Nontraditional User Needs for Aerosols, Clouds, Convection, and Precipitation (ACCP)

NASA Designated Observables (DO) Applications Study

June 2021
RTI Final Report

RTI Innovation Advisors

Sections

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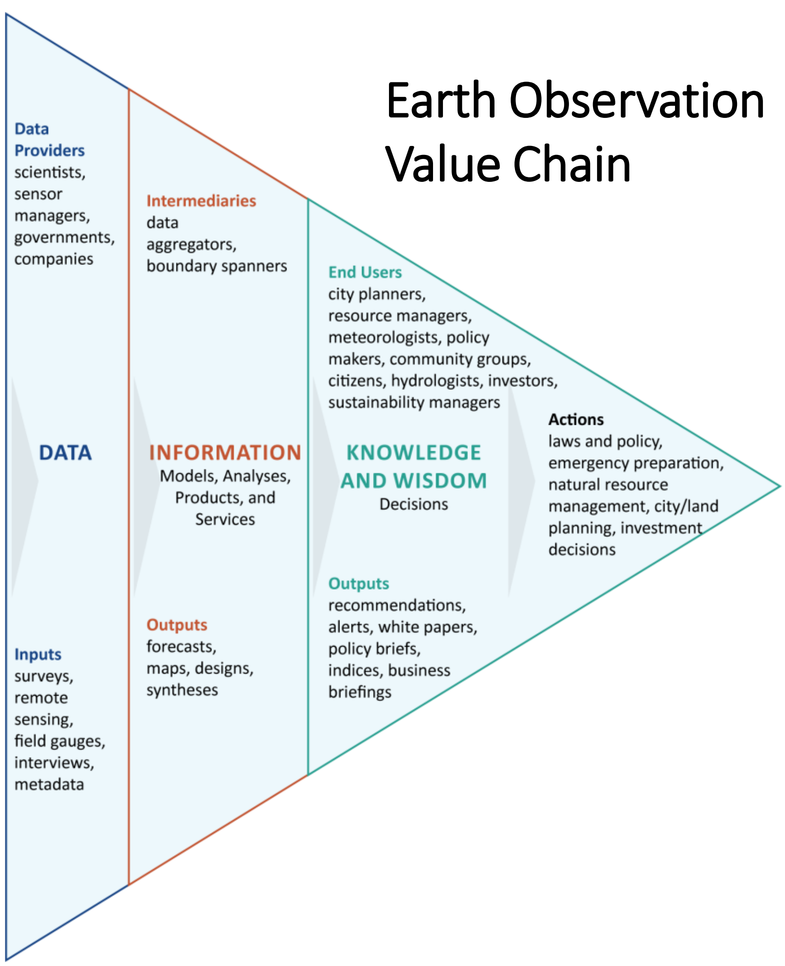
RTI uncovered private-sector users across the EO value chain who may use or benefit from future ACCP data.

RTI International[1], working with the NASA Earth Science Division (ESD) Aerosols, Clouds, Convection, and Precipitation (ACCP) Applications Team, conducted this study to capture the needs and priorities of nonresearch Earth observation (EO) data users who may be future users of ACCP data. Specifically, the goals of our Applications Study were to:

- Bring private-sector user insights to the ACCP Designated Observables (DO) team to consider when appropriate during mission design
- Broaden NASA's understanding of nonresearch applications by:
  - defining potential user communities
  - summarizing their current uses of data products
  - highlighting decisions they make using satellite-based data products (or could make with future satellite data)
  - providing limitations in terms of awareness and technical realities
- Identify ways in which NASA might engage with these communities



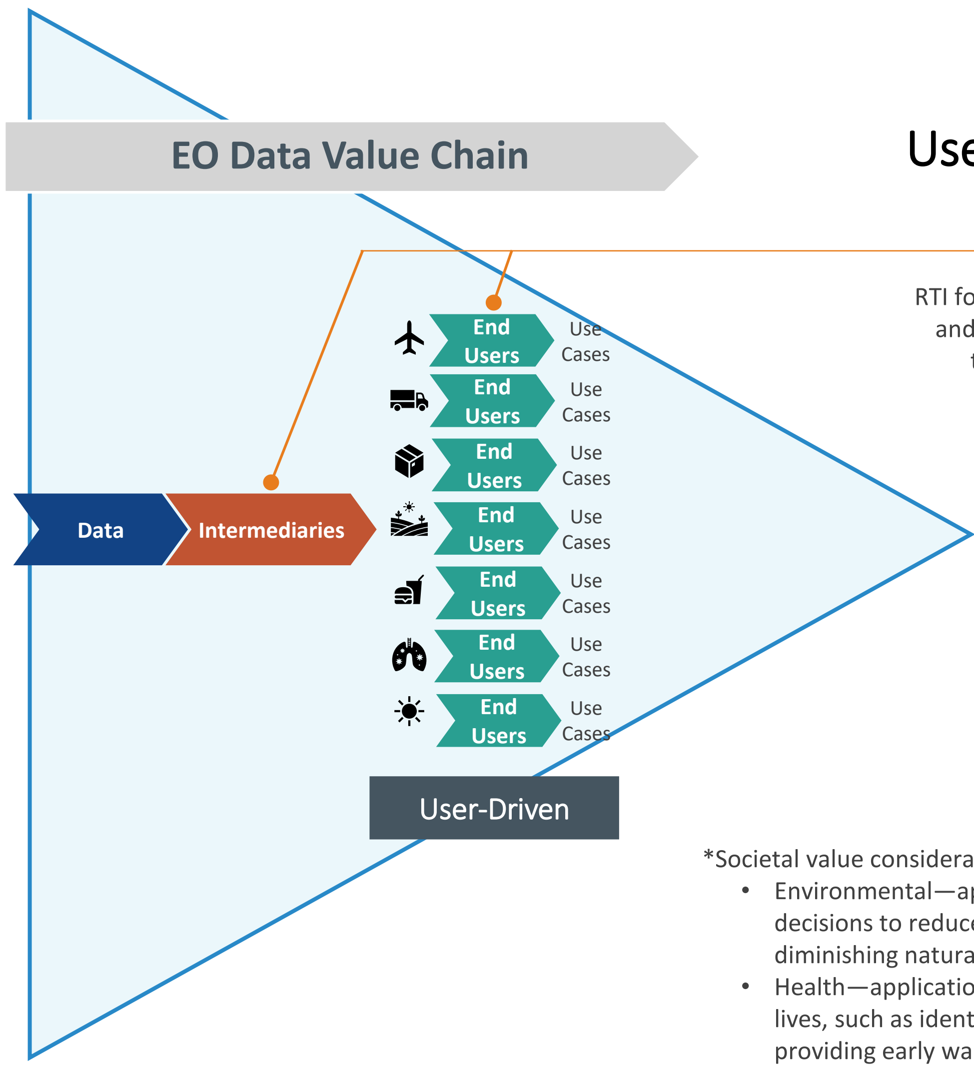
As described by Virapongse et al.[2], significant opportunities exist for EO data to improve societal impacts related to energy production, agriculture, weather, health, and safety. Translating data into information for decision-making requires effective presentation and availability of the data for the specific purposes of societal and economic goals. Traditional users of NASA EO data have been government and university researchers focused on theoretical and applied sciences spanning collaborations with closely related government agencies. By expanding the user base in the applications community within the private sector, nonprofit organizations, and other government entities, NASA can ensure its EO data inform and enhance decisions on critical issues such as preventing damage to life and property.

The figure to the left, adapted from Virapongse et al., captures the EO value chain and shows how data is transformed by users to information, then knowledge and wisdom, which leads to action. The RTI effort focused on incorporating user perspectives to identify insights and needs across the value chain.

1. RTI International is an independent nonprofit research institute dedicated to improving the human condition, see rti.org.
2. Figure adapted from Virapongse, A., Pearlman, F., Pearlman, J., Murambadoro, M., Kuwayama, Y., & Glasscoe, M. (2020). Ten rules to increase the societal value of earth observations. Earth Science Informatics. 13. 10.1007/s12145-020-00453-w.

This study supported NASA ESD's goal of broadening the use of future EO data and data products.

This ACCP study was part of a broader study—which also included Mass Change and Surface Deformation and Change—that brings potential private-sector user perspectives and desires to NASA ESD DO teams to consider for future mission designs. This study focused on understanding user **desirability** as a key element in user-centered design, which also considers feasibility and viability. Learning what drives users, what key decisions they make, and how they want to access and use the type of data that the DO missions can deliver is the first step toward broadening NASA's nontraditional user communities and increasing the impact of NASA's data.



User-Centered Design

Desirability *(this study)*

RTI focused on uncovering data intermediaries and end users who have needs and desires that could be supported by EO data.

Feasibility

DO teams consider feasibility of nontraditional user desires with respect to DO mission plans and potential data products.

Viability

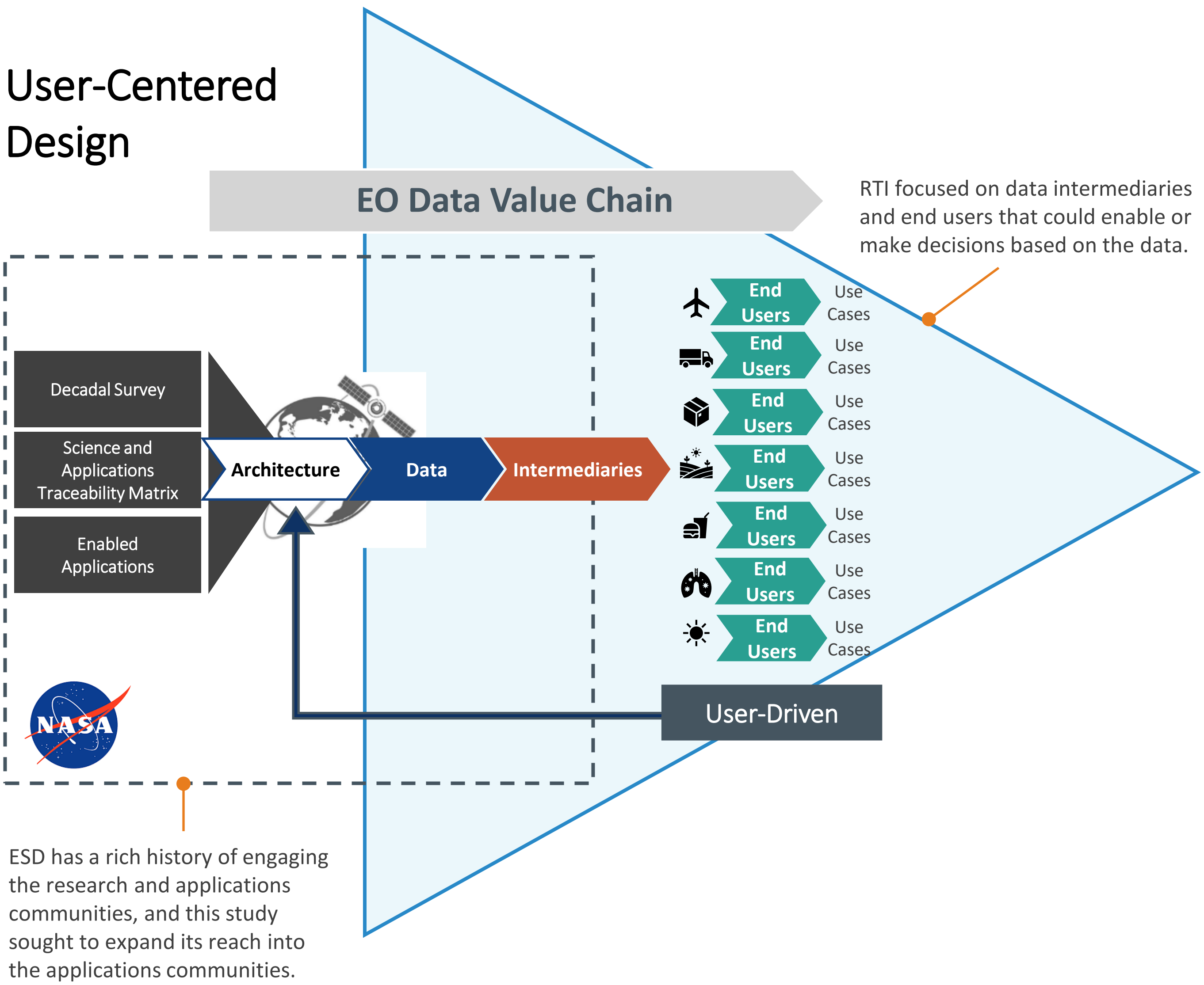
ESD prioritizes mission efforts based on potential use cases that would best meet NASA ESD's value drivers.*

*Societal value considerations may include:

- Environmental—applications that could help users make decisions to reduce environmental damage or preserve diminishing natural resources
- Health—applications that can improve human health or save lives, such as identifying heavy aerosols in the air or providing early warnings for natural disasters
- Economic—applications that could create new products or services, avoid property damage or loss, or reduce risk of job loss by helping companies maintain steady operations

RTI applied a user-centered approach to understand and convey the voices of various user communities.

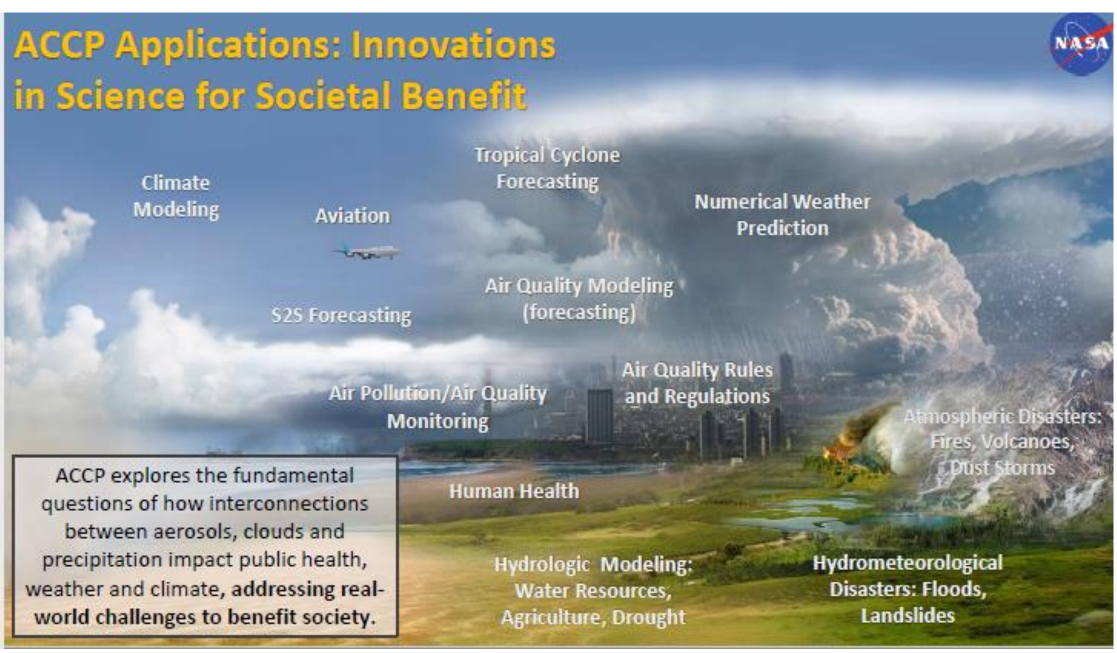
To extend the impact of DO data, RTI's goal was to identify, investigate, and understand the nonresearch user types along the EO data value chain and explore their interest in using DO data for decision-making. Our methodology, detailed in the **Appendix**, was based on a user-centered design framework. This process focused on key user-centered variables—uncovering potential EO end users across multiple industries, characterizing their needs, and learning how they use data to make decisions—to help identify and select user communities and users. This user-centered research was a pilot effort for NASA to consider best practices and methods related to engaging and assessing needs of nontraditional private- and public-sector users. This approach enabled the ACCP and RTI teams to tackle the ambiguous task of uncovering potential nontraditional, unknown users of future mission data.



ACCP sought to understand nontraditional applications for future data products that enhance predictions of weather, AQ, and climate.

Goals of NASA's ACCP DO System

- NASA's ACCP DO team is working to understand the relationship between aerosols, clouds, and precipitation and how these observations ultimately affect the atmosphere, air quality (AQ), weather, and climate. The ACCP DO system was recommended by the National Academies of Sciences, Engineering, and Medicine 2017 Decadal Survey as a cost-capped, process-based mission to address key science objectives related to climate variability and change, as well as weather and AQ.
- The ACCP team is developing an observing system intended to jointly measure aerosol-cloud-precipitation properties to (1) improve understanding of the processing of water and aerosols through the atmosphere and (2) develop societal applications enabled from this understanding. The ACCP team is considering a broad range of observing instruments and measurement capabilities, including radars, radiometers, lidars, polarimeters, and spectrometers. ACCP will deliver integrated space-based, airborne, and ground-based observations fundamental to characterizing these coupled aerosol-cloud-precipitation processes.
- Potential ACCP applications are being identified early in the mission planning, shown by the graphic,[1] to incorporate stakeholder needs in mission design and ultimately maximize the societal benefit of these future observations. Through mission design, ACCP's applications impact team (AIT) is interested in understanding nontraditional applications of these data products to the greatest extent possible.



1. Image from https://vac.gsfc.nasa.gov/accp/applications.htm

ACCP and RTI collaborated to select areas of interest, resulting in the characterization of seven diverse user communities.

Initial brainstorming with the ACCP AIT led to documentation of approximately 50 potential application areas for ACCP data. To down-select to our seven user communities, we prioritized applications (and relevant user communities) based on their alignment with goals, objectives, and potential enabled applications outlined in ACCP's Science and Applications Traceability Matrix, as well as priority communities of potential suggested by the team. [1] Our chosen user communities focused on commercial/private-sector use of data products and were selected to address specific areas of interest beyond traditional NASA outreach efforts. The following descriptions define the scope of these communities and the user profiles and use cases covered.

User Community	Description	User Profiles Covered in Study	Use Cases Covered in Study
Commercial Aviation	Community focused on commercial passenger air travel, including meteorologists, pilots in airline companies, and airline engine manufacturers.	• **Airline Meteorologist** • **Commercial Airline Pilot** • **Airport Chief Operations Officer**	• International flight planning • Convection and turbulence prediction modeling • Volcanic ash modeling • Urban air mobility models
Major Logistics Carriers	Community focused on companies involved in parcel transport, especially those that leverage air-based transport modes. Includes meteorologists, pilots, and planners in logistics firms, as well as weather planners and companies related to unmanned aerial vehicle (UAV)-based logistics transport.	• **Meteorologist in Air-based Logistics Firm** • **Data Analyst for Weather Firm Serving UAV market**	• Fog forecasting • Determining safe flying conditions for UAVs
Logistics Arms of Major Brands	Community focused on consistently delivering food and retail products, which are sourced from around the world, to its distribution facilities and stores. Includes crisis managers, supply chain managers, and developers of weather products who enable business continuity planning.	• **Crisis Manager in a Regional/Global Retail Company** • **Data Scientist for Weather Services Company that Serves Logistics and Transportation Clients**	• Allocating resources to maintain business continuity • Identifying disruptions in supply chains
Data-Driven Agriculture	Community directly involved with improving agricultural yields through implementing EO data; includes growers at small to medium farms; smallholder farmers; data scientists enabling decision-making in farm management and agricultural practices; and data scientists in smallholder advisory and financial services, large agricultural input, and agribusiness companies.	• **Growers at Small to Medium Farms** • **Data Scientist in Companies Developing Agricultural Decision-Making Platforms** • **Data Scientists in Smallholder Farmer Advisory Services**	• Effective application of farm inputs • Mitigation of plant pests and disease • Site similarity analysis of crops • Crop and AQ monitoring
Food Companies Operating in Tropical Areas	Community focused on sourcing food and beverage ingredients that are found in tropical regions. The community includes growers, ingredient buyers, food product manufacturers, and others involved in the supply chain for food and beverage companies.	• **Tropical Ingredient Buyer** • **Food Product Manufacturer**	• Monitoring global weather trends • Monitoring micro weather conditions
Health and Short-Term Air Quality Monitoring[2]	Community focused on near real-time and short-term monitoring of AQ. Includes patients suffering from respiratory health issues and their caretakers; health care providers supporting them; and data scientists creating platforms that incorporate AQ, such as digital health platforms; eventually this community may include private health insurers, public purchasers, health care analytics companies, and charting software providers.	• **Individual or Caretaker Managing Respiratory Disease** • **Clinician/Health Care Provider** • **Technical Lead in Outdoor AQ Monitoring Company**	• Individual or cohort health monitoring • Personalized medicine • Environmental monitoring of a location
Solar Energy	Community focused on stakeholders responsible for siting, developing, and operating a solar power plant. Includes hardware and software manufacturers, service providers, financiers, site developers, solar service providers, and solar plant operators.	• **Solar Energy Service Providers** • **Solar Plant Operators**	• Solar site development and financing • Solar site operational optimization

Key
- **Intermediary**
- **End User**

1. See factors and associated analysis in the Appendix.
2. Note that the greater health community is investigating long-term exposure, from months to years to decades.

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Future ACCP data products, supported by targeted engagement strategies, can bring value to varied private-sector user communities.

User Community	Key Takeaways
Commercial Aviation	• Safe and efficient transportation by air depends on a thorough understanding of weather conditions. This community is keenly interested in collaborating with NASA and improving data, models, and forecasts used for flight planning and en route decision-making, although resource limitations from the COVID-19 pandemic are affecting the ability to partner in the near term. • Users rely on satellite data for convective storm information and to see gaps in coverage over oceans, which affect their long-haul transoceanic flight planning. Turbulence and wind dynamics near developing convective storms are of high interest. • Aerosol data needs for AQ interests, including volcanic ash, dust, and smoke in flying routes and on the ground around airports, are increasing.
Major Logistics Carriers	• Vertically resolved weather data represent an opportunity to address needs of multiple growing markets UAV-based and vertical takeoff and landing [VTOL] aircraft) through research and development (R&D) projects. Companies in these markets recognize current gaps in cloud ceiling, wind dynamics, convection, and precipitation data in the lower atmosphere and may be more likely to work together to address these gaps. • These users share similar needs to the commercial aviation users (convective storms, volcanic ash and smoke data, vertically resolved fog cloud layers above 12,000 feet), work closely with aviation users, and may have more current bandwidth and resources to commit to working with NASA than their passenger transportation counterparts.
Logistics Arms of Major Retail Brands	• Because this user community almost exclusively relies on third-party weather data, effective engagement could occur through technology developers in weather insights companies—value-added service providers who serve many types of end users. • These users care most about large weather events but are starting to be interested in aerosols and AQ, mostly related to wildfire smoke, to monitor employee health and safety.
Data-Driven Agriculture	• Growers rely on data products that help inform agricultural practices. They need accurate observations of precipitation, intensity of precipitation, conditions leading to temperature inversions, temperature, humidity, and leaf wetness. • Although most growers do not consider AQ impacts, decision-making platform developers are considering adoption of AQ data because the community is starting to better understand its relationship to crop health. They would need surface-based quantification of particulate matter 2.5 ($PM_{2.5}$) and ozone. • Students and entrepreneurship communities, often funded by large agribusinesses, serve as key drivers of novel EO data uses in agritech and represent key engagement partners.
Food Companies Operating in Tropical Areas	• Food manufacturers, ingredient buyers, and growers use long-term agreements to manage demand, so long-range seasonal weather data are important to them. • Each of these users actively monitors weather conditions around the world, where key ingredients are grown throughout the year. • Understanding weather's influence on yield, price, and volume risks is vital to these users. • Emerging interests center around sustainable farming and understanding of potential impacts of climate change.
Health and Short-Term Air Quality Monitoring	• Understanding aerosol particle type and quantity is a key need, but there are also research needs to establish the relationship between specific particle types, health outcomes, and appropriate care. Short-term community engagement could include research funding opportunities with federal environmental and public health agencies. • Although low-cost, ground-based sensors offer high-resolution and near real-time data that address individual monitoring needs, coverage of satellite-based data represents an opportunity to glean health insights for larger populations. • Understanding the impacts of weather on aerosol movement can help improve AQ forecasting abilities beyond 2 days (desired is 2 to 7 days out).
Solar Energy	• Historical irradiance data for a specific geographic location are used to forecast future irradiance and secure funding—sometimes hundreds of millions of dollars—to build a solar energy plant. • A significant effort is expended to remotely monitor solar sites for performance issues. Conditions at a solar site are monitored by expensive weather stations. • This community is interested in expanding to satellite data to more accurately understand weather and AQ conditions at specific locations and their potential effect on power generation. The community is interested in developing forecast models and ground-truthing satellite data products through R&D partnerships.

Multiple aerosols, clouds, convection, and precipitation observable needs are shared across user communities.

RTI identified several observations and phenomena that provide value to multiple communities. Potential data products related to these observations have the potential to deliver wide-ranging impact across the communities explored.

	Aerosol Needs			Clouds, Convection, and Precipitation (CCP) Needs				
Community	Aerosol Type	Vertical Resolution of Aerosol Distribution	Colocated Aerosol and Weather Data	Precipitation	Temperature Inversions	Low Clouds	Convective Hazards	Wind
Commercial Aviation	●	●	●	●		●	●	●
Major Logistics Carriers	●	●	●	●		●	●	●
Logistics Arms of Major Brands	●	●	●	●			●	
Data-Driven Agriculture	●		●	●	●	●	●	●
Food Companies Operating in Tropical Areas				●	●			●
Health and Short-Term Air Quality Monitoring	●	●	●		●			
Solar Energy	●	●	●	●		●		

User communities expressed a variety of specific EO needs related to weather and AQ.

This table reflects the specific observation needs communicated by a representative selection of users within the specified user communities, and it is meant to be an illustrative, not exhaustive, representation of needs. RTI's interviews revealed that most user communities profiled actively incorporate CCP data (both satellite- and ground-based sources). The aviation, major logistics carriers, health and pollution, and solar energy communities are actively applying satellite- and ground-based aerosol and AQ data for decision-making, but other communities demonstrated an interest in future data use for monitoring crops and managing the safety of employees who may be exposed to unhealthy AQ conditions.

User Community	Aerosol EO Needs	CCP EO Needs
Commercial Aviation	• Vertically resolved aerosol data, focused on volcanic ash and smoke • Incorporation of weather and aerosol data to improve modeling of ash and smoke plumes	• Finer-scale observations of precipitation intensity and improved forecasts of precipitation intensity and type • Understanding of convective activity that may lead to turbulence • Improved observations of cloud layers with vertical resolution
Major Logistics Carriers	• Vertically resolved aerosol data, focused on volcanic ash and smoke • Incorporation of weather and aerosol data to improve modeling of ash and smoke plumes	• Accurate observed and forecasted precipitation, including type of precipitation (freezing drizzle, ice pellets, and hail) • Cloud ceilings and depths above 12,000 feet (14,000, 16,000, and 22,000 feet) • UAVs: Precipitation, convection, wind in lower atmosphere (300 to 500 feet off the ground); accurate cloud ceiling readings in lower atmosphere
Logistics Arms of Major Brands	• Surface-based $PM_{2.5}$ • Incorporation of weather and aerosol data to improve modeling of ash and smoke plumes	• Accurate observation of precipitation and forecasted prediction of precipitation, especially large weather events
Data-Driven Agriculture	• Surface-based $PM_{2.5}$, other particulates in future • CO_2, methane, ozone	• Accurate observations of precipitation—what has fallen and at what intensity • Conditions that may lead to temperature inversions • Temperature, humidity, wind, and leaf wetness
Food Companies Operating in Tropical Areas	• Improved observations of wind/aerosol relationship (e.g., Harmattan winds)	• Precipitation, humidity, wind speed, temperature, and fog data
Health and Short-Term Air Quality Monitoring	• Improved characterization of aerosol types—specific interest in wildfire smoke • Surface-based $PM_{2.5}$ and other particulates	• Understanding of weather extremes such as convective activity and temperature inversions, which trap pollutants near the surface • Understanding of cloud-aerosol interactions—how precipitation, wind, and humidity affect deposition and dissemination of particles
Solar Energy	• Aerosol particle type • Aerosol size distributions and vertical profile	• Accurate observed and forecasted precipitation (including precipitation type, snowpack) • Improved understanding of intermittent cloud cover

There are numerous opportunities for ACCP data products to provide impact to the private sector.

Potential Impacts of ACCP Data

- Commercial Aviation: Data may improve route planning around dangerous weather; minimize flight cancellations and delays; and enable safer, turbulence-free flights, even across oceans.
- Major Logistics Carriers: Data may reduce delays from fog and volcanic ash and enable users to work around weather challenges to ultimately deliver parcels on time. Data may also enable new markets such as UAV delivery and VTOL systems to expand.
- Logistics Arms of Major Brands: Data may help users strategically equip facilities with the right resources to serve their customers during major weather events, maintain the health and safety of employees, and anticipate supply chain disruptions.
- Data-Driven Agriculture: Data may inform users on the right seed varieties to use; types of crops to plant; and when to plant, spray, and harvest, ultimately improving crop yields and quality.
- Food Companies Operating in Tropical Areas: Data may help communities anticipate and react to climate change effects through novel observations.
- Health and Short-Term Air Quality Monitoring: Data can help the health care community better understand the health impacts of specific aerosols, forecast AQ crises, deliver appropriate therapies, and implement mitigation strategies.
- Solar Energy: Data may enable increased usage and dependence on solar power, fostering long-term success and the impact that solar power delivers in the United States and other regions.

"Satellite data are absolutely essential and by far the most important component of very short-term solar generation forecasts. Thank you for all you do to provide high quality and usable data."

—Grid Solutions Engineer, Private Research Organization

"Weather data help us understand where snow, rain, wind, and heat may affect our buildings. It provides us the visibility to effectively deal with severe events before they come and surprise us."

—Global Crisis Manager, Major Retail Brand

"The next big thing is UAVs—all of the logistics companies are in the business now and working on FAA approvals. Therefore, there's demand for weather data in the lower atmosphere that will influence drone operations."

—Meteorologist, Major Air-Based Logistics Firm

"We need better links to air quality and health. Satellite data with global coverage would be readily used for health applications."

—Clinical Researcher in Large University Healthcare System

Use cases within communities span new and existing user types, offering ACCP multiple ways to engage.

The user communities and use cases covered in this report span a selection of both current users (commercial aviation, major logistics companies, data-driven agriculture) of ACCP-relevant NASA program of record (PoR) observations and potential new users of these data (logistics arms of major brands, food companies operating in tropical areas, short-term health monitoring, and solar energy). Among these users, we identified a selection of existing and new use cases for future ACCP data. Placement in the below quadrants was based on conversations conducted for this study and is not representative of entire industries. The use cases profiled represent opportunities to engage existing EO data users with new data uses, facilitate adoption of existing use cases for new users, or help new users create new uses for ACCP data. As illustrated below, the bottom left quadrant represents a current state of engagement with known users in known use cases; the other three quadrants represent areas of opportunity where ACCP may engage and potentially increase the impact of its data with nontraditional users. These communities and use cases are indicative of broader impacts that future ACCP data products can bring to other communities and represent some of the many opportunities to further engage with nontraditional users.

NEW USES

***New Uses** include current NASA EO data users who identify new ways to use ACCP data and new purposes for the data.*

Site Similarity Analysis for Crops
Crop and Air Quality Monitoring
Mitigation of Plant Pests and Disease

Forecasting Fog
Determining Safe Flying Conditions for UAVs

International Flight Planning
Volcanic Ash Modeling
Urban Air Mobility Models

***New-New** describe new uses for ACCP data by new users who previously did not use ACCP PoR or other NASA EO data.*

Individual or Cohort Health Monitoring
Clinical Decision Support
Environmental Monitoring

Solar Site Development and Planning
Solar Site Operational Optimization

KNOWN USES

***Known Users** encompass current ACCP PoR data users.*

Effective Application of Farm Inputs

Convection and Turbulence Prediction Modeling

***New Users** describe users who do not currently use ACCP PoR data but have the potential to use it for known applications or uses.*

Allocating Resources to Maintain Business Continuity
Identifying Disruptions in the Supply Chain

Monitoring Global Weather Conditions
Monitoring Micro Weather Conditions

KNOWN USERS

NEW USERS

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User communities share common needs across technical data attributes and accessibility preferences.

Technical Data Needs

Although applications for aerosol and CCP data varied across user communities, many of these communities communicated similar needs for technical data.

- Most user communities shared spatial resolution needs of less than 1 km and subhourly temporal resolution.
- Latency needs varied across communities: the commercial aviation, major logistics carrier, and solar communities expressed needs for consistent low latency down to a few minutes, while other communities were comfortable with longer latency times or quick data delivery in certain circumstances.
- Forecasting needs were shared across multiple communities, although needs varied across communities and use cases from hourly to daily, weekly, monthly, seasonally, and yearly outlooks.
- Global coverage of data, especially in areas outside of North America and Europe, is desired across communities.
- The Analysis and Recommendations sections provide specific technical attribute needs by community, including spatial and temporal resolution, latency, forecasting, and coverage needs.

Data Accessibility Preferences

Users consistently expressed needs for improved data accessibility, interoperability, and ease of integration. Data users interviewed in this study preferred the following:

- Gridded and processed data sets, even though users profiled in this study ranged in technical maturity. The analysis and recommendations section provides specific preferred data formats and needs by community.
- Easy-to-find data sets that clearly convey the value of the product across user communities
- Ground-based data sources integrated with satellite-based data sources
- Standardized data formats, data structures, and documentation
- Reliable and flexible data, with the ability to pull large amounts of data into end users’ systems
- EO data sets with multiple variables that are aligned temporally and spatially
- Data with clearly labeled values and accuracy checks

RTI recommends ACCP further engage with the profiled communities via several different approaches.

Engagement Opportunities

All seven communities profiled in the study demonstrated strong interest in further collaboration. Based on feedback from these communities, RTI identified possible engagement strategies and short-term engagement opportunities.

- Interviewees desired the following engagement strategies:
    - Leveraging their expertise as **industry advisors** to provide consistent feedback on data product application and value
    - Tapping existing **professional networks** to understand community needs
    - Creating **user-centered training and data products** to help communities understand the potential value of future ACCP data products
    - Developing **industry R&D projects** that may lead to development of operational data products and engaging with **entrepreneurship communities** supported by corporate initiatives, such as incubators and hackathon communities
- Short-term engagement recommendations include the following:
    - **Deepen existing relationships with focus group participants and interviewees**, keeping these leads "warm" through consistent communication and participation in future workshops and conversations with the private sector.
    - **Expand from existing relationships into broader community engagement**, identifying and participating in nodes of industry collaboration and congregation. Start with communities that are "right and ready" for partnership such as solar energy, agriculture, food, and logistics.
    - **Engage in joint R&D in rapidly growing markets to increase impact**, especially for the UAV logistics and solar energy communities, who expressed near-term interest in collaborative R&D with NASA. Users and potential partners in these emerging markets are actively looking for data products that can help them meet those needs.
    - **Raise awareness about existing data products** to help users understand and see potential applications to their operations. NASA should review existing informational and training material from the perspective of users in these communities, refresh or create new materials when necessary, and then launch campaigns to raise awareness among users in the high-profile communities.
    - **Create communities-of-practice mechanisms to engage with value-added service providers**. RTI recommends that NASA explore ways to partner with these intermediaries in a precompetitive manner to improve access to data and enhance modeling and forecasting systems that will benefit many users.

User communities are eager to collaborate, although engagement strategies and readiness vary widely.

User study participants across user communities consistently demonstrated interest in and eagerness to address key industry needs through NASA engagement. Users offered a variety of potential engagement methods, which differ in levels of effort for both ACCP and industry collaborators. Although not indicative of the entire community, the selection of users we interviewed demonstrated interest in the following engagement strategies:

	Engagement Strategies						
Community	Industry Advisors	Professional Networks	User-Centered Training and Data Products	Industry R&D Projects	Entrepreneurship Community Engagement	Value-Added Service Provider	Recommendations
Commercial Aviation	●	●				●	Plug into industry associations such as Airlines for America and engage through air-based major logistics carriers because the industry currently has limited bandwidth.
Major Logistics Carriers		●		●		●	Leverage professional networks to jointly benefit aviation and air-based logistics users (latter have more bandwidth). Capitalize on rapidly growing UAV and VTOL industry through R&D opportunities.
Logistics Arms of Major Brands			●			●	Leverage value-added service providers for impact across multiple user communities and demonstrate value of future ACCP products to the community.
Data-Driven Agriculture	●	●	●		●	●	Ensure that products are discoverable to the community, and work with standards and documentation working groups. Use the agritech community as a testing ground for new applications with help from industry advisors.
Food Companies Operating in Tropical Areas	●		●			●	Disseminate training opportunities to community and communicate how new products may improve their operations.
Health and Short-Term Air Quality Monitoring	●	●	●		●	●	Engage the traditional research community and possibly consider supporting environmental health funding opportunities. Leverage expertise from current ground-based data users and entrepreneurship communities leveraging that data.
Solar Energy	●			●	●	●	Capitalize on the growing solar and solar + storage market through R&D opportunities such as ground-truthing and development of new data products.

Sections

NASA's ACCP DO team aims to enable enhanced predictions of weather, air quality, and climate.

Weather and air quality (AQ) data influence business decisions in almost every sector. Accurate observations and forecasts can play a key role in managing transportation of goods and people across the globe, monitoring health and safety, enabling advancements in renewable energy, reacting to hazards and climate change, and more. NASA's Aerosols, Clouds, Convection, and Precipitation (ACCP) designated observables (DO) team is working to understand the relationship between aerosols, clouds, and precipitation and how these observations ultimately affect the atmosphere, AQ, weather, and climate. The ACCP DO system was recommended by the National Academies of Sciences, Engineering, and Medicine (NASEM) 2017 Decadal Survey as a cost-capped, process-based mission to address key science objectives related to climate variability and change, as well as weather and AQ.

NASA currently offers near-global, low-latency products for the community at no cost. Examples of these products include:

- Global precipitation measurement (GPM) mission's gridded, multisatellite product that provides near-global precipitation estimates from 2000 to the present every 30 minutes at a 100-km spatial resolution.
- The Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) Aerosol product that provides daily profiles of "fine" aerosols (anthropogenic/pollution) and "course" aerosols (natural particles; e.g., dust) over the globe at a 10-km spatial resolution.
- Over 20 other NASA missions produce data products related to aerosols and precipitation processes. End users from universities, government agencies, national and international nonprofit organizations, and private companies use the data for a range of diverse applications that directly benefit society.

The ACCP team is currently developing an observing system intended to jointly measure aerosol-cloud-precipitation properties to (1) improve understanding of the processing of water and aerosols through the atmosphere and (2) develop societal applications enabled from this understanding. The table below provides an overview of observable priorities and anticipated measurement approaches for ACCP data.

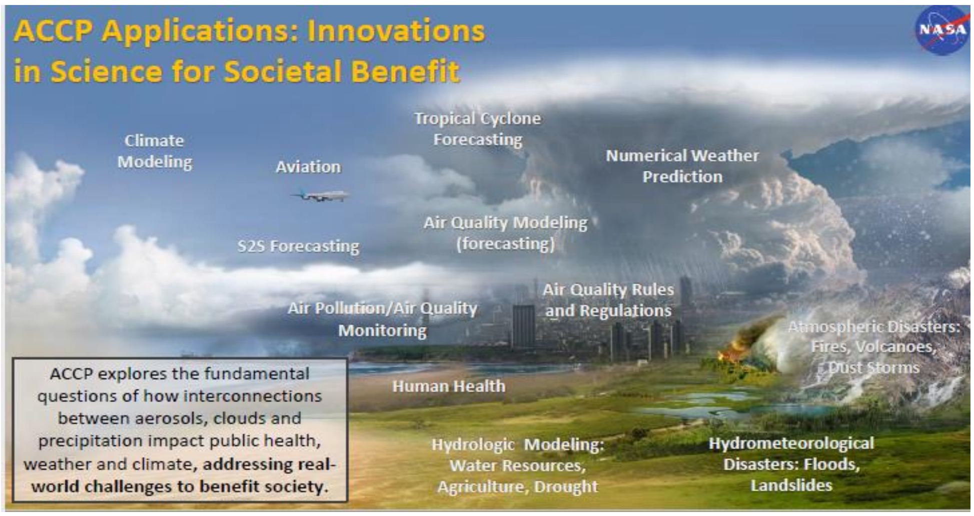
The ACCP team is considering a broad range of observing instruments and measurement capabilities, including radars, radiometers, lidars, polarimeters, and spectrometers. ACCP will deliver integrated space-based, airborne, and ground-based observations fundamental to characterizing these coupled aerosol-cloud-precipitation processes.

	Aerosols	**Clouds, Convection, and Precipitation (CCP)**
Observable Priorities	Aerosol properties, aerosol vertical profiles, and cloud properties to understand their effects on climate and AQ	Coupled cloud precipitation and dynamic state for monitoring the global atmospheric hydrological cycle and understanding contributing processes and cloud-climate feedback
Anticipated Measurement Approaches*	Backscatter lidar and multichannel, multiangle/polarization imaging radiometer	Radar(s), potentially with Doppler, with multifrequency passive microwave and sub-mm radiometer

*Space-based, with expectations of complementary suborbital field programs with more capable airborne instruments.

ACCP is considering nontraditional applications of their future data products through mission design.

ACCP's efforts will build on NASA's prior missions to capture new science-enabling observations related to specific science goals, including cloud feedbacks, storm dynamics, cold cloud and precipitation processes, aerosol processes, and aerosol impacts on radiation. Potential ACCP applications are being identified early in the mission planning, shown by the graphic,[1] to incorporate stakeholder needs in mission design and ultimately maximize the societal benefit of these future observations.



Key benefits of these future data products include the following:

- Improved severe storm forecasting and modeling decisions through an enhanced ability to observe vertical motion in extreme storms, cold clouds, and snowfall estimates;
- More accurate estimates of AQ from colocated temporal and vertical measurements of aerosol distribution and properties and precipitation measurements, which may benefit disaster response and management (e.g., wildfires); and
- Better operational AQ forecasting from improved characterization of aerosol amounts and properties, including measurements of aerosol optical depth, aerosol extinction profiles, absorption aerosol optical depth, and aerosol single-scatter albedo.

Through mission design, ACCP's applications impact team (AIT) is interested in understanding nontraditional applications of these data products to the greatest extent possible. This study reflected a user-centered approach to understanding how a variety of nontraditional user communities use weather and AQ data for business and operational decision-making purposes. This study also explored users' technical needs for data products that can enhance current and future decision-making capabilities.

1. Image from https://vac.gsfc.nasa.gov/accp/applications.htm

Selected user communities and use cases illustrate opportunities for ACCP to create greater application impact.

RTI engaged with a cross section of stakeholders across the value chain for each user community to understand their day-to-day roles, their applications of weather and AQ data, and opportunities for future data products. This report profiles a selection of users and use cases for each community. Although not exhaustive, these profiles are meant to illustrate and lead to deeper engagement with these communities.

User Community	User Profiles	Use Cases
Commercial Aviation	• Airline Meteorologist • Commercial Airline Pilot • Airport Chief Operations Officer	• International Flight Planning • Convection and Turbulence Prediction Modeling • Volcanic Ash Modeling • Urban Air Mobility Models
Major Logistics Carriers	• Meteorologist in Air-Based Logistics Firm • Data Analyst for Weather Firm Serving Unmanned Aerial Vehicle (UAV) Market	• Fog Forecasting • Determining Safe Flying Conditions for UAVs
Logistics Arms of Major Retail Brands	• Crisis Manager in a Regional/Global Retail Company • Data Scientist for Weather Services Company that Serves Logistics and Transportation Clients	• Allocating Resources to Maintain Business Continuity • Identifying Disruptions in Supply Chain
Data-Driven Agriculture	• Growers with Small to Medium Farms • Data Scientist in Companies Developing Agricultural Decision-Making Platforms • Data Scientists in Smallholder Farmer Advisory Services	• Effective Application of Farm Inputs • Mitigation of Plant Pests and Disease • Site Similarity Analysis of Crops • Crop and AQ Monitoring
Food Companies Operating in Tropical Areas	• Tropical Ingredient Buyer • Food Product Manufacturer	• Monitoring Global Weather Trends • Monitoring Micro Weather Conditions
Health and Short-Term Air Quality Monitoring	• Individual or Caretaker Managing Respiratory Disease • Clinician/Health Care Provider • Technical Lead in Outdoor AQ Monitoring Company	• Individual or Cohort Health Monitoring • Personalized Medicine • Environmental Monitoring of a Location
Solar Energy	• Solar Site Service Providers • Solar Site Operators	• Solar Site Development and Financing • Solar Site Operational Optimization

RTI Innovation Advisors

Each community profile highlights a unique value chain, set of data users, and use cases with specific technical needs.

The report synthesizes RTI's extensive user interviews and focus group insights into community-level summaries that are intended to inform the reader of how a given community and its users currently use or may use Earth observation (EO) data in the future. These profiles reflect the perspectives and needs of users across roughly 50 private companies and nontraditional organizations. Although these writeups are not intended to be an exhaustive summary of all possible data uses and use cases within the community, they provide illustrative examples of possible stakeholders to engage, their "personas," and their uses and needs.

Each user community writeup is divided into five sections:

- The **Community Overview** summarizes the community, its stakeholders, and how ACCP data may affect the community.
- The **Organizational Assessment** covers 1) the types of decisions made by data users in the community, 2) stakeholders along the value chain, and 3) users' general appetite for risk and innovation.
- The **Technical Assessment** covers stakeholders' level of maturity with EO data, their technical observation needs, and their data attribute and format preferences.
- **Use Cases** demonstrate how ACCP or EO data may be used (currently or in the future) to make decisions.
- **User Profiles** provide a "persona" of a potential data user to illustrate how they may use ACCP and other EO data.

ACCP User Community Profiles

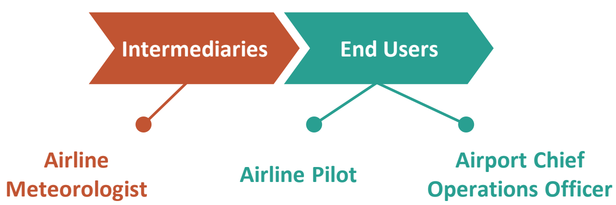
	Commercial Aviation
	Major Logistics Carriers
	Logistics Arms of Major Retail Brands
	Data-Driven Agriculture
	Food Companies Operating in Tropical Areas
	Health and Short-Term Air Quality Monitoring
	Solar Energy

Commercial Aviation

Community Overview

The U.S. commercial aviation sector is massive 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.[1] 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.

Selected User Profiles for ACCP



Potential Use Cases for ACCP Data Products

- International flight planning
- Convection and turbulence prediction modeling
- Volcanic ash modeling
- Urban air mobility models
- Fog forecasting[2]

Moving Forward with ACCP

Members of this community expressed high levels of interest in collaborating with NASA in future development of applications to address several use cases outlined below—tempered only by the uncertainty and downsizing that the community is currently experiencing because of the COVID-19 global pandemic. Individual organizations in this community (e.g., airlines, data service providers) could become collaboration partners. There are also convening bodies, such as the A4A, through which a broader collaboration could develop.

RTI identified five use cases that can serve as opportunities to collaborate with the aviation community to deliver improved solutions derived from EO data: (1) international flight planning, (2) convection and turbulence prediction modeling, (3) volcanic ash modeling, (4) urban air mobility models, and (5) fog forecasting.[2]

1. Historical flight data and economic impact from FAA by the Numbers (https://www.faa.gov/air_traffic/by_the_numbers/).
2. See major logistics carriers section for more details on forecasting fog.

Commercial Aviation

Organizational Assessment

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 community is 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 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.

The **airline**, in conjunction with air traffic control advice from the Federal Aviation Administration (FAA), makes decisions about taking off and landing. Although **airports** are distinctly separated from this decision-making, airport operations crews have their own set of needs and decisions to make based on weather conditions. Of primary importance is lightning in the vicinity. Lightning presents a risk to aircraft fueling operations; fueling is halted for a specific time frame, typically 12 to 15 minutes, when lightning is spotted within a defined radius of an airport, typically 3 to 5 miles. The threat of high winds will set airport and airlines crews in motion to secure or store aircraft and other ground-based equipment.

Commercial Aviation

Organizational Assessment (cont.)

Aircraft engine manufacturers are increasingly interested in AQ and aerosol-related conditions for their products because most major engine manufacturers have shifted their business model away from selling the physical product of an engine to selling reliable hours and use of that engine. This shift means that the engine manufacturer still owns the engine and is responsible for all maintenance and repair necessary to keep the engine operating reliably and safely. As a result, these manufacturers are tracking the flight paths of every engine on every flight. They are increasingly interested in the conditions through which their engines are flying. Volcanic ash, sand, dust, and ice crystals present conditions that may trigger additional repairs or maintenance; thus, the ability to better identify those conditions and fly around them is of great interest to these manufacturers.

Given the criticality of weather data to safe and efficient operations, it should be no surprise that this set of users is very familiar with weather data sources, formats, and applications and very open to exploring new data sets, data products, and increased levels of forecasting accuracy that may be available in the future. NASA’s current program of record (PoR) is relatively well known in this community, and NASA is perceived as a valuable, trusted partner. New and better data and data products that can improve knowledge of weather and AQ conditions could have a significant positive effect on this community.

Data	Intermediaries	End Users
Data are collected from satellite sources (e.g., National Oceanic and Atmospheric Administration’s [NOAA’s] Geostationary Operational Environment Satellite [GOES] and NASA's ISS-Lightning Imaging Sensor), from ground-based radar, and from in-flight weather observations. Satellite data are fed to the National Weather Service’s (NWS’s) Satellite Broadcast Network and viewed in the Advanced Weather Interactive Processing System via the National Hurricane Center, Aviation Weather Center, or other proprietary display or data systems.	Intermediaries integrate data from government and ground-based sources to create value-added products for the aviation community. Users in this community include airline meteorologists and value-added service providers. Illustrative examples of firms active in this community that enable customized mapping and graphics are IBM/Weather Channel, Jeppesen, Sonalysts, Pivotal Weather, Weather Bell, Cirrhus Lighter, and Tropical Tidbits.	Users in this community include airline pilots, airport chief operating officers, and aircraft engine manufacturers. Each user is highly interested in weather data, and some expressed increasing interest in applying AQ data to their decision-making. Users interviewed by RTI expressed a high level of interest in collaborating with NASA in future endeavors.

Commercial Aviation

Technical Assessment

The safe and reliable operation of a single plane is a highly technical marvel. Scaling that effort up to safe and reliable global operation of all commercial aircraft is a highly complex technical operation, requiring close coordination among airline planners, airline meteorologists, regional operations centers, FAA air traffic control, and local airport operations. Understanding current and forecasted weather conditions at each airport location and along each flight path is critical to the successful operation and safe transport of passengers and crew. This set of users is already highly dependent on weather data on a daily and hourly basis, is 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.

Weather and AQ data are consumed from a variety of sources: satellites, ground-based radar, and even the aircraft themselves. Despite the richness and variety of data currently available, this community has articulated clear needs. Latency of data was mentioned many times and varies by application. For understanding fast-moving convective storms, rerouting around turbulence, or adjusting long-range flight plans, latency in minutes is desired. For other applications related to ozone or volcanic ash, much lower latency is acceptable. Spatial resolution needs to follow a similar pattern, in which tens of meters is desired in urban areas near airports and 1 km resolution is acceptable in less dense areas. Easier integration of data sets from different sources to formulate a global view is desired. Examples are summarized here and expanded on in the “Use Cases” section.

Improved localized weather forecasting—Current forecasts on convective storms are insufficient for predicting actual conditions in very localized settings, such as a specific airport. For example, a categorical or statistical risk outlook or broad forecast from the NWS that overly generalizes threat, region, or timing might be insufficient for minute-to-minute flight planning and operations (i.e., 40% of thunderstorms in a large region this afternoon). Airline meteorologists want to give a very specific forecast to their flight crews and ground-based operations in the path of the storm and, thus, have to create their own forecasts using a variety of data products to deliver the desired spatial and temporal fidelity.

Commercial Aviation

Technical Assessment (cont.)

Convection and turbulence prediction modeling—Turbulence in flight presents potential hazards to passengers and crew. The community desires improved understanding of convective activity that leads to turbulence and better prediction of turbulent areas along flight paths. Understanding convective activity is a very challenging issue given the dynamic nature of the conditions that lead to turbulence.

International flight planning—Long-haul flights across the Pacific Ocean have very little data to predict weather conditions along the flight path or detect meaningful changes in the conditions that could adversely affect the flight path (e.g., high winds that increase fuel consumption, convective storms, turbulence conditions). Unlike domestic flights, these transoceanic flights do not have ground-based radar feeds to assist them, nor are there a meaningful number of other aircraft in the air to serve as weather sensors. Thus, satellite data that address global conditions becomes the most important data asset to help the flight crew and air traffic controllers.

Volcanic ash modeling—Volcanic ash can cause significant damage to an aircraft's engines; therefore, flights avoid any area assumed to have airborne ash. Users interviewed for this project believe current models are too conservative and would benefit from the integration of timely data from satellites. Better characterization of the plume, its direction, and change over time is desirable.

Urban air mobility models—New aircraft, known as "air taxis" or electric vertical takeoff and landing (eVTOL), are expected to enter the market in the next few years and create a new alternative to ground-based transportation (taxis, buses, personal vehicles) for short-distance transport. Weather data, particularly a deeper understanding of wind and turbulence dynamics in urban environments, are critical to the successful launch and expansion of this new mode of transportation.

Several notable technology trends and developments may positively influence further adoption of weather data. Significant efforts are underway to develop more advanced algorithms for systemwide information management and planning systems. Similarly, developments are underway to explore turbulence detection using passive systems in the cockpit. Synthetic vision/visibility systems in development may help pilots "see" through fog and other limited visibility conditions. Several users commented that climate change is leading to more disruptive storms, more turbulence, and more conditions that create wildfires.

Commercial Aviation

Use Cases

Within this community, users may leverage EO data in a range of use cases to enhance current and future decision-making capabilities. Examples of use cases within this community are as follows:

- International flight planning
- Convection and turbulence prediction modeling
- Volcanic ash modeling
- Urban air mobility models
- Fog forecasting (covered in the Major Logistics Carriers section)

International flights rely on satellite data to avoid convective storms and turbulence.

Pilots have a critical need for up-to-date and accurate information on the weather and AQ conditions into which they are flying.

Getting up-to-date and accurate information becomes increasingly difficult for long-haul international flights, especially over large bodies of water, such as the Pacific Ocean. Flying over land, especially U.S. geographies, provides the benefit of extensive ground-based radar systems. In contrast, flying over the Pacific means pilots are operating with significantly less information and are increasingly reliant on satellite systems for up-to-date changes.

The contrast to domestic flights is significant. With domestic flights, other aircraft in the vicinity or those that flew similar routes earlier in the day, serve as data sources—in combination with radar and satellite data—to characterize storm fronts and turbulence. With ocean crossings, a smaller number of planes are traversing a larger geographic space. Improved access to data before and during transoceanic flights will improve flight planning and may become the differentiator between operating the flight nonstop, forcing an unexpected stop, or canceling the flight altogether.

Improved convection data are critical for accurate turbulence prediction models that ensure smooth, safe flights.

Turbulence and visibility are two of the greatest concerns to pilots. Turbulence is hard to predict; is difficult to identify; and can lead to uncomfortable, sometimes injury-causing, flying conditions. Pilots want to better predict when and where turbulence will appear to provide a smoother flight and minimize the risk of injury to passengers and crew. Airline meteorologists and flight planners want to improve guidance regarding altering flight paths to avoid convective storms. Current industry norms of 5 to 20 miles are artifacts from times when data were not as readily available. The impact of wind on urban environments, especially around airport terminals, is of great interest.

Airlines are trying to find ways to deliver better information to pilots in the air about the turbulent conditions ahead of them. Examples of current efforts include:

- Creating in-house turbulence data tools incorporating grid data and meteorologist input;
- Testing service provider products such as Turbulence Aware, which creates an index for absolute turbulence (rather than relying on subjective input from pilots); and
- Sending pilots nowcasts for graphical turbulence guidance to give pilots representation of computer-based turbulence modeling.

What pilots want most is high-resolution, 3D models of wind and turbulence, but several challenges are associated with providing this type of data. One is constructing easy-to-interpret data that require minimal bandwidth when uploading to an aircraft. Another is characterizing turbulence readings beyond where airplanes currently fly. Data beyond that captured on aircraft en route are limited. Models to characterize high-risk areas cannot be validated because planes should not fly into those areas.

Commercial Aviation

Use Cases (continued)

Volcanic ash is the greatest AQ concern expressed by airlines and pilots; improved data and modeling are needed.

Volcanic ash is consistently cited as the greatest AQ concern for airlines and pilots. Particles from volcanic ash can cause serious damage to aircraft engines, resulting in potential risk of performance issues mid-flight. Volcanic ash is an irregular occurring issue, but when volcanic activity occurs, it can have a significant and long-lasting effect on flight planning in and around the affected regions.

Currently, airlines rely on data and models provided by the Volcanic Ash Advisory Centers (VAAC), a collection of nine centers spanning the globe. The VAACs are responsible for monitoring volcanic activity and generating volcanic ash advisories when volcanic activity occurs. The VAAC is a partnership between NOAA and the International Civil Aviation Organization.

The current tools and models used for tracking the spread of volcanic ash are generally considered overly conservative and lacking in accuracy and latency, thus leading to unnecessary levels of cancellations. More accurate data and models would help improve forecasts of the size and movement of the ash. Airline meteorologists stated that determining the concentration of airborne ash based on current models is difficult. They desire a way to independently verify ash concentration. Improvements would help minimize the disruption to air traffic.

For example, the ash concentration models used during the 2010 Iceland eruption did not quickly incorporate new satellite observations to portray the evolving size and shape of the plume. Days later, satellite data and direct observations in air at several altitudes confirmed a perfectly clear day over central Europe, yet the entire European airspace was closed. Ash concentration models, validated and regularly updated by ground-truthing and satellite input, would be considered a major improvement.

"Flying taxis" and other VTOL vehicles may be the future of air travel. Greater insights on wind and turbulence in urban areas are critical to successful launch and expansion of this new mode of transportation.

The commercial aviation industry is expanding in new directions. Most notable is the rapid growth of investment in urban air mobility vehicles. Known by many names—flying taxis, eVTOL, etc.—these aircraft are electric powered and deploy VTOL maneuvers that enable them to take off and land quietly. These new types of aircraft will be deployed in the next few years, perhaps as early as 2024. Applications include shuttles to and from airports and intra-city transport as an alternative to taxis, buses, and other ground-based transportation.

Many unknowns must be resolved before effectively introducing and expanding the market for these aircraft. Users in the community cited a need for a deeper understanding of wind, turbulent conditions, and other weather phenomena in urban environments. Improved data and models are needed to manage flight routing and optimization to provide safe and efficient transportation. Spatial resolution in the tens of meters is desired for this use case and will require integration of ground-based and satellite-based sensing. Developing solutions to harness wind and turbulent conditions in urban environments is seen as critical to achieving the full economic impact that urban air mobility promises.

RTI Innovation Advisors

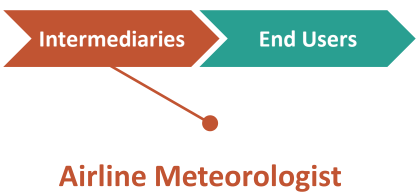
Airline Meteorologist

User Community:

Commercial Aviation

Who are they?

Certified meteorologist, background and education in meteorology



Who do they work for?

Major airlines employ teams of meteorologists to provide weather and AQ decision support in the form of guidance, alerts, and recommendations.

> *"Predicting convective storms is really troublesome. We need more information than 'the conditions are right' for convective storms. Accurately predicting the storms' time, duration, location is a nine-figure opportunity."*
>
> —Director of Operations Center for Major Airline Carrier

Airline meteorologists are avid users of a variety of sources for weather and AQ data; they are eager to collaborate with NASA.

What decisions are they making (and how) today?

Airline meteorologists provide support to a variety of internal customers, including national and regional operations centers, flight-planning teams, flight dispatchers, ground crews servicing aircraft, and pilots.

Data products in use include satellite data, fed through government systems, and commercial products that enable customized mapping and graphics. Data available from sources like these, coupled with input from ground-based radar, satellites, and the aircraft themselves, provide a high level of actionable insights across North America.

Weather-related planning horizons tend to be in the 4- to 12-hour range, with the exception of major weather events, such as hurricanes, tropical storms, and large winter storms. These are large, slow-moving weather events that are tracked and forecast days in advance. If weather or AQ issues are going to force a cancellation or delay, the airlines want to be able to make that call as early as possible to direct passengers to best alternatives.

Do they have experience with EO data?

Airline meteorologists are mature, avid users of a variety of data sources for weather and AQ data. They are able to interpret data products at a lower level (levels 2 and 3) or leverage these data to develop their own in-house weather forecast models, such as thunderstorm or wind models.

What do they care about?

Airline meteorologists are primarily concerned with tracking and predicting weather phenomena.

Weather phenomena of the highest impact to airline operations 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.

Airline Meteorologist

> *"I can't think of another industry that is impacted by weather more than aviation."*
>
> —Director of Operations Center for *Major* Airline Carrier

> *"We are always exposed to extreme weather based on where we fly. Hubs like San Francisco, Chicago, Houston, and Newark are uniquely impacted by weather phenomena."*
>
> —Meteorologist for Major Airline Carrier

What are their technical needs?

The quality, quantity, and fidelity 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.

What would motivate them to use NASA EO data?

Airline meteorologists already use NASA data. Users in this community have a high level of interest in collaborating with NASA, and some have collaborated with NASA in the past.

What are their adoption barriers for using NASA EO data?

Adoption barriers noted by these users include difficulty of integrating data integration from various data sources, plus limitations on latency for tracking convective storms and turbulence. These barriers currently limit their use of NASA EO data.

What are they afraid of?

Commercial airlines are heavily dependent on understanding weather and AQ conditions to operate smoothly and safely. These companies rely heavily on their meteorologists and the tools and data they use to provide the best insights possible to ensure safe operations for passengers and crew.

What do they NOT care about?

AQ is a lesser concern, but areas of interest center around volcanic ash and ozone. Volcanic ash can harm a jet engine. Ozone levels inside the aircraft must be monitored to stay within federally mandated limits. The ozone level is more of an issue with aircraft flying at altitudes above 28,000 feet.

What are some key use cases?

- International flights over oceans
- Turbulence insights
- Volcanic ash
- Urban air mobility models
- Forecasting fog

RTI Innovation Advisors

Commercial Airline Pilot

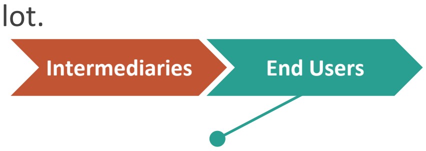
Airline pilots rely on satellite- and ground-based weather and AQ data throughout each flight to avoid convective storms and turbulence.

User Community:

Commercial Aviation

Who are they?

Airline pilots are end users of weather and AQ data provided by airline meteorologists, and they bear the ultimate responsibility for the safety of passengers on their aircraft. Many join commercial airlines after a career as a military pilot.



Who do they work for?

The airlines for which they fly employ pilots.

> *"On a long-haul flight at the margins of an aircraft's range capability, an en route flight time difference of 10–15 minutes due to strong winds, convective weather avoidance, etc. could easily be enough to cause that flight to replace paying customers with fuel, or not operate at all."*
>
> —Meteorologist, Major Airline Carrier

What decisions are they making (and how) today?

Pilots, in conjunction with ground-based air traffic controllers, must make decisions throughout a flight about any changes to the flight path that will avoid convective storms or turbulence. Decisions to land the plane early, and where to do so, also are made by the pilot. Data available in North America, from government and private sources, coupled with input from ground-based radar, satellites, and the aircraft themselves, provide a high level of actionable insights for pilots. Planning horizons for weather data range from a few hours before domestic U.S. flights to several hours before international flights. Planning horizons shift to minutes while in flight; pilots have a critical need for up-to-date and accurate information on the weather and AQ conditions into which they are flying.

Do they have experience with EO data?

Pilots are consumers of gridded, highly processed weather and AQ data, which are essential for the smooth and safe operation of each flight.

What do they care about?

The quality, quantity, and fidelity of data greatly decrease outside of North America, specifically over oceans and in other countries. A pilot's need for up-to-date and accurate information is satisfied for most domestic U.S. flights but becomes increasingly difficult to address with long-distance flights, flights over large bodies of water, flights in and around storm fronts, and flights encountering freezing conditions and fog.

Pilots and technology developers at airlines and service providers are working on improving data products to use in the cockpit during a flight. New products are being developed for use in avionics systems in cockpits and on portable devices, such as tablets that can be placed in the cockpit. These products deliver information to the pilot. In some cases, the tablet is used as a sensor to share data such as turbulence measurements back to airline operation centers and with other aircraft in the vicinity.

RTI Innovation Advisors

Commercial Airline Pilot

"Inaccurate turbulence data can cause significant injuries to crew and passengers and can ultimately lose us customers."

—Strategy Director,
Major Airline Carrier

What are their technical needs?

Turbulence and visibility are two of the greatest concerns to pilots. Turbulence is hard to predict; is difficult to identify; and can lead to uncomfortable, sometimes injury-causing, flying conditions. Pilots want to better predict when and where turbulence will appear to provide a smoother flight and minimize the risk of injury to passengers and crew. Pilots also want to understand any visibility constraints related to fog as they approach a landing site.

What would motivate them to use NASA EO data?

Pilots would value improved data assets that address localized convective, turbulent, and foggy conditions.

What are their adoption barriers for using NASA EO data?

One of the technical hurdles during flight is receiving high-fidelity data as a small file size in the cockpit.

What are they afraid of?

Pilots are afraid of unpredictability of weather or AQ conditions and how that can affect the safety of passengers and crew.

What do they NOT care about?

Pilots generally are not interested in being "developers" of new data products. However, they want to have a strong voice in how those new data products will be used in the cockpit.

What are some key use cases?

- International flights over oceans
- Turbulence insights
- Volcanic ash
- Urban air mobility models
- Forecasting fog

Airport Chief Operations Officer

User Community:

Commercial Aviation

Who are they?

The chief operations officer of an airport oversees all of the operations for which the airport is responsible: primarily runway and terminal site maintenance and development. This is distinctly different from airline operations. Airlines are responsible for the safety of their passengers, equipment, and crews. Airlines work closely with the FAA, air traffic controllers, and their internal meteorologists and staff to make all decisions, including flight planning, delays, cancellations, rerouting, and deicing.

Who do they work for?

They are members of the leadership team of an airport, likely reporting to the CEO/president.

Airport operations teams focus on the safety of ground-based crews and equipment and actively monitor lightning conditions that can halt fueling operations.

What decisions are they making (and how) today?

Airport operations are less sensitive to weather conditions than airline operations. Aside from major weather events, such as hurricanes or snow/ice storms, airport operations teams are monitoring one critical weather phenomena: lightning. Lightning detected within a 3-mile radius of the airport triggers a halt to any aircraft refueling operations.

Airport operations centers monitor weather data separately from airlines and air traffic controllers.

Do they have experience with EO data?

These users are daily consumers of EO data via intermediaries. Weather data sources include NWS, National Hurricane Center, and the Weather Channel.

What do they care about?

When lightning is detected, the airport notifies the airlines, who then notify their refueling crews to stand down. Refueling crews must wait a mandatory period of time (typically 12 to 15 minutes) before returning to work. Any new lightning strike resets the clock. In the summer, and at busy airports, the refueling delay begins to prevent numerous aircraft from taking off, which blocks gates and keeps other aircraft from landing or from approaching gates after landing.

High winds associated with tropical storms or hurricanes (over 40 mph) prompt airport operations to activate emergency response plans, which include securing or moving ground-based vehicles. The planning horizon time frames used by airport operation centers are in minutes because their focus is primarily on lightning in the vicinity.

Airport Chief Operations Officer

"Extreme climate events are increasing insurance risks and premiums. High wind and hail are two of our greatest insurance concerns."

—Vice President, Environmental Affairs, International Airport

"Improved lightning detection can make the difference between passengers waiting ten minutes and three hours."

—Chief Operations Officer, International Airport

What are their technical needs?

Current NWS forecasts and terminal aerodrome forecasts (TAFs) are not always sufficient to address the particular needs of a given airport. For example, mountainous terrain makes it difficult to predict summer thunderstorms in Denver. The users desire improved models of winds and air flows, cloud height, lightning data, and temperature. They want better spatial resolution that provides a highly localized view of convective and lightning activity around the airport region.

What would motivate them to use NASA EO data?

Tools to better predict or track lighting activity would help reduce operational delays. Users in this community have a high level of interest in collaborating with NASA, and some have collaborated with NASA in the past.

What are their adoption barriers for using NASA EO data?

Users rely primarily on radar-based data. EO data that complement or improve on local radar would increase adoption.

What are they afraid of?

Risk of injury to ground crews and damage to aircraft and ground support vehicles are their primary concerns.

What do they NOT care about?

AQ data are not in high demand at most airports. Airlines are responsible for their own emissions and for visibility-related takeoff and landing decisions.

What are some key use cases?

- Turbulence insights
- Urban air mobility models
- Forecasting fog

RTI Innovation Advisors

ACCP User Community Profiles

	Commercial Aviation
	Major Logistics Carriers
	Logistics Arms of Major Retail Brands
	Data-Driven Agriculture
	Food Companies Operating in Tropical Areas
	Health and Short-Term Air Quality Monitoring
	Solar Energy

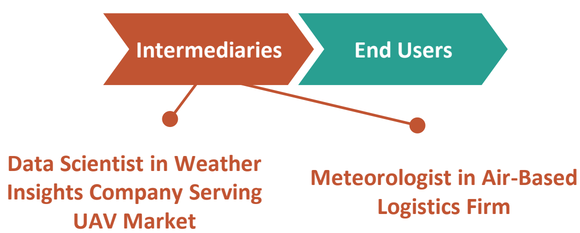
RTI Innovation Advisors

Major Logistics Carriers

Community Overview

Logistics carriers are in the business of transporting parcels quickly and reliably all around the world. Parcel shipping was a $317 billion business in 2018, with 87 billion parcels shipped around the world, and the United States held just over a third of the world's spending on parcel shipping.[1] Major logistics companies rely on a combination of air-, sea-, and land-based transportation modes to get parcels to the intended recipients. In this industry, time is money. Timely delivery of goods is vital for maintaining customers' trust and future business. As UAV technology and regulations evolve, these companies are looking to UAVs as an approach to parcel delivery. This nascent UAV market was sized at $642 million in 2019 and is projected to grow to $7.4 billion by 2027. [2] These companies must work around weather and AQ challenges to get their cargo to its intended destination, so they need high-quality data products to help them accurately assess safety threats and strategically invest resources to deliver on time. Any delays to their operations cost them time, fuel, and their reputation.

Selected User Profiles for ACCP



Potential Use Cases for ACCP Data Products

- Fog forecasting
- Determining safe flying conditions for UAVs
- International flight planning[3]
- Convection and turbulence prediction modeling [3]
- Volcanic ash modeling[3]

Moving Forward with ACCP

This user community avidly uses EO data for air-based applications and appears to actively look for ways to improve its ability to fly around inclement weather conditions. ACCP's focus on improving understanding of convective events and weather events at a variety of elevations, such as low clouds, high clouds, and fog, will enable this user community to better navigate weather challenges that affect parcel delivery. Data coverage in higher latitudes will help companies operating in many of their northern hubs. Air-based carriers often work closely with commercial airline providers, in organizations such as Airlines for America, to collectively improve the safety of air transport. Engagement with these collaboratives may enable greater evaluation and adoption of NASA data in day-to-day flight activities.

1. Statista. (2019, November 8). 87 billion parcels were shipped in 2018. https://www.statista.com/chart/10922/parcel-shipping-volume-and-parcel-spend-in-selected-countries/
2. Fortune Business Insights. (n.d). Drone package delivery market size, share & COVID-19 impact analysis by type, by package size, by end-use, and regional forecast, 2020-2027. https://www.fortunebusinessinsights.com/drone-package-delivery-market-104332
3. See aviation user community.

Major Logistics Carriers

Organizational Assessment

Logistics firms are interested in understanding weather phenomena—especially related to air travel—that may affect their ability to deliver a parcel to its specific destination at the predicted time. Although most major parcel carriers use air- and land-based modes to transport parcels, their dispatching and operations sections are siloed and use different data products to manage weather-related threats. The air-based side, led by **meteorologists**, operates in a network communications center that coordinates with internal stakeholders, such as flight dispatchers, operations coordinators, and pilots, as well as external stakeholders, such as the FAA. They rely on a number of weather products and information, including script-based systems, to create quickly consumable data sets for these end users. Although they navigate in a risk-averse environment, their technical background enables them to try and evaluate new data products. Ground-based transportation arms are more likely to rely on inexpensive third-party providers and communication with other drivers to monitor weather conditions.

Many logistics companies are currently looking to UAVs as a means of delivering parcels. As FAA and airspace policies are changing to accommodate the possibility of UAV-based delivery mechanisms, weather products suited for the needs of commercial drone pilots are required. Because these aircraft are very small and fly at significantly lower altitudes than airplanes (<1,000 feet), they are prone to being taken off course by strong winds. **Data scientists for weather insights companies serving UAV markets** provide forecasts and guidance for UAV operators, but logistics operations centers may incorporate UAV-tailored weather forecasts in the future.

Air-based firms monitor storms and convective activity that affect the plane in flight, as well as fog, wind, and ice, which affect the plane's ability to take off, land, and unload. Users in this community use weather and AQ data to make decisions that balance the safety of company staff with on-time parcel delivery. Data can be used to delay, cancel, or reroute flights and trucks; identify locations to house planes so that they do not become iced over in cold conditions; and understand fuel necessary for planes and trucks to get to their destination, even with rerouting. UAV companies use weather data for go/no-go flight decisions and route planning around weather phenomena.

Data	Intermediaries	End Users
Data are collected from ground-based radar sources and from a variety of satellite providers, including NOAAPort products (AWIPS, SBN), Himawari, GOES-16, and private satellite firms, such as Spire.	Data may be aggregated into detailed and gridded weather data products for air-based applications and used along with TAFs or warnings from NOAA's Automated Surface Observing Systems (ASOS). Meteorologists leverage these data sources: they may create their own weather forecasting models or use script-based systems to communicate weather insights to internal stakeholders.	Meteorologists communicate weather insights from these tools to flight dispatchers, operations coordinators, and pilots. Using these data products, meteorologists provide guidance on flight rerouting and delays around hazards such as convective storms, volcanic ash, and ice, for example.

Major Logistics Carriers

Technical Assessment

Meteorologists employ data through ports that are commonly used by the aviation industry, such as NWS data, NOAAPort, outputs from NOAA's ASOS, and TAFs that are provided by NOAA in coordination with the FAA. They often use third-party vendors that create high-resolution, gridded data products, which are routed to the appropriate command center decision-maker. Often, the meteorologist uses script-based systems, such as MeteoStar's Leading Environmental Analysis and Display System (LEADS), to create customized and easy-to-read data sets for their customers. For air-based logistics, some users managing weather operations are highly trained or technically literate in meteorology and can use data that are at a lower level (levels 2 and 3 data). Ground transportation users often rely on freely available, simple, highly processed tools, such as everyday radar weather applications and highway updates. Updates from satellite data providers like NOAA are used by dispatchers and drivers alike. Ground-based transportation carriers are less likely to employ advanced satellite data products than air-based carriers.

These users note that small satellites using radio occultation for atmospheric sounding may enable global coverage of weather with high resolution and improvement of weather models. This technology may compete with large satellites.

Because of the quickly changing nature of weather, the user community generally needs high-resolution, low-latency data that have excellent coverage within the areas they ship to: roughly 500 m to 1 km is helpful outside of urban areas and down to 100s to 10s of meters in urban areas to better understand wind dynamics. Although observed weather data—including precipitation, clouds and fog, and wind—play a key role in weather models, data end users need forecast models that give them roughly 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. Both air- and ground-based users noted instances where radar or meteorological aerodrome (METAR) reports had not indicated freezing rain or freezing drizzle, which led to slippery or icing conditions. Improved models to detect and accurately forecast this type of precipitation would improve safety conditions for these carriers. Examples of needs are summarized further in the following use cases:

Forecasting Fog: Understanding fog and low clouds at a number of altitudes can help meteorologists better predict burn-off times and reduce delays and overtime costs. Improved understanding of fog conditions can also help drivers in freight-based logistics understand the best times and routes to avoid problem areas.

Determining Safe Flying Conditions for UAVs: UAVs are lighter aircraft that are strongly affected by wind, precipitation, and convective activity (such as wake turbulence off of a building). UAV operators need accurate, vertically and horizontally resolved data to prevent losing control of the craft or losing parcels.

Major Logistics Carriers

Use Cases

Within this community, users may leverage EO data in a range of use cases to enhance current and future decision-making capabilities. Examples of use cases within this community are as follows:

- Fog forecasting
- Determining safe flying conditions for UAVs
- International flight planning (covered in Commercial Aviation section)
- Convection and turbulence prediction modeling (covered in Commercial Aviation section)
- Volcanic ash modeling (covered in Commercial Aviation section)

Improved understanding of fog at different altitudes can help predict burn-off times more accurately, lessening delay times.

For users within the logistics community, fog affects visibility, which limits the ability to operate. In air-based firms, fog may prevent the pilot from being able to take off and land safely, and fog may delay or reroute ground-based transportation. Fog is difficult to forecast and may significantly affect operations, depending on the station; mountainous or coastal terrain may be more susceptible to fog.

For air-based logistics, NOAA's ASOS, a key weather resource for pilots, provides a view of fog ceilings at 12,000 feet (i.e., "clear" skies mean clear below 12,000 feet), but users have indicated a need to understand visibility at higher altitudes (namely, 14,000, 16,000, and 22,000 feet). Current measurement methods do not give insights into the vertical height of the fog, which affects predictions on its burn-off times; if fog has not burned off by a certain amount of time before the flight, many airlines delay or cancel the flight. Users need a more accurate three-dimensional view of low clouds and fog (including vertical heights of the fog clouds) and improved forecasting abilities to understand when certain areas are clear or fogged. Improved prediction will provide more certainty and reduce downtime for flights.

Current air regulations require that the pilot be able to see the runway before landing (i.e., "flying by sight"), but some airlines are looking into enhanced vision technology to augment flight management systems. This technology would enable pilots to "see through the clouds" using a camera, even at lower visibilities, and increase capacity to fly on bad-weather days. Development of these value-adding vision tools will need accurate models and observations of the hazards that they help address.

Accurate wind and convective data in the lower atmosphere are critical to the successful implementation of UAV-based parcel carriers.

In the logistics sector, both major carriers and brands are exploring the use of drone-based delivery. For example, UPS has created a subsidiary—UPS Flight Forward [1]—to explore drone-based delivery networks for hospitals, and Walmart is piloting drone delivery services with drone startup Flytrex.[2]

Although drones must abide by FAA regulations, their weather needs are quite different than those of airlines. The ability to forecast and operate around these conditions will be key for eventual implementation of this technology and serve as a key opportunity and challenge for weather-based insights companies. Drones are much lighter than aircraft and fly around 300 to 500 feet off the ground. Wind and precipitation significantly affect a drone's battery life and ability to fly. Because these devices are piloted from the ground, the operator relies on value-added service providers to understand whether the UAV can fly in current and future weather conditions.

These providers described a need for improved precipitation and wind observations in this low altitude (with a vertical resolution of 50-65 feet, or roughly 15 to 20 m) to improve predictive models that help determine safe flying conditions for UAVs.

1. Ward, T. (2020, September 9). Walmart now piloting on-demand drone delivery with Flytrex. https://corporate.walmart.com/newsroom/2020/09/09/walmart-now-piloting-on-demand-drone-delivery-with-flytrex
2. UPS. (n.d.). UPS Flight Forward™ drone delivery. https://www.ups.com/us/en/services/shipping-services/flight-forward-drones.page

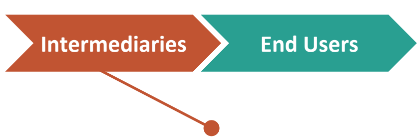
Meteorologist in Air-Based Logistics Firm

User Community:

Major Logistics Carriers

Who are they?

In a logistics firm relying on air travel, the meteorologist oversees the development and communication of timely and accurate forecasts to flight dispatchers, operations coordinators, and pilots. Meteorologists may also consider turbulence effects when the firm is carrying fragile cargo.



Meteorologist in Air-Based Logistics Firm

Who do they work for?

Often based in the firm's network operations command center, meteorologists are primarily interested in weather conditions that affect the flight route—such as precipitation, thunderstorms, and other convective events—as well as phenomena around the hubs that affect the plane's ability to take off and land, such as icy conditions and fog.

Meteorologists in air-based logistics companies are looking for improvements for fog and AQ conditions, which often threaten on-time parcel delivery.

What decisions are they making (and how) today?

Meteorologists relay weather information that can lead to flight delay, rerouting, or cancellation. For these organizations, time is money. Decision-makers must balance the safety of their crews while ensuring that parcels arrive at the right destinations on time. Meteorologists communicate with decision-makers, who use these data to understand where to route resources for deicing planes; where to route planes to avoid freezing over; what may be the quickest method to get cargo to a distribution center, which may include diversion and use of ground methods to reach the destination; how much fuel should be used to ensure planes get to their destination despite possible flight-path changes; possible impacts on ground operations, such as high winds preventing unloading of lightweight or empty carriers; how to time flights to prevent crews from timing out; and when fog will burn off, making it safe to land and take off. Often, meteorologists use script-based systems, such as MeteoStar's LEADS system, to create customized and easy-to-read data sets for their customers. These stakeholders rely on data products, such as NOAAPort, and often use satellite feeds, such as data from GOES-16 and JAXA's Himawari satellite, but they may use third-party vendors to help them write scripts for gridded, easily interpretable products to communicate with less-technical data users, such as pilots or ground staff.

Do they have experience with EO data?

Meteorologists managing weather operations are often sophisticated users of EO data. They are able to interpret data products at a lower level (levels 2 and 3) or leverage these data to develop their own in-house weather forecast models, such as thunderstorm or wind models.

What do they care about?

Meteorologists care about accurately understanding risks across their network of hubs. Because these carriers often fly in the Pacific Northwest and to higher latitude hubs, such as Anchorage, they must avoid safety threats such as volcanic ash and wildfires. Current modeling and data products for improved fog and volcanic ash modeling do not tend to accurately reflect when these elements dissipate, so meteorologists must take a conservative approach. For example, meteorologists may recommend delaying or canceling a flight if fog does not dissipate by 1 am the morning of the flight. Because of the quickly changing nature of weather, the user community generally needs high-resolution, low-latency data that have excellent coverage.

Meteorologist in Air-Based Logistics Firm

"Weather helps pinpoint the risks, the time frame of the risk, and the impact to operations, especially around our hub airports."

—Senior Meteorologist, Major Carrier

What are their technical needs?

Users need a more accurate three-dimensional view of low clouds and fog (including depth of the fog clouds) and improved forecasting abilities to understand when certain areas are clear and fogged. Improved prediction will provide more certainty and reduce downtime for flights. Current measurement methods do not give insights into fog depth, which affects predictions on its burn-off times. Users need improved volcanic ash data that accurately model the size and shape of the plume and where it may be heading, given weather predictions. These users have similar technical needs for the aviation community—comparable needs for resolution, lead time for data, and improved ability to understand convective activities of weather phenomena. Users need a means to detect freezing drizzle, ice pellets, and hail, which the ASOS often does not pick up.

What would motivate them to use NASA EO data?

Meteorologists are motivated by data that could easily fit into TAFs or be incorporated into the script-based systems that they use to disseminate information to relevant stakeholders. Despite the regulation and safety needs for air-based transport, these users seemed eager to try new data products.

What are their adoption barriers for using NASA EO data?

The time for understanding, evaluating, and incorporating these data in the current workflows could be an adoption barrier.

What are they afraid of?

Flight-based operations are a risk-averse industry; meteorologists must know that the data sources they are using are accurate and reliable enough to ensure crew safety.

What do they NOT care about?

These users share many needs with meteorologists based in the aviation community. One point of differentiation is mitigating turbulence—turbulence is often mitigated for passenger comfort in commercial aviation, but most logistics carriers do not focus on turbulence (unless it is present in intense storms) because it is not often a safety threat.

What are some key use cases?

- International flights over oceans
- Volcanic ash
- Urban air mobility models
- Forecasting fog

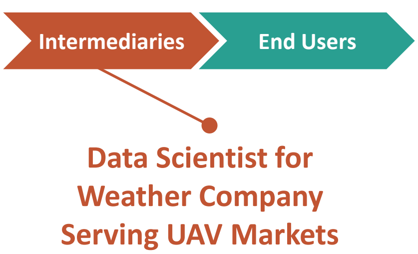
Data Scientist for Weather Company Serving UAV Markets

User Community:

Major Logistics Firms

Who are they?

These users aggregate and incorporate weather data into actionable insights that recreational and commercial drone pilots can use.



Who do they work for?

These individuals work for weather services companies: large enterprises serving multiple markets or small companies with data products tailored to UAVs. Ultimately, they could be part of drone companies in the future, should these entities decide to offer or acquire weather service providers.

Data scientists serving UAV operators emphasized a need for improved convective and precipitation data in the lower atmosphere.

What decisions are they making (and how) today?

Weather phenomena can significantly affect operations of UAVs. Because they are operating small craft, operators must be wary of updrafts, high winds, and precipitation that can cause friction and drag on a battery. Turbulence caused by convective activity, or even wake turbulence off of a building, can affect a UAV. Weather, such as rain or hail, can damage the drone or necessitate flying in higher or lower areas. UAVs should not be within 500 feet of a cloud ceiling, which may cause visibility issues and difficulty in operating. These users create weather products that can help operators make the following decisions:

- At what altitude can I miss clouds and fog that affect my visibility?
- Which route can help me save battery?
- Can I fly my UAV safely today?
- Is my craft at least 500 feet away from a cloud ceiling?

These users consider data that are pertinent to the lower atmosphere (<1,000 feet), where drones fly. They often incorporate satellite-based weather data sources from public sources such as NASA and NOAA (although they would not divulge which sources) and commercial satellite-based data from Spire and other providers that have lower-orbiting craft with higher resolution.

Do they have experience with EO data?

Data scientists in these companies have a sophisticated level of expertise in EO data that enables them to aggregate multiple types of satellite and nonsatellite data products and develop predictive weather models.

What do they care about?

They care about weather data in the lower atmosphere that may cause damage or failure to a UAV. Improved predictability for wind, moisture (which can help them understand visibility), and convective events (like microbursts) can help an operator avoid areas that could lead to parcel loss or damage.

Data Scientist for Weather Company Serving UAV Markets

"Drone pilots are not like airline pilots—they can't exactly see the weather that is happening, and it is hard to recover from issues when you don't know with accuracy what is going on."

—CEO, Drone-Based Weather Company

"The next big thing is UAVs—all of the logistics companies are in the business now and working on FAA approvals. Therefore there's demand for weather data in the lower atmosphere that will influence drone operations."

—Meteorologist, Major Air-Based Logistics Firm

What are their technical needs?

These users need better measurements 300 to 500 feet off the ground for wind and improved moisture profiles to understand clouds and visibility. They require an improved understanding of dynamic convective changes that could affect a UAV, such as being able to predict weather and microbursts, and an improved ability to forecast icing in clouds, which affects a drone's ability to fly. They would prefer to have the data around 0 to 6 hours ahead of time, 500 m spatial resolution, and 15-m or 20-m vertical resolution.

What would motivate them to use NASA EO data?

Data that are easily discoverable with the vertical resolution that the industry needs would motivate them to adopt EO data.

What are their adoption barriers for using NASA EO data?

Although there is a large amount of commercially available weather data, few users are aware of NASA's weather data products, what might set them apart, and how these can benefit them.

What are they afraid of?

Eventual adoption of UAVs in logistics and other applications hinges on their ability to fly safely and reliably. Accurate and comprehensive weather data in the lower atmosphere are key to establishing this.

What do they NOT care about?

They do not care about weather data that are too high in terms of altitude: wind conditions over 1,000 feet are not useful to them. Currently, AQ is not a known issue for UAV engine mechanisms. Thunderstorms are often not concerning for users either, because UAVs often do not operate long enough to run into unexpected thunderstorms and will plan around them.

What are some key use cases?

- Determining safe flying conditions for UAVs: This information can be useful not only to UAVs but also in future VTOL aircraft that may operate in the lower atmosphere.

RTI Innovation Advisors

ACCP User Community Profiles

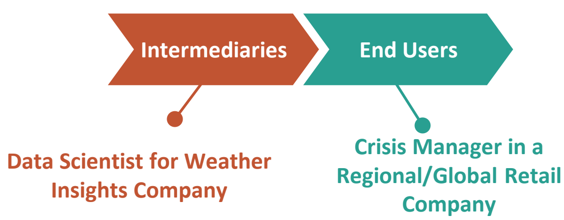
	Commercial Aviation
	Major Logistics Carriers
	Logistics Arms of Major Retail Brands
	Data-Driven Agriculture
	Food Companies Operating in Tropical Areas
	Health and Short-Term Air Quality Monitoring
	Solar Energy

Logistics Arms of Major Retail Brands

Community Overview

Major retail brands—whether they sell grocery items, hardware supplies, housewares, or other products—work to consistently bring high-quality products to their consumers all over the world. These companies, which operate regionally or globally, source goods from a variety of locations, and weather can affect many points of their supply chain. Grocery stores, which generated $634 billion in sales in 2018 in the United States alone, are especially vulnerable to global and local weather effects when delivery and quality of perishable goods are affected.[1] Customers appreciate the ability of these retail brands to serve as a "go-to" store when they need items and their consistency of goods between stores. As such, these retailers rely on their logistics arms to ensure business continuity across all stores. Although their direct use of satellite-based weather data products is low, this user community depends on value-added service providers that integrate these data.

Selected User Profiles for ACCP



Potential Use Cases for ACCP Data Products

- Identifying disruptions in the supply chain
- Allocating resources to maintain business continuity

Moving Forward with ACCP

Continued incorporation of EO data will be an opportunity for logistics companies to monitor and anticipate impacts to their facilities and supply chain partners. ACCP data, through value-added service providers, may ultimately improve accurate predictions of precipitation and AQ that may affect supplier and customer access, disruptive AQ events, and seasonal weather that could affect supplier availability and pricing. ACCP could engage this community through targeted training events to help crisis managers understand the value of these data products, but adoption will happen through service providers.

1. U.S. Department of Agriculture, Economic Research Service. (2021, May 25). Retail trends. https://www.ers.usda.gov/topics/food-markets-prices/retailing-wholesaling/retail-trends.aspx

Logistics Arms of Major Retail Brands

Organizational Assessment

Even during extreme weather events, retailers such as grocery stores and hardware stores must meet the needs of their consumers before the event and be operational as soon as possible. This user community values weather and AQ information that can help them identify and address potential affects on store operations and distribution of vital inventory, while maintaining staff and property safety. These data are used to make decisions that optimize trucking routes; identify stores that need protection measures, such as sandbags and boards; and allocate proper resources to affected areas. This information can help decision-makers allocate commodities to surrounding stores when one store may be inaccessible and to staff when appropriate. Ensuring continuity of service also requires close monitoring of suppliers that ship in commodities from all over the globe. Weather may affect price or availability of a commodity at its source, and weather events en route may delay or spoil the commodity if it is perishable.

Users within this community represent **crisis managers** from brands that sell goods directly to the consumer, as well as companies that directly supply their stores. Although smaller retail brands may rely solely on free sites, such as Weather Channel phone applications, larger companies may use dashboard-based platforms, such as StormGeo, which create personalized and actionable insights for users, with access to meteorologists for decision-making needs and capabilities to communicate key information to relevant staff across the nation or world. **Data scientists for these weather insights companies** integrate satellite- and ground-based data sources into platforms that enable supply chain managers, crisis managers, and pricing specialists to understand potential business disruptions.

Data	Intermediaries	End Users
Data are collected from ground-based radar sources and from a variety of satellite providers, including NASA, NOAA, and the European Space Agency.	Data may be aggregated into platform companies that provide gridded weather and AQ insights. These value-added service providers may create their own atmospheric models or rely on intermediaries that create global numerical weather prediction models.	Crisis managers use data products and disseminate information across the company, communicating risks to store managers, distribution leads, and drivers. These data help facilities make decisions on allocating manpower and commodities and reacting to possible supply chain disruptions from weather.

Logistics Arms of Major Retail Brands

Technical Assessment

Users within this community often do not have experience with satellite data outside of third-party data sources. Although smaller companies may rely solely on free sites, such as Weather Channel phone applications, larger companies use dashboard-based platforms, such as StormGeo, which provide access to meteorologists for decision-making needs and help communicate key information to relevant staff across the nation or world. Gridded and highly visual data products help communicate crisis needs to store managers, distribution leads, and drivers. Probabilistic, rather than deterministic, forecasts can provide more information to help these users effectively balance business risks.

These users are interested in events that may affect the ability of staff and customers to access the store, such as snow and storms with power outages and damaging winds. They need an accurate precipitation forecast and must understand what routes and areas have been flooded or are prone to flooding. Most major brands have multistate or nationwide coverage and may source commodities such as produce from tropical and coastal areas.

For end users of data, forecast models are much more relevant to their decision-making than observed data. Users need at least 24 to 48 hours' notice to react to potentially adverse day-to-day weather events, while larger events, such as hurricanes and large snowstorms, need about 3 to 7 days' notice. Data analysts in weather insights companies are looking for accurate observations of weather data, such as precipitation, temperature, and wind, over global coverage to incorporate into their decision-making platforms. These users also expressed needs for global measurements of surface-based particulate matter and a better understanding of weather and aerosol interactions, which may enable improved forecasts in response to AQ events, such as wildfires.

Although high-resolution (less than 1 km) data help provide a clear picture of how an individual store may react in terms of flooding, region-level data can provide users a more holistic, time-saving, and easy-to-interpret picture of possible problem areas. Hourly data capture would be ideal for data analysts. Examples of needs are summarized further in the following use cases:

Identifying disruptions in supply chain—Many retail brands and their downstream supply chain rely on goods shipped from all over the world, including those that may be perishable. Long- and short-term weather events, such as droughts and typhoons, may affect the availability or price of goods. Crisis managers must rely on accurate global gridded data to help identify and react to potential impacts to the supply chain.

Allocating resources to maintain business continuity—During inclement weather, such as a hurricane, store and facility operations and access may be limited. Weather may also affect specific needs of customers, such as nonperishable goods, in response to events that may lead to power outages. Accurate weather and AQ forecasts help crisis managers make decisions on how to allocate their resources and best serve their customers and employees safely.

Logistics Arms of Major Retail Brands

Use Cases

Within this community, users may leverage EO data in a range of use cases to enhance current and future decision-making capabilities. Two examples of use cases within this community are as follows:

- Allocating resources to maintain business continuity
- Identifying disruptions in the supply chain

Accurate observations and forecasts of storms and AQ events can help ensure the right facilities are prepared for weather events.

Weather not only has a profound effect on business operations for a major brand, but it also affects how customers shop. Threats of severe storms, winter weather, or wildfires require crisis managers to allocate resources to best address needs. Crisis managers of major brands work closely with their marketing department to configure a store setup to highlight useful products—essentials like batteries, nonperishables, and generators—and with their supply chain to ensure that enough supplies are allocated to the right stores. Managers may also direct supplies from one store to another, knowing that an area is historically prone to flooding or other adverse weather phenomena, and they may use historical data to understand appropriate staffing for stores and distribution centers. Crisis managers run into challenges when forecasts are inaccurate. This may lead to overstocking one store while leaving other stores out of critical items or leaving stores prone to weather damage. Users hope to have accurate data products predictable as far out as possible—ideally, 24 to 48 hours or more, with 3 to 7 days for severe events such as hurricanes. End users also hope to have data products that provide insights for large regional areas—in addition to high-resolution data—so they can easily ingest high-level data before diving into potential problem areas.

Global forecasts help crisis managers make informed purchasing decisions and identify potential supply chain threats.

Weather affects the locations of a major retailer's stores, customers, and sourcing partners. Major brands (including distribution companies such as grocery suppliers) often source commodities from different parts of the globe. For example, grocery stores may rely on suppliers in tropical and coastal areas for fruit, especially during winter months. Many of these areas are subject to hurricanes and severe weather events. Crisis managers and logistics leads monitor weather to identify which suppliers may be affected and seek out alternative sources to prevent store shortages. Long-term weather data (closer to 3 months out) with global coverage can also indicate locations with commodity shortages and pricing changes due to drought or destructive precipitation.

1. Ward, T. (2020, September 9). Walmart now piloting on-demand drone delivery with Flytrex. https://corporate.walmart.com/newsroom/2020/09/09/walmart-now-piloting-on-demand-drone-delivery-with-flytrex
2. UPS. (n.d.). UPS Flight Forward™ drone delivery. https://www.ups.com/us/en/services/shipping-services/flight-forward-drones.page

Crisis Manager in a Regional/Global Retail Company

User Community:

Logistics Arms of Major Retail Brands

Who are they?

Crisis managers for large retailers, such as grocery, home improvement, and housewares stores, monitor threats to operations of their stores, distribution centers, and transportation fleets.

Who do they work for?

In larger multinational companies, the manager may sit within a corporate communications center or manage a small team divided by region.

Retail crisis managers rely on accurate global weather data to anticipate and mitigate impacts to business operations.

What decisions are they making (and how) today?

Crisis managers route weather and AQ information to the right decision-makers and advise how to direct supplies, staff, and other resources necessary to maintain business operations. These managers must balance continuity of their services with the safety of their customers, staff in stores and distribution centers, and partner sites. Weather data help them assess potential weather threats and make informed and risk-mitigating decisions. AQ is increasingly a safety concern in areas with frequent wildfires.

These data help crisis managers make the following decisions: What commodities do our customers need to deal with the incoming weather? Where should we strategically distribute our limited supply of commodities, such as dry goods, batteries, and generators? Which stores and distribution facilities may have access challenges because of inclement weather? Which facilities may need materials for storm preparations? When are wind speeds or AQ readings too dangerous for distribution center staff to load and unload or for transportation fleets to operate? How might a weather event affect supply chains for the products we sell? What alternative routes should we take to source a commodity?

Typically, these users rely on third-party data sources that are highly visual, offer built-in insights, and are easily shared via mobile device or email. Most of these are disparate data sources that are free, such as Weather Channel graphics and NOAA's National Hurricane Center, but some invest in subscriptions, such as StormGeo and Climacell, that have meteorologists on staff to advise the managers. Users often monitor AQ using AirNow.gov. Weather affects different parts of the country in different ways, so the company may rely on thresholds to understand when weather conditions may be dangerous. For example, a few inches of snow in mountainous, remote areas may not cause disruptions, but on the East Coast and for the South, it may spell shutdowns and rushes on supplies.

Do they have experience with EO data?

The crisis manager relies heavily on gridded and highly visual data and is often unable to process or interpret lower-level data.

Crisis Manager in a Regional/Global Retail Company

"Weather data help us understand where snow, rain, wind, and heat may affect our buildings. It provides us the visibility to effectively deal with severe events before they come and surprise us."

—Global Crisis Manager, Major Retail Brand

What do they want or care about?

Crisis managers strive to find the most accurate forecast that gives them the most amount of time to prepare. Users need a better tool to understand and prepare for the effects of high winds so they can reduce downtime in distribution centers. They also need a more accurate and easy-to-use tool to understand which areas may be more prone to flooding or are currently inaccessible due to flooding or water on the road (which may cause safety issues for ground transportation). Users also noted lack of predictability for changes/improvements in AQ; adding predictive qualities can help crisis managers understand when employees can safely load and unload in distribution centers.

What are their technical needs?

The users prefer having information 24 to 48 hours before the weather event and around 3 to 7 days for large events like hurricanes so that they are able to enact proper safety procedures. They need high-resolution data—to the city block—so they can understand the impacts of weather on the surrounding facilities and roads.

What would motivate them to use NASA EO data?

Global data that are gridded and easy to interpret would be beneficial. Our interviewees were interested in being part of this conversation to understand current capabilities, limitations, and opportunities for use of NASA data.

What are their adoption barriers for using NASA EO data?

Because of their lack of technical maturity, these users rely on third-party data sources, often management products that enable them to quickly identify risks and disseminate information to their local and global partners. They need data that are gridded and easy to interpret.

What are they afraid of?

Inaccurate weather predictions can cause companies to lose money sending supplies to the wrong store, leading to shortages in other areas and, ultimately, decreasing customer trust in product availability.

What do they NOT care about?

Crisis managers do not really care how their weather service providers incorporate data.

What are some key use cases?

- Allocating resources to maintain business continuity
- Identifying disruptions in supply chain

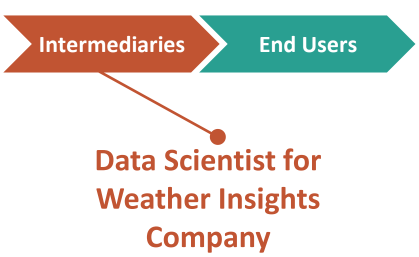
Data Scientist for Weather Insights Company

User Community:

Logistics Arms of Major Retail Brands

Who are they?

This user works at a weather insights company that supports a number of industries, including logistics. These analysts often have a geographic information system (GIS) or meteorological background and work to integrate large amounts of data into their modules. Some of these companies, such as StormGeo, serve as large platforms that not only deliver weather data to end users but also serve as management platforms, enabling companies to monitor and disseminate information across multiple locations.



Who do they work for?

These users work in companies serving as data integrators or value-added service providers to customers such as retail brands.

Data analysts in weather service companies seek out value-adding data sources to help companies anticipate effects of weather on supply chain and store operations.

What decisions are they making (and how) today?

These users are collecting a variety of weather data to incorporate into their models. These companies create products that are meant to help end users across a wide variety of industries make informed decisions, especially related to weather extremes that could affect supply chains, operations, and safe travel. When considering which types of weather data to use, these users consider questions such as these: Which EO data are reliable and accurate? Where do I get the most “bang for my buck” with the sources I choose? What types of data are the easiest to incorporate into my existing models?

Specifically, these users can create products that help end users within retail supply chains make informed decisions about questions such as these: Will droughts in a specific tropical area affect the pricing or availability of a certain good that I stock in my stores? How might Wednesday’s upcoming hurricane affect our weekly fruit shipments? When might we expect effects from a wildfire on the West Coast and have to shut down our loading docks because of poor AQ?

These providers incorporate a large number of weather data sources, from ground-based networks to publicly available and privatized satellite-based data (although interviewees declined to specify which sources).

Do they have experience with EO data?

Users are sophisticated data users: they are able to incorporate multiple types of data sources at different levels into their platforms and models.

What do they care about?

Improved observations of precipitation, wind, temperature, and surface-based $PM_{2.5}$. They care about “discoverability” of data: these sources are often hard to find unless one is looking for them specifically. These users need a means to easily find satellite-based weather data and understand its value compared with traditional sources. These users care about flexibility within their data sources: they would appreciate having a mechanism to request data products that focus on specific locations and for different timescales (e.g., Northeast U.S. region with daily, weekly, and monthly weather data). These value-added service providers keep on top of end users’ needs across multiple sectors and are a great “barometer” for understanding who may be the “community of potential” in additional sectors.

RTI Innovation Advisors

Data Scientist for Weather Insights Company

"Right now, access to data for us is not an issue. It's how we can use and analyze the data."

—Lead Data Scientist, Weather Insights Company

What are their technical needs?

They need less than 1-km resolution, hourly capture. They want interoperability between NASA and other data sources, for example, having the European Space Agency and NASA create data products in similar formats. They need more sources that have global coverage, because many areas where logistics firms source goods are in tropical areas or more remote areas with limited ground-based data.

What would motivate them to use NASA EO data?

Data that have global reach and are easy to incorporate into their library of aggregated weather data products would motivate their adoption of NASA EO data.

What are their adoption barriers for using NASA EO data?

Data sources are plenty (and affordable) for many of these companies. Finding and sifting through data sources can take a significant amount of resources. These companies must consider whether incorporation of additional data sets can offer true value compared with their existing data library.

What are they afraid of?

The weather prediction community is expansive and competitive; interviewees were hesitant to identify limitations of their current data sources.

What do they NOT care about?

Private satellite data are getting less expensive to purchase, so larger providers may not see the benefits in "free" data over data that could be tailored to their needs.

What are some key use cases?

- Allocating resources to maintain business continuity
- Identifying disruptions in supply chains

RTI Innovation Advisors

ACCP User Community Profiles

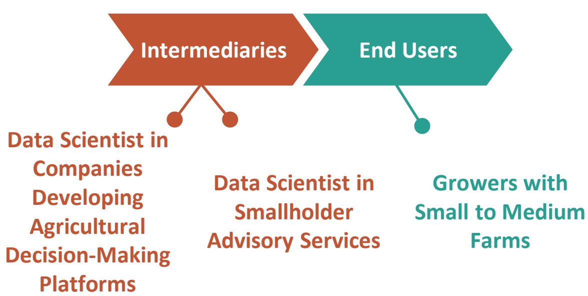
	Commercial Aviation
	Major Logistics Carriers
	Logistics Arms of Major Retail Brands
	Data-Driven Agriculture
	Food Companies Operating in Tropical Areas
	Health and Short-Term Air Quality Monitoring
	Solar Energy

Data-Driven Agriculture

Community Overview

The agriculture community has relied on weather since its inception. Agricultural yield is a critical performance metric that has significant downstream effects on availability and pricing of food and beverage commodities, consumer goods, and more. Agricultural experts point to three factors that drive yield: genetics, management practices, and the environment. Stakeholders across the value chain have sought to better understand weather effects and help growers make decisions based on observations and forecasts on a variety of temporal scales—from daily weather to subseasonal (1 to 2 weeks) to seasonal (3-month) outlooks. The breadth of this community can span ingredients manufacturers, food and beverage companies, and logistics firms (covered in other sections). Access to accurate, timely weather data is especially important when anticipating challenges related to climate change, which affects growing conditions and may influence certain crop yields.

Selected User Profiles for ACCP



Potential Use Cases for ACCP Data Products

- Effective application of farm inputs
- Mitigation of plant pests and disease
- Site similarity analysis for crops
- Crop and AQ monitoring

Moving Forward for ACCP

The agricultural sector has been a strong adopter of EO data to monitor fields and growing areas. ACCP weather data products can offer the agricultural community an improved understanding of the microphysical properties of precipitation and clouds, enabling more accurate and comprehensive predictions of seasonal weather and climate modeling.

Agritech is an area rich in development, especially in developing economies. Large agribusiness firms are sponsoring hackathons and other opportunities where students, innovators, and entrepreneurs leverage EO data to develop digital and mobile products that create agricultural insights. Focus group attendees noted a lack of awareness of NASA data products that have direct ties to agriculture and the value they can bring to the already crowded world of weather data products. Attendees emphasized needs for data observations across instruments for certain geographic locations over periods of time, flexibility to pull the data they need (leaving unnecessary data behind), and the ability to quickly extract and visualize information. NASA should engage not only the large agribusiness firms with in-house platform development capabilities, but also the entrepreneurial community this industry relies on. Focus group participants would like to collaborate with NASA through evaluating the value of ACCP data sets, making data delivery more accessible through the cloud and other dissemination avenues, and engaging with the greater agritech community of practice.

Data-Driven Agriculture

Organizational Assessment

The agriculture community has been consistently incorporating new technologies into its day-to-day practices, shifting the practice from an art to a science. Weather knowledge positively affects stakeholders across the value chain, from the farmers growing crops to the input companies developing seeds, fertilizers, pesticides, and herbicides to the food and beverage companies that source ingredients. The agricultural community makes decisions using daily weather data, and it needs accurate forecasts across three types of timescales.

Short term (1 to 2 days)—Next-day information can help the agriculture community understand whether it may be prudent to apply input such as fertilizer or herbicides. Precipitation can wash away the inputs, or high pressure or windy systems may lead to temperature inversions, where sprayed chemicals can drift to different locations. A 2-day outlook can also help decision-makers seek labor on good-weather days.

Medium term (7 to 14 days)—A slightly longer time window can help the agricultural community understand when moisture conditions may be the best within a certain planting window and when is the right time to harvest. For example, knowledge of likely hailstorms during the harvesting window may prompt growers to harvest early, balancing potential damages over lower yields or shorter drying times. Strategically timed harvest periods can also enable farmers to pull up the crop without significant physical labor or tools, maintaining the quality of the crop.

Long term (seasonal outlook, 3 months)—Understanding the likelihood of potential rainy periods, freezes, droughts, or natural disasters can help agricultural decision-makers understand what types or varieties of crops to plant. For example, growers may consider choosing a rice variety that can survive in flood conditions, or they may consider planting more acres of corn to offset lower yields due to weather. In areas where freezing may occur near harvest time, a grower may invest in a seed that matures 10 days longer than normal to avoid potential damage. These seasonal conditions may play into commodities pricing and help growers understand what kind of crop to invest in and when to sell.

The agriculture sector spans a number of stakeholders across the value chain, and the industry regularly incorporates a variety of satellite- and ground-based data products that can help gather insights about field and crop conditions. Although precipitation is a key data point, users are also concerned with soil moisture; normalized difference vegetation index (NDVI); and weather conditions such as wind, temperature, and humidity.

Within the value chain, mature data users may incorporate low-level satellite data into data products that help reveal trends and insights. These may be developers of agricultural platforms or input companies helping growers make decisions on agricultural practices, sourcing, and purchasing. Users also include data scientists in smallholder advisory services, who leverage these data to help smallholder growers in developing economies make informed decisions (through financial products and short messaging service [SMS]-based data delivery). Some data aggregators may create data products that could be incorporated into other platforms. Users of these data include growers but may also include ingredients manufacturers, commodity traders, and those up the value chain (many of these are covered in the "Food Companies Operating in Tropical Areas" section).

Data-Driven Agriculture

Organizational Assessment (continued)

Typically, users developing farm management tools, decision tools, and advisory services incorporate a variety of EO data products into their platforms, including data from the Tropical Rainfall Measuring Mission (TRMM), Integrated Multi-satellite Retrievals for GPM (IMERG) products, and Metop data products. They may also use other EO products, such as satellite imagery from Sentinel, Landsat, and MODIS. In addition, on-ground sensors and weather stations offer important insights on a field. Although large agricultural input companies have the resources to purchase or process many data products, organizations serving developing economies focus primarily on publicly available data sets, which offer free global coverage that many private data sources lack. These users can integrate data at different levels, depending on the use case: advisory services communicating insights to growers via SMS may want some level of preprocessing or gridded data to easily interpret, while developers of management platforms and insurance products may want low-level data to incorporate into their models. Growers monitor weather stations, their on-ground sensors, and third-party apps such as farm management tools and AccuWeather.

Data	Intermediaries	End Users
Data are collected from ground-based radar sources, in-field sensors, weather stations, rain gauges, and satellite data products such as TRMM, GPM/IMERG, and Metop data products. They may also use other EO products, such as satellite imagery from Sentinel, Landsat, and MODIS.	Value-added service providers, such as farm management or agricultural input platform companies, incorporate multiple satellite- and ground-based data sources to develop actionable insights for growers. Smallholder advisory services may incorporate satellite data products into financial products such as insurance platforms and farm management insights delivered via SMS.	Growers, whether managing small to medium farms or small areas of land as smallholders, leverage these aggregated and processed data sources to inform their seed selection, planting, harvesting, and spraying decisions.

Data-Driven Agriculture

Technical Assessment

The data-driven agriculture community emphasized needs for both observation of weather phenomena and weather forecasting.

Weather observation needs:

Users need accurate observations of total precipitation: what type has fallen, how much has fallen, and at what intensity. Intensity of precipitation can help users understand immediate irrigation needs and where crops might be damaged because of hail. Accurate real-time weather observations can help understand the risk of temperature inversion, which ultimately leads to drift of products applied to a field. For a 24-hour set of weather data, subhourly temporal resolution would be ideal (or less than a half hour, because storms can pass quickly through fields). Data latency after this 24-hour set should be available at least 2 to 3 hours after capture, although less than a half hour is ideal.

Weather forecasting needs:

Users need to know whether in the next 7 to 14 days they will encounter potential disease conditions; therefore, data on humidity, temperature, and leaf wetness are important in a mid-term forecast.

For a seasonal forecast, users need a more accurate outlook of the next 3 months with more information, for example, approximations of the first frost and distribution of rainfall across the season.

Improved spatial resolution enables users to break down needs across the field; 1-km resolution would be ideal. Value-adding data products cover as much geographic area as possible, especially in tropical regions in developing economies where few on-ground data inputs exist. In addition to precipitation, the agriculture community is interested in wind, temperature, humidity, NDVI, and soil moisture to better understand crop health.

The data-driven agriculture community incorporates a large amount of on-ground and satellite-based data sources, which can be quite resource intensive. Some major input companies dedicate resources solely to identifying and cleaning data sources into a usable format. Users expressed preferences for current data formats, such as Zarr, that are “ready for analysis” and data structures on cloud-based infrastructure. Many NASA data products (beyond precipitation) regularly provide value to the community. Data scientists would like to see EO data sets with multiple variables (e.g., temperature, humidity, precipitation, wind, and AQ) that are aligned temporally and spatially. For example, users would like to be able to choose a data set over a certain time and geographic area that contains IMERG and MODIS data products. The fusion of these data products may also make cross-sensor calibration and atmospheric correction easier.

Many interviewees indicated a desire for improved soil moisture data sets—preferably at different depths than 5 cm—and improved methods of understanding biomass and evapotranspiration. Although ACCP data products are not geared toward these applications, NASA’s Surface Deformation and Change and Surface Biology and Geology DO teams are looking into these use cases. However, for weather applications, most users were willing to work with NASA to identify these gaps.

Data-Driven Agriculture

Technical Assessment (continued)

Incorporating data from multiple sources can be time consuming. Users mentioned a need for improved consistency and communication of data format. Interviewees indicated that companies must dedicate substantial 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 type of change can lead to inaccurate data labels.

Data users also emphasized the importance of “flexible” data sets that consider end users’ needs. For example, enabling the user to pull a time series of data over a certain period (e.g., 60 days) without requiring them to manually pull 60 days’ worth of data into their systems.

Specific technical needs for satellite-based weather data were discussed over four use cases, summarized here and expanded on later:

Effective application of crop inputs: Growers, who often operate on slim margins, must optimize their use of fertilizer, pesticides and herbicides, equipment, and seed varieties. Accurate knowledge of weather conditions over a variety of time frames (from the next day to a seasonal outlook) can help growers make effective use of these limited inputs and ultimately save money.

Mitigation of plant pests and disease: Pests and diseases are significant risks that have an effect on the grower’s yields, crop quality, and bottom line. Comprehensive data on observed and forecasted weather can help identify patterns when crops may be at risk for pests or disease, enabling the grower to proactively spray and limit crop damage.

Site similarity analysis for crops: Changing temperatures and weather patterns are modifying the most appropriate growing locations for crops. Access to accurate global observed weather data such as precipitation, temperature, and humidity can help growers understand the highest quality/yield crops for their specific area over time or help ingredient suppliers and large agricultural firms identify where they may be able to grow or source the highest quality or yield variety of a certain crop.

Crop and AQ monitoring: As the research community better understands the correlation between AQ and crop health, data scientists are looking to incorporate global measurement of aerosols, greenhouse gases, and other AQ indicators in their platforms.

Data-Driven Agriculture

Use Cases

Within this community, users may leverage EO data in a range of use cases to enhance current and future decision-making capabilities. Four examples of use cases within this community are as follows:

- Effective application of farm inputs
- Mitigation of plant pests and disease
- Site similarity analysis of crops
- Crop and AQ monitoring

CCP data can inform growers of the right conditions for effective fertilizer, pesticide, and herbicide application.

Managing a farm includes effectively making use of the limited resources growers have; inputs such as fertilizer, pesticides, and herbicides are expensive, and growers may have limited sprayers across miles of fields. Growers must limit overspraying because it wastes money and can be harmful to the environment, and weather conditions such as precipitation and temperature inversions can dilute and disperse the inputs across the field. Improved understanding of current and future weather conditions, including the conditions that cause temperature inversions, can help growers identify when to apply inputs in the most effective way. This use case requires high spatial resolution (less than 1 km) and subhourly temporal resolution.

Spatially resolved observed and forecasted precipitation data patterns can help identify conditions that may lead to crop damage from plant diseases and pests.

Leaf wetness, which may be influenced by weather conditions such as extended precipitation, temperature, fog, and humidity, is a risk factor for foliage fungi and other plant diseases.[1] Extended precipitation could create conditions that put crops at risk for significant damage. Agricultural platform developers can integrate satellite weather data in models that can help identify when crops may be liable to diseases and pests, enabling growers to spray prophylactically and maintain crop yield and quality. Accurate records of observed precipitation, enhanced forecasting models, and improved resolution (less than 1 km) could help create more specific data products that can detect patterns of weather activity that may lead to disease and pest risk. Beyond precipitation, developers creating these data products need weather data such as temperature, wind speed, and humidity.

1. Velásquez, A. C., Castroverde, C. D. M., & He, S. Y. (2018). Plant and pathogen warfare under changing climate conditions. *Current Biology, 28*(10), R619–R634. doi: 10.1016/j.cub.2018.03.054.

Data-Driven Agriculture

Use Cases (continued)

Extensive multiyear weather data records can help identify ideal crop growing conditions and locations as the Earth's climate changes.

Climate change has altered the growing seasons for many locations. As a result, growers may have lower yields for crops that had been grown successfully in years past. Changes in average precipitation, maximum and minimum temperature, and other growing factors can affect growers' livelihoods, and may affect the supply chain of large food and beverage companies. Site similarity analysis can help growers and large agriculture companies understand (1) what crops may be successful in certain regions based on the upcoming season and (2) where the best place is to grow an important crop variety, such as a certain rice or potato product. Companies have developed data products leveraging satellite data that can look for ideal locations or ideal crops for a location within a specific growing time. Although spatiotemporal resolution requirements are lower for this use case than other use cases, this case requires global coverage and long precipitation and temperature records for these areas. Developers of these products value accurate observations of precipitation, maximum and minimum temperature, freeze possibility, and other factors.

Colocated aerosol, convection, and precipitation data may help growers anticipate and react to AQ threats.

Although AQ information is not currently used in decision-making platforms, scientists developing agricultural platforms indicated that AQ information will be considered in the future for quality monitoring purposes. In some developing economies, farms near factories that produce smoke and nitrates may be subject to damaging acid rain, and weather such as convective activity and precipitation may disperse or deposit aerosols on fields. Wet and dry deposition to plants, as well as damage by ozone and other gas pollutants, may affect the growth of the plant. Poor AQ or consistent cloud cover in certain areas may also limit photosynthetic activity.

Although growers may look to AQ data as another means to optimize farm management practices (e.g., closing greenhouses or covering plants to avoid deposition), large food companies or cooperatives could rely on these data in the future to understand when to anticipate and react to effects from wildfire smoke moving across the country. Urban planners may leverage these data to understand the right types of vegetation to plant in cities, where the plants are often in direct contact with pollution.

Similar to precipitation data, high spatiotemporal resolution would be useful for monitoring crop quality. Coverage for ground-based and satellite AQ data is quite low in regions that are growing many key commodities, such as tropical zones in Africa and Latin America. Surface-based measurements would be most helpful for understanding direct pollution effects at ground level, while the aerosol column could help understand the impacts of air pollution on photosynthetic activity. Colocated data can help the community understand the relationship between precipitation, convective activity, and aerosol distribution.

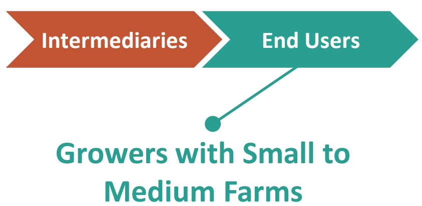
Growers with Small to Medium Farms

User Community:

Data-Driven Agriculture

Who are they?

These individuals grow crops that may be used for food, beverages, or other consumer products. In the United States, small family farms make up about 88% of the farmland and typically span approximately 320 acres; medium to large farm acreage spans an average of 1,420 acres.[1]



Who do they work for?

Growers produce food in partnership with larger conglomerates (as a collective or in contract with a food or beverage company) to sell within their community or to subsist on themselves.

> *"Farmers often only see 45 paychecks in their lifetime. They take weather data seriously and use every tool they can to ensure they are making the right decisions."*
>
> —Geospatial Lead, Agricultural Input Company

Growers need accurate high-resolution data to effectively manage their crops.

What decisions are they making (and how) today?

Farmers with small to mid-size farms oversee a large amount of land, with weather conditions and microclimates that may differ widely across their acreage. Weather plays a key role in how farmers decide to use their limited inputs, labor, and equipment. Weather station data can provide some of the most comprehensive information to farmers, including temperature, humidity, wind speed, visibility, and current weather conditions, at subhourly timescales. Although the data are quite valuable, data points from a few weather stations do not represent accurate and precise coverage of the entire field. Weather stations are extremely expensive to install and maintain (at least $30,000), and microclimates can vary even across one field. Many publicly available weather stations are placed at medium or high elevations, while farms tend to experience different conditions in lowlands. Farmers may also use their own rain gauges, but across farmland there can be a large range of precipitation intensity, even across a large field.

Do they have experience with EO data?

Users typically employ gridded, highly processed data, although some may have a more technical agronomy background with the ability to interpret weather station data inputs. In developed economies, growers rely on third-party applications, such as AccuWeather, for short-term weather forecasts and farm management tools and decision platforms to understand longer weather outlooks, which may rely on satellite- and sensor-based data. Smallholder farmers, who oversee a much smaller amount of land in developing economies, typically rely on SMS-based weather sources to make these decisions. More about their experience can be found in the "Data Scientist for Smallholder Farmer Advisory Services" section.

What do they care about?

The land that these growers oversee can be vast—even on a small farm—and they cannot directly monitor each acre of a field. To understand field conditions, these users need accurate, high-resolution observations of weather that has occurred and high-quality mid-term (7 to 14 days) and seasonal forecasts. These users demand more concrete information for seasonal forecasts beyond "this season will be wetter than last year's." Information on distribution of rains across the next 3 months and estimates on the season's first frost would be quite useful.

1. U.S. Department of Agriculture. (2015, March). 2012 Census of Agriculture: Highlights. Family farms. https://www.nass.usda.gov/Publications/Highlights/2015/Family_Farms_Highlights.pdf

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Growers with Small to Medium Farms

> *"Weather drives upward of 40% of crop behavior, yet it is something we don't have much control over."*
>
> —Geospatial Lead, Agricultural Input Company

> *"Accurate data optimize the entire value chain."*
>
> —Data Scientist, Agricultural Decision-Making Platform Company

What are their technical needs?

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. Users need temporal resolution on a subhourly rate, which can help them track weather systems across fields. They also need to have information on a 24-hour data set in a few hours, so this observed data can be used to make decisions on farm management for the next day. Users need to know how much precipitation has fallen, what type, and at what intensity across the field. Incorporating data such as temperature, wind, and humidity can help inform agronomic practices. An improved understanding of convective motion in clouds can help growers understand the conditions that lead to temperature inversions.

What would motivate them to use NASA EO data?

Tools that can help them save money on inputs (e.g., those that help strategic application of fertilizer) or those that help provide a seasonal forecast would be beneficial. Although growers themselves are not the ones directly working with satellite-based weather data, their needs are addressed by organizations creating and selling data products to fit their needs.

What are their adoption barriers for using NASA EO data?

Because they are not the direct end users of these data, their adoption of NASA EO data depends on the weather sources and management platforms they use.

What are they afraid of?

Agriculture margins for growers are extremely low, even in developed economies. These users need demonstrated accuracy so that they can best use their limited resources. One incorrect weather prediction could significantly affect their yields and may even drive the grower into poverty. Although some growers keep on top of the newest agricultural innovations, many are conservative about technology adoption for this very reason.

What do they NOT care about?

Currently, growers do not consider aerosol characteristics and exposure in their day-to-day agricultural practices.

What are some key use cases?

- Effective application of farm inputs
- Mitigation of plant pests and disease
- Site similarity analysis

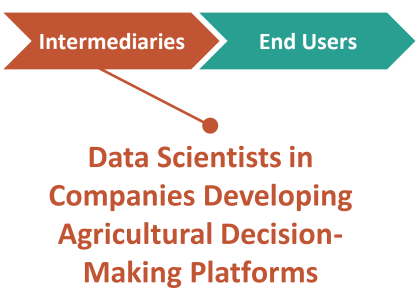
Data Scientists in Companies Developing Agricultural Decision-Making Platforms

User Community:

Data-Driven Agriculture

Who are they?

Data scientists developing agriculture decision-making products incorporate weather and other data products to help different agricultural stakeholders, such as growers, make decisions. Users may also be part of value-added service providers that create maps or other data products that can be integrated into platforms.



Who do they work for?

These developers may be independent software providers or subsidiaries of larger agriculture input companies that create digital farming tools geared toward effective use of their products. These products are ultimately geared to helping users across the value chain.

Data scientists in agricultural platform companies incorporate a variety of satellite data products to help growers make decisions.

What decisions are they making (and how) today?

These users aggregate various data sources in platforms that create insights for a variety of end users. Growers 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 inputs (fertilizer, pesticides) to apply. However, data scientists may develop platforms that might help ingredient-sourcing leads and commodities 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. Beyond weather products, these firms also may use satellite imagery from Sentinel, Landsat, and MODIS.

Do they have experience with EO data?

These users are mature and can incorporate low-level data products, which are easier to incorporate into their own gridded products or heat maps. Some larger input companies may have departments dedicated to incorporating and cleaning new EO data sources for use in their platforms.

What do they care about?

These users are seeking and incorporating a variety of EO data tools into their platforms. When they are creating models, they need to consider data redundancy—ensuring that they can deliver reliable and timely data to their customers even when some data systems fail (e.g., in response to government shutdowns).

Like their grower customers, these users care about accurate, high-resolution precipitation observations and data that can be used for mid to seasonal forecasts. Although most farming platform products have incorporated weather data to make deterministic forecasts, some are considering moving toward a model that outlines risk potential and helps end users understand the breadth of potential outcomes.

RTI Innovation Advisors

Data Scientists in Companies Developing Agricultural Decision-Making Platforms

"Oftentimes with data products, we see 80% of the time used to standardize and clean up the data, and only 20% for modeling the data. We would like to move that to fifty-fifty."

—Data Scientist, Digital Agriculture Team for Agricultural Input Company

"Our goal is to make the value chain more data driven. We're a decision-making tool that incorporates weather data."

—CEO, Agricultural Insights Platform Company

What are their technical needs?

Like the growers, down to 1-km x 1-km resolution, subhourly temporal resolution, and latency of 30 minutes to 3 hours after a 24-hour data set are needed.

Users requested appropriate channels to easily merge bulk data into the end users' systems, such as application program interface (API) or file transfer protocol (FTP) sites. EO data sets that are aligned temporally and spatially, such as IMERG and MODIS data products, would make cross-sensor calibration and atmospheric correction simpler and facilitate introduction of new EO data. Users would like clearly labeled data values and accuracy checks or clearly defined error rates, so they do not need to source this information from relevant papers.

Users prefer flexibility in data delivery. For example, they would rather pull selected data elements across a 2-month time period rather than pull daily records over 2 months. They often look for data that build on long programs, which ultimately improve their models.

What would motivate them to use NASA EO data?

Data scientists would be motivated to use data that are easily imported into their systems and do not require the user to import a large amount of extraneous data that must be cleaned. Although weather station or farm sensor-based data can help build a hyper-localized picture of weather conditions, satellite-based data are needed to validate against the ground-truth and improve on weather models, which can help improve models that work around the world.

What are their adoption barriers for using NASA EO data?

Lack of awareness of NASA weather data is an adoption barrier.

What are they afraid of?

Although many companies can afford multiple sources of data, maintaining a consistent and reliable cube of data is time-consuming.

What do they NOT care about?

The cost of data sets is not extremely important to them, if using the data sets saves time.

What are some key use cases?

- Site similarity analysis
- Crop and AQ monitoring
- Mitigation of plant pests and disease
- Effective applications of inputs

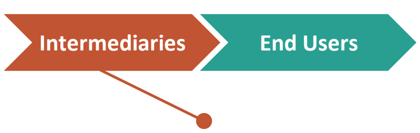
Data Scientists in Smallholder Farmer Advisory Services

User Community:

Data-Driven Agriculture

Who are they?

These users develop and deliver data products meant to help smallholder farmers, mostly those in developing economies. Smallholders manage a small amount of land, usually up to 2.5 hectares (roughly 6 acres). These agencies may deliver agricultural management guidance or financial insurance products to help protect smallholders against drought and storm damage. Many of their customers do not have access to smartphones or other digital technologies, so these organizations often deliver insights in the form of SMS text messages or via direct interaction with their customers.



Data Scientists in Smallholder Farmer Advisory Services

Who do they work for?

These users work in organizations that create tools that can help farmers in developing economies use their assets effectively and protect their crops. These organizations may contract with country governments to provide advisory services to smallholders, or they might be funded by corporate or private foundations.

Smallholder advisory services leverage low-cost or free data sources to help growers in developing economies.

What decisions are they making (and how) today?

Like the growers on small to medium farms, smallholders use these products to make decisions on types of seeds to use, when to plant and harvest, which crops to plant, and whether conditions are right for day laborers to work in the fields. Precipitation data are incorporated into risk "calculators" that ultimately inform the pricing of premiums and claims. These data can be used to help data scientists understand the return on investment for their financial products and whether they are properly covering their constituents in certain geographical areas. These users leverage databases that are low cost and include publicly available data, such as GPM/TRMM data and Climate Hazards Group InfraRed Precipitation with Station data. Coverage for ground-based radar systems and weather station data may be quite sparse. These organizations seek out other sources of weather data, relying on operational forecasts, such as the European Centre for Medium-Range Weather Forecasts models. Data scientists in the organization interpret these data, which often takes some preprocessing, and communicate it to their stakeholders. For agricultural products related to risk insurance, data scientists rely on data that have a historical database of at least 20 years: GPM/TRMM data, for example, has helped some organizations develop premium pricing mechanisms.

Do they have experience with EO data?

Users developing smallholder data products are not creating models but are integrating data from multiple satellite sources that have some preprocessing. Users incorporating satellite data into financial systems are sophisticated users and prefer low-level data products.

What do they care about?

Precipitation (namely rainfall) is most important to their end users. These developers are looking for publicly available, reliable data sources: coverage of weather data across the globe is important, especially in tropical areas, because current weather models have been developed for and are more accurate in temperate regions. Many smallholders that play a key role in worldwide commodity trading are located in tropical regions, such as western Africa. Accurate, highly spatially resolved data are important: many smallholders operate in areas that are very small. In addition to precipitation observations, data scientists bringing insights to 7 to 14 days out and seasonal outlooks would be helpful. Users developing financial products are also interested in evapotranspiration and soil moisture for their insurance pricing models.

Data Scientists in Smallholder Farmer Advisory Services

"One of the most demanded services by smallholders is weather information."

—Program Manager, Smallholder Advisory Service

"Volatility can lead to increased profit variability. The information is extremely helpful when it's good, but catastrophic when it is inaccurate, and can push smallholders back into poverty."

—Program Manager, Smallholder Advisory Service

What are their technical needs?

Data scientists would like accurate observations of precipitation; understanding the relationship between clouds and precipitation can help lead to the development of models with a probabilistic , rather than a deterministic, weather recommendation. Spatial resolution needs are 1 km x 1 km or less. Because users incorporating data into agricultural advising provide guidance daily, or every few days, daily temporal resolution can work well, if the latency is short (30 minutes to 3 hours). For financial products, ideal temporal resolution is daily, but weekly could also work.

What would motivate them to use NASA EO data?

Free tools that require little post-processing, backed by a long precipitation record and demonstrated accuracy, would be helpful. In the agricultural world, some stakeholders are aggregating publicly available data products to improve data exchange and use for smallholders' benefit. For example, the center for Global Open Data and Nutrition is an initiative that advocates against "digital feudalism." These stakeholders could be promising channels for disseminating data products and acquiring a better understanding of how to create data products that many user community members can easily employ.

What are their adoption barriers for using NASA EO data?

Lack of geographical coverage in relevant tropical areas and developing economies and lack of awareness can be barriers to using NASA EO data.

What are they afraid of?

Data scientists in these services help smallholders make decisions that have direct effects on their margins. Accuracy of these data is important, and many countrywide meteorological systems are unreliable. Some smallholder farmers may lose trust in advisory services that provide inaccurate data.

What do they NOT care about?

These users do not care about AQ data at the moment.

What are some key use cases?

- Effective application of farm inputs
- Mitigation of plant pests and disease

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ACCP User Community Profiles

	Commercial Aviation
	Major Logistics Carriers
	Logistics Arms of Major Retail Brands
	Data-Driven Agriculture
	Food Companies Operating in Tropical Areas
	Health and Short-Term Air Quality Monitoring
	Solar Energy

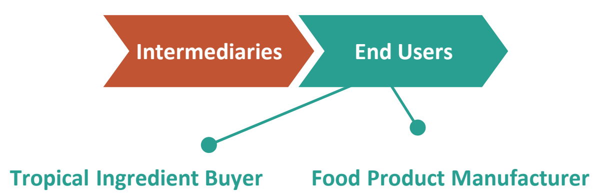
RTI Innovation Advisors

Food Companies Operating in Tropical Areas

Community Overview

Food production and consumption is a big business. With nearly 8 billion people worldwide, there's a constant growing demand for food.[1] Several major food ingredients are grown in tropical regions, where conditions are ideal for growing and harvesting specific crops. In this community overview, we focus on three such ingredients: cocoa, coffee, and almonds. Each of these represents multibillion-dollar enterprises, and the success of each largely depends on understanding weather conditions in tropical environments. Cocoa beans are converted to chocolate powders and liquors used in a variety of food and beverage products, representing a $140 billion business annually.[3] Seventy percent of the world's cocoa is grown in West Africa. Coffee sales worldwide exceed $400 billion per year, and nearly two-thirds of coffee beans are grown in Columbia, Brazil, and Vietnam.[2] Almonds require specific environmental conditions found in Northern California, where 80% of the world's supply is grown. Other key growing regions are Spain and Italy. For companies involved in tropical ingredients like these, understanding current and future weather conditions is critical to their success.

Selected User Profiles for ACCP



Potential Use Cases for ACCP Data Products

- Monitoring global weather trends
- Monitoring micro weather conditions
- Site similarity analysis for crops[4]

Moving Forward for ACCP

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, 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. These needs are elaborated on in two use cases: monitoring global weather trends and monitoring micro weather conditions.

These use cases speak to current needs to monitor and predict crop yields in proven growing regions. Beyond these needs, users also expressed the need to predict detrimental affects of climate change on growing regions and anticipate new regions that might become suitable for growing certain types of crops. Several companies and research organizations 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.

1. Population estimate from U.S. Census Bureau. (2020, July 11). Stats for stories: world population day: July 11, 2020. https://www.census.gov/newsroom/stories/world-population-day.html
2. Revenue estimate from Statista. (n.d.). Coffee. https://www.statista.com/outlook/cmo/hot-drinks/coffee/worldwide. Top countries from RTI interviews
3. Revenue estimate from Statista. (2021, May 11). Size of the chocolate confectionery market worldwide from 2012 to 2025. https://www.statista.com/statistics/983554/global-chocolate-confectionery-market-size/
4. See the Data-Driven Agriculture section for more information on site similarity analysis.

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User Community: Food Companies Operating in Tropical Areas

Organizational Assessment

Companies in this community are engaged in production, distribution, quality control, sales, and marketing of ingredients grown in tropical environments, as well as the final food and beverage products manufactured from those ingredients. Examples include raw ingredients consumed as food products (e.g., almonds), plus ingredients that are incorporated into food or beverage products (e.g., chocolate candies, coffee). Companies involved in this community make decisions based on a near-global view of weather and environmental conditions, because these key ingredients are grown in specific regions around the world where growing and harvesting conditions are ideal. 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. To provide an illustration of the complexities of this community, we focus on cocoa, coffee, and almonds.

Food manufacturers produce the final food and beverage products that are sold to consumers and wholesale and institutional buyers. They buy ingredients from suppliers via long-term contracts, using forecasted demand for their end products to establish a volume of ingredients needed to satisfy that demand. These companies are interested in weather patterns and forecasts but tend to rely on ingredient suppliers to closely monitor conditions and apprise them of potential risks that would lead to price escalation or an inability to deliver ingredients at the agreed upon volume. These users receive weather data reports from suppliers or brokers. Market reports are typically produced by a research institute or government agency affiliated with the country where the tropical ingredient is grown.

I**ngredient suppliers** sit between growers and food manufacturers. They take on the majority of risk in delivering high-quality ingredients at specified volumes to food manufacturers; thus, they have a lot to lose or gain when weather conditions change. These companies work closely with regional entities and directly with growers, in some cases, to source their tropically grown ingredients. These suppliers establish long-term contracts with growers to lock in a designated volume of production from the growers' crops. However, the real crop yield from any grower is heavily dependent on weather conditions and the grower's ability to act on those conditions in a timely manner. To understand the potential risks to crop yields before, during, and after a growing season, ingredient suppliers are heavy consumers of weather data around the world.

Data	Intermediaries	End Users
To stay abreast of local and global weather, users rely on data from a variety of sources, including satellite data from NASA (e.g., GPM), NOAA (e.g., GOES), and other countries (e.g., National Institute of Water and Atmospheric Research and Bureau of Meteorology in New Zealand); other federal agencies in the United States (e.g., NWS); and free data aggregators (e.g., Weather Underground, Weather Channel). Nonsatellite data sources include on-site weather stations provided by county or other regional agencies.	Intermediaries in this community include free data aggregators (e.g., Weather Underground, Weather Channel) and regional or national entities that monitor and report on conditions relevant to specific crops. Value-added service providers are not as apparent in this community as in others. The service providers engaged in this community tend to align with agricultural applications, such as farm management and agricultural input platforms.	Ingredient suppliers and food manufacturers represent the end users in this community. Ingredient suppliers are responsible for delivering high-quality ingredients at specified volumes to the food manufacturers; thus, they have a lot to lose or gain when weather conditions change. Food manufacturers are dependent on their ingredient suppliers to deliver ingredients at a specified quality, volume, and price. Their interest in weather has more to do with future disruptions to supply as a result of climate change.

Food Companies Operating in Tropical Areas

Organizational Assessment (continued)

These users monitor how a crop is developing, tracking weather models that may affect the market and price and how they source supplies in response to weather effects. Understanding the weather's impacts on potential supplies of ingredients is critical. When these risks can be understood, users can make alternative plans to find other sources or try to "buy ahead" to mitigate price increases. Weather data are being used to answer industry-critical decisions related to questions such as the following:

- When are appropriate times to buy specific ingredients (harvesting time and cycles vary around the globe)?
- Who do we buy from to ensure good pricing, continuity, and quality?
- How do we price futures contracts knowing what may happen in the next few months/year?

Ingredient suppliers and the organizations they partner with to source various tropically grown ingredients are familiar with a variety of weather data sources, including satellite-based data from NASA and other organizations worldwide. The companies interviewed in this project are interested 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 knowledge of weather conditions worldwide could have a significant positive impact on this community.

Food Companies Operating in Tropical Areas

Technical Assessment

Sourcing ingredients for food and beverage products is a global undertaking, with different regions around the globe excelling in specific ingredient quality and yield based on local growing conditions. 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.

To stay abreast of local and global weather, users currently seek out data from a variety of satellite (e.g., GOES, GPM) and nonsatellite sources. Data products that more easily integrate a variety of data sources against county, state, and country mapping are desired. Generally, users are interested in data products that are more visual and more easily accessible (e.g., via common data formats across federal agencies and across countries).

This community has a simultaneous need for better data, models, forecasts, and predictions on both a hyper-local and a near-global scale. Examples of needs are summarized here and expanded on in the "Use Case" section.

Monitoring global weather conditions—This community desires greater data accessibility and availability in regions around the world. Improved understanding and modeling of global weather conditions could help commodity markets more accurately predict crop yields and pricing. These users desire improved long-term (12- to 18-month) and near-term forecasting models, greater accuracy in the models, and improved coverage to monitor conditions more closely in specific regions of the world (West Africa, California valleys, Brazil, Columbia, Vietnam) that are the primary locations for crop production. Improved data products for precipitation, wind speed, humidity, temperature, and fog are desired.

Monitoring hyper-local weather conditions—In addition to the global view described above, these users have a need to predict and monitor weather conditions in specific farms and fields. Users in this community, especially those who work closely with growers in specific regions, are extremely interested in improved methods to forecast and monitor weather conditions at a site-specific level of resolution. They want near real-time sources of reliable data that can help guide decisions on a farm-by-farm basis. These users shared that microclimate conditions vary across the region in which certain crops are grown, and those variations affect decision-making throughout the growing cycle. They desire improved accessibility, availability, latency, and resolution for precipitation, wind speed, humidity, frost, temperature, and fog.

Food Companies Operating in Tropical Areas

Use Cases

Within this community, users may leverage EO data in a range of use cases to enhance current and future decision-making capabilities. Examples of use cases within this community are as follows:

- Monitoring global weather trends
- Monitoring micro weather trends
- Site similarity analysis for crops (covered in the Data-Driven Agriculture section)

Improved understanding and modeling of global weather conditions could help commodity markets predict crop yields and pricing.

Food production is a global undertaking. The ideal growing regions for several major food ingredients are in tropical, often remote, locations with limited resources. Users in this community expressed a strong desire to better understand weather conditions across the globe. They are relatively satisfied with the accessibility and variety of data available for North America and desire similar attributes for weather data in other regions of the world. Some of the critical global weather phenomena influencing predicted and actual crop yields are the following:

- Droughts across Australia and New Zealand that may affect dairy production
- Tropical cyclones in India and Pacific typhoons affecting palm/palm kernel production in Indonesia and Malaysia
- Snow cover, cold air outbreaks (polar vortex), hurricanes, and floods that may affect sugar crops
- La Niña/El Niño events and ocean temperatures as early signals of storms
- Harmattan winds in West Africa and soil moisture index and vegetative index for canopy cover across the Ivory Coast
- Precipitation in regions where coffee and chocolate are grown—Colombia, West Africa, Brazil, and Vietnam

Users expressed a need for improvements in accuracy, reliability, and timeliness (latency) of these and other weather conditions. Users also expressed a need for improved models that better predict and interpret precipitation deviations from historical norms and enable comparative analysis tools to assess current conditions against prior years that most closely match current conditions. These models are desirable in order to improve estimates of crop quality, timing of harvesting, and yield. Improved models and predictions lead to better understanding of potential risks to supply chains and earlier actions to mitigate those risks so that disruptions to food supply chains are minimized and prices are less likely to experience large fluctuations.

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Food Companies Operating in Tropical Areas

Use Cases (continued)

Understanding "micro" weather conditions in near real time at the resolution of a specific farm is highly desired.

Users in this community, especially those who work closely with growers in specific regions, are extremely interested in improved methods to forecast and monitor weather conditions at a site-specific level of resolution. Users in this community consistently expressed a desire for spatial resolution at 1 km or less.

Users are seeking near real-time sources of reliable data that can help guide decisions on a farm-by-farm basis. These users shared that microclimate conditions vary across the region in which certain crops are grown, and those variations affect decision-making throughout the growing cycle.

These users, along with growers in the region, are ingesting data from a variety of sources: grower-managed weather stations (probes for soil moisture, rain, atmospheric conditions, frost); Weather Channel; GOES 16, 17 imagery; and local radar and doppler sources. They are tracking several weather conditions that affect crop yield, including temperature, wind gusts, wind speed, humidity, frost conditions, and precipitation.

These data are particularly critical at key times in the growing cycle (e.g., timing of pollination events, blooming and flowering stages, harvesting and drying). Weather data during bloom and 60 days beyond are essential for predicting the crop yield. In between these critical stages, weather data are used to monitor conditions that might lead to disease or pest infestation.

Some of the specific areas of interest and improvement expressed by this community include the following:

- Near real-time data—Low latency to within the day (most data are accessible the day after) is needed.
- Reliable data—Current temperature and wind speed sources are inconsistent in accuracy.
- Precipitation—Real-time satellite precipitation data are desired to understand cocoa pod setting, flowering, and development .
- Frost—Real-time data to predict and interpret frost conditions in the orchards are desired.
- Fog—Understanding hours of fog and density of fog would help growers with effective orchard management.
- Evapotranspiration and moisture stress—These data are useful to guide decisions on irrigation, but data collection is currently labor intensive and time restrictive.
- Leaf wetness can help determine whether crops are liable to get foliage fungi and other disease conditions.

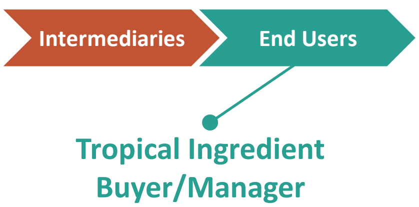
Tropical Ingredient Buyer/Manager

User Community:

Food Companies Operating in Tropical Areas

Who are they?

Heads of procurement, sourcing strategy, and grower relationships at major food ingredient companies



Who do they work for?

Major ingredient companies 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.

Companies involved in sourcing tropical ingredients closely track weather effects on the growing cycle and supply chain.

What decisions are they making (and how) today?

These users 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.

Do they have experience with EO data?

Many of these users are avid consumers of EO data from a variety of sources. Some were familiar with advancements in GOES sensing and data products.

What do they care about?

These users desire improved forecasting models, greater data accuracy, 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). They named specifically improved data products for precipitation, wind speed, humidity, temperature, and fog. They are interested in understanding the physiological processes of trees (evapotranspiration, moisture stress) and their interdependencies with weather. Understanding this concept and automating decision-making for the farmer are considered the holy grail.

Tropical Ingredient Buyer/Manager

"Our [almond] bloom weather is critical—the other 50 weeks mean nothing if these two weeks are bad."

—Vice President, Almond Growing Company

"It would be great if [weather] data could be easily aggregated by county/state or country level relatively easily."

—Senior Buyer, Chocolate Ingredient Company

What are their technical needs?

Higher resolution is important because some of the regions of interest have unique microclimates. The conditions in one valley can be completely different from the conditions in the next one. These users need improvements in accuracy, reliability, and latency of all data, especially precipitation data across regions outside the United States (e.g., West Africa). Any data that can improve models that predict crop quality, nature of harvesting, and flow of crop are beneficial. They need better ways to determine shade canopy and health of crops that are low to the ground. They want methods of understanding evapotranspiration and moisture stress.

What would motivate them to use NASA EO data?

They would use NASA EO data if the data had improved availability, latency, and resolution—more real-time data in higher spatial resolution; improved accessibility of data in key geographies outside the United States (e.g., West Africa, Pacific storms, New Zealand/Australia); and improved data products for U.S. regions (e.g., better resolution of temperature, precipitation, fog, and moisture data through Sacramento San Joaquin Valley, Central Valley).

What are their adoption barriers for using NASA EO data?

They want high-level models and data products that incorporate EO data, not raw data feeds.

What are they afraid of?

Poor-performing crops, surprises and disruptions to the growing cycle, and the economic impact of those things are all concerns.

What do they NOT care about?

These users do not care about data coverage outside tropical regions.

What are some key use cases?

- Monitoring global weather trends
- Monitoring micro weather conditions
- Site similarity analysis for crops

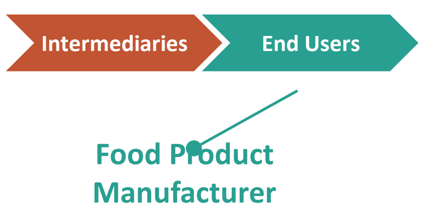
Food Product Manufacturer

User Community:

Food Companies Operating in Tropical Areas

Who are they?

As quality or sourcing managers at branded food companies, these users work closely with ingredient suppliers and the suppliers' farmers, to assess, evaluate, and verify that ingredients meet their sensory and qualitative performance criteria. They are accountable to consumers; thus, they must confirm that ingredients brought into the company are safe for consumption and will deliver high-quality final food products.



Who do they work for?

These companies buy ingredients to produce final food products for institutional (hotels, university cafeterias), commercial (restaurants, catering firms), and retail customers.

Food product manufacturers rely on ingredient suppliers to manage supply chain risks; interest in satellite data aligns with bigger issues, such as climate change.

What decisions are they making (and how) today?

These users make buying decisions. Coffee, cocoa, and other tropically sourced ingredients are purchased via long-term agreements. Quality and sourcing managers have to make long-term decisions such as which contracts will be fulfilled, from which regions, and what the contingency plans are if those contracts cannot be fulfilled or the quality of the ingredient is not satisfactory.

Do they have experience with EO data?

These users are historically less familiar with EO data. They rely on weather and AQ forecasts from their ingredient suppliers and other sources.

What do they care about?

These users greatly desire long-term weather forecasts (12 to 18 months) that provide increased confidence levels. These forecasts are monitored to understand precipitation levels, dryness, and ocean temperatures (for risk of major storms). These forecasts help buyers understand where future issues with crops may arise in regions around the world and thus how supply and pricing might be affected. During critical times in various growing seasons, they desire near real-time status of weather conditions in key areas of the globe, such as Columbia, Brazil, and Vietnam, which produce 60% to 65% of the world's supply of coffee.

RTI Innovation Advisors

Food Product Manufacturer

"The impact of climate change on coffee crops is a big concern. There are pessimistic predictions that in 15 years Brazil will not be able to produce coffee anymore due to climate change. The big coffee companies—Unilever, Nestle, Keurig Dr Pepper—have internal research teams working on this issue."

—Quality Control Manager, Coffee Company

What are their technical needs?

These users need improved accuracy in long-term precipitation models, especially models that can help assess risks in remote growing areas in South America and Asia. They also need improved data and models that can forecast long-term impacts that climate change will bring and how regions and countries can prepare for those changes.

What would motivate them to use NASA EO data?

They would be motivated to use EO data if they have data that lead to improved confidence in long-range forecasts, greater visibility into weather conditions in tropical growth areas in near real time, or predictions on the effects of climate change on current growing regions.

What are their adoption barriers for using NASA EO data?

Ingredient/sourcing managers at major food manufacturers are not likely to adopt NASA EO data for daily use. Instead, they will rely on their ingredient suppliers to monitor weather conditions for them as a way to de-risk their own ingredient supplies. However, researchers at some of these companies are trying to understand and predict the effects of climate change on their industry. Increased awareness of and access to NASA EO data could be the beginning of deeper engagement with this community.

What are they afraid of?

These users are concerned about the pace and intensity of climate change. For example, key questions in the coffee industry include how will climate change affect coffee farming? What regions will become unsuitable? Will other regions become more suitable and, thus, coffee production will shift over time? Many companies and research organizations around the world are exploring these questions currently. Data and models that could improve confidence levels in long-term forecasts like these would be immensely helpful.

What do they NOT care about?

Ingredient/sourcing managers do not care about day-to-day weather, unless it is severe and may compromise their supply chain. Long-term seasonal data and outlooks are more important to them.

What are some key use cases?

- Monitoring global weather trends
- Monitoring micro weather conditions
- Site similarity analysis for crops

ACCP User Community Profiles

	Commercial Aviation
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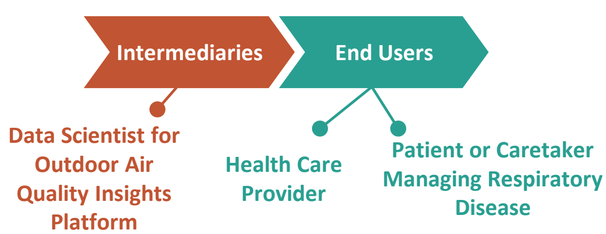
	Food Companies Operating in Tropical Areas
	Health and Short-Term Air Quality Monitoring
	Solar Energy

Health and Short-Term AQ Monitoring

Community Overview

Researchers, health care providers, and policy-makers recognize the impact of air pollution on public health: fine particulate matter ($PM_{2.5}$) may exacerbate chronic respiratory and cardiovascular diseases and has been correlated to conditions such as lung cancer and breast cancer. Understanding the impact of pollution on health outcomes has long been a research priority. The State of Global Air initiative considers fine-air outdoor air pollution "the largest driver of air pollution's burden of disease worldwide," contributing to 4.14 million deaths globally, a 23% increase over the past decade.[1] In general, the health community is interested in understanding both short- and long-term health impacts from air pollution. Users interviewed in this particular community subsection focus primarily on acute health effects of pollution, such as respiratory attacks from chronic obstructive pulmonary disease (COPD) and asthma. These acute reactions can have large effects on health care visits and costs. For example, a 2018 Environmental Health Perspectives Study discovered that air pollution played a role in up to 33 million emergency room visits for asthma attacks in 2015.[2] A 2010 RAND Corporation Report indicated that pollution-related hospital admissions in California cost health care purchasers/payers over $193 million in hospital care.[3] Understanding and avoiding AQ conditions leading to these acute respiratory events could help patients prevent costly and life-threatening health consequences and help health care providers best treat their patients.

Selected User Profiles for ACCP



Potential Use Cases for ACCP Data Products

Individual or cohort health monitoring

Clinical decision support

Environmental monitoring

Moving Forward with ACCP

Future data products can raise the bar within this user community by providing global coverage of vertically resolved data broken down by types of particulates, including ultrafine (PM 1) aerosols, filling in gaps to the ground-based sensor network. Colocation of weather and aerosol data will improve understanding of how aerosols are dispersed and deposited across an area of land and, ultimately, help with forecasting.

Although private-sector health care applications offer a number of opportunities for using these data, current research gaps must be addressed before incorporating these data into some use cases. For example, the research community must establish clear links between aerosol types and health impacts. Engaging with entities such as the Environmental Protection Agency (EPA), Centers for Disease Control and Prevention (CDC), and the National Institute of Environmental Health Sciences (NIEHS) for joint research to understand these links may better set up successful use of this data in the private sector.

1. State of Global Air/2020. (2021). Health impacts of $PM_{2.5}$. https://www.stateofglobalair.org/health/pm
2. Anenberg, S. C., Henze, D. K., Tinney, V. et al. (2018). Estimates of the global burden of $PM_{2.5}$, ozone, and NO_2 on asthma incidence and Emergency room visits. *Environmental Health Perspectives, 126*(10). https://ehp.niehs.nih.gov/doi/full/10.1289/EHP3766
3. Romley, J. A., Hackbarth, A.,& Goldman, D. P. (2010). *The impact of air quality on hospital spending*. RAND. https://www.rand.org/pubs/technical_reports/TR777.html

Health and Short-Term AQ Monitoring

Organizational Assessment

Air pollution is widely studied across communities within the environmental public health profession, including researchers, regulatory agencies, industry, and policy-making organizations that incorporate AQ data into large epidemiological studies. This specific user community focuses on the stakeholders in the health care community that are interested in near real-time monitoring of current conditions and short-term forecasting. These data help make decisions related to acute care for a patient's cardiorespiratory needs, which may ultimately decrease acute respiratory crises, improve patient care, and reduce health care costs.

Ultimately, this user community is most interested in small PM that has been shown to negatively affect health, such as $PM_{2.5}$ and PM 1. The community currently relies on readings from ground-based sensors that provide a real-time estimate of pollution at "nose level" across the world. Platforms such as the EPA's AirNow network incorporate calibrated, on-ground EPA sensor networks and are starting to incorporate readings from low-cost, real-time AQ sensors provided by companies such as PurpleAir. Advanced users may incorporate satellite-based AQ data products (like MODIS outputs), but current satellite data products measure aerosol within the column of air, and more information is needed to use those observations to estimate surface-level $PM_{2.5}$ and augment the spatially limited ground-based observations.

Many users within health care currently (or may in the near future) incorporate AQ data in their decision-making. **Patients and caretakers monitoring respiratory disease symptoms** actively monitor environmental stimuli , including outdoor air pollution, that may trigger an attack. Air pollution data help them make better decisions on opportunities to be outside, exercise, or travel that mitigate the risk of respiratory symptoms.

Management of behavior using air pollution data is encouraged by **clinicians and health care providers**, who may use these data to better manage their cohort of patients. Ultimately, this information will help these providers understand what their patients are regularly exposed to and inform how to best treat their conditions. Individuals in these health care settings could use these data to anticipate times when asthma and COPD attacks may increase based on the AQ forecast.

Patients and health care providers rely on platforms that aggregate AQ data with other data products, such as rescue inhaler use, to better understand and predict the impact of the environment on an individual's health outcomes. **Data scientists creating outdoor AQ platforms** aggregate data and insights to help users understand what cohorts of patients may be at risk for acute respiratory events, who might be underserved based on current therapies, and what sorts of health risks may be more prevalent in certain areas based on type of air pollution. In the next 5 to 10 years, users of short-term AQ data colocated with health data may expand the data to uses such as charting software products, modules, and other clinical decision support systems that help create recommendations for care based on a patient's experience.

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Health and Short-Term AQ Monitoring

Organizational Assessment (continued)

Private health insurers and public purchasers such as Medicare and Medicaid may be future users of data, especially in their managed care programs. Understanding AQ trends and forecasting in certain regions could serve as an important data point to understand risk. **Data analysts** could use AQ data to understand the health burden on a particular population subset and use these data to inform their premium pricing. Insurance providers have a vested interest in promoting healthy behaviors in their enrollees, which ultimately reduces their costs.

Data	Intermediaries	End Users
Data are collected from ground-based sensor networks and satellite sources, including MODIS, Multi-angle Imaging Spectroradiometer (MISR), Visible Infrared Imaging Radiometer Suite (VIIRS), Ozone Monitoring Instrument (OMI), and Tropospheric Monitoring Instrument (TROPOMI) data.	Data are aggregated into a gridded network that maps sensor readings or satellite-based observations. These platforms may leverage individual or population health data and other environmental factors to understand links between AQ and health outcomes.	Patients with respiratory diseases and their caretakers may plan outdoor activities around AQ readings given by these gridded data products. Health care providers often recommend use of these data sources to patients and may also use these products to understand what their patients may have been exposed to or when to expect a higher level of emergency room visits.

Health and Short-Term AQ Monitoring

Technical Assessment

This user community focuses on near-time to short-term forecasting of air pollution and its effects on health, which requires data with high spatial and temporal resolution. Community members prefer a spatial resolution of 250 m or less (and, ideally, 50 to 100 m) and subhourly temporal resolution. Latency needs depend on whether there is a real-time AQ event. For example, when wildfire smoke comes through an area, data within the hour would be ideal. For AQ forecasting, users are interested in understanding AQ conditions approximately 2 to 7 days in advance.

Currently, this user community mostly relies on ground-based sensor networks, such as those maintained by the EPA, and low-cost sensor networks, such as PurpleAir or Plume sensors. This network, however, is difficult to maintain and has limited coverage. Therefore, coverage in rural areas can be extremely low. Health care researchers and practitioners may be missing out on key information on what individuals in rural areas are routinely exposed to, such as agriculture-related pollution data. Global-scale coverage is the true value of satellite-based data compared with current on-ground sensor networks, especially in developing economies and rural areas where sensor coverage is low.

Specific aerosol data needs for this user community include the following:

Improved characterization of the types of aerosols they are encountering—Exposure to different types of particles (beyond PM size) may affect individuals in different ways. Understanding what types of particles an individual may be exposed to, including dust, new and old smoke, ash, pollen, and other “biotic” particles, could help researchers and clinicians better understand the relationship between exposure and health outcomes. This community would especially value measurement of ultrafine particles (~PM 1).

Highly resolved, ground-based $PM_{2.5}$ data across a global scale—To understand an individual’s level of exposure to aerosol and PM, users must consider not only the aerosol optical depth of the entire column of air but also the vertical distribution of aerosols across that column, mostly those at nose level. Users are interested in satellite data products with high global coverage that can provide an understanding of particle concentration at the surface level.

Improved understanding of three-dimensional aerosol motion—Colocated aerosol, CCP data can help users better understand dispersion and deposition of particles due to weather events such as rain and wind, painting a more accurate picture of aerosol forecasting (e.g., when to expect smoke from recent wildfires to enter the area and when dust may leave the area).

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Health and Short-Term AQ Monitoring

Technical Assessment (cont.)

Colocated and easily accessible data—Users often incorporate many data sources (including satellite-based sources) to understand the effects of AQ on health. Users indicated a desire for additional colocated data, such as surface heat, visibility, humidity, wind, and wind direction. In addition, users noted the value of pulling both surface-based and satellite-based AQ data into one database for a universal AQ platform. Cleaned, validated downloadable data sets, with API calls or ArcGIS layers, can help users more easily incorporate these data sets into their own platforms in a timely and accurate fashion.

Although this user community focuses on near-time and short-term forecasting of AQ data, their eventual use of satellite-based AQ data products requires an improved understanding of the impacts of certain types of pollution on an individual's health outcomes, which may require epidemiological studies with a long range. These data will enable the community to move beyond "green, yellow, and red" stoplight data products and into more actionable data that can inform health risks.

Specific technical needs for satellite-based AQ data were discussed with respect to three use cases, summarized here, and expanded on later:

Individual and cohort health monitoring—Managing care for individuals afflicted by respiratory diseases such as asthma and COPD may involve day-to-day monitoring of outdoor AQ around them. Understanding what particles they may be exposed to and when AQ may be sufficient for them to leave the house can help reduce rescue inhaler use; emergency room visits; and, ultimately, health care and quality-of-life costs.

Clinical decision support—Understanding an individual's exposure to types of air particulates could help health care providers make personalized care recommendations. Digital health platforms on patients' phones are helping them understand the link between AQ and health outcomes, and these platforms may be incorporated into clinical support software and decision-making tools later.

Environmental monitoring—Short- and long-term monitoring of many environmental factors in a certain location, including AQ data, can help understand key trends and needs, identify hot spots, and help many potential end users identify links between environmental exposure and specific health outcomes.

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Health and Short-Term AQ Monitoring

Use Cases

Within this community, users may leverage EO data in a range of use cases to enhance current and future decision-making capabilities. Three examples of use cases within this community are as follows:

- Individual or cohort health monitoring
- Clinical decision support
- Environmental monitoring

Colocated aerosol and weather data may help patients and health care providers better anticipate conditions that may lead to respiratory distress.

Patients and caretakers managing cardiorespiratory diseases consider outdoor AQ when making everyday decisions. For the world's roughly 339 million asthma patients and 251 million COPD patients, exposure to PM may trigger an acute respiratory event, which could be life-threatening. Monitoring outdoor AQ conditions is one of the most effective ways to avoid these events. Therefore, health care providers recommend that these patients actively monitor the current state of AQ based on phone "stoplight apps" that let them know whether the current AQ may affect people in sensitive groups. Users leverage these resources to make decisions on whether to (or when to) leave the house, exercise, travel, and more. In areas with frequent AQ crises such as wildfires, educational institutions and companies may limit their outdoor activities based on real-time or forecasted AQ readings that could be unhealthy to sensitive groups.

Users of this information are looking for real-time AQ information, as well as short-term forecasting: What might the next 2 to 7 days look like? A better understanding of weather and aerosol relationships, incorporating barometric pressure, wind, and precipitation, may help improve forecasting what the week of AQ might look like. Readings for specific types of aerosol and PM, such as pollen or dust, can help different populations react and prepare for AQ events. For this use case, satellite data can provide coverage across geographic areas that may not have nearby on-ground sensors, such as rural areas in the United States or in developing economies across the world. These users are concerned with surface-based readings at nose level and have the highest spatial resolution needs, down to the neighborhood level and preferably less than 250 m.

Detailed aerosol data can be used in clinical decision support models that optimize health care treatments and therapies.

Clinical decision support incorporates a patient's personal health data and experiences to provide personalized care recommendations. For example, what might be the best therapy for an asthma attack? By understanding what specific types of particles an individual has been exposed to, and for how long, health care providers can move toward therapies and approaches that best fit the needs of a specific patient.

Although a significant amount of research has been done to understand the relationship between air pollution and both short- and long-term health consequences, the research community still needs to understand the relationship between particle types and specific health outcomes. Even though researchers may be the primary users of this information now, in the next 5 to 10 years, this information could be incorporated into products such as clinical charting software and dashboards to help health care organizations understand patients' short-term needs. Software applications, such as Propeller Health, which colocate a patient's rescue inhaler use with AQ and weather factors such as precipitation, visibility, temperature, and wind are moving toward offering personalized, data-driven insights using environmental inputs such as AQ data.

This community will value enhanced abilities to determine the specific particles the patient or patient cohort has been exposed to. Because these users are interested mainly in exposure to past and current aerosols rather than a forecast, they value a short latency for data products (less than a day) and high resolution (ideally, less than 250 m), which can best help them understand an individual's total exposure to particles.

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Health and Short-Term AQ Monitoring

Use Cases (continued)

Aerosol and weather data can be used in environmental monitoring to help understand human health patterns, links, and hot spots.

Environmental monitoring incorporates a variety of data sources to help identify general health needs for a population in a certain location. Environmental monitoring leverages a number of satellite- and ground-based data sources to help understand specific locations. For example, data on weather, light pollution, NDVI, and surface temperature, along with colocated health outcomes data, could help establish whether populations in urban areas are more susceptible to certain acute and chronic conditions. Users are looking for data that offer surface-based aerosol measurements that are highly spatially resolved, provide global coverage, and can differentiate between particles. Global coverage of satellite-based AQ data would help augment on-ground sensors and wearables. Although this data aggregation can help identify current and acute needs based on short-term data, it may rely on long data records to identify anomalies with current conditions. Environmental monitoring could be used in several ways:

- Anticipate potential community health needs in response to environmental conditions, including AQ events and natural disasters, enabling health care providers such as emergency departments to better equip themselves for patients with acute respiratory issues.
- Identify hot spots of poor AQ, especially in rural areas and developing economies, where on-ground sensor concentration is quite low.
- Identify if current respiratory therapies are treating patients effectively and if there are areas of unmet need because of high pollution.
- Understand health risk trends for certain areas and create indices for certain health conditions, such as depression and anxiety, which may be influenced by AQ.

These data could be used by government policy-makers and AQ management districts, health care data analytics companies that serve pharmaceutical and medical device companies, and companies and agencies that may consider offering "hazard pay" to employees operating in areas with AQ risks. Insurance companies may also use these data to understand health burdens on a particular population, which may inform their premium pricing.

Because this application incorporates a significant amount of data from disparate sources, users would like data sources that can provide clean, validated, downloadable data sets that are flexible (e.g., can change units quickly) and have some mechanism to easily transfer data to the user's platform, such as APIs or ARC GIS layers. For NASA data specifically, users would like to tap into all of NASA's data sources for one location easily (e.g., all satellite-based information for the city of Raleigh, North Carolina).

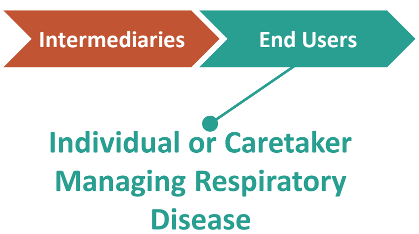
Individual or Caretaker Managing Respiratory Disease

User Community:

Health and Pollution

Who are they?

These users live with respiratory conditions such as asthma and COPD and have noticed a linkage between AQ and the onset of respiratory symptoms. They may have serious symptoms that could require rescue inhaler use or hospitalization. They are health conscious and "do their research" to find information that can help them make decisions.



Who do they work for?

Could be everyday people, parents of children with asthma, or caretakers/teachers in daycare centers and schools who look after people with respiratory challenges. They keep abreast of current AQ detection technologies, may be early adopters of personal air purifiers, and like having data to help them make decisions. They may also be early adopters of wearable technologies.

Satellite data can help inform AQ forecast models that help patients manage their respiratory conditions.

What decisions are they making (and how) today?

These data users rely on AQ data to determine when they can safely avoid days and times where particulate concentrations might cause a respiratory event. AQ information helps them weigh risks on day-to-day activities (e.g., whether to let children with asthma play outside), and it also may help them incorporate products or approaches to reduce their home's indoor air pollution. Most users rely on easily available AQ applications, such as AirNow, that are available for smartphones. These sources leverage data from ground-based sensor networks. Users may consider purchasing and incorporating low-cost AQ sensors around their own home. They are interested in $PM_{2.5}$ and other PM, as well as other types of pollutants, such as pollen and ozone.

Do they have experience with EO data?

They employ data via third-party, highly gridded, and processed sources and typically lack the capability to interpret data from satellite sources.

What do they care about?

These users are most concerned about $PM_{2.5}$ and other PM, such as pollen, in their immediate environment. Thus, they could need high-resolution data, approximately the size of a city block (to 50-m resolution) data.

Ultimately, these users want to proactively, rather than reactively, manage their respiratory conditions and how they relate to AQ; improved forecasting abilities can help them make decisions beyond the current 1- to 2-day forecasts.

These data users are especially interested in wildfire smoke: When can we expect smoke from West Coast fires, for example, to reach the Great Plains? When can we expect AQ to improve?

These users are interested in understanding their exposure to ozone and volatile organic compounds.

Individual or Caretaker Managing Respiratory Disease

> *"Improved aerosol data would help us to predict and avoid costly asthma or COPD exacerbations."*
>
> —VP of Science and Research, Digital Health Platform Company

What are their technical needs?

These users want high spatiotemporal resolution data: spatial resolution less than 250 m and near real-time capture (needs that are currently satisfied by low-cost sensor networks). They need accurate AQ forecasts approximately 2 to 7 days out, which are informed by convective weather and precipitation data. They would like the ability to identify and understand the specific particulates that they might be exposed to, including $PM_{2.5}$, ultrafine particles such as PM 1, pollen, dust, and other types. They require AQ data at the surface-based level.

What would motivate them to use NASA EO data?

They would be motivated by having data that are easy to use and interpret (most likely incorporated in the AQ or health applications they currently use) and that provide actionable information beyond just a "red, yellow, green" type of app, for example, when might AQ improve in the next 3 days?

What are their adoption barriers for using NASA EO data?

These users have a low maturity level of employing NASA data products. Low-cost sensors are designed to be easy to set up and interpret by everyday users and may be preferred by these users.

What are they afraid of?

Accurate information about current and future AQ can play a significant role in managing an individual's health. Acute respiratory events may be unpleasant for the sufferer, could lead to significant health care costs, and may even be life altering or threatening. These users, however, tend to leverage multiple data sources and approaches for making health-related decisions.

What do they NOT care about?

These users typically only care about AQ observations and forecast models where they are currently located; real-time AQ sensors close to an individual's home can effectively work for them. However, to better understand additional locations where they work or travel and to appropriately forecast AQ, coverage over a large area is more important.

What are some key use cases?

- Individual or cohort monitoring

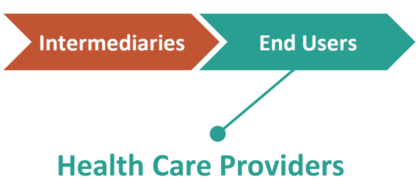
Health Care Providers

User Community:

Health and Pollution

Who are they?

Highly trained medical professionals who directly work with patients with respiratory issues. Includes family medicine and pediatric physicians and specialized respiratory experts. Their job requires diagnosing respiratory issues and helping patients manage symptoms of their disease effectively. They are patient advocates for resources from the health care network. They keep abreast of the latest research in respiratory health and are interested in personalized medicine.



Who do they work for?

Belong to health care network or private practice, ultimately interfacing with patients. These users answer to department heads, directors, and health care administrators. They are acutely aware of the link between AQ and hospital spending and understand that AQ crises can lead to an influx of patients needing acute respiratory care. They can be advocates of using new types of information for hospital administration, but they would need to show that adopting AQ data leads to a high return on investment in terms of fewer hospital visits.

Health care providers look to AQ information as data that can help them treat their patients more effectively.

What decisions are they making (and how) today?

These users may leverage AQ data to monitor health outcomes of a certain cohort. Physicians recommend using third-party AQ applications or digital health monitoring platforms, such as Propeller Health, to help their patients avoid circumstances that could trigger an acute attack. Understanding what these patients have been acutely exposed to, as well as what their baseline exposure to environmental pollutants is, may in the future help health care providers recommend courses of treatment that can better manage respiratory symptoms. Understanding potential hot spot areas could help providers proactively reach out to patients living in these areas to help them avoid potential health effects of pollution. Health care providers use AQ information as a data source to understand the health needs or trends that might occur in the next few days: for example, how might we prepare our urgent care facilities to deal with wildfire smoke?

Do they have experience with EO data?

They employ data via third-party, highly gridded, and processed sources and typically lack the capability to interpret data from satellite sources.

What do they care about?

These users are interested in regional or global coverage of data, especially in rural areas and developing regions where low-cost sensor networks are not abundant. These users would like better information on the types of particles an individual has been exposed to and how exposure may affect their treatment and health outcomes. Ultrafine particles are a specific and growing area of interest because there is a current gap in ground-based sensor technologies for detection. Health care providers are also interested in understanding how specific weather events, such as convective activity that leads to temperature inversions, may affect the way air pollution is dispersed. They recognize an important gap in understanding how natural disasters, such as tornados and hurricanes, may affect AQ. This information would help health care facilities better prepare for addressing any resulting health issues in the affected population. Accurate forecasts, which take into account weather data such as convective activity and precipitation, may help health care facilities (and their patients) plan appropriately for events that may trigger acute respiratory events. Health care facilities may be investing in means to anticipate health care demand from environmental factors in response to COVID-19. Health care administrators may adopt these data products in the next 5 years.

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Health Care Providers

> *"We suggest that patients with asthma, COPD, [and] other respiratory issues monitor their health with an air quality app."*
>
> —Family Physician, Lead of Respiratory Health Foundation

> *"We need better links to air quality and health. Satellite data with global coverage would be readily used for health applications."*
>
> —Clinical Researcher, Large University Healthcare System

> *"Combined data on weather, air quality, and pollen could provide patients with data about high-risk periods. This type of data could be used by health care facilities like urgent care and emergency departments so they might be ready for an increase in visits."*
>
> —Family Physician, Lead of Respiratory Health Foundation

What are their technical needs?

These users need real-time and forecast models to help them understand convective activity that may lead to temperature or atmospheric inversions. Forecasts of 2 to 7 days out would be helpful, especially in circumstances such as natural disasters. They require high spatial resolution less than 250 m and near real-time capture. Latency needs depend on whether a real-time AQ event is occurring. For example, when wildfire smoke comes through an area, data within the hour would be ideal. They want improved understanding of particulate type and amount of that certain particulate, including $PM_{2.5}$, dust, wildfire smoke, pollen, and especially PM 1, where there is a current gap. Global coverage of data, especially in rural areas where agricultural pollution is a growing challenge and health risk, is also a need.

What would motivate them to use NASA EO data?

They would be motivated by having data that are incorporated into a gridded, easy-to-interpret platform (such as a digital health platform).

What are their adoption barriers for using NASA EO data?

These users are more apt to use ground-based sensor networks, even though they are limited, because they offer readily available and ingestible products. Health care providers typically leverage freely available or low-cost data sources. Health care facility–wide use of data products is yet to happen. Although research has linked air pollution with health care costs, users must demonstrate that implementation reduces hospital admissions, ER visits, and health care costs.

What are they afraid of?

Health care providers fear a lack of adoption of tools to manage respiratory diseases, which ultimately puts some patients at risk for acute respiratory events. Although some individuals are early adopters of technology, some do not want to try new data sources to manage their symptoms. In addition, cost barriers may limit providers' ability to bring data products to patients. They may also fear current research gaps that limit their ability to readily use detailed AQ data.

What do they NOT care about?

These users do not care about resolution as much as patients and caretakers managing respiratory diseases—accurate observations of particle types and a patient's exposure are more interesting.

What are some key use cases?

- Individual and cohort monitoring
- Clinical decision support

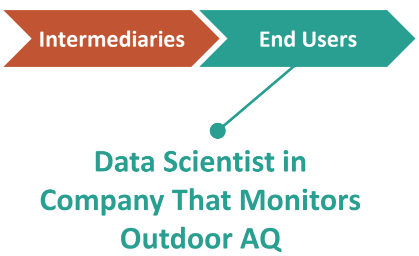
Data Scientist for Outdoor AQ Platform

User Community:

Health and Pollution

Who are they?

These companies are working to create AQ data sets that can help end users in a variety of industries, including health, make informed decisions. These individuals often have a background in geospatial or satellite-based systems and experience in integrating and modeling data.



Who do they work for?

These companies may create products for (1) individuals to monitor their own health, (2) clinicians and public health professionals to understand, address, and potentially mitigate pollution exposure, and (3) health care–related companies that may be interested in understanding unmet needs or health outcomes in certain areas. These users aggregate and create insights from these data.

Data scientists leverage AQ with additional environmental factors to create health-related insights.

What decisions are they making (and how) today?

These users incorporate multiple sources of data to help their customers create a link between AQ, additional environmental factors, and health outcomes. This information could help identify hot spots of poor AQ and unmet health care needs, help establish the relationships between AQ and specific health conditions or therapies (such as rescue inhaler use), and help users understand when to expect specific types of air pollution.

These companies are often platform based and meant to work across multiple industries, creating insights from multiple data sets. Many rely on ground-based satellite networks and use satellite-based data to help fill in the gaps missing in the sensor network. Modeling experts have mentioned use of MODIS, Deep Blue models, MISR, VIIRS, OMI, and TROPOMI and are ultimately looking to use data from the upcoming Tropospheric Emissions: Monitoring Pollution (TEMPO) mission, GIS Climate Model, and Planet Lab data.

Do they have experience with EO data?

Many are sophisticated users and can interpret and integrate satellite and nonsatellite data into their own models. Although they prefer data with some preprocessing steps, they can employ lower level data.

What do they care about?

These users value integration and colocation of data with other satellite data (weather data, light pollution data) and ground-based measurements such as wearables, phone accelerometers, and ground-based sensors over a time series. A large gap in satellite-based AQ data is the current inability of the air column data to directly correlate to surface-based $PM_{2.5}$ data; a satellite-based resource with global coverage could help address gaps in areas without ground-based data. These users would like high spatiotemporal data as well: users would ideally like to pull real-time air pollution data from anywhere around the world. Despite needing high temporal resolution, many users request data in specific locations over long time records, which helps create models and understand linkages between certain factors.

These users also care about data that are easy to find, pull, and incorporate into their existing platforms. Many companies are looking to incorporate ozone data and methane detection data.

Data Scientist in Company That Monitors Outdoor AQ

"There is currently no industry standard for data architecture. Lip service to fusion—being able to fuse terrestrial with space—based data. There are lots of sources of sensors, but a lack of leadership to integrate disparate sources. We need to do this before fusing aerosol data with health effects."

—CEO, Air Quality Insights Platform Company

"Improved data on air pollution, weather, pollen, and wildfire exposure would help us do research and develop support mechanisms (such as education, app features, exacerbation prediction models, alert notification systems for higher risk periods) for people with respiratory and sleep conditions. We typically examine $PM_{2.5}$, NO_2, SO_2, O_3, precipitation, visibility, temperature, wind and wind direction, and pressure."

—VP of Science and Research, Digital Health Platform Company

What are their technical needs?

They can accept weekly or even monthly data product updates at a spatial resolution of 250 m or less (ideally 50 to 100 m) and subhourly temporal resolution.

They need improved methods to distinguish between particulates, for example, incorporating a broader spectral range, from ultraviolet to infrared, and multiangle capabilities to better characterize aerosols.

These users need both short-term data observations and long, consistent data record (20 years) to help them link environmental exposure to health effects.

They need to incorporate weather data into forecast modeling.

They require cleaned, validated data sets with some preprocessing steps available predownload.

They need API calls that can handle high demand and incorporation of an ARC GIS layer to save time when pulling these data into their platforms.

What would motivate them to use NASA EO data?

They need data that are easy to incorporate into their platforms.

What are their adoption barriers for using NASA EO data?

Lack of surface-based $PM_{2.5}$ data limits the value of satellite-based data. Ground-based sensors, though limited in coverage, offer near real-time data sets at surface level.

What are they afraid of?

These companies often incorporate large data sets, so importing, cleaning, and ensuring quality and continuity of these data sets can be time consuming. Users are more inclined to adopt data sets that are already cleaned and validated.

What do they NOT care about?

Aerosol optical depth of the column are not a concern—surface-based measurements are more important.

What are some key use cases?

- Individual or cohort monitoring
- Environmental monitoring

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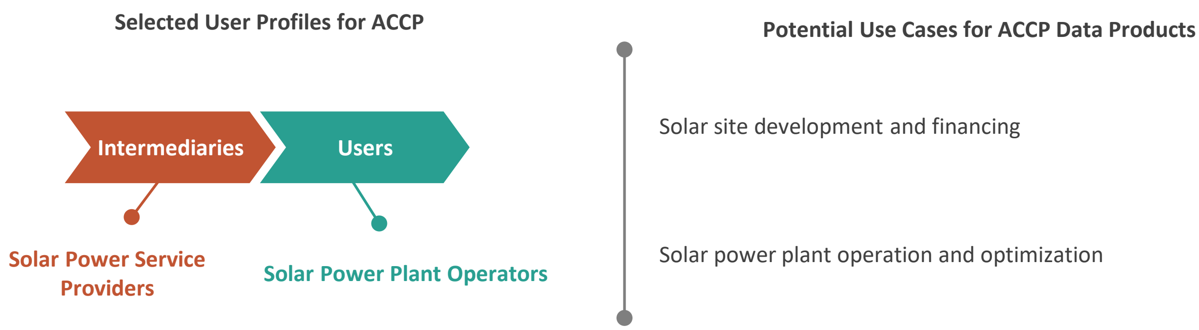
ACCP User Community Profiles

	Commercial Aviation
	Major Logistics Carriers
	Logistics Arms of Major Retail Brands
	Data-Driven Agriculture
	Food Companies Operating in Tropical Areas
	Health and Short-Term Air Quality Monitoring
	Solar Energy

Solar Energy

Community Overview

Solar energy is finally having its moment. After a decades-long introductory period, the U.S. solar energy industry is now experiencing rapid growth and adoption. Fueled by falling prices, low interest rates, regulatory incentives, and increased desire to invest in alternative energy sources, solar energy capacity in the United States has exploded from 2.6 gigawatts in 2010 to 97 gigawatts in 2020.[1,2] 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.[3] Energy utility companies are diversifying their energy production options by investing in solar power generation plant installations. Other companies are also investing in solar plants to place on their property and provide off-grid alternative energy sources, making them less dependent on fossil fuel sources from utilities. Still others are taking a more entrepreneurial approach, building solar plants and contracting with utility companies and others to deliver alternative energy to the power grid.



Moving Forward with ACCP

As utility companies expand the use of alternative energy sources such as solar, they need to have an accurate understanding of local conditions and their impacts on power generation. Similarly, the need increases to accurately predict power generation forecasts. Without this fundamental data, utility companies and plant operators risk overestimating the mix of solar power in their daily power generation plan.

Users in this community expressed a high level of interest in NASA's current and future data products. They seek a better understanding of the factors that affect irradiance levels at the solar panel surface, including cloud cover and its impact on shading, aerosol concentration and types, distribution in the vertical column, and deposition rates at the surface. Greater understanding of precipitation will help improve understanding of soiling conditions on the solar panels and provide information for determining optimal maintenance schedules for cleaning the panels. Models and forecasts can be enhanced using a combination of satellite- and ground-based sensing, and near real-time data from upcoming satellite observations and models could perhaps replace the need for expensive weather stations.

NASA's data products, the ability to interpret EO data in AQ and weather phenomena, and the ability to help this community integrate satellite- and ground-based data could have a tremendous influence on the long-term impact that solar energy delivers in the United States and beyond.

1. Solar Energy Industry Association. (2021, March 16). *Solar market insight report, 2020 year in review*. https://www.seia.org/research-resources/solar-market-insight-report-2020-year-review
2. Historical data from SEIA: https://www.seia.org/solar-industry-research-data
3. Investments 2010–2019, data from Statista: https://www.statista.com/statistics/186823/global-investment-in-solar-technology-since-2004/

Solar Energy

Organizational Assessment

The solar industry value chain comprises hardware and software manufacturers, service providers, financiers, and a variety of users. The hardware required for a solar installation includes solar panels; inverters to collect and distribute the energy; wiring; stationary or pivoting panel stands; and, in the case of larger plants, ground-based weather stations placed around the plant. Solar-specific software products are used to model and predict power generation, given current and forecast weather conditions, and to troubleshoot performance issues when actual power output is less than predicted.

This industry includes several types of participants and users, downstream of hardware and software manufacturing. **Site developers** seek out optimal site locations for solar power plants, then build a business case and seek funding, sometimes in the tens or hundreds of millions of dollars, to build the plant. Their ability to secure large amounts of funding relies primarily on historical and forecasted solar irradiance levels at that specific location. **Solar service providers** develop the models and tools used by site developers and operators in this industry, and they are eager to access improved data products that will enhance their models and lead to better predictions of energy output. **Solar plant operators** comprise energy utility companies, companies in other industries that opt to install a solar plant on their property, independent owners that sell their power output, and third-party operators who are hired to manage solar plants for others. All these operator types rely on software products and data from on-site weather stations to optimize operation of the plant. Solar plant operation is largely done remotely, where multiple solar plants are operated from a central command center. It is largely a “hands-off” operation. Plants are rarely visited in person. In-person visits occur either as a routine check or as a last resort when remote troubleshooting fails.

Users in this community make several types of decisions every day, each of them based primarily on weather and aerosol data. Examples include the following:

- When should we turn on the solar plant? How soon will the available irradiance reach our minimum threshold?
- What is the forecasted power output today, tomorrow?
- How much energy will we be able to produce to sell or consume?

When actual output is lower than predicted, even by 1%, this causes a great deal of concern. Lost revenue and potential penalty payments loom for plant operators. They ask questions such as the following: Why is our output lower? Is it a hardware performance issue? Is something external blocking our panels? Is something wrong in our models? How soon can we resolve it?

Solar Energy

Organizational Assessment (continued)

Solar energy production is entirely dependent on the available solar irradiance at any given plant at any given moment. Understanding the weather, aerosol loading, and cloudiness that will limit or reduce that solar irradiance is of extreme importance to members of this community. Thus, these users have a high level of familiarity with EO data, a high level of confidence in and familiarity with NASA data products, and abundant interest in collaborating with NASA in the future. The organizations interviewed in this project are interested 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. Better data products can improve predicted and actual power output from solar plants, effectively reducing the amount of unsustainable power generation required to satisfy electricity demand.

Data	Intermediaries	Users
Data for decision-making in this community come from satellite- and ground-based sources. Historical irradiance data generally come from geostationary sources satellite data sources, including NOAA's GOES and similar missions operated by other countries (e.g., EUMETSAT, Japan Meteorological Agency). Real-time irradiance, temperature, windspeed, and relative humidity conditions at a solar plant are monitored via weather stations placed at the plant.	Solar service providers develop the models and tools used by site developers and operators in this industry. They are actively developing improvements to models and forecasts. They are eager to access any data products that will improve their models and lead to better predictions of energy output.	Solar plant operators include energy utility companies, companies in other industries that opt to install a solar plant on their property, independent owners that sell their power output, and third-party operators that are hired to manage solar plants for others. These end users rely on software products from intermediaries and data from on-site weather stations to optimize operation of their plants.

RTI Innovation Advisors

Solar Energy

Technical Assessment

Users in the solar power community have an appreciation for, if not firsthand experience with, EO data. Weather and aerosol data from satellite sources are seen as a potential answer to many of the technical challenges facing this community. The solar power community anticipates that NASA's PoR and upcoming ACCP observations will provide high-fidelity data to satisfy their needs. This community uses models incorporating historical and forecast irradiance data to select sites and secure financing to build a solar power generation plant. Mean annual irradiance at a location is one of, if not, the most important variable in determining the financial feasibility of siting a new solar plant.

Once a solar plant is built, ground-based weather and AQ data are the primary sources of input for daily, even hourly, operational decision-making. Most solar power generation plants have one or more expensive weather stations set up on site to provide ground-based sensing of weather and AQ conditions. The phenomena most influential on solar panel performance are irradiation, ambient temperature, windspeed, and relative humidity. In addition, 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. Solar plant operators rely on these data for forecasting projected power generation on a daily and hourly basis. When actual power generation falls below the projected amount, these same data are used to troubleshoot the system and determine where and why performance is lacking.

Given the rapid expansion of solar power generation and the projected expansion in the near future, it is not surprising that users in this community have a high level of interest in more accurate and reliable data to use in selecting sites and operating plants and optimizing their energy production. Users in this community expressed a high level of interest in NASA's current and future data products. They seek a better understanding of all the contributors that affect irradiance levels at the solar panel surface, including various aerosol types and size distribution as well as cloud cover and its available irradiance. In addition, a greater understanding of precipitation (rainfall, snowfall, snowpack) can help improve understanding of soiling conditions on the solar panels. Models and forecasts could be enhanced using a combination of satellite- and ground-based sensing, and perhaps expensive weather stations could be replaced. Users expressed a desire for data with high spatial resolution (on the order of 1 km or less) so they can evaluate conditions at specific plants. If satellite-based data are to be used for real-time and short-term power forecasts, subhourly temporal resolution (ideally a 1-minute or 5-minute interval, delivered at 5-minute latency) is essential to understand irradiance and performance issues in a timely manner.

Users are interested in collaborating with NASA on developments to ground-truth satellite data and provide greater confidence in satellite data. Users in this community expressed a desire to easily access a variety of satellite data from different sources via API, streaming services, or standard formats, such as NetCDF or GRIB2.

Solar Energy

Technical Assessment (continued)

This community has a simultaneous need for long-term data for trend analyses and real-time data for global model forecasts for solar plants across the world. Examples of needs are summarized here and expanded on in the "Use Case" section.

Solar site development and financing—To secure financing to build a new solar power generation plant, historical irradiance data for the specific location are assessed. These data are converted to a future projection of irradiance that can be converted into power generation. Upwards of hundreds of millions of dollars are secured in financing based on these data.

Solar plant operation and optimization—Once a solar power generation plant is built, a deep understanding of the weather and aerosol conditions (vertical distribution, type, size distribution) at that plant are of high interest to the plant's owner, the (most likely remote) plant's operator, and the utility company (or other downstream customer) that expects to receive the power generated from the plant. Plant operators and service providers use complex models to understand real-time conditions and long-term forecasts and derive projections for power generation based on weather and aerosol conditions. As one 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 on how much fuel will be available and what type of performance should be expected."

Solar Energy

Use Cases

Within this community, users may leverage EO data in a range of use cases to enhance current and future decision-making capabilities. Two examples of use cases within this community are as follows:

- Solar site development and financing
- Solar site operational optimization

Solar site developers rely on historical irradiance data to select sites, estimate future revenue, develop a business case, and secure financing.

The rapid expansion of solar power generation plants has been fueled by lower hardware costs, improved panel performance, regulatory incentives, and low interest rates. The ability to secure tens to hundreds of millions of dollars in funding to build these plants is completely dependent on irradiance data, both historical and forecast. For historical data, typically a 20-year historical record of irradiance at the specific site is used. Historical data come from a variety of satellite data sources, including GOES (NOAA), Meteosat (the European Organization for the Exploitation of Meteorological Satellites [EUMETSAT]), and Himawari (Japan Meteorological Agency).

Long-term projections are built from historical data as well (e.g., using climatological data to project future irradiance levels). Those levels are converted to an estimate of gigawatt-hours of potential energy production per year, which is then converted to a revenue forecast. That revenue forecast provides the basis for calculating a return on investment and securing financing for construction of the plant.

Users in this community expressed a need for simpler and more expansive access to historical data. Specific geophysical variables of interest from a historical perspective, in addition to irradiance, include temperature, rainfall, and snow depth at the specific site of potential solar power generation plant. Further, these data are desired at a spatial resolution of 1 km or less to align with the footprint of a specific solar site and increase the accuracy of the data related to that particular site.

Solar plant operators are seeking ways to integrate satellite- and ground-based sensor data to optimize operation of specific plants.

For every solar power generation plant, there is an operator organization closely monitoring the plant in real time, most of which is done remotely. Plant operators are continuously looking for anomalies where actual power production performance diverges from the forecast. Some plant operator companies manage and monitor on the order of 1,000 solar plants. The continuous monitoring and desire for high accuracy are driven by concerns for lost power production and revenue. At some large solar plants, one percentage point of error in forecast accuracy correlates to millions of dollars in lost revenue and the potential for penalty payments for underdelivering expected power. Thus, users in this community have a strong interest in improving the accuracy of weather and aerosol forecasting and for gathering the best data available to understand and interpret real-time conditions. Users in this community currently rely on ground-based sensors for local conditions on irradiance, temperature, windspeed, and relative humidity. Typically, these data come from one or more expensive weather stations located on site at the solar plant. Users in this community have a strong interest in determining how satellite data could complement, perhaps even replace, ground-based sensors, leading to improved accuracy in real-time observation and forecasting of weather and aerosol conditions. In addition to weather (precipitation, cloudiness), these users have an increasing awareness and desire to better understand aerosol conditions (vertical distribution, type, particle size distributions). Unequivocal evidence indicates that aerosols affect the performance of solar plants both by blocking irradiance and soiling the plates. Users in this community would like data that:

- Increases accuracy in near real-time or subhourly observations of irradiance, cloud optical depth, aerosol optical depth (AOD), and particle size and type, leading to a better understanding of the actual irradiance reaching the solar panel
- Better predicts intermittent cloudiness over specific solar plants
- Brings understanding of when the conditions are right for generating solar power (e.g., how early in the morning to turn on inverters)
- Brings insight on soiling conditions at the panel: dust, other particles, aerosol type and size distribution, and snowpack are very localized conditions that affect panel soiling
- Enables access to more accurate, localized information that helps offset the costs of expensive on-ground weather stations
- Provides better longer range forecasts for precipitation

Having these types of data made available more frequently (subhourly, down to a 1-minute or 5-minute interval) and at a higher spatial resolution (less than 1 km) would improve real-time and forecasting models, ultimately improving the ability to predict and deliver solar power.

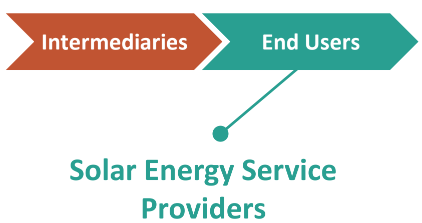
Solar Energy Service Providers

User Community:

Solar Energy

Who are they?

Solar energy service providers develop value-added models and forecasts of solar irradiance, which are used to develop and operate solar power generation plants. The results are essential for securing financing for new solar sites and for operating plants and optimizing their energy production.



Who do they work for?

They sell their data products to site developers, plant operators, utility companies, and investors who want to establish or optimize operation of a solar plant.

Solar energy service providers are active users of EO data, skilled at converting it to high value-added models and forecasts for solar power sites.

What decisions are they making (and how) today?

Solar energy providers use data to help them answer the following questions:

How can we improve our models? Where are there more accurate and reliable data sources?

How might we combine satellite- and ground-based data sources for improved accuracy and confidence levels?

Do they have experience with EO data?

Solar energy service providers regularly use EO data, such as AOD, to develop and enhance solar irradiance models and forecasts.

What do they care about?

These users need more data on aerosols, their vertical distributions and particle size distributions, and their impact on irradiance. They want a better understanding of suspended particles and their deposition rates, snowfall and snowpack, precipitation forecasts, and cloud cover. Each of these phenomena has an impact on solar irradiance and panel performance.

These users need better quality data in regions outside of North America and Europe (e.g., Middle East and Northern Africa, China), where AQ is not as good and ground-based weather stations are sparse.

These users want access to historical data (20 to 25 years) plus high confidence in long-term projections (forecasting ahead in similar time horizons).

Solar Energy Service Providers

> *"Satellite data are absolutely essential and by far the most important component of very short-term solar generation forecasts. Thank you for all you do to provide high quality and usable data."*
>
> —Grid Solutions Engineer, Private Research Organization

What are their technical needs?

These users need improved spatial resolution (less than 1 km) to assess conditions at a specific solar site. They want improved temporal resolution and latency so that data can be used and decisions made in near real time. For example, some derived products from GOES data, such as AOD, are important, but because latency is low, the data are not used for real-time forecasts. Cloud cover and other atmospheric variables affect solar power generation performance at a subhourly rate; thus, data that can help predict and monitor conditions at a similar rate and resolution are desired.

What would motivate them to use NASA EO data?

They already use NASA EO data. Users in this community have a high level of interest in collaborating with NASA, and some have collaborated with NASA in the past.

What are their adoption barriers for using NASA EO data?

They want easier access to data and the ability to access the data more quickly. They need common data formats to more easily integrate data from multiple sources.

What are they afraid of?

These users fear losing access to, or having interruptions of, long historical records of irradiance data, which is essential for site evaluation models.

What are some key use cases?

- Solar site development and financing
- Plant operation and optimization

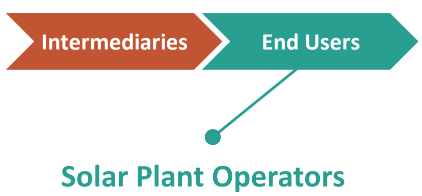
Solar Plant Operators

User Community:

Solar Energy

Who are they?

Solar plant operators include energy utility companies, companies in other industries that opt to install a solar power generation plant on their property, independent owners that sell their power output, and third-party operators who are hired to manage solar plants for others.



Who do they work for?

Utility companies, site developers, and companies with solar panels installed on their property are seeking firms to manage and optimize operation of their solar plants.

Plant operators rely on models and local weather stations to optimize the operation of their solar plants.

What decisions are they making (and how) today?

Data helps solar power operators with load balancing and supply demand balancing among traditional and renewable power generation assets. This data also helps them understand:

How much power can we generate from this plant today? How much power might we be able to generate based on a 3- to 5-day forecast?

How much power is being generated "behind the meter," meaning directly generated at a solar plant vs. pulling in from the grid?

Why is our actual production lower than forecast?

Why are our panels underperforming? Is there a technical issue? Is it a panel, inverter, tracker, or other hardware issue?

Are the panels dirty? Should we send someone to clean them or wait for the next rainstorm or wait for snow to melt?

Do they have experience with EO data?

Given the dependency on solar irradiance for successful plant operation, most of these users are familiar with and appreciative of EO data.

What do they care about?

These users need a better understanding of the actual irradiance reaching the solar panel and of when the conditions are right for generating solar power (e.g., how early in the morning to turn on inverters). They require better insight on soiling conditions at the panel: dust, other particles, aerosol size distribution, and snowpack are very localized conditions that affect panel soiling. Improvements in satellite data are needed to get more accurate localized information, which could help offset the costs of expensive on-ground weather stations. These users require better longer range forecasts for precipitation type and intensity. Bifacial (two-sided) solar panels are the newest technology being installed. Understanding albedo at the ground can help estimate upwelling irradiance that is able to reach the underside of the panel.

Solar Plant Operators

> *"We blindly trust data from weather stations. Accuracy always in doubt. The solar industry is relying on data that everyone has doubt about."*
>
> —Head of Analytics, Performance and Prediction, Solar Service Provider

What are their technical needs?

These users need subhourly temporal resolution (ideally a 1-minute or 5-minute interval, delivered at 5-minute latency) to help understand shading, intermittent cloud cover, and other irradiance and performance issues more quickly.

They also need improved spatial resolution for rainfall, snow depth, aerosol deposition, and cloud cover, which would allow plant-specific readings vs. averages across a large gridded area. Current gridded maps from NOAA are 10 km x 10 km, which is too big for accurate analyses.

What would motivate them to use NASA EO data?

They would use NASA EO data if they could more easily access historical data (e.g., global horizontal irradiance, temperature, rainfall, snow depth) for any location with improved spatial resolution. They require proof that satellite data are more accurate or reliable than ground-based weather station data. These stations are expensive, and many doubt the accuracy of their sensors, but to date they are the most common source of on-site weather information.

What are their adoption barriers for using NASA EO data?

Barriers include the lack of ease of access, global coverage, latency, and temporal resolution. They need the ability to use satellite data without massive computing power or data science expertise. They want to determine how to combine satellite- and ground-based data sets for a better understanding of local conditions.

What are they afraid of?

This user community is concerned with load imbalance penalties because when actual power output is lower than predicted, solar plant operators can incur penalty payments for underdelivering. They are also concerned about the accuracy of long-range irradiance forecasts and forecasts based on historical performance. They wonder what will change that disrupts future performance.

What are some key use cases?

- Solar site development and financing
- Solar site operation and optimization

Sections

1 Executive Summary

2 User Communities

3 **Analysis**

4 Recommendations

5 Appendix

User communities stated a variety of EO needs related to weather and AQ.

This table reflects the specific EO needs communicated by a representative selection of users within the specified user communities, and it is meant to be an illustrative, not exhaustive, representation of needs. RTI's interviews revealed that most user communities profiled actively incorporate CCP data (both satellite- and ground-based sources). Only the aviation, major logistics carriers, health and pollution, and solar energy communities actively apply satellite- or ground-based aerosol and AQ data for decision-making, but other communities demonstrated an interest in future data use for monitoring crops and managing the safety of employees who may be exposed to unhealthy AQ conditions.

User Community	Aerosol EO Needs	CCP EO Needs
Commercial Aviation	• Vertically resolved aerosol data, with a focus on volcanic ash and smoke • Incorporation of weather and aerosol data to improve modeling of ash and smoke plumes	• Finer scale observations of precipitation intensity and improved forecasts of precipitation intensity and type • Understanding of convective activity that may lead to turbulence • Improved observations of cloud layers with vertical resolution
Major Logistics Carriers	• Vertically resolved aerosol data, with a focus on volcanic ash and smoke • Incorporation of weather and aerosol data to improve modeling of ash and smoke plumes	• Accurate observed and forecasted precipitation, including type of precipitation (freezing drizzle, ice pellets, and hail) • Cloud ceilings and depths above 12,000 feet (14,000, 16,000, and 22,000 feet) • UAVs: precipitation, convection, wind in lower atmosphere (300 to 500 feet off the ground); accurate cloud ceiling readings in the lower atmosphere
Logistics Arms of Major Brands	• Surface-based $PM_{2.5}$ • Incorporation of weather and aerosol data to improve modeling of ash and smoke plumes	• Accurate observation of precipitation and forecasted prediction of precipitation, especially large weather events
Data-Driven Agriculture	• Surface-based $PM_{2.5}$, other particulates in future • Carbon dioxide, methane, ozone	• Accurate observations of precipitation—what has fallen and at what intensity • Conditions that may lead to temperature inversions, affecting product drift • Temperature, humidity, wind, leaf wetness
Food Companies Operating in Tropical Areas	• Improved observations of wind/aerosol relationship (e.g., Harmattan winds)	• Precipitation, humidity, wind speed, temperature, and fog data
Health and Short-Term Air Quality Monitoring	• Improved characterization of aerosol types—specific interest in wildfire smoke • Surface-based $PM_{2.5}$ and other particulates	• Understanding weather extremes such as convective activity and temperature inversions, which trap pollutants near the surface • Understanding of cloud-aerosol interactions—how precipitation, wind, and humidity affect deposition and dissemination of particles
Solar Energy	• Aerosol particle type • Aerosol size distributions and vertical profile	• Accurate observed and forecasted precipitation (including precipitation type, snowpack) • Improved understanding of intermittent cloud cover

Certain geophysical variables and observations have the potential to affect multiple user communities.

Interviews and focus groups across seven communities led to expression of common data needs for both aerosols and CCP observations. The tables spanning the next several pages describe several geophysical variables and observations that provide value to multiple communities. Potential data products related to these observations have the potential to deliver wide-ranging impacts across the communities explored.

Observed precipitation (including intensity and type) can increase NASA's impact in almost all ACCP user communities explored. In addition, users in the data-driven agriculture, food and beverage, and health and pollution communities specifically mentioned a desire to better understand and forecast conditions that may lead to temperature inversions. Temperature or atmospheric inversions are a specific weather phenomenon where a mass of cooler air gets trapped under a layer of warmer air. This weather phenomenon may lead to trapping of aerosols including pesticides, herbicides, and PM. Improving weather and AQ modeling of the conditions that lead to temperature inversions and the associated development of fog or trapping of pollutants can help a wide range of users make decisions relevant to spray coverage or particulate exposure.

Observation/ Phenomena	Use Case	User Community	Needs	Better Data Enable
Precipitation	Effective application of agricultural inputs; mitigation of pest and plant disease; site similarity analysis	Data-Driven Agriculture	Type and intensity of precipitation	Informed agricultural practices and, ultimately, improved yields
	Monitoring global weather trends; monitoring micro weather trends	Food Companies Operating in Tropical Areas	Type and intensity of precipitation, snowpack	Informed assessment of crop yield and risks, insights to forecast quality and pricing of goods
	International flight planning; fog forecasting; safe flying conditions for UAVs	Commercial Aviation Major Logistics Carriers	Type of precipitation	Safer takeoff and landing, route planning
	Plant operation and optimization	Solar Energy	Type and intensity of precipitation, snowpack	More accurate assessment of solar panel soiling conditions and associated performance loss, when to manually clean panels
	Allocating resources for business continuity	Logistics Arms of Major Brands	Higher resolution, type of precipitation	More accurate knowledge of facilities affected by flooding and storms
Temperature Inversions	Effective application of farm inputs (fertilizers, pesticides)	Data-Driven Agriculture	Identification of temperature, wind, and convection properties that lead to inversions	Safer and more efficient use of strong agrochemicals
	Individual and cohort monitoring, clinical decision support, environmental monitoring	Health and Short-Term Air Quality Monitoring	Identification of temperature, wind, and convection properties that lead to inversions	Better understanding of particulate exposure and dissemination
	Monitoring micro weather trends	Food Companies Operating in Tropical Areas	Surface temperatures	Understanding and reaction to conditions that may lead to cooler surface temperature

Aviation and logistics communities value improved data on low clouds, convective activity, and wind to understand impacts on operations.

Aviation and air-based logistics users value "3D cloud data," especially vertically resolved data that informs them of conditions at multiple altitudes. Convective and wind data may also enable surface-based measurements that help these communities react to potentially damaging storms for both flight and ground-based operations. As shown in the table below, the impacts of these improvements extend from improved on-time flight departures to safer, more comfortable airline travel for transoceanic passengers to enabling new modes of transportation and logistics, such as UAV deliveries and VTOL air taxis.

Observation/ Phenomena	Use Case	User Community	Needs	Better Data Enable
Low Clouds	Forecasting fog	Commercial Aviation Major Logistics Carriers	Data on cloud layers above 12 k feet (14, 16, 22 k feet)	More accurate prediction of fog burn-off times; fewer delays; safer takeoffs and landings
	Determining safe flying conditions for UAVs	Commercial Aviation Major Logistics Carriers	Accurate cloud ceiling information	Ability for UAV operators to fly 500 feet below the cloud ceiling (per FAA regulations)
	Site similarity analysis of crops	Data-driven Agriculture	Observed and forecasted cloud cover	Improved understanding of potential impacts to photosynthetic activity
	Solar site operational optimization	Solar Energy	Observed and forecasted cloud cover	Improved understanding of factors impacting solar irradiance at the solar panel surface
Improved Convective Storm Systems	Mitigating turbulence; Executing international flights across oceans	Commercial Aviation Major Logistics Carriers	Vertical information about and improved forecasts of convective hazards	Safer and more comfortable flights; reduced disruption to flight schedules; reduced congestion in airspace; reduced waste of jet fuel
	Determining safe flying conditions for UAVs; Urban air mobility models	Commercial Aviation Major Logistics Carriers	Data on convective activity happening in lower atmosphere	Safe and informed operation of UAVs and VTOL air taxis
	Allocating resources for business continuity; Identifying disruptions in supply chains: Monitoring global weather conditions	Logistics Arms of Major Brands	Improved forecasts of severe weather	More efficient use of resources and mitigation practices
	Mitigation of plant pests and disease	Data-driven Agriculture	High-resolution data on damaging storms (like hailstorms) that may damage crops	Ability for growers to proactively protect their crops, or harvest their crops early
Wind	Mitigating turbulence; Executing international flights across oceans	Commercial Aviation Major Logistics Carriers	Speed and direction of surface winds and winds at multiple altitudes	Avoidance of wind shear; safe ground operations and parcel unloading
	Determining safe flying conditions for UAVs; Urban air mobility models	Commercial Aviation Major Logistics Carriers	Surface winds and winds in the lower atmosphere	Safe and informed operation of UAVs and VTOL air taxis (wind may cause battery drain on small craft)
	Monitoring microclimate conditions; Effective application of crop inputs; Pest and disease mitigation	Food Companies Operating in Tropical Areas Data-Driven Agriculture	Speed and direction of surface winds	Cost-effective input application; improved planning for harvesting and drying conditions

Users need to know what types of aerosols are in a specific column of air, as well as vertical distribution.

Use for aerosol data across user communities has been driven in part by pollution and more frequent disasters, such as wildfires. Though not current users of this data, the data-driven agriculture and logistics arms of major brands communities both expressed needs to better understand and eventually incorporate aerosol data to mitigate impacts of pollution. Improved abilities to characterize these particles will inform response to particulate exposure; multiple users demonstrated special interest in ultrafine particles, wildfire smoke, and other particles. Many users need measurements of this data at specific altitudes, often surface based (e.g., where people, crops, and solar panels are located) but also to understand the height of smoke and volcanic ash plumes.

Observation/ Phenomena	Use Case	User Community	Needs	Better Data Enable
Aerosol Types	Individual and cohort monitoring; Clinical decision support; Environmental monitoring	Health and Short-Term Air Quality Monitoring	Global coverage; high spatiotemporal resolution; characterization of pollen, dust, and ultrafine particles	Understanding of health outcomes as a result of exposure; improved patient care
	Solar plant operation and optimization	Solar Energy	Deeper understanding of how aerosol types, sizes, and distribution impact solar irradiation at the panel surface	Improved models for more accurate power generation forecasts and real-time monitoring of performance
	Monitoring crop quality through AQ	Data-Driven Agriculture	Global coverage of agricultural areas, especially coverage in tropical areas	Enhanced ability to react to AQ events that might impact crop health
	Volcanic ash and wildfire smoke detection	Commercial Aviation Major Logistics Carriers	Interest in smoke and volcanic ash, vertical resolution	Awareness of what aerosols may impact a flight path
Vertical Resolution of Aerosols (Including Surface $PM_{2.5}$)	Volcanic ash and wildfire smoke detection	Commercial Aviation Major Logistics Carriers	Improved accuracy in modeling of ash plumes; ash and smoke concentrations	Fewer flight cancellations and disruptions due to volcanic and wildfire activity; reduced risk of damage to aircraft engines
	Individual and cohort monitoring; Clinical decision support; Environmental monitoring	Health and Short-Term Air Quality Monitoring	Lack of surface-based $PM_{2.5}$ coverage (current solutions include ground-based monitor networks, inferring from satellite using atmospheric models)	Improved understanding of an individual or population's exposure to aerosols
	Solar plant operation and optimization	Solar Energy	Deeper understanding of how aerosol types, sizes, distribution impact solar irradiance at the panel surface	Improved models for more accurate power generation forecasts and real-time monitoring of performance
	Allocating resources for business continuity	Logistics Arms of Major Brands	Surface-based $PM_{2.5}$ and other particulates	Ability to limit ground-based transportation and dock activities during AQ crises

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Colocation of ACCP data may provide a significant impact to AQ forecasting.

Characterizing aerosol type and distribution across a column of air will help user communities understand exposure at a specific time interval. Colocation of ACCP data provides an opportunity to investigate the relationship between weather and AQ and, ultimately, create improved forecasting models. These observations will help users understand when they might expect impacts of wildfire smoke or ash cloud, how it may dissipate through an area, and how precipitation may lead to deposition of particulates.

Observation/ Phenomena	Use Case	User Community	Needs	Better Data Enable
Colocated Aerosol and Weather Data	Individual health monitoring	Health and Short-Term Air Quality Monitoring	Forecasting capabilities: When to expect surface-layer aerosols (like wildfire smoke)	Avoidance of potentially harmful particulate exposure, reduced health care costs
	Allocating resources for business continuity	Logistics Arms of Major Brands	Forecasting capabilities: When to expect surface-layer aerosols (like wildfire smoke)	Ability to limit ground-based transportation and dock activities during AQ events
	Monitoring crop quality using AQ data	Data-Driven Agriculture	Forecasting capabilities: When to expect surface-layer aerosols (like wildfire smoke)	Proactive means to protect crops from wildfire smoke and other AQ hazards
	Solar site development, solar plant operation and optimization	Solar Energy	Increased use of satellite-based data instead of, or in combination with, ground-based sensing	More accurate assessment of sites for future solar plants, more accurate forecasting for power generation from each power plant, greater reliance on this clean energy source
	Volcanic ash and wildfire monitoring	Commercial Aviation Major Logistics Carriers	Improved accuracy in modeling of ash plumes and ash and smoke concentrations	Fewer flight cancellations and disruptions due to volcanic and wildfire activity, reduced risk of damage to aircraft engines

Improved data can help ACCP user communities proactively plan for and react to climate change.

Changes in weather patterns and climate affect decision-making in the ACCP user communities:

- Growers, ingredient buyers, input companies, food and beverage companies, and crisis and supply chain managers are actively monitoring changes in growing conditions for various crops. These communities noted detailed long-term outlooks (~3 months out) as a key data need. Trends in the growing season (first frost dates, growing degree days, average forecasted precipitation) can help inform site suitability for crops, seed varieties, planting/harvesting times, crop investments, and contract/commodity pricing. An active area of research is establishing the link between air pollution and crop health and quality.
- Meteorologists in commercial aviation and air-based logistics, as well as ground-based logistics for major brands, must keep apprised of and react to natural disasters such as hurricanes, wildfires, and volcanic eruptions. These weather phenomena may become more frequent or intense in a warming climate. Appropriate forecasting can ensure continuity of operations and safety of customers, employees, and facilities.
- Weather and AQ outlooks play an important role in appropriate solar plant siting, management, and operations. Historical irradiance data for a specific location are used to project long-term future irradiance forecasts. Climate change increases uncertainties in projections of future weather cycles and elevates the frequency of forest fires, both of which complicate siting and management of solar sites. More robust models for long-term forecasting and real-time performance modeling of solar plants can help accelerate the adoption of solar as a mainstream energy production source.
- Industrial pollution, fossil fuel combustion, and other activities that have contributed to climate change also have affected global AQ, leading to unhealthy levels of pollution. Likewise, rising temperatures have led to increased wildfire activity that releases harmful smoke. Understanding AQ trends at a global level helps the health care and regulatory communities identify and react to poor AQ hot spots and ultimately helps health care professionals treat patients more effectively in light of their pollution exposure.

Along with accurate forecast capabilities over a variety of time frames (from daily to hourly, weekly, seasonal, yearly, and decadal forecast outlooks), accurate and long-term records of observed precipitation and AQ are good indicators of changing climate patterns.

"The impacts of climate change on coffee crops is a big concern. There are pessimistic predictions that in 15 years Brazil will not be able to produce coffee anymore due to climate change. The big coffee companies—Unilever, Nestle, Keurig Dr Pepper—have internal research teams working on this issue."

—Quality Control Manager, Coffee Company

"I would also like more information on air quality around disasters—tornadoes, hurricanes, earthquakes. The air quality consequences are often ignored."

—Family Practitioner and Lead of Respiratory Health Professional Organization

Communities had similar desires for spatial and temporal resolution, while forecasting and latency varied.

This table reflects specific technical specifications communicated by a representative selection of users within the ACCP user communities, and it is meant to be an illustrative, not exhaustive, representation of needs. These communities shared spatial resolution needs that were less than 1 km and subhourly temporal resolution. While the solar, aviation, and major logistics carriers expressed needs for consistent low latency, down to a few minutes, other communities were comfortable with longer latency times or quick data delivery only in certain circumstances. Most users expressed needs for global coverage.

Community	Spatial Resolution	Forecasting	Temporal Resolution	Latency	Coverage
Commercial Aviation	• 500 m–1 km outside of urban areas • 10–100s of meters in urban areas	• 3–4 hours for domestic flights • 12–14 hours for international flights • 2–3 days for large weather events	Subhourly (to the minutes)	ASAP—few minutes	Coverage especially across oceans (even 15- to 30-minute-old data would be helpful there)
Major Logistics Carriers	• 500 m–1 km outside of urban areas • 10–100s of meters in urban areas	• 3–4 hours for domestic flights • 12–14 hours for international flights • 2–3 days for large weather events	Subhourly (to the minutes)	ASAP—few minutes	Global (overseas too), especially in areas of high latitude (Alaska)
Logistics Arms of Major Brands	<1 km	• 24–48 hours' notice for day-to-day weather • 3–7 days for natural disasters	Subhourly	ASAP—few minutes	Global coverage
Data-Driven Agriculture	10 km acceptable, ideally <1 km	• 1–2 days • 7–14 days • 3-month seasonal forecast	• Subhourly for field management • Daily or weekly for financial products	30 minutes–3 hours for 24-hour data set	Global coverage, especially in tropical areas
Food Companies Operating in Tropical Areas	1–2 km	• 1–2 days • 7–14 days • 12–18 months long-term forecast	Subhourly	ASAP during key times of growing seasons	Global coverage
Health and Short-Term Air Quality Monitoring[1]	250 m or less (50–100 m)	2–7 days in advance for large AQ events	Subhourly	Data within the hour	Global coverage—especially in rural areas and developing economies
Solar Energy	<1 km	3- to 5-day forecast	Subhourly (1- to 5-minute intervals). Noted specific need for predawn data	ASAP—1–5 minutes from data capture	Long data histories (20+ years)

1. Note that the greater health community is investigating long-term exposure, from months to years to decades.

Global coverage and forecasting of ACCP data sources is a common need across user communities.

High-quality, high spatiotemporal data sources for weather and AQ exist but are often limited to North America and Europe. Consistent levels of coverage are desired worldwide.

Four of seven user communities profiled intersect with the global agriculture/food/logistics supply chain, which spans multiple continents. Private-sector demand for key commodities and crops often depends on smallholder farmers and cooperatives in tropical regions and areas in developing economies. ACCP data may be able to make the most impact as freely available data to smallholder advisory services and agricultural insights firms working in tropical areas and developing economies.

Convective storm and weather data coverage across oceans is a large need for aviation and air-based logistics companies. Current data products are low resolution and high latency; even data with a 30-minute latency can help meteorologists make decisions that help transoceanic flight routes avoid dangerous storms or fuel emergencies from long reroutes.

"70% of cocoa comes from West Africa, mostly smallholder farmers. It's more of an art vs. science to understand what's happening there."

—Commodity and Risk Management Executive, Ingredient Company

"Improved data on hazardous weather in remote oceanic environments would help me make decisions about safe and efficient pre-route planning and tactical adjustment while en route."

—Meteorologist, Major Airline Company

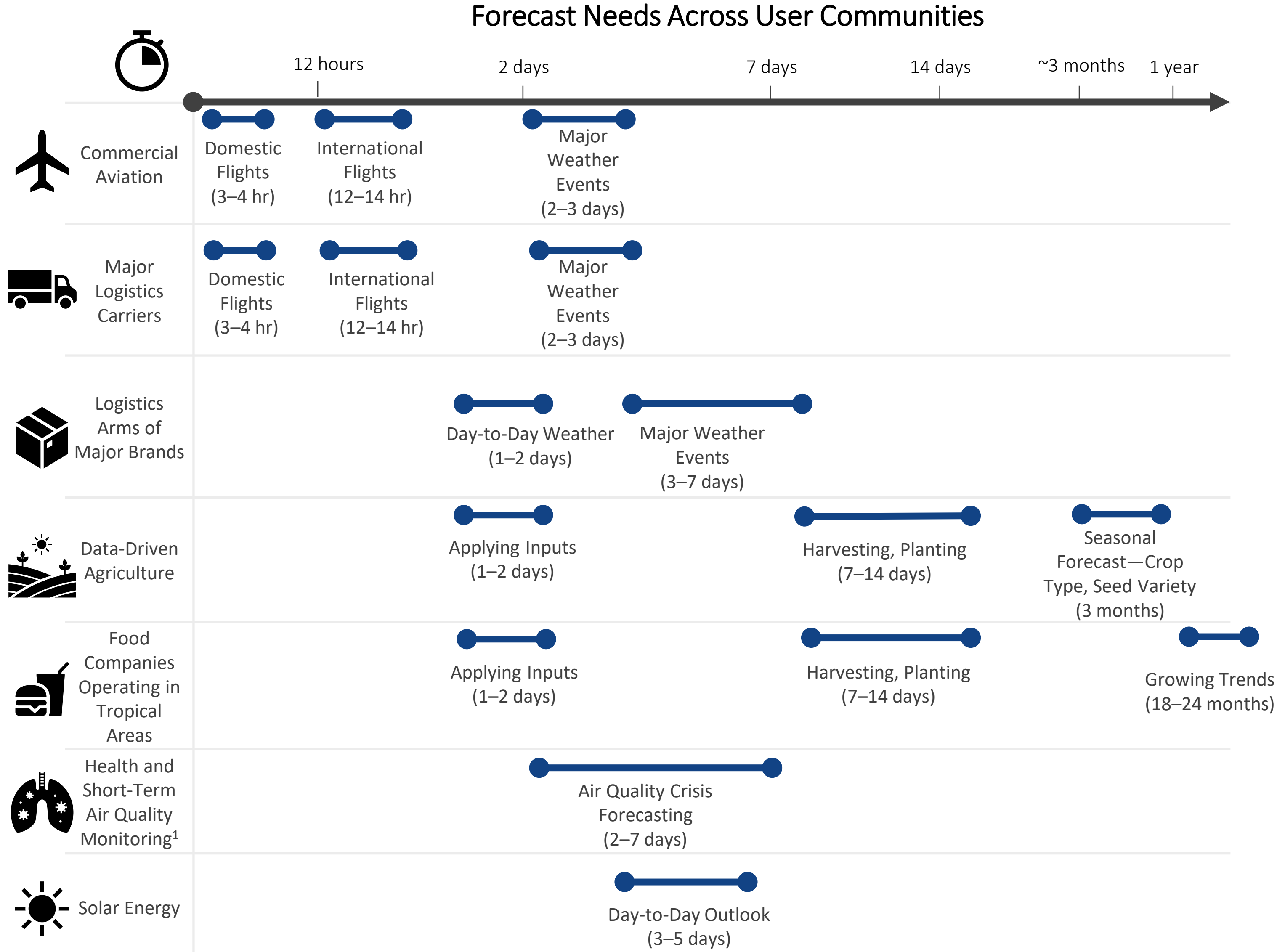
Satellite-based weather and AQ observations may be used to augment— not replace—ground-based data.

- In areas where ground-based weather and AQ provide high-resolution, near real-time data coverage, satellite data can be leveraged to help fill in the gaps. Conversely, ground-based measurements can be used for ground-truthing satellite data, ultimately improving the accuracy of remote sensing observations.
- For example, while ground-based AQ sensors can provide near real-time, ground-based readings for a particular area (such as an individual's house or block), very few ground-based networks in rural areas or in developing economies may be affected by agricultural and industrial pollution. Satellite-based AQ products represent an opportunity to understand global areas of AQ concern and may inform where to put ground-based sensors for more high-resolution, real-time monitoring.
- Users across these communities (such as the health and short-term AQ monitoring and solar communities) expressed the need for ground-truthing and suggested related R&D projects as a means of engaging with NASA and ACCP data.

Forecasting needs are universally important, although specific time frames vary across communities.

- Communities demonstrating needs for convection, cloud, and precipitation data desired longer range forecasting (weeks to months) because the accuracy of current weather models drops off after 7 to 14 days.
- While the food companies and data-driven agriculture community demonstrated needs for the furthest range forecasting (3 to 18 months), solar energy, aviation, and air-based logistics demonstrated needs for forecasting out to days and hours. Latency time needs are naturally shorter for these communities.
- Users expressed a desire for development of probabilistic, rather than deterministic, forecasts that help end users manage both risks and data uncertainty.
- Interviewees noted that the accuracy of current aerosol and AQ forecasting models decreases after 2 days. AQ forecasting capabilities out to a week would be valuable.

Forecast Needs Across User Communities



1. Note that the greater health community is investigating long-term exposure, from months to years to decades.

Data accessibility, interoperability, and ease of integration bring value across user communities.

Users consistently expressed a need for improved data accessibility, interoperability, and ease of integration. These improvements play key roles in enhancing the perceived value of satellite data products. Common themes for data formats included the following:

- **Easy-to-find data sets** labeled with clearly conveyed potential value for certain user communities, such as data-driven agriculture.
- Availability of **ground-based data sources with satellite-based data sources** (e.g., ground-based AQ sensor networks and satellite-based aerosol data) for integration and ground-truthing purposes.
- **Standardization in data formats**, data structure, and documentation properties to reduce errors or slowdowns in data flow that require manually pulling over data.
- **Data reliability**—High-quality data that are consistently delivered and accurate.
- **Data set flexibility**—The ability to pull the necessary data and leave behind the unnecessary data, for example, pulling 30 days of a specific geophysical variable or observable without having to download 30 discrete data sets.
- **Appropriate channels to easily move bulk data** into the end users' systems, such as API/FTP sites.
- EO data sets that are **aligned temporally and spatially**, such as IMERG and MODIS data products, that would make cross-sensor calibration and atmospheric correction simpler and facilitate the introduction of new EO data (such as synthetic aperture radar data). The data-driven agriculture community and health and pollution user community requested colocation of multiple NASA data products across specific locations, such as soil moisture and light data, in one location.
- Users would like **clearly labeled** data values and **accuracy checks** or clearly defined error rates in databases so that they do not need to source this information from relevant papers.

"Data format can be a time suck—up to 80% of the work can be taking what you want from the data set."

—Data Scientist, Agricultural Decision-Making Platform Owned by Agrochemical Company

"When there are changes to how a file is named, file formats, or documentation, it slows down our ability to provide daily data updates to our customers."

—Data Scientist, Agricultural Decision-Making Platform

"We are always looking for better ways to provide value to our customers, often just knowing what is available from NASA is the hardest part."

—Senior Vice President, Weather Insights Company

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Data users prefer gridded, processed data sets, although formats and accessibility needs vary by community.

For data scientists directly incorporating data products, "no cost" data are not necessarily "free data"; it requires time to clean, 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 cleaning data products. "Easy-to-use" data may mean different things to different user communities. The table lists examples of needs expressed by a selection of users in these communities.

Preference for gridded data sets was consistent across user communities, even across users who have the technical capability to work with low-level data products. Users who identified as value-added service providers or intermediaries, or those who create tools and provide services to clients that make decisions for their organizations, often had more comfort in using low-level products than end users.

Community	Preferred Data Formats and Accessibility Needs	Preferred Levels of Data Products
Commercial Aviation	• Data delivered in packages that can be delivered to pilots in-air via Wi-Fi (bandwidth challenges)	**Meteorologists** prefer gridded data sets (level 3/4) but are comfortable working with lower level data products. **Pilots and chief operations officers** prefer gridded data sets (level 3/4).
Major Logistics Carriers	• Easy to incorporate into existing model, reports, and systems (METAR reports, script-based communication systems)	**Meteorologists and data scientists** in weather companies prefer gridded data sets (level 3/4) but are comfortable working with lower level data products.
Logistics Arms of Major Brands	• Data that are gridded, easy to interpret • Flexibility in data sources to avoid pulling in unnecessary data	**Crisis managers** prefer gridded and highly visual data (levels 3/4), **data scientists** in weather companies are comfortable working with lower level data products.
Data-Driven Agriculture	• Zarr, NetCDF, TIF format • Temporally and spatially aligned (for cross-sensor calibration and atmospheric correction) • Data accessibility through the cloud • Improved documentation	Spatiotemporally aligned data sets are especially interesting to **data scientists in agriculture platforms**. Gridded data are helpful, but they can work with low-level data. **Growers** prefer gridded, highly visual data sets (level 3/4). **Smallholder advisory data scientists** typically need data with some preprocessing; gridded data (level 3/4) are ideal for most applications, but for insurance purposes, level 2 data are desired.
Food Companies Operating in Tropical Areas	• Desire for standardized formats across agencies, countries • NetCDF, TIF are common formats • Data that are easy to interpret	**Tropical ingredient buyers** and **food product manufacturers** prefer gridded data sources (levels 3/4).
Health and Short-Term Air Quality Monitoring	• Colocated data for a specific area, with surface-based data products as well • Cleaned, validated data set with preprocessing steps available before download.	The **individual or caretaker, as well as health care providers,** require highly visual, gridded (level 4) data. **Data scientists in outdoor air insights companies** prefer data that are gridded and have some preprocessing steps (level 3/4), but they can work with lower level data.
Solar Energy	• Means to access data quickly, such as API, or stream selected data to users via map selections • Easier way to align grids from different data sets • NetCDF, GRIB2 are common formats	**Solar site service providers** tend to use level 2/3 data in their models. **Solar plant operators** prefer gridded data sources (levels 3/4).

Sections

ACCP private-sector engagement should start with understanding data needs and partnering with professional organizations.

Focus group participants across all user communities consistently demonstrated interest in engaging with NASA and were eager to address key industry needs. Users offered a variety of potential engagement methods, which differ in levels of effort for both ACCP and industry collaborators.

ACCP could leverage private-sector stakeholders as "industry advisors" to provide consistent feedback on data product application and value across user communities.

NASA could lean on "industry advisors" to help it 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.

> *"I'd like to collaborate with NASA to provide context in air quality measurements and appropriateness on how to use the data."*
> –Senior Scientist, Environmental Consulting Company Monitoring Air Quality

> *"I'd like to collaborate with NASA to determine the value of certain data sets and their applicability to our markets including agriculture."*
> –Senior Vice President, Weather Insights Company

ACCP could tap into existing professional industry networks and research organizations to understand needs and communicate data product value.

Plugging into professional networks can help NASA directly engage with data users; gauge their level of knowledge and interest in data products; and, ultimately, disseminate data products. Many technology-focused groups, such as Airlines for America, value continuous improvement and often include potential early adopters.

> *"It might be good to partner with A4A and allow for a broad-based approach so that we can agree as an industry or argue the case for specific directions."*
> —Meteorologist, Major Airline Carrier

> *"NASA could leverage focus groups, industry meetings, and conversations with users to keep their finger on the pulse and understand potential needs and value."*
> —Meteorologist, Major Logistics Firm

> *"Focus groups like this are fine, working groups on data standards/ documentation are also good; they can help [with] connecting private company needs with public."*
> —Data Scientist, Agricultural Platform

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Strategic engagement can help ACCP convey value to nontraditional user communities and drive R&D with societal impact.

ACCP could create easy-to-interpret products and training opportunities that could help users understand the potential value of NASA data.

User-centered training modules and gridded, processed data products can help users understand how ACCP data could affect them. Targeting marketing and training toward less sophisticated users could help expand the use of NASA EO data and improve discoverability of these data sources by more sophisticated users.

"We could collaborate with NASA to help growers understand weather and climate impacts through use of NASA data."

—Scientist, Agricultural Platform Company

"Making the hard-core science more approachable for public consumption and use in improving [the] public's quality of life is key to future success of programs."

—Commodity and Risk Management Executive, Ingredient Company

"Think like an entrepreneur—show value, explain access, case studies."

—Commodity and Risk Management Executive, Ingredient Company

NASA could engage with industry data users via R&D partnerships that may ultimately lead to development of operational data products that address community needs.

R&D projects executed by the user community, in conjunction with NASA support and data resources, could help create products that solve current gaps. The solar energy user community demonstrated significant interest in ground-truthing and forecast improvements.

"I'd like to collaborate by vertically partitioning aerosol and cloud optical depth to improve cloud advection forecasts."

—Consultant, Solar Power Plant Siting

"I'd like to work with NASA to improve the data quality and make it friendly for data analytics, and to improve the quality of historical satellite images (for selected areas) through comparative studies."

—Data Scientist, Weather Insights Company

"I'd like to collaborate by helping ground truth satellite models (now!) and improve the geographic granularity of irradiance forecasts (one to two years)."

—Performance Data Analyst, Solar Energy Operator

Industry partners could serve as connectors to amplify the impact of ACCP data products.

ACCP could leverage innovation ecosystem stakeholders supported by corporate initiatives, such as incubators and hackathon communities.

Companies often support entrepreneurship communities to keep their finger on the pulse of innovative data uses. These stakeholders often rely on freely available data sources and may serve as a channel to understand the value and applications of these data products to certain communities.

"I'd like to collaborate with NASA to extend the community of practice to entrepreneurs and innovators."

—Lead, Agricultural Insights Platform

"I'd like to collaborate with NASA to help commercialize or look at funding/subscription/interest for future application development—connect science with real market need."

—Commodity and Risk Management Executive, Ingredient Company

ACCP users want to collaborate with NASA; some are "right and ready" for near-term engagement.

- The solar energy user community demonstrated a readiness for collaboration, and almost every engagement suggestion was an R&D project opportunity. Validating satellite data, improving soiling and solar irradiance models, and enhancing granularity of forecasts were noted as major opportunities for collaboration. Engagement in the next 5 years aligns well with the developing solar and solar plus storage market.
- Because the health community requires additional research to understand the impacts of specific aerosol species and health outcomes, their engagement strategies mostly centered around engagement with federal environmental health agencies.
- The aviation community, while equipped with the technical capabilities and professional organizations to facilitate collaboration, is currently limited by tight budgets as a result of the COVID-19 pandemic. These users have much in common with users in air-based logistics firms, who might have more bandwidth and resources to collaborate sooner.
- The food and data-driven agriculture communities, eager to incorporate new data sources, can leverage a world of agritech entrepreneurship and food security innovations.

"It would be ideal to have NASA work with National Institute of Environmental Health Sciences (NIEHS) on encouraging use of NASA data sources in proposed research. You might be surprised how much of this happens through 'nudging' to commit to such programs."

—Environmental Health Expert

"Interest in 'early-adopter' [is] highly dependent on financial stability of the airline. We have ZERO resources currently to commit to such programs."

—Meteorologist, Major Airline Carrier

Value-added service providers and intermediaries serve as the highest potential engagement partners for ACCP.

- Although high-maturity users, such as airline and air-based logistics meteorologists, and solar power service providers can easily create meaning out of level 1 to 2 data, they often rely on value-added service providers to integrate many disparate sources and develop insights that are easily incorporated into community-specific solutions.
- Many value-added service providers serve multiple industry types and are acutely aware of their needs. Engagement via value-added service providers could amplify the use and impact of ACCP data products.

Representatives from each user community indicated interest in a variety of engagement approaches.

Focus group participants across user communities consistently demonstrated interest and eagerness to address key industry needs through NASA engagement. Users offered a variety of potential engagement methods, which differ in levels of effort for both ACCP and industry collaborators. Although not indicative of the entire community, the selection of users we interviewed demonstrated interest in the following engagement strategies:

	Engagement Strategies						
Community	Industry Advisors	Professional Networks	User-Centered Training and Data Products	Industry R&D Projects	Entrepreneurship Community Engagement	Value-Added Service Provider	Recommendations
Commercial Aviation	●	●				●	Plug into industry associations such as Airlines for America and engage through air-based major logistics carriers because the industry currently has limited bandwidth.
Major Logistics Carriers		●		●		●	Leverage professional networks to jointly benefit aviation and air-based logistics users (latter have more bandwidth). Capitalize on rapidly growing UAV and VTOL industry through R&D opportunities.
Logistics Arms of Major Brands			●			●	Leverage value-added service providers for impact across multiple user communities and demonstrate value of future ACCP products to the community.
Data-Driven Agriculture	●	●	●		●	●	Ensure that products are discoverable to the community and work with standards and documentation working groups. Use the agritech community as a testing ground for new applications with help from industry advisors.
Food Companies Operating in Tropical Areas	●		●			●	Disseminate training opportunities to the community and communicate how new products may improve their operations.
Health and Short-Term Air Quality Monitoring	●	●	●		●	●	Engage the traditional research community and possibly consider supporting environmental health funding opportunities. Leverage expertise from current ground-based data users and entrepreneurship communities leveraging that data.
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.

RTI recommends ACCP further engage in the high-priority communities via several different approaches.

The ACCP User Applications Study uncovered key insights on ACCP data uses and needs across seven high-priority user communities. All seven communities demonstrated strong interest in further collaboration. Based on feedback from these communities, RTI recommends ACCP pursue the following steps to keep the momentum going:

- **Deepen existing relationships with focus group participants and interviewees**—Keeping a steady line of communication with interested users will help keep these leads "warm" as the mission develops. Strategies include bringing them onto the ACCP email listserv, setting up one-on-one conversations to discuss needs, and inviting them to future conferences and early adopter groups.
- **Expand from existing relationships into broader community engagement**—Use the relationships established during this project to create a broader network of contacts and engagements in the high-priority communities. Start with communities that are "right and ready" for partnership such as logistics, agriculture, food, and solar energy. For each community, identify nodes of collaboration and congregation where groups of related users may gather. Examples include professional associations, conferences, and working groups where users participate, as well as organizations that fund and support entrepreneurial events like hackathons and start-up weekends. Participating, sponsoring activities, and, ultimately, disseminating information in these groups will help NASA effectively broaden a network of followers, advocates, and influencers and gain further insights on how NASA data products can be fully used.
- **Engage in joint R&D in rapidly growing markets to increase impact**—Two user communities (UAV weather within major logistics carriers and solar energy) expressed near-term interest in collaborative R&D with NASA. Both of these user communities are operating in markets that are poised to expand rapidly in the next 5 to 10 years. Users and potential partners in these communities are actively looking for data products that can help them meet those needs.
- **Raise awareness about existing data products**—Many users indicated that the "right" NASA data for them were difficult to find or that they may not easily identify where existing products could provide value. NASA should review existing informational and training material from the perspective of users in these communities, refresh or create new materials when necessary, and then run campaigns to raise awareness among users in the high-profile communities. For example, NASA may consider "one pagers" or site pages directed toward these user communities with relevant links to direct users to the right data products.
- **Create communities-of-practice mechanisms to engage with value-added service providers**—Value-added service providers and other intermediaries play a key role in these communities, and many are in a position to deliver value-added data products to multiple communities. Recognizing their pivotal and influential role, RTI recommends that NASA explore ways to partner with these intermediaries in a precompetitive manner to improve access to data and enhance modeling and forecasting systems that will benefit many users.

Sections

Methodology

- NASA's PoR preceding ACCP contains a long history of engagement with a wide array of user communities, mostly with federal agencies and domestic and international research organizations. RTI's focus extended beyond known users to include nontraditional users and applications. As needed, we considered other potential users in the selected communities, such as state agencies, nongovernmental organizations, and international organizations, that could provide a complete perspective.
- The ACCP team helped RTI engage with a portfolio of users that currently know or use satellite data (e.g., levels 2 through 4 data from GPM, Aqua, Aura, CALIPSO, and the future TEMPO missions) to understand the value proposition of current data products and engage with potential users.
- Because ACCP was preparing a workshop focused on transportation and logistics applications in November 2020, RTI conducted a trial run of this engagement plan focused on outreach to those two industries. Engagement in transportation and logistics first helped the ACCP team create interest in the workshop and helped RTI fine-tune the engagement model and value proposition hypotheses before expanding to other industries and applications.

Approach

- Review NASA inputs about user communities, ideal candidates for interviews, and questions from Workshop #1.
- Review information provided by the ACCP team regarding thematic areas, applications, and potential (industrial) users.
- Work with the ACCP team to create value proposition messages:
  - Select several examples of levels 2 through 4 data products already in use in current missions.
  - Gather descriptions of the value or benefit the data products provide.
  - Identify existing end users who can speak to the value of current NASA data.
  - Develop sector-specific value proposition statements and collateral to test with current and potential users.
  - Interview a set of current users to test and refine value proposition statements.
- Work with the ACCP team to down-select to 10 user communities:
  - Develop initial, annotated list of users to approach through ACCP's input, RTI's networks, and secondary research.
  - Develop an interview guide to facilitate conversations with potential users.
- Test-run outreach efforts, value propositions, and the interview guide with transportation and logistics communities (in advance of the November 2020 workshop):
  - Interview industry observers for market "smart pill."
  - Identify and interview representatives from each potential user community.
  - Document interviews.
  - Invite engaged users to attend the November workshop.
- Apply learnings from transportation and logistics; repeat the process with other eight communities:
  - Conduct outreach, arrange interviews, test the value propositions, and inquire about current and future needs for EO data.
- Invite engaged users to focus group webinars and record the group discussions.
- Arrange one-on-one recorded interviews with willing participants.

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ACCP User Engagement Plan

Targeted User Communities

RTI's goal was to create user and community profiles for seven unique communities. RTI and ACCP agreed to explore 12 user communities within these six sectors to arrive at a deeper understanding of seven user communities.

1. Agriculture
2. Food and Beverage
3. Logistics
4. Transportation
5. Energy
6. Health

Tools

1. List of selected user communities and sectors
2. Two-page overview of ACCP data products/value propositions
3. Interview guide
4. Contact spreadsheet

Based on AIT feedback, we selected 12 potential user communities in six sectors. These communities spanned ACCP applications. Representative examples of potential nontraditional users are shown below.

Agriculture	Food and Beverage	Logistics	Transportation	Energy	Health
Precision agriculture Agriculture institutes	Vertically integrated food companies Companies operating in tropical areas	Major carriers Logistics arms of major brands	Commercial airlines Aircraft engine manufacturers	Alternative energy companies	Medical device companies Companies with pollution restrictions Exposure and hazards groups

User communities of potential: High-priority list down-selected from brainstorming.

The following list comprises nearly 40 user communities of potential for ACCP data products. The RTI and ACCP teams initially selected 12 user communities for RTI to explore in our project with the goal of developing profiles for seven. RTI's recommended 12 communities are listed in bold. These provided a blend of user communities with potential needs related to ACCP.

Priority	Sector	Relevance to Aerosol (A) and Clouds, Convection, Precipitation (CCP)	User Communities	Examples of Users
High	Agriculture		Large agricultural intermediaries	Cargill, Archer Daniels Midland, Monsanto/DuPont, BASF, ConAgra
		A + CCP	**Precision agriculture**	John Deere, The Climate Corporation, Bayer Agriculture
		A + CCP	**Institutes/research**	World Resources Institute, National Drought Mitigation Center, USDA Agricultural Research Centers, CGIAR Centers, Bill & Melinda Gates Foundation
High	Food and Beverage	**CCP**	**Vertically integrated food companies—brands and intermediaries**	PepsiCo, Kraft Heinz, Molson Coors
		A + CCP	**Food companies operating in tropical areas (coffee, chocolate, fruit)**	Hershey, Nestle, Dole, Chiquita
			Grocery stores (together with food logistics companies)	Kroger, Food Lion
			Food and beverage companies that use a lot of water	Bottling companies: Coca Cola, PepsiCo, Nestle, AB InBev
			Disaster relief	World Central Kitchen
High	Logistics	**CCP**	**Major carriers**	FedEx, UPS, DHL
		CCP	**Logistics arms of major brands**	Walmart, Target, Amazon Logistics
			Maritime	Ocean Shipholdings, TOTE Services, Bering Marine Services/Lyden
			Trucking/freight	Transfix, JF Hillebrand
			Cargo/air	FedEx
			Rail freight	Norfolk Southern Corporation, BNSF, RailNC
			Drone-based delivery	Amazon, DHL
High	Transport-ation	**A + CCP**	**Commercial airlines, airports**	Delta, United, American Airlines, DFW, RDU
			Chartered airlines	NetJets
		A	**Aircraft engine manufacturers**	GE, Pratt & Whitney, Rolls Royce
			Boating companies	Brunswick
			Tier 1 manufacturers for automobiles	Bosch, Garmin
			Rail transport	Amtrak
			Chartered bus/private car companies	Greyhound, White Horse
High	Energy	**A + CCP**	**Alternative energy (e.g., solar, wind, hydro)**	First Solar, GE Wind, LM Wind Power, BC Hydro and Power Authority
			Power/utility companies	EPRI, Duke Energy Company

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User Communities of Potential: Medium and lower priority list down-selected from brainstorming (con't).

Priority	Sector	Relevance to Aerosol (A); Clouds, Convection, Precipitation (CCP)	User Communities	Examples of Users
Medium	Health	**A**	**Medical device companies**	Johnson and Johnson, Baxter, Medtronic, Medline, corporate foundations (such as the Aetna Foundation), Global Alliance on Health and Pollution, Health Effects Institute
		A	**Companies that adhere to pollution restrictions** ($PM_{2.5}$)	Recognized leaders in pollution reduction efforts: MARS, Inc. (EPA Climate Leadership award winner), Kimberly Clark, Xcel Energy
		A + CCP	**AQ exposure and hazards groups**	World Health Organization, CDC, Army Public Health Center, UNICEF, NIEHS, EPA Center for Corporate Climate Leadership, Climate and Clean Air Coalition, Committee on Aviation Environmental Protection (International Civil Aviation Organization)
Medium	Insurance		Microinsurance and reinsurance	Swiss Re, MiCRO
			Crop insurance	Chubb, Zurich Insurance Group
			Commercial property insurance	FM Global
Low	Development and Real Estate		Big box retailers	Target, Walmart
			Critical infrastructure (e.g., bridges)	Bechtel Group, Jacobs Engineering Group
			Urban planning/consulting	City planning commissions
			Flood mapping	CoreLogic, FEMA
Low	Investment/ Finance		Futures traders	Charles Schwab
Low	Media/ Tourism		Resorts and theme parks	Disney, Universal Studios
			Professional outdoor sports teams/leagues	ESPN, NFL, MLB, golf, tennis, NASCAR
			Large venues (e.g., for outdoor concerts, festivals)	Star Events, Quick Global Priority Logistics
Low	Governance		Disaster relief	FEMA

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Thank you to the people from the following organizations who provided input to this report.

User Community		Organizations Engaged
	Commercial Aviation	American Airlines, Delta Airlines, Southwest Airlines, United Airlines, Dallas Fort Worth International Airport, Raleigh-Durham International Airport, Charlotte Douglas International Airport, GE Aviation
	Major Logistics Carriers	UPS, FedEx, Climacell, TruWeather, Old Dominion
	Logistics Arms of Major Retail Brands	Target, HEB, C&S Wholesale Grocers, StormGeo
	Data-Driven Agriculture	Xarvio (BASF), Global Open Data Center for Agriculture and Nutrition (GODAN), Precision Agriculture for Development, Gro Intelligence, DTN, ACRE Africa, aWhere, ADAS, CGIAR'S International Potato Center, Syngenta, FarmWest
	Food Companies Operating in Tropical Areas	Blommer Chocolate, MARS, Hershey's, Blue Diamond Almonds, Green Mountain, Keurig Dr Pepper
	Health and Short-Term Air Quality Monitoring	Propeller Health, Scepter Air, CHEST Analytics, Clean Air Carolina, Health Effects Institute, American Association of Family Physicians, World Resources Institute, American Thoracic Society, SPARTAN Network, Asthma and Allergy Foundation of America, Air and Waste Management Association, PurpleAir, AIR Louisville
	Solar Energy	Underwriters Laboratories, First Solar, SolarGIS, DNV, EPRI, SMA Solar, Clean Power Research, Strata Solar, Microlink Devices Inc., Duke Energy, Duke University

Acronyms

The acronyms below are typically defined at first use in the text. They are also defined here for reference.

ACCP	Aerosols, clouds, convection, and precipitation
AIT	Applications impact team
AOD	Aerosol Optical Depth
API	Application Programming Interface
AQ	Air quality
ArcGIS	A geographic information system for working with maps and geographic information maintained by the Environmental Systems Research Institute
ASOS	Automated Surface Observing Systems
AWIPS	Advanced Weather Interactive Processing System
CAR	Community assessment reports
CCP	Clouds, Convection, and Precipitation
CDC	Centers for Disease Control and Prevention
CoP	Community of practice
COPD	Chronic Obstructive Pulmonary Disease
EO	Earth observation
EPA	Environmental Protection Agency
ESD	Earth Science Division
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
eVTOL	Electric vertical takeoff and landing
FAA	Federal Aviation Administration
FTP	File Transfer Protocol
GDP	Gross domestic product
GIS	Geographical Information System
GODAN	Global Open Data Center for Agriculture and Nutrition
GOES	Geostationary Operational Environmental Satellite
GPM	Global precipitation measurement
GTG	Graphical turbulence guidance
ICAO	International Civil Aviation Organization
IMERG	Integrated multi-satellite retrievals for GPM
LEADS	Leading Environmental Analysis and Display System
MENA	Middle East and North Africa
METAR	Meteorological aerodrome reports; format for reporting weather information standardized through the ICAO
MetOp	Meteorological operational satellite
MISR	Multi-angle Imaging Spectroradiometer
MODIS	Moderate Resolution Imaging Spectroradiometer
NASEM	Natural Academies of Sciences, Engineering, and Medicine
NDVI	Normalized Difference Vegetation Index
NetCDF	Network Common Data Form
NIEHS	National Institute of Environmental Health Sciences
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OMI	Ozone Monitoring Instrument
PM	Particulate matter
PoR	Program of Record
R&D	Research and development
SATM	Science and applications traceability matrices
SBN	Satellite Broadcast Network
SMS	Short messaging service
TAFs	Terminal aerodrome forecasts
TEMPO	Tropospheric Emissions: Monitoring Pollution mission
tif	Tag Image File Format
TRMM	Tropical Rainfall Measuring Mission
TROPOMI	Tropospheric Monitoring Instrument
UAV	Unmanned aerial vehicles
VAAC	Volcanic Ash Advisory Centers
VASP	Vienna Ab initio Simulation Package
VIIRS	Visible Infrared Imaging Radiometer Suite
VTOL	Vertical takeoff and landing