., develop APIs that can provide an answer to a practical application need – e.g. "where did it rain in the past month so nomadic shepherds can take their herds there".

C) Food and Beverage: Production and Distribution of Goods in Tropical Climates

Tropical ingredient buyers include major companies, such as Chiquita, Starbucks, and Hershey, that are partially or completely focused on ingredients, including coffee, chocolate, sugar, and almonds. These ingredients are grown in unique microclimate environments around the world. These ingredient companies serve as a critical link between growers and major food brands that manufacture and distribute final food products. Buyers need to determine when to buy specific ingredients, who to buy from, what to expect from a pricing and volume standpoint, and where the risks are in terms of delivery and quality of ingredients.

Many of these users are avid consumers of EO data from a variety of sources, including NASA and NOAA. However, these consumers would prefer higher level data and models that are derived from EO datasets, specifically gridded precipitation, evapotranspiration/crop stress, and relevant crop modeling for tropical regions outside the United States.

These users desire improved forecasting models (12-18 months), greater data accuracy, lower latency (within a day), data products with improved resolution on specific farms/fields of interest, and improved coverage to monitor conditions more closely in specific regions of the world (West Africa, California valleys, Brazil, Columbia, Vietnam). Key observations include precipitation, wind speed, humidity, temperature, and fog. Additionally, users expressed interests for tools that predict and interpret precipitation deviations from historical norms and enable comparative analysis in order to assess current conditions against prior years that most closely match current conditions. Understanding these weather concepts in conjunction with evapotranspiration and automating would greatly impact decision-making for farmers and buyers.

While NASA and primarily the AIT have not actively engaged with many stakeholders from this community, RTI noted eagerness across interviewed stakeholders to work with NASA to understand AOS capabilities and communicate their data needs.

D) Analysis and Findings for Water, Agriculture, Food and Beverage Communities

The three communities outlined above use satellite observations either directly or indirectly for decision-making. AOS will contribute to the POR to continue and advance a long record of global precipitation vital for monitoring the variability of terrestrial water and enable crop yield assessments that are fundamental for a wide range of stakeholders. Users in this community actively monitor weather conditions around the world throughout the year, as growing and harvesting seasons occur at key times during the year and vary across the globe. Adverse weather conditions in these regions disrupt crops, leading to major supply issues and price escalation. This community has a simultaneous need for better data on extreme precipitation, hail impacts, and air quality issues to inform models, forecasts, and predictions on both a hyper-local and a near-global scale. Having greater clarity on weather and AQ conditions around the world, and with improved latency and spatial resolution, would be highly valued by this community. Many other food and beverage ingredients play a major role in global markets and could be included in this community, including dairy products and sugar. Beyond these needs, users also expressed the importance of predicting detrimental effects that climate change may have on growing regions and anticipate new regions that might become suitable for growing certain types of crops. Several companies and research organizations (such as World Resources Institute, FEWS NET, Syngenta, BASF agriculture) are tackling these questions and desire any type of data that can help improve prediction models. The effects on food quality, food security, and the economic benefits of farming worldwide could be significant.

Factors that may enhance applications for this community include working directly with third-party platform organizations and NWP (Section 3.1) and S2S (Section 3.2) communities to improve short-term and longer-term forecasts. Additionally, working among this community to improve data access, accessibility, and work towards API development for level 3 and level 4 precipitation products is critical. This community has also expressed the need for communicating the accuracy of data products.

3.10 SOLAR ENERGY

Community Overview

More energy from the sun falls on Earth in one hour than is used by everyone in the world in one year. The U.S. has some of the richest solar resources in the world. Solar energy capacity in the U.S. has increased from 2.6 gigawatts in 2010 to 97 gigawatts in 2020 (RTI Report). The solar energy industry is experiencing rapid growth, fueled by falling prices, low interest rates, regulatory incentives, and increased desire to invest in alternative energy sources. By 2030, U.S. capacity is expected to quadruple to 400 gigawatts. Since 2010, over $1.5 trillion has been invested worldwide in solar technologies.

Solar energy production is almost entirely dependent on the locally available output of light energy from the Sun, measured at the Earth, technically referred to as the solar irradiance. New solar power generation plants are established based on historical irradiance data for the specific location and used to estimate future power generation capacity. Upwards of hundreds of millions of dollars are secured in financing based on these data. Understanding how precipitation, aerosol loading, and cloudiness will limit or reduce solar irradiance is of extreme importance to this sector. Their goal is to optimize their processes and maximize the efficiency of their installations, leading to high energy outputs, maximum profit and enhanced sustainability. Atmospheric aerosols, together with aerosols dry-deposited on solar panels have a non-negligible impact on solar energy generation. For example, aerosols reduce energy production of solar cells in China by up to 20%. Over the years, solar energy providers and operators have developed familiarity with EO and NASA data, though new and better data and data products will improve prediction of solar irradiance availability and solar panel efficiency.

Solar Energy Sub-Communities

A) Solar Energy Service Providers

Solar energy service providers develop the models and tools used by site developers and operators. As one RTI interviewee stated: "Unlike other power generation methods, we know where fuel is coming from, but we can't control the fuel or buy more of it. We are reliant on data to make predictions of how much fuel will be available and what type of performance should be expected." In the absence of ground measurements, satellite and model-based products have been shown to be accurate enough to provide reliable solar and meteorological resource data over most of the Earth. Solar energy service providers have the expertise to access and download satellite EO data and use EO data products to verify, validate, and improve their models. They assimilate EO data to develop forecasts of irradiance availability to deliver better predictions of energy output to the solar plant operator communities. An example of a data service provider is the NASA Prediction Of Worldwide Energy Resources (POWER) project (https://power.larc.nasa.gov/) which provides mean daily values of meteorological and solar data in a time series format as shown below for relative humidity, insolation, and temperature (Figure 3.10.1). The POWER project currently provides these data to user communities in Renewable Energy, Sustainable Buildings and Agroclimatology. The data is provided as a daily time series at a horizontal resolution of the user's choice, i.e., the data delivery system supports variable grids.

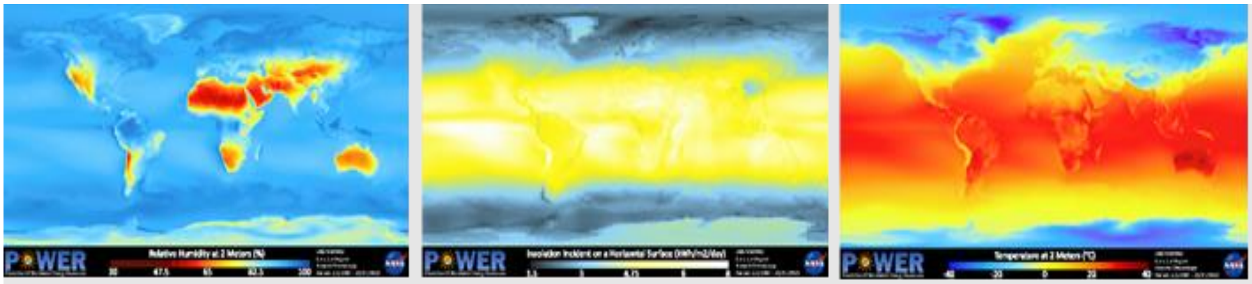


Figure 3.10.1. Mean daily relative humidity, insolation and temperature from assimilation of satellite products, including aerosol and cloud distributions. These data are used by solar plant operators. Credit: NASA POWER, https://power.larc.nasa.gov/.

As such, these applications require global data coverage, long records of metrological data, data certainty, and preference to vertical aerosol information.

Organizations and project representatives such as from NASA POWER are already engaging with NASA and have expressed a high level of interest in continued collaboration. Moving forward, these service providers noted the need for easier access to data and the integration of data using similar formats as well as the ability to access the data more quickly.

B) Solar Plant Operators

Solar plant operators include energy utility companies, independent organizations, and citizens who have installed solar panels on their properties. Operating plants need data on weather and aerosol conditions (vertical distribution, type, size distribution) to enable efficient and cost-effective operation of the plant. For the most part, solar plant operators currently rely on ground-based weather stations, models and tools developed by solar energy service providers to forecast output at a generating site. As such, solar plant operators would be considered a community of potential as they are familiar with satellite data but generally are not considered data experts.

Most solar power generation plants have one or more expensive weather stations set up on site to provide ground-based measurements of weather and aerosol conditions. There are commercial companies that set up the ground environmental monitoring stations critical to optimizing the efficiency of solar power generation. For example, Columbia Weather Systems markets monitoring systems that provide daily data on solar irradiance , temperature, wind speed/direction and precipitation at the plant. The additional atmospheric parameters useful for solar panel performance are cloudiness, and aerosol loading, which are fundamental geophysical variables that can be provided by NASA to fill gaps where the ground monitoring station do not provide these data. The satellite-based observations also provide inputs for providing forecasts of these parameters that enable the plant to predict future solar energy production capacity. Rainfall sensors on site are used to estimate soiling conditions on the panels to determine when manual cleaning is necessary and to create maintenance schedules for the plant.

General technical desires expressed by this community include sub-hourly temporal resolution and improved spatial as current gridded maps of 10 km x 10 km are too coarse for accurate analyses. The community also noted that adopting new data into their systems requires long continuous records of data, global data coverage and data uncertainty estimates for operations to be carried out and needs to be considered. Additionally, ease of data access is essential as many of these users lack the time, expertise, and resources to handle lower-level (L0-L2) data products. This community expressed willingness to engage with NASA, however certain technical needs and capacity building needs should be considered to facilitate a forthright assimilation of EO products in their systems.

C) Analysis and Findings for Solar Energy Community

Currently most of these parameters are measured at the ground by weather stations but are not very useful for model prediction since they are point measurements. This provides an ideal opportunity for AOS and the POR to provide data complementary to the ground sites and access to model data from which operators can make decisions. These include aerosol and cloud distributions, and precipitation data from AOS and the POR, and meteorological data (temperature, relative humidity, and wind velocity) from the POR and NASA's assimilation products, e.g., GMAO's MERRA-2, appropriately gridded at the best available spatio- temporal resolution.

Some factors that may enhance the use of the data for decision at the plant operator level include providing data with high spatial resolution (on the order of 1 km or less) and near-real time for assimilation into forecast models using via Application Programming Interface (API), streaming services, NetCDF, and GRIB2.

NASA's Applied Sciences Program (ASP) and relevant Flight Missions can engage these communities by providing long-term data for trend analyses and real-time data for model forecasts for solar plants in the U.S. and in regions of the world with abundant solar irradiance. The ASP funded POWER project has so far been the most successful at reaching these users by providing relevant data (irradiance, temperature and humidity) at the spatial and spectral resolutions defined by the user since each application is different. As such, the NASA POWER team would be fundamental to engage as AOS applications moves forward.

Both the service providers and operators would benefit from NASA training since there is little evidence that these communities have been exposed to vertically resolved aerosol and cloud data from the AOS lidars and radars, respectively. The vertically resolved parameters are more complicated and have been successfully used by sophisticated users at weather forecasting organizations such as ECMWF, NWS and JMA but not extensively by smaller independent organizations that serve the solar energy communities.

In general, these communities have expressed interest in collaborating with NASA to apply improved data products to new models and forecasts. NASA is perceived in this community as a valuable, trusted partner. New and better data and data products that can improve prediction of weather and AQ conditions at specific plants could have a significant positive effect on this community. This includes improved predicted and actual power output from solar plants, effectively reducing the amount of unsustainable power generation required to satisfy electricity demand.

4 ANALYSIS

In this section, we summarize the commonalities, differences, and variations in organizational characteristics and technical aspects across the communities presented in Section 3. We also trace the flow of AOS data across communities to assess the impact toward applications (see Section 4.4). While this Section 4 presents a summary across communities, we note that this may be quite subjective in that many communities acknowledged key characteristics and technical aspects that vary significantly within a community's given subcommunities. As a result, we encourage readers to view Section 5 as well as our separate *AOS CAR Findings and Recommendations* document to see how we articulate key take-aways and pose opportunities for the project's applications-oriented activities throughout the lifecycle to enhance applications that can directly benefit society.

4.1 Experience: User communities stated a range of levels of expertise and comfort downloading and processing satellite data

This table is meant to be a high-level representation of the current spectrum of stakeholder expertise with the POR: *Community of Practice*- people who are familiar with NASA products and routinely use satellite remote sensing data in processes or decision support and *Community of Potential*- people who are unfamiliar with satellite data products and POR capabilities, but might be able to leverage and benefit from AOS data products.

Community	*Community of Practice*	*Community of Potential*
Weather Forecast	●	
S2S & Climate Modeling	●	
Aviation	●	●
Logistics	●	●
Public Health	●	●
Air Quality Modeling	●	●
Wildfire Smoke	●	●
Floods & Landslides	●	●
Water Resources, Agriculture & Food and Beverage	●	●
Solar Energy	●	●

4.2 Data Needs: User communities stated a variety of EO needs and desires related to aerosol, clouds, convection and precipitation data

Community	Sub community	Latency	Spatial Resolution	Temporal Resolution	Coverage	Forecast time needs	Data Continuity	Data Format Preference
Weather Forecast	Civil Forecasting	< 1 hr	5-20 km horizontal	Sub-hourly to hourly	Regional to Global	Forecasts range from 6-hour to several days	Enough to assess trend and impact of data on forecast	Existing formats currently used (e.g., HDF5, netCDF)
	Modeling Research	Several days to months	<1-5 km horizontal; < 1-km vertical	Sub-hourly to hourly	Regional to Global	Sub-hourly to weekly	At least a year or two to build robust statistics	HDF5, netCDF
	Private Sector	< 1 hr up to 12 hrs	< 5-20 km horizontal	Sub-hourly to hourly	Locally to Regional to Global	Up to several days	Enough to assess trend and impact of data on forecast	Gridded products, netCDF, GeoTIFF
S2S & Climate Modeling**	S2S/Climate Modeling Validation and Improvements	N/A	At or finer than model spatial resolution	< 1 hr	Global; Using limited swaths of observations should still be useful	N/A	Very Important; Long (>30 years) records of homogeneous data are very desired	NetCDF is preferred Maintaining formatting standards is very important
	S2S/Climate Forecasting for Supporting Water Resource Management	< 30 days	Watershed scale	1-7 days	Global	< 1	Important	
	S2S Forecasting for Disaster Preparedness:	<1 day for landslides; < 1 week for floods	Watershed scale	<12 hrs	Global	< 12 hrs prior the event	Important	
	S2S/Climate Forecasting of hurricane activity	< 30 days for S2S	Ocean Basin Scale	7 days	Global	daily	N/A	
	Sub-seasonal Agricultural Forecasting	< 5 days	<5-10km	10 min to Hourly	global and gridded	daily	Very important; Need consistency in accuracy and reliability	
	S2S/Climate Forecasting for Agricultural Seasonal planning	< 1 month	Farm-scale	6-12 hours	global and gridded	Weekly		

Community	Sub community	Latency	Spatial Resolution	Temporal Resolution	Coverage	Forecast time needs	Data Continuity	Data Format Preference
Aviation	Airline Meteorologist	< 1 hr ideal; 3-6 hrs is acceptable	5-20 km	Sub-hourly to hourly	Global	6-72 hrs	Enough to assess trends	Level-2 or 3 products, netCDF
	Commercial Airline Pilot	< 1 hr	< 20 km	Sub-hourly to hourly	Regional to Global	3-12 hrs	N/A	High level information like Text and images
	Airport Chief Operations Officer	< 1 hr	< 20 km	Sub-hourly to hourly	Regional	6-72 hrs	N/A	High level information like Text and images
Logistics	Air-based Logistics	< 4-6 hrs	airport scale; UAVs need very high vertical resolution within lowest 100s m of ground	Sub-hourly to daily	Regional to Global	4 hrs, domestic; 12-14 hrs, international; 2-3 days, large disaster events	N/A	Level-2 or 3 products in HDF5, NetCDF, text, GeoTIFF format
	Ground-based Logistics	< 12 hrs	Ideally, city-block level	Sub-hourly to daily	Over land	1-2 days prior to event, 3-7 days large storm systems	N/A	N/A, desire gridded products
	Sea-based Logistics	< 12 hrs	5-20 km	30 min, hourly, daily, similar to GPM IMERG	Over ocean and coastal	6-72 hours	N/A	Text, GeoTIFF
Public Health	Burden of Disease Researchers	N/A	Ideally, city-block level, but can work with lower	Ideally daily, but weekly or monthly averages ok	Whole urban/suburban areas.	N/A	Multi-year datasets ideal	Text, Excel spreadsheet
	Environmental Justice Advocates	N/A	Ideally, city-block level, but can work with lower	Ideally daily, but weekly or monthly averages ok	Whole urban/suburban areas.	N/A	Multi-year datasets ideal	Text, Excel spreadsheet
	Environmental Public Health Mitigation and Policy Planners	N/A	Ideally, city-block level, but can work with lower	Ideally daily, but weekly or monthly averages ok	Whole urban/suburban areas.	N/A	Multi-year datasets ideal	Text, Excel spreadsheet

Public Health	Air Pollution Real-Time Avoidance Behavior	< 3 hrs	Ideally, city-block level, but can work with lower	Hourly	Whole urban/suburban areas.	Short-term forecasts. Work with AQ forecasters	Needs similar to AQ forecasters. Work with AQ forecasters	Needs similar to AQ forecasters. Work with AQ forecasters
Community	**Sub community**	**Latency**	**Spatial Resolution**	**Temporal Resolution**	**Coverage**	**Forecast time needs**	**Data Continuity**	**Data Format Preference**
Air Quality Modeling	AQ Forecasting	< 6 hrs (< 3 hrs ideal); < 1 hr for plume monitoring	At or finer than model spatial resolution	Daily or higher	Additional coverage adds value to application	Provide daily or sub-daily near-term AQ forecasts for stakeholder communities	High priority given resource investment to incorporate new observations	HDF5, NetCDF, text
	AQ modeling for regulatory science and research	N/A	At or finer than model spatial resolution	Daily or higher	Additional coverage adds value to application	N/A	Low priority	HDF5, NetCDF, text
Wildfire Smoke	AQ Monitoring and Forecasting	<3 hrs; <1 hr ideally	At or finer than model spatial resolution	Sub-daily, hourly ideal	Regional, national coverage	Provide daily or sub-daily near-term AQ forecasts	High priority for immediate ingest into models; low priority for monitoring	HDF5, NetCDF
	Weather and Climate	Sub-daily for weather, months or more for climate	Regional for climate; model spatial resolution for weather	Sub-daily for weather, seasonal or longer for climate	Regional, national, global coverage	Provide daily/seasonal outlooks	Long continuous records high priority	HDF5, NetCDF
Floods & Landslides	Floods	< 3 hrs	10 km, similar to GPM IMERG	30 min, hourly, daily, similar to GPM IMERG	Near global coverage, similar to GPM IMERG	Provide near real time information for disaster response	Long, continuous record needed to parametrize models	HDF5, NetCDF, Text, Excel spreadsheet
	Landslides	< 3 hrs	10 km, similar to GPM IMERG	30 min, hourly, daily, similar to GPM IMERG	Near global coverage, similar to GPM IMERG	Provide near real time information for disaster response	Long, continuous record needed to parametrize models	HDF5, NetCDF, Text, Excel spreadsheet

Community	Sub community	Latency	Spatial Resolution	Temporal Resolution	Coverage	Forecast time needs	Data Continuity	Data Format Preference
Water Resources, Agriculture & Food and Beverage	Water Resource Management	Sub-daily for weather, months or more for climate	Basin-scale or finer to characterize approximate water fluxes	Sub-daily to monthly depending on how informatio n is aggregated	Global coverage	Daily/sea sonal outlooks	Long, continuous record needed to characterize anomalies in behavior	HDF5, NetCDF, Text, Excel spreadsheet
	Data-driven Agriculture	<3 hrs for short term forecasts	10 km acceptable, ideally <1 km	Sub-hourly for field manageme nt; Daily or weekly for financial products	Global coverage, especially in tropical areas	1–2 days; 7–14 days; 3-month seasonal forecast	High priority	HDF5, NetCDF, GeoTiff
	Food and Beverage	<3 hrs	10 km acceptable, ideally <1 km	Ideally, Sub-hourly	Global coverage	1–2 days; 7–14 days; 12–18 months long-term forecast	High priority	HDF5, NetCDF, GeoTiff
Solar Energy	Solar Energy Service Providers	<3 hrs	10 km acceptable, ideally <1 km	Sub-hourly	Global coverage	1-5 days	High priority	HDF5, NetCDF, GRIB2 GIS Compatible,
	Solar Plant Operators	N/A	10 km acceptable, ideally <1 km	3-6 hours	Global coverage	3-5 days	High priority	HDF5, NetCDF, GIS Compatible, Text, Excel spreadsheet

***Note:** S2S Community: This table includes more specifics on beneficiaries of S2S communities than what is included in Section 3.2.

4.3 L3/ L4 Data Products: Several communities expressed similar desires for gridded, processed data sets to enable applications

For stakeholders directly incorporating lower-level data products, “no cost” data are not necessarily “free data”; it requires time, resources, and knowledge to assess, validate, and incorporate data into systems. Incorporating these data may be a significant investment comparable to purchasing an expensive, cleaned data set. Some companies, like large agricultural input companies, may create entire teams dedicated solely to scouting and incorporating lower-level data products into their systems and processes.

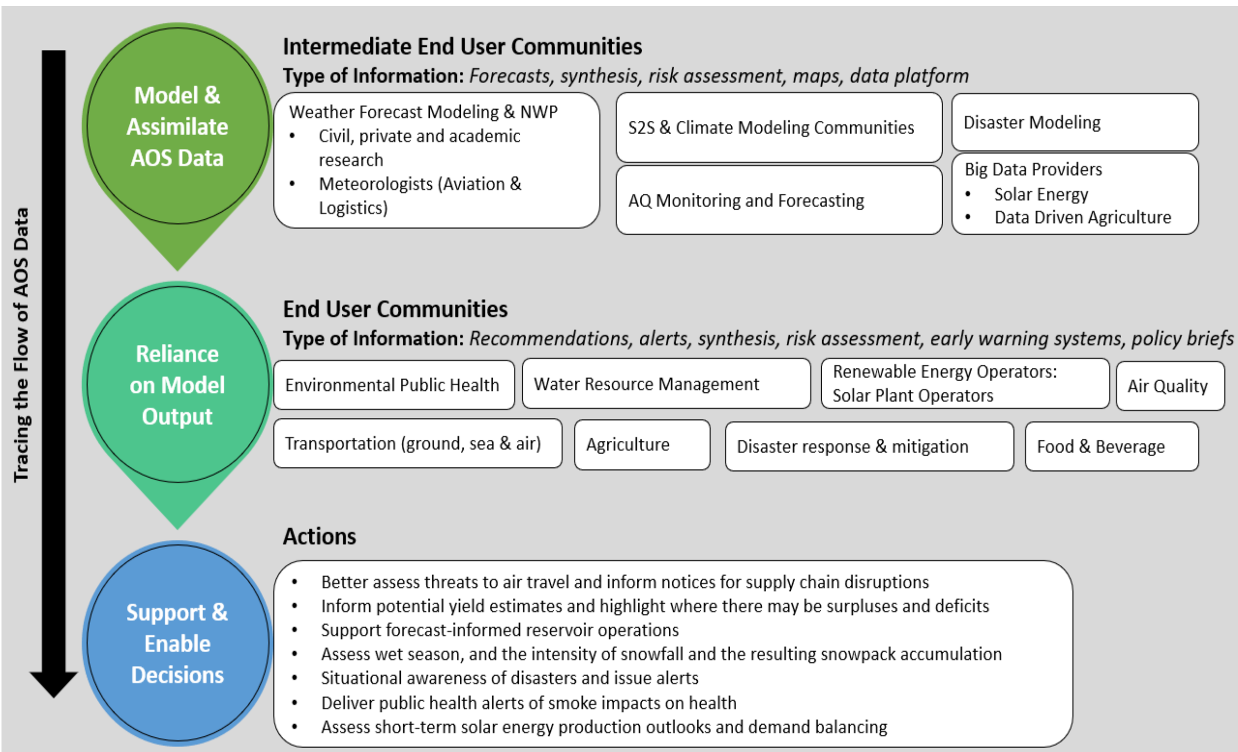
As such, preference for gridded datasets and data from model output, specifically level 3 and level 4 data products, were consistent across user communities, even across users who have the technical capability to work with low-level data products. Below we note each community that expressed desire for L3 and L4 data products and how these products would enable applications.

Community	*Noted desire for products of higher data processing levels*	*L3/L4 Products Enable*
Weather Forecast	-	-
S2S & Climate Modeling	●	Use of L3 products to validate models, improve model parameterizations, and create L4 products
Aviation	●	Easy to interpret data for en route flights and ground delays
Logistics	●	Ease of data to incorporate into existing model, reports, and systems, and enable easy and direct access to specific thresholds (e.g., snow amounts) that may influence transport routes and delivery of goods
Public Health	●	Wider use of $PM_{2.5}$ data products for public health mitigation/ alerts and policy as most users will continue to rely on the development of L4 products by experts.
Air Quality Modeling	●	Ease to incorporate data into existing model, reports, and systems, and enable model validation and model parameterization improvement
Wildfire Smoke	●	Data access ease and data familiarity for applications
Floods & Landslides	●	Data access ease and data familiarity for regional to global characterization of extreme precipitation and flood/ landslide hazard assessment and inform public alerts
Water Resources, Agriculture & Food and Beverage	●	Ease of data access and use within systems, and enables quick decision-making for downstream users that do not have the data expertise
Solar Energy	●	Data access ease, and incorporation into existing model, reports, and systems to inform decisions

4.4 AOS User Value Chain: Modeling communities have the potential to amplify the impact of AOS observations

AOS promises a suite of novel measurements, such as representation of the diurnal signal, the vertical structure of clouds and precipitation, in cloud vertical velocity profiles, vertical motion, and vertical aerosol information, which could greatly improve model parameterizations, thus model performance, as well as could lead to development of new level 4 data products. Many communities including disaster response, public heath, energy, water, and agricultural sectors strongly depend on these model outputs and reliable forecasts developed by agencies and/or third-party vendors to inform their decisions across local and global scales.

The image below provides a simplistic overview of tracing the flow of AOS data to actions and the relationship among some communities that would directly or indirectly use AOS data for decisions. Intermediaries are considered as stakeholders that are sophisticated or technical users of satellite data that synthesize, integrate, manage and translate information that is meaningful to support downstream users' decisions (e.g., end user decisions). In this sense, intermediaries are made up of stakeholders that are proficient at data assimilation and model development. End users receive much of the information from intermediaries so that they can make decisions and provide recommendations and alerts that directly impact society. As such, the direct use of AOS data by data assimilation and modeling communities will indirectly benefit applications across many end user communities.



4.5 Data Priorities and Risk Tolerance: Data priorities and risk tolerance for using new data varied across communities, and most importantly, across given subcommunities

Community	Subcommunity	Risk tolerance to adoption of new data	Latency	Spatio-temporal Resolution	Data Coverage	Data Continuity	Ease of Data Access and Interoperability	Quantification of Uncertainties	Development of L3/L4 Products
Weather Forecast	Civil Forecasting	M	H	M	M	H	M	M	M
	Modeling Research	L	L	H	M	H	M	H	L
	Private Sector	M	H	H	M	H	H	M	M
S2S & Climate Modeling	S2S and Climate Modeling	L-M	L	H	L-M	H	L-M	H	L priority for observations; H priority for developing products
	S2S and Climate Forecasting	M-H	L	M-H	H	M-H	H	H	H
Aviation	Airline Meteorologist	M	H	M	H	H	H	L	M
	Commercial Airline Pilot	H	H	H	M	H	H	M	H
	Airport Chief Operations Officer	H	H	H	L	M	H	M	H
Logistics	Air-based Logistics	H	H	M	H	M	H	L-M	M-H
	Ground-based Logistics	L	M-H	M	M	M	H	L	H
	Sea-based Logistics	M	M-H	M	H	H	H	M	M

Community	Subcommunity	Risk tolerance to adoption of new data	Latency	Spatio-temporal Resolution	Data Coverage	Data Continuity	Ease of Data Access and Interoperability	Quantification of Uncertainties	Development of L3/L4 Products
Public Health	Burden of Disease Researchers	L	L	M	H	H	H	L	H
	Environmental Justice Advocates	L	L	M	H	H	H	L	H
	Environmental Public Health Mitigation and Policy Planners	L	L	M	H	H	H	L	H
	Air Pollution Real-Time Avoidance Behavior	L	H	M	H	H	H	L	H
Air Quality Modeling	AQ Forecasting	L	H	H	H	H	H	H	L
	AQ modeling for regulatory science and research	H	L	H	H	L	H	H	H
Wildfire Smoke	AQ Monitoring and Forecasting	L	H	H	H	H	H	H	L
	Weather and Climate	H	L	M	H	L	M	H	H
Floods & Landslides	Floods	M	H	H	M	H	M	M	H
	Landslides	M	H	H	M	H	M	M	H
Water Resources, Agriculture & Food and Beverage	Water Resource Management	M	L	M	L	M	H	H	H

Water Resources, Agriculture & Food and Beverage	Data-driven Agriculture	M	M	M	L	M	H	H	H
	Food and Beverage	L	M	M	L	M	H	H	H
Community	**Subcommunity**	**Risk tolerance to adoption of new data**	**Latency**	**Spatio-temporal Resolution**	**Data Coverage**	**Data Continuity**	**Ease of Data Access and Interoperability**	**Quantification of Uncertainties**	**Development of L3/L4 Products**
Solar Energy	Solar Energy Service Providers	H	M	H	M	H	H	H	M
	Solar Plant Operators	M	L	H	M	H	H	H	M

4.6 Several communities indicated willingness to work with NASA through a variety of engagement approaches

Analysis from the AIT and RTI report indicated various opportunities to engage communities. The information below mostly represents analysis conducted by RTI through several focus groups. For more information, see the RTI report HERE.

RTI identified through focus groups that participants across user communities consistently demonstrated interest and eagerness to address key data needs through NASA engagement. Users offered a variety of potential engagement methods, which differ in levels of effort for both the AIT and external collaborators, which include:

- Leveraging "industry advisors" to help understand how particular user communities may use and value data products. Offering these users a seat at the table could consistently bring in the voice of different customers as data products are developed.
- Work directly with professional networks and research organizations to understand needs and communicate awareness of data product value.
- Develop user-centered trainings and data products to create opportunities for awareness and increase data use of products.
- Engage with industry data users via R&D partnerships that may lead to development of operational data products that address community needs.

Although not indicative of the entire community, the table below is a representation of communities selected by RTI (*) as well as a few from AIT's engagement efforts that indicated interests in the following engagement strategies:

Community	**Industry Advisors**	**Professional Networks and Research Organizations**	**User-Centered Training and Data Products**	**Industry R&D Projects**	**Value- Added Service Provider**	**Comments**
Weather Forecast	●	●			●	Continue dialogue with federal agencies and private sector to facilitate use of AOS observations for their applications.
S2S & Climate Modeling	●	●			●	Continued engagement with NASA, NOAA, ECMWF and data-driven ag companies will further inform preferred data formats, methods of data access, and opportunities for model performance.
Aviation*	●	●			●	Plug into industry associations such as Airlines for America (A4A) and engage through air-based

						major logistics carriers (e.g., UPS and FedEx) because the industry currently has limited bandwidth.
Logistics*	●	●	●		●	- Leverage professional networks to jointly benefit aviation and air-based logistics users - Leverage value-added service providers (ex. Accuweather) for impact across multiple user communities and demonstrate value of future ACCP products to the community.
Public Health*		●	●		●	- Engage the traditional research community - Leverage expertise from current ground-based data users
Air Quality Modeling		●				Continued engagement with agencies, such as NASA, NOAA, NCAR, and ECMWF, to facilitate the use of AOS observations for their applications.
Wildfire Smoke		●	●			Continued engagement with wildfire smoke modeling community and hold training opportunities for communities that will benefit from improved smoke monitoring. Ability of the users to understand AOS data products before launch will be key for successful application of operational data.
Floods & Landslides		●	●			Continued engagement with academia and research organizations to facilitate the use of AOS observations for their applications and improve model parameters.
Data-driven Agriculture & Food and Beverage*	●	●	●		●	- Ensure that products are discoverable to the community and work with standards and documentation working groups. Use the agritech community (e.g., Syngenta, Cargill) as a testing ground for new applications with help from industry advisors. - Disseminate training opportunities to the community and

						communicate how new products may improve their operations (e.g., representatives from World Bank).
Solar Energy*	●		●	●	●	- Capitalize on growing solar and solar plus storage market through R&D opportunities such as ground-truthing and development of new data products through engagement with third party meteorological platforms - Continue dialogue with NASA tool developers (e.g., NASA POWER) to facilitate use of AOS data in the tool

5 CONCLUSIONS: FINDINGS AND IMPLICATIONS

The proposed AOS mission design (see AOS architecture) meets the science objectives of the mission and will lead to the development of new and novel data products that will advance scientific research as well as "raise the bar" for applications. The AIT has been engaged in the mission planning process throughout the study and mission development. Overall, we found that the instrument suite and orbits that "raise the bar" for science also do the same for applications. That is, *there is no substantial aspect of the AOS mission design, including instrument capabilities and orbits, that enhances the potential of the mission for scientific research at the expense of applied research.*

In our assessment of stakeholder communities, we found common features and requirements among most or all of the communities which pose implications for the project's applications-oriented activities throughout the lifecycle. As a result, two fundamental outcomes were driven by the development of the CAR: (1) key community findings and (2) recommendations. Both are essential to help formulate a path forward with the AOS to enhance applications.

Below, we provide a high-level list of our findings of the AOS community assessment and the recommendations that were inspired by these analyses and activities. As we move forward through the AOS project life cycle, the AIT will continue to update and assess these findings in order to articulate key NASA opportunities (e.g., through recommendations) that could enhance applications across several communities from pre-Phase A and beyond mission launch. **The *AOS CAR Findings and Recommendations* document presents a detailed description of our recommendations and findings, interpretation of results, and implications from the CAR.**

Summary of findings of all stakeholder communities:

Finding	Description
Diverse Needs of Stakeholders, including within a Given Community	Several communities have distinct requirements to integrate AOS satellite data into their operating procedures and that these requirements often vary widely within subcommunities of a given community (e.g., latency, continuity of data, spatio-temporal coverage).
Wide Range of Organizational Resources and Capacity	Majority of stakeholders agencies do not have the financial resources to devote to hiring satellite data experts to download and process satellite data. Therefore, many stakeholders cited the need for NASA investment to facilitate the ease-of-access to AOS satellite data and the development of two level data products, L3/L4 (i.e., surface gridded rain rates and $PM_{2.5}$).
Spectrum of Stakeholder Expertise with Satellite Data	Range of levels of expertise and comfort downloading and processing satellite data among the communities, but, more importantly, within a given community's subcommunities.
Hesitancy of the Accuracy of Satellite Data	Majority of stakeholders were hesitant to incorporate satellite data into their operating procedures. These stakeholders cited a number of concerns, including the lack of characterization of data uncertainties, data products not being in quantities that they are familiar with, and poor validation of the satellite data with their in situ observations.
Reliance of Certain Stakeholder Communities on Intermediary Data Product Providers	Many of the stakeholder communities do not work with satellite data themselves by choice, and, instead, rely on intermediaries or vendors to provide the L3/L4 data products that they require for their decision-making.
Reliance on Improved Models	Most communities rely on or benefit from model output from a core group of communities of practice, primarily those who make time-critical decisions (i.e., weather, disaster, and air quality forecasters).

Summary of recommendations inspired by key findings:

Mission Component	Description
AOS Ground Segment	Prioritization of product latency discussions in consultation with the AIT.
Development of Level 3/4 Data Products	Creation of Level 3 and Level 4 data products and atmospheric products based on the definition provided.
AOS Suborbital Activities	Inclusion of AOS observations relating to quantities that stakeholders are familiar with (e.g., surface monitor data)
AOS Retrieval Algorithms	Collaboration among AOS algorithm developers, the AIT and Early Adopters to guide data product development and assess uncertainties/ errors for both science and applications.
AOS Data Access	Facilitate ease-of-access to AOS data products through development of data processing and visualization tools and APIs.
AOS Documentation and Formats	Development of an “AOS Guidance Directory” that includes data, tools and documentation best suited for stakeholders, including consistent data formats and data products catering to specific applications.
Capacity Building	Collaboration between AIT and NASA ARSET to develop targeted training materials to build capacity for Early Adopters.
Continuity	Consideration of connecting new observations to the POR to help assist in the pivot toward assimilating observations for operational needs.
Data Coverage	Creation of data products with maximum spatio-temporal information content to benefit and broaden the use of the AOS data products among stakeholders.
DO Synergies	Identify synergies across DOs to efficiently engage communities and enhance applications value.

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