NASA ARMD WILDFIRE MANAGEMENT WORKSHOP

Workshop – 13 May 2021

Authors:

Dr. Parimal Kopardekar
Laurie Grindle

Additional Contributors:

Dr. Richard Mogford
Richard Walsh
Christine Clark
Anna Cavolowsky
Jonathan Nguyen

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Executive Summary

In response to the increasing severity and cost of wildfires in the United States, the NASA Aeronautics Research Mission Directorate (ARMD) conducted a one-day Wildfire Management Workshop on May 13, 2021. This document represents a summary of the discussions of workshop participants. The NASA Aeronautics Research Institute (NARI) at the NASA Ames Research Center organized the event. The goal of the workshop was to provide a forum for representatives from wildfire organizations (government, private, and academic) to share insights into community needs, challenges, and solutions, and help to inform NASA's contributions to the wildfire community. The proceedings consisted of presentations from the U.S. Forest Service, NASA Space Technology Mission Directorate, and NASA Applied Sciences Disasters Program. Also included were two sessions of breakout groups that focused on specific wildfire management issues.

Major themes that emerged from the breakout groups included data access and management, wildfire modeling, improving organizational collaboration, the use of aircraft in fighting fires and collecting data, and providing front line firefighters with the information tools they need to be effective. The output of the workshop is being shared with the broader community for consideration of national challenges and opportunities and used by NASA to consider avenues where the agency might contribute expertise and technology to assist with wildfire management.

The possible next steps were derived from multiple facets of the Wildfire Management Assessment Activity, including the workshop discussions, Subject Matter Expert (SME) inputs, literature review, and Request for Information (RFI) responses. They are summarized below and in Appendix D and organized in alignment with NASA aeronautics capabilities for further consideration by NASA and the broader wildfire community.

Comprehensive Concept of Operations, Systems Engineering Practice, and Transition to Reality: Develop multi-agency unified concept of operations to align priorities, response strategies, information exchanges and integration, technologies and their interoperability requirements, and coordinated wildfire management approach to maximize the impact. Use systems engineering approach to identify multiple types of users’ needs, map the users’ needs into functional requirements, and identify technology and procedure related considerations. This could result in a product roadmap for multiple users in the wildfire management community. Develop an approach to transition research and concepts into reality. The users need mature high technology readiness level products. This will require coordination and collaboration among multiple government agencies, industry, and non-profit organizations.

Leverage NASA Efforts and Programs: Collaborate with NASA STMD for wildfire focused competitions, prizes, and SBIR/STTR topics. Partner with NASA SMD to leverage data assets and tools that are beneficial to wildfire management

Data and Modeling: Conduct comprehensive data and models inventory analysis, identify gaps and overlaps, and identify integration and interoperability considerations for multiple types of users. This will maximize value of data and information to the respective users when they need it most.

Persistent Surveillance: Improve the surveillance of the fire regions by using a combination of sensor data from satellite and High-Altitude Long Endurance (HALE) flights.

Organizational Considerations: Improve coordination between federal, state, county, municipal, and private organizations involved in wildfire prevention and management, and break down barriers that impede information flow to produce significant benefits.

Wildfire Management Aircraft: Assess the needed aircraft fleet, their capabilities, and associated technologies that will be most effective in wildfire management. Relevant use cases include surveillance, suppression, and remedial inspections.

Persistent Communication: Develop concepts and technologies that will provide reliable, persistent communications (voice and data) in remote, hazardous areas.

Cooperative Airspace Management for Manned and Unmanned Operations: Develop roadmap for automated (e.g., UTM-in-a-box) airspace management technology. The roadmap could include common situational awareness capability as an early step and fully automated self-contained airspace operations as the end goal.

Wildfire Suppression Duration: Increase the suppression duration in day and night (24/7) through automated aircraft, automated airspace operations, and safety assurance methods to ensure persistent and safe operations.

Support Firefighting Personnel: Provide the timely, accurate knowledge needed by the firefighters through improvements in gathering data, running models, and collaborating between agencies.

Background

In the United States, wildfires are becoming increasingly severe and costly in terms of acreage burned, property damage, and most importantly, lives lost. Wildfire frequency and intensity is escalating, inducing budgetary, personnel, and equipment challenges. Furthermore, California and other western states have been facing persistent drought conditions and much hotter temperatures, which are fueling wildfire intensity and duration. These alarming trends have made it urgent to recognize how wildfires could be better predicted, mitigated, and managed to reduce their impact.

NASA's Science Mission Directorate (SMD) and Space Technology Mission Directorate (STMD) have a history of contributions to wildfire management including remote sensing, instrumentation, mapping, data fusion, and prediction. Additionally, NASA's aeronautics community has possible contributions to manage suppression and mitigation efforts through decision support tools for airspace operations coordination that would reduce human workload during firefighting operations.

The NASA ARMD is seeking to gain insights from the stakeholder community to identify technology needs to support the management of wildfires, map NASA ARMD technology investments and capabilities to community requirements, and determine areas where ARMD, in collaboration with others internal and external to NASA, can contribute to better planning, prediction, mitigation, and remediation of wildfires and their impact. To accomplish this, a Wildfire Management Assessment Request for Information (RFI) was initiated and NASA hosted a Wildfire Management Workshop on May 13, 2021. It is important to note that, although we will share high-level input received from the RFI, this document will primarily focus on the feedback received during the workshop.

NASA ARMD, in collaboration with SMD, the U.S. Air Force and U.S. Forest Service, conducted the workshop on Wildfire Management. The United States Forest Service and NASA SMD, working through the Tactical Fire Remote Sensing Advisory Committee (TFRSAC),[1] were instrumental in the development, planning and orchestration of the event. The workshop was comprised of a General Session and two Breakout Sessions. The former established the setting, objectives, and goals of the event as well as emphasizing the importance NASA places on wildfire management in the broader context of disaster management and recovery, viewing both as national priorities. The latter provided relevant information that will be used to inform decisions regarding ARMD's potential contributions to wildfire solutions.

This document provides an overview of the workshop, including key findings, takeaways, and gaps to improve the efficiency and effectiveness of the state of the art of wildfire management.

Wildfire Management Assessment Activity Overview

Mr. Robert Pearce, the Associate Administrator of NASA ARMD, created the Wildfire Management Assessment Activity to listen to the wildfire management community, understand their needs, and determine how NASA ARMD can best contribute to addressing those needs. The activity's general approach includes standing up a NASA Wildfire Management Assessment

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[1] https://fsapps.nwcg.gov/nirops/pages/tfrsac

Team; conducting an internal ARMD research and technology inventory assessment; engaging in discussions with the wildfire community; developing plans and potential near-, mid-, and far-term activities for consideration; and identifying potential cost sharing partners. The RFI and workshop are integral to this approach.

Wildfire Management Assessment Request for Information

NASA invited the wildfire management community to respond to an RFI. The purpose of the RFI was to aid NASA in gaining insights from the stakeholder community regarding potentially relevant technologies and capabilities. RFI responses were reviewed, revealing seven primary themes with corresponding challenges and solutions proposed by respondents. These themes and challenges are detailed below.

One key challenge is ensuring sufficient funding for wildfire management. Currently, most of the funding is spent on fire suppression costs. A proposed solution would be to increase or re-focus a portion of the funds on research (including attracting more students from relative fields of study), technological development, service testing, and deployment/implementation.

Another challenge is related to data management and availability as it pertains to procurement of new technology and equipment. There needs to be a way to swiftly license, customize, deploy, and train at scale. A couple of recommendations were to create a “steering board” or to establish a process for transitioning Small Business Innovation Research (SBIR) Phase III technologies to the applicable government agencies.

Collective access to higher resolution and improved real-time wildfire-related data is instrumental in improving tactical utility and supporting cross-organizational coordination. This information includes satellite remote sensing data (e.g., accurate fuels mapping) and data that is otherwise only available during public disasters or located on separate systems (e.g., lightning, neighboring incidents, and transitioning aircraft).

Furthermore, data sources are scattered across agencies and programs creating training and operational inefficiencies. The wildfire disaster management community needs seamlessly integrated equipment to view and understand relevant data, which does not require extensive training for scaled, cross-jurisdictional use and, in turn, enables collaborative decision making. Solutions proposed to address operational efficiencies included an intuitive, streamlined computing infrastructure, applicable products delivered to the field, quick reaction forward bases for vertical takeoff and landing (VTOL) aircraft, non-pilot operator training, a testing environment to simulate fire conditions, mission specific unmanned aircraft systems (UAS) (e.g., for monitoring/detection, firefighting (liquid payload), etc.), dimensional products to visualize airspace structures, and more.

Another challenge is to develop relevant and consistent standards and regulations for wildfire management. Advances in technologies and capabilities have outpaced the scope of current policy. A couple of examples are UAS cyber security within civilian and science-based organizations and airspace management. Overall, there is a need for common language and tools for preplanning, training, establishing an operating picture, alerts and notifications, and community engagement.

As we move more into the digital age, there is concern regarding the security and reliability of the Internet infrastructure that supports the field equipment. Many wildfires are in remote locations where Internet connectivity may not be available or able to handle the amount of data and applications required to manage the fire.

Lastly, buy in from the wildfire management community is key in order to assess and adopt new capabilities. New systems and technologies must be user friendly, reliable, and dependable in the circumstances in which they are intended to be used in order to ensure their acceptance. Several federal, state, and local entities are involved in firefighting, and through continued collaboration, effectiveness could be increased. New concepts and technologies should enable such collaboration.

It is important to note that this section is a summary of inputs provided by RFI respondents and is not considered prioritized or exhaustive. Additionally, the RFI is still open. To complete the RFI, visit: https://nari.arc.nasa.gov/wildfiremgmt.

Wildfire Management Workshop Overview

Dovetailing off the Tactical Fire Remote Sensing Advisory Committee's (TFRSAC) Spring 2021 Bi-Annual Meeting, NASA assembled a day-long workshop, including a general session and two breakout sessions. To view the complete event webpage, visit: https://nari.arc.nasa.gov/tfrsac-wildfire. (Please reference Appendix A for the event agenda.)

The purpose of the workshop was to facilitate NASA's understanding of wildfire management, challenges, and obstacles. Participants, including government organizations involved in forest and land management (e.g., U.S. Air Force, U.S. Forestry Service, U.S. Geological Survey, National Guard, CAL FIRE, etc.), the firefighting community, industry, and academia, worked to identify challenges and gaps where help is needed and discussed how NASA's capabilities in research, development, testing, and implementation could improve the state of the art. In the following sections, this paper will document the deliberations and key outcomes from the workshop.

General Session

The General Session established the setting, objectives, and goals of the workshop, as well as hosted keynote speakers and a fireside chat.

To start the event, Robert Pearce, Associate Administrator of NASA ARMD, Richard Barhydt, Station Director for the Pacific Southwest Research Station of U.S. Forest Service, and Nathan

Diller, Director of AFWERX, provided opening remarks. Mr. Pearce spoke about the goals of understanding community needs, better identifying challenges, and helping to inform NASA's contributions to the wildfire community. There may be aspects of the wildland fire community mission that could be enhanced through aviation.

Richard Barhydt shared his excitement about new partnerships and how the workshop could be a steppingstone to collaborate on a much larger scale. This opportunity brings new ideas and solutions. Col. Diller talked about the AFWERX approach to the changing technology space and how new tools can address some of these growing threats from wildfires. AFWERX is looking forward to supporting NASA and the U.S. Forest Service in pushing the limits of key technologies that can better manage wildfires.

Robert Baird, Regional Director of Fire and Aviation Management in the Pacific Southwest Region of the U.S Forest Service, was the keynote speaker for the workshop. He provided an operational overview and talked about the critical requirements of the Wildland Fire Program and services in California. Overall, the community needs a common operating picture across all devices. Other needs include near-real-time infrared (IR) wildfire detection and tracking; projection in highly dynamic, remote, austere environments; capabilities for nighttime operations; air attacks (e.g., having a person in the air to observe the important areas for suppression); early detection and synthesis across platforms; and game-changing air tankers (e.g., VTOL, autonomous, large-capacity, etc.).

After the first breakout session, Jenn Gustetic, Director of Early Stage Innovations and Partnerships for NASA’s STMD, shared the variety of opportunities for industry, as well as other entities, to collaborate in terms of prizes and competitions, Small Business Innovation Research (SBIR), and Small Business Technology Transfer (STTR). STMD Early Stage Innovations and Partnerships Portfolio makes available approximately $300 million in annual funding for these and other programs.

David Green, Program Manager for NASA’s Earth Science Applied Sciences Disasters Program, presented on research and development, focusing on the Mapping Portal.[2] The portal is informed by global observations and analyses that are used to support real-world events throughout the disaster cycle. NASA looks at the full cycle, including planning, prediction, mitigation, suppression, and integration with airborne aerial and supporting satellite components. The challenge is processing the information on a scale that will help make decisions for early action. The Disasters Program is looking forward to collaborating with NASA Aeronautics to make even greater contributions in this area.

After the second breakout session, Parimal Kopardekar hosted a fireside chat with Vincent Ambrosia and Everett Hinkley, the co-leads of the TFRSAC. The TFRSAC is a longstanding “Community of Practice” co-hosted by the U.S. Forest Service and NASA SMD, which focuses on sharing best practices and creating knowledge to advance the wildland management domain. In the fireside chat, Vince and Everett shared their views about how the TFRSAC has matured over the last 18 years.

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[2] https://data.nasa.gov/Earth-Science/NASA-Disasters-Mapping-Portal/vyzu-gm3d

To conclude the general session, Jon Montgomery, Deputy Associate Administrator for Policy of NASA ARMD, provided closing remarks. He spoke about how technology has matured in the last 20 years and that near-term operationalization or integration of unmanned systems into the national airspace is possible. In addition, there have been great advances in artificial intelligence (AI) and machine learning, data management and gathering, and data fusion. There is a lot more information at our fingertips today and the time has come for NASA Aeronautics to help improve the state of the art of wildfire management.

Breakout Sessions

There were two, one-hour breakout sessions organized around five themes. The five themes were Planning for Fire Season, Prediction Modeling and Challenges, Aerial Fire Surveillance, Suppression and Mitigation, and Post-Fire Remedial Efforts. Each breakout session was comprised of 10 separate, moderated group discussions with a total of 54 questions asked. Each group had a cross-section of participants (e.g., government, industry, and academia) to promote education and inclusivity. (Please reference Appendix B for the full list of breakout questions and Appendix C for the top three outcomes from each breakout group.)

Breakout Sessions’ Discussion Notes

This section is a summary of workshop participant contributions from the breakout discussions, organized by the five themes. This includes a recounting of the various views shared during breakout sessions. The top three outcomes from each breakout session are listed in Appendix C. It is important to note that this section is not prioritized or exhaustive, nor does it represent a consensus of participant views. In some places, the summary highlights possible alignment with NASA capabilities and participant recommendations for NASA ARMD activities, as well as recommendations for the broader wildfire community.

Planning for Fire Season

The four Planning for Fire Season breakout groups focused on acting before fires occur. This included strategies to reduce the frequency, severity, and size of wildfires and the associated losses and costs. Examples are fuel breaks to stop wildfires, wildfire protection zones to protect communities, maintaining healthy forests, prescribed burns, predicting fire risks, and community involvement. It is also important to assess and identify public and private resources that could be damaged by wildfires. There is a need to develop and mobilize around improved plans for fire management that include considerations of economic and financial impact. The Planning for Fire Season breakout groups included discussion on computational fire modeling. This material has been moved to the Prediction Modeling and Challenges section.

To accomplish this planning, wildfire management agencies need current, reliable, comprehensive, and regularly updated data sets that include information about cities, counties, and state governments. Also essential is information on commercial oil and gas pipelines, electric transmission lines, building footprints, roads, structures, water and power infrastructure, fire weather, fuel moisture, vegetation, etc. Data is currently captured in paper form (e.g., Facilitated Learning Analysis, Incident Management Reports) but is moving to be increasingly digital. Proposed solutions include increasing digital data capture, overcoming barriers to sharing restricted digital data, and utilizing this for simulations and incident planning and management. There is also a requirement for timely and actionable real-time information (e.g., wind and weather predictions and tracking and prediction of fires).

The participants in the Planning for Fire Season breakout groups also noted there could be Department of Defense (DoD) and NASA capabilities to understand how to assess situations and develop tactics and strategies. They suggested that these agencies could develop partnerships with the National Wildfire Coordinating Group (NWCG).[3] The NWCG is the umbrella organization that sets training and certification standards. NASA could connect with NWCG to open channels of communication. This could help with collaboration on physics-based modeling, advanced computing methods, and data collection and distribution techniques. Sustained collaboration with the research community outside of fire season would help improve the quality and availability of data.

Lessons learned are largely retrospective. Opportunities exist and could be expanded to be more anticipatory and pro-active, translating lessons into predictions while recognizing that that fires are now year around. Lessons learned are being captured by the Wildfire Lesson Center[4] over different time scales. However, the data is heterogeneous, and this hampers analysis. It might be possible to leverage other similar real-time processes and data solutions for disasters such as volcanoes, earthquakes, floods, etc.

Solutions are needed for funding, procurement, data management, operationalization of data analyses, and communications (including distribution of data and information). There is also a need for firefighters to participate in research and development (as future users) for the practical maturation of technology for real world use. The fire community is small and widely distributed. More community exchanges are needed to work out possible solutions. Perhaps there could be another focused workshop on partnerships and problem solving that primarily includes front line operators. It was suggested that NASA could act as a facilitator of communications and collaboration.

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[3] https://www.nwcg.gov/

[4] https://www.wildfirelessons.net/home

There is an opportunity for better integration of DoD. DoD has a tremendous amount of technology and experience in regards to knowing where people are, strategy, intelligence, etc. DoD is recognizing this and working on a cohesive wildland fire strategy, which is still in its infancy stages. DoD research is looking at prescribed fire (planned burns) as well as research called FASMEE.[5]

The National Guard is a state asset that might be leveraged to support coordination between DoD, NASA, the national fire agencies, U.S. Forest Service, and Department of the Interior. Participants suggested NASA could serve as a conduit for agreements. CAL FIRE has a good model for how to interact with state and federal agencies to establish rapid agreements, training, and understanding to support wildfire activities. This or a similar model could be used to improve coordination and collaboration.

The firefighting community needs the state of the art from 2010 to be an operational capability in 2021. "The state of the art is useless when you're all alone digging a fire ditch, unless it's in your pocket or in your pack." Operators could talk with short term technology infusers (one to two-year solutions) to work out how commercial-off-the-shelve tools can be applied today. Community building and coalitions are integral in synchronizing state governments and private bodies. Once the fire can be observed, small UAS (sUAS) methods could be applied. Innovative technologies are out there but are not operational. Participants suggested NASA could fund companies to push development and move new tools to an operational state. It is important to apply technologies that are now available. An organization is needed that can work with the private sector and implement these changes, creating a process to apply these technologies and to evolve the community.

Prediction Modeling and Challenges

The four Prediction Modeling and Challenges breakout groups discussed data acquisition, transmission, and application, and computational modeling of wildfires. Information and predictions are critical for wildfire management, but there are issues with managing and using large data sets and complex models.

Fire services use models to predict fire impacts (e.g., effects on roads, structures, and vegetation) for fire treatment planning, tree mortality, fire danger operating plans, and developing preplanned fire scenarios for expected response. These models could be integrated into the Wildland Fire Decision Support System, which assists fire managers and analysts in making strategic and tactical decisions for fire incidents. New modeling techniques could be used to predict fire spread. AI could be trained with small controlled fires.

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[5] The Fire and Smoke Model Evaluation Experiment (FASMEE) is a multi-agency, interdisciplinary collaborative effort to identify and collect critical measurements of fuels, fire behavior, fire energy, meteorology, smoke, and fire effects that will be used to evaluate and advance operational-used fire and smoke models. https://www.fasmee.net/

Fire services also use computer models to anticipate various factors that affect wildfires. The Rothermel fire-spread model was developed by Richard Rothermel and first published in 1972. It “reduces a forest fire to a set of equations operating in a hypothetical universe in which fires burn only small, uniform, dead fuels on the forest floor. The model does not need to know what species of trees or shrubs are growing on a site, except as they are represented as “fuel” of one type or another. The model attempts to describe mathematically the physical and chemical processes of fire.” However, the Rothermel model needs to be updated.

Other models for predicting fire behavior include BehavePlus, FARSITE, FlamMap, FireFamily Plus, Rear Event Risk Assessment Process, WindWizard, FireStem, and the Wildland Fire Assessment System. NASA has developed the Global Fire Weather Database[6] that provides wind, temperature, and humidity data to forecast where fires could begin. There are currently no models to predict impact to water and power infrastructures. There might be people available on innovation teams at insurance and energy companies that could help with this.

A participant noted that the Los Alamos National Lab is doing great work with a fluid dynamics program called Firetec. Next Generation physics-based fire behavior models have the potential to be game changers, but they are very data intensive. For instance, they require 3D fuel information, e.g., light detection and ranging (LiDAR) data. Efforts are underway on how to directly input LiIDAR and moisture data.

The many different proprietary data sources can be problematic. Lack of standards creates problems when using data updates for models. The data can be for different time scales, densities, and rates. Information on fuels and localized weather are especially important for modeling and prediction. Predictive computer models should have access to the best data available. More coordination is needed between modelers, data producers and data providers.

The community at large probably has a good idea of what standard data formats should be used. This may need a push from one of the government agencies to help define and structure those standards. Standards, such as OpenGIS, may be adequate. It would be very helpful if a university or similar entity would conduct a periodic comprehensive survey of data sources and modeling efforts and publish the results. The information could be posted publicly for reference by the modeling community.

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[6] https://data.giss.nasa.gov/impacts/gfwed/

The current procedure in fire behavior modeling is spatially limited (i.e., localized). There is a great potential to improve the predictive capabilities of fire behavior models using tools like computational fluid dynamics. It might be possible to predict where fire could happen before it starts. However, the computational power required will be high, likely requiring the use of supercomputers.

Researchers want to be able to validate their technology in real world conditions, but firefighters are rightfully concerned about testing low maturity technologies in life-threatening conditions. A framework could be developed that allows for better interaction between operators, technology developers, and researchers.

It is important to identify situations where there can be tests before fire situations develop. Prescribed burns could provide a laboratory for evaluations of new models. The wildfire world is a small technological community.

Participants noted that NASA Aeronautics has some interesting technology initiatives that might be relevant to address wildfire related challenges, such as those related to aircraft and airspace operations, data management, safety technologies, flight tests, etc.

In August 2020, there were 600 fires at the same time, making model building very difficult. Many models take six hours to run which limits their use for real time decision making. Real, actionable data is needed on what is going on with the population in the area of the fire. This year CAL FIRE started GPS tracking of their units, but there is limited information on the location of the public.

A California system has been up and running since last season. The web site has an integration bar with incidents. The tracking of resources comes from the audio calls and 911. It runs an automatic simulation that shows on a scale of 1 to 5 how complicated the fire is. A new system called JEDI displays wind conditions and impacts on buildings or population. It delivers the information with a one-page report that the firefighters have when they are dispatched and go into the field. It includes tracking of resources, communications, and provides situation awareness.

Some of the data sets from NASA (such as the Geostationary Operational Environmental Satellite Program (GOES))[7] have not been fully integrated with available tools. There is also interest in higher resolution (temporal as well as spatial) data for prediction modeling. Soil moisture for topography is one specific data set identified for possible inclusion in data models. High resolution atmospheric “vertical data” provides information on weather, particularly at a small scale, with different altitudes and effects from topography. The stratospheric infrastructure could be sampled by balloons and other airborne platforms.

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[7] https://www.nasa.gov/content/goes

Small drones with sensing capabilities could track rapidly moving fires and provide high resolution imagery when needed. The fire policy considerations may be a limiting factor. It is difficult for non-federal fire fighters to get the training, approval, and aircraft for that mission. Drones from China sometimes cannot be used. There are bigger drones, operated by private contractors, assigned into the large fires. They perform like the multi-mission aircraft and can provide overwatch on areas that are rapidly burning, but they struggle at mapping the fire. Because they have a constricted view (i.e., soda straw effect), they have to slowly fly around the entire perimeter at lower elevations than manned aircraft.

It is important to deliver appropriate information to the right people at the right time. Communication is very difficult in remote areas and in extreme conditions. There is an opportunity to take ground truth data collected during a fire and make it more available to people developing models. All participants carry cell phones. The fire engines have larger radios that are more powerful. It is also important to get the information to the people on the ground. For the Camp Fire, casualties resulted when the wind shifted, and they were caught unaware.

Cell phones and radios can be linked via Bluetooth to augment capabilities and provide access to greater amounts of data. The goal is a 15-minute data update. Anything outside 15 to 30 minutes is more than the operational loop time. There needs to be a better way for scientists and engineers to interact with the user community and to have time in actual incidents to understand requirements.

There are wide area sensors (not whisk[8] or IR scanners) that are able to capture a broad view of the fire and identify the perimeters, but they are not on aircraft yet. These sensors could deliver a frequent, high-resolution picture of the fire and provide a low-resolution image of where the fire is strongest at any given time.

Data is needed at a higher spatial and temporal resolution (100 meters with a 15 to 30-minute update) to be relevant for fast moving fires. Data should be integrated and shared across sources and users. Geo-location accuracy of fires is important (+/- 50 meters). There is no need to update an entire map if data size or transmission time is a concern. Instead focus on an area of the map to update to reduce size or transmission requirements.

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[8] https://svs.gsfc.nasa.gov/12754

Aerial Fire Surveillance

Two breakout groups focused on aerial fire surveillance. The main themes of discussion included improved aircraft and sensors, advantages of autonomous vehicles, and a safe airspace environment for these operations.

In these discussions, it was suggested that it is time to replace aging aircraft with specifically designed aircraft that consider sensors, payload, distribution processes, and efficiency of drops. Previously mentioned issues regarding data transmission and machine learning to amalgamate and create usable information were noted. Participants stated that not enough funding is directed at data collection, fusion, integration, and delivery. So even with better aerial surveillance equipment, real time information flow to the field is challenging without policies, procedures, and workflows in place.

Specific sensor equipment was not discussed, but when it comes to data collection, altitude is more important than range. A combination of ground cameras (especially on peaks), aircraft, and satellites would be needed to provide data from all altitudes. For detection, a GOES satellite has a 2-km pixel capability and can see a 1-hectare brush fire on a typical day. However, fires tend to be 15 – 25 minutes old when noted.

Unlike satellites, aircraft can get “under the weather,” which offers surveillance advantages; satellite data is macro, but near-earth data can be more tactical. sUAS also have limited detection capabilities. However, at wildfire system alert, a vertical takeoff sUAS could launch and provide an image and be out of area before a temporary flight restrictions area is declared and manned aircraft arrive. A systems engineering approach could determine how to bring forward all aerial and space assets such as those that collect hyperspectral and multi-spectral sensor data.

For surveillance during mitigation and suppression, thermal cameras that collect low pixel data could be mounted on air tankers or sensors added to sUAS or electric VTOL (eVTOL) vehicles if they are already flying resupply missions. The group also suggested dropping drones or similar hand-thrown devices from manned aircraft. Capabilities such as multi-view and multi-perspective camera images are needed. It was also mentioned that better data collection is required on where fire retardant drops are made.

Aircraft are effective for high-resolution, wide area surveillance to conduct damage assessment of destroyed structures and enable classification of perimeters. However, smoke obscuration and strong updrafts affect daytime aviation capabilities. For pilots flying by visual flight rules, night operations are not possible. For safety reasons, air operations are shut down at night. The exception is fire-mapping aircraft that fly in early morning hours when cooler backgrounds enable better discrimination. Unpiloted aircraft with terrain avoidance could better manage night-time operations. The best time to fight a fire is when it is laying down. Continuous aircraft firefighting operations would be beneficial.

It could be useful to use larger, autonomous, unmanned or remotely operated aircraft with retardant dropping capability that can operate day and night and under low visibility especially if their engine configuration can avoid stalling out in really smoky air. For effectiveness, aircraft normally drop retardants from 150 feet at 100 – 121 knots. CAL FIRE operates turboprop aircraft that have little to no issues with the smoke ingestion and use an added water system for spraying water into the inlet to reduce power loss from smoke. A similar engine on an autonomous vehicle where the engine could be remotely monitored could be useful. Very large air tankers on the ridges are the best option for autonomous operations, but smaller air tankers or even swarms of sUAS may be more maneuverable and provide more rapid support especially during initial attack operations.

UAS operations are currently difficult for several reasons. Drones have limited battery time, operate poorly in bad weather conditions, and can have connectivity issues. However, drones fly slower and at lower elevations which could enable surveillance of focused areas of fire. In addition, drones can get into tighter places, are more expendable, and less expensive to operate. The National Defense Authorization Act (NDAA) has made UAS application more difficult with restrictions on certain foreign made drones and parts that currently dominate the market.

Integrated airspace operations with large aircraft and small drones is a challenge, especially with radios operating at different frequencies. Pilots need to feel confident in the other operators in the airspace. Improved communications between manned and unmanned assets, the ability to detect rogue actors, and deconfliction of airspace are examples of potential high priority solutions to operational challenges. In addition, sUAS must have consistent communication with their ground operators. Currently, if a sUAS loses ground contact, all operations are suspended or grounded until the connection can be re-established.

There were several members in the breakout group who thought that a crawl, walk, run approach could allow earlier access to guidance tools (i.e., heads-up displays), augmented flight operations, and integrated sensors for pilots while large UAS platforms are brought into operational context. These incremental technology developments on manned aircraft could then be tested and moved to autonomous operations in a spiral development process. Otherwise, development and certification could prolong access to tools.

Suppression and Mitigation

There were seven breakout groups that focused on mitigation and suppression. The objective was to understand the primary challenges, provide some clarification on existing operations, and gather feedback on what breakthroughs or process flow changes could provide the greatest impact. It should be noted that some discussion points on mitigation and suppression concerned aerial operations. To avoid duplication, those topics are discussed in the preceding Aerial Fire Surveillance section.

There was a call among participants for real-time, actionable data to assess the source of the fire risk and impact on the population, including rapid intervention for extraction. Any collected data needs to be aligned with existing data standards for tactical as well as strategic planning. Fire incidents do not have a fixed command and control structure for all fires and there are different response teams and coordination efforts depending on where the fire starts (i.e., local, state or federal land). Reducing the time between detection and fire classification can enable faster resource assessment and placement and safety prioritization.

Most useful could be technologies that provide rapid detection and situational awareness for suppression with 15-minute and potentially real-time updates. Persistent monitoring was emphasized to map escape routes and to understand encroachment factors, hot spots, critical infrastructure and community impact. Currently, there is gap between data collection and distribution. Ideally, firefighters want a map of the fire perimeter and how it is moving, state of fuels, and weather trends. The spatial and temporal resolution of the data is important; it can take 15 - 30 minutes to relocate if resources respond to the wrong location. Specifications range from 1- to 100-meter accuracy.

Suggestions for LiDAR and spectrum data were mentioned as well as use of machine learning techniques to parse through information and display it in a useable manner. It was noted that intelligent solutions must include a confidence level and a low number of false alarms to be useful. In addition, deep learning has implications for infrastructure, where data will reside, and standardization for accessibility. Most importantly, data needs to be transferrable over phone networks in extreme conditions and in sometimes remote areas where communication is difficult.

Data can be outdated by the time it is received due to long transmission times, and firefighters are already struggling to keep cellphone batteries alive all day. Updating an entire map, for instance, can take much longer than for a focused area of the map. Data for the Incident Command Center should be more detailed and broader than what the field operators need. Another complication is the cascade of data from twitter feeds, cellphone video, and social media posts. Multiple data streams are being used to collect massive amounts of data and that can become confusing. As mentioned earlier, there are hopes that machine learning can process this information so that a cellphone could become a situational awareness tool.

Connectivity is also a challenge. Improved cellphone coverage is needed, especially on larger fires with incident command teams, and alerting mechanisms for low bandwidth and asynchronous connectivity would be helpful. Fire crews typically use very high frequency radios, but this can require airborne repeaters, and there can be interoperability issues between different communication systems.

Problems with sharing data can result from privacy issues. Firefighters are from both public and non-public entities. Sensor data from military sources can have sharing restrictions, and there are some initiatives to allow unlimited distribution rights. There are also privacy concerns associated with using mobile phone data or social media to determine people's locations.

Smoothing out data formats, interoperability, and use of standard formats would simplify communications. Even simple solutions such as standardized color schemes across map products would result in quicker scans and decision-making. Firefighters need visual information. To be most useful, the research products need to be aligned with existing data standards (e.g., NWCG).

The need for cooperative public-private partnerships and developing revenue streams was stressed. The participants felt that there is a lack of quantitative analysis on the value of investing in new tactics. The private sector needs to develop an increased awareness of market potential. Overall, an alliance of researchers and operational teams in the field could contribute to effectively collecting observations for better coordination and technology development, including safe prototype testing.

Post-fire Remedial Efforts

During the three breakout groups on post fire remedial efforts, areas identified for improvement, in addition to better access, included data collection methods, standardization of reporting, and methods of analyzing and using the data.

Inspections for erosion and post fire debris flow are done very quickly (even before the fire is contained) to assess post-fire threats from flooding, soil erosion, and instability. Depending on intensity, wildfire can change the chemistry of the soil and flash flood guidance. In mountainous regions, damaged vegetation and soil structure are inspected. NDVI products are used for mapping burn severity. The purpose is to assess land, damage, immediate rehabilitation, and long-term risk to groundwater and soil surfaces.

Multiple organizations collect this data. Burned Area Emergency Response (BAER)[9] teams typically conduct the inspections for the U.S. government, but BAER teams from different departments operate independently and California, for instance, uses the Watershed Emergency Response Team (WERT).[10] BAER teams are dynamic in how they are formed so finding information later is based on the type of incident – depending upon whether it is a CAL FIRE, Forest Service, or a USGS topic, for instance. Cross-government collaboration is needed to harmonize and access this data more easily.

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[9] https://fsapps.nwcg.gov/baer/

[10] https://www.bing.com/search?q=Watershed+Emergency+Response+Team+&form=QBLH&sp=-1&pq=watershed+emergency+response+team+&sc=2-34&qs=n&sk=&cvid=AA82212D34BA4C34B3124F1C9C10E32B

Satellite and airborne imagery are used to create Burned Area Reflectance Classification[11] products, but timelines can be problematic depending on orbit schedule and cloud cover issues. Imagery taken by aircraft is also used to assess sediment level and debris flows but standards are needed to ensure all spectral data from aircraft and satellites is consistent to better enable burn severity algorithm development.

Sensors that can obtain high-resolution optical imagery of burned areas through smoke and cloud cover in addition to hyper- and multi-spectral data are desired to assess how much cover is left to protect soils, if soils are hydrophobic, and to anticipate the effect of storms that may affect the watersheds during recovery. High resolution topography with detailed spatial scales would be valuable for modeling. Also, sensors to understand safety levels of chemical residuals \toxicity of soils, and other hazards (e.g., old mines) are desired for determining when areas are safe to enter.

Remote detection of debris flow and erosion would reduce the time and resources needed for teams to gather this data daily as the fire progresses. Remote sensing to assess the quality of the soil is currently not possible. There has been great success with use of small, off-the-shelf drones, but many USGS assets have been grounded for post wildfire science due to the NDAA.

Timeliness of data is critical. Post assessment reports are published within a few days of the fire, requiring quick data acquisition and analysis. Distillation and machine learning techniques would benefit cross-agency users for future incidents. NASA developed case studies and rapid prototypes to support post fire remedial efforts, but there was no method to actually use the prototype. Comprehensive technology capability portfolios are lacking, which has fractured development and transition.

For analysis, pre-fire and post-fire imagery are needed for comparison. The Normalized Burn Ratio (NBR) index designed to highlight burnt areas in large fire zones. dNBR is the delta between pre-fire and post-fire NBRs. The USGS Landslide Hazards Program[12] produces good models for pre- and post-fire debris flow probability and likelihood. USGS also does debris flow hazard modeling. Debris flows are channels that have a lot of dry sediment and are particularly dangerous to life and property. Continual collection of data and images for years after the fire is desired. Temporal data would help to understand land, vegetation, and watershed rates of recovery.

A collaborative hub where responding agencies and field agencies can operate is needed for better coordination and data sharing. A digital infrastructure could be developed to gather post-fire response datasets and support analysis for those impacted. Most post-fire assessment and remediation plans are only distributed among fire management entities. If they were public-facing, communities would be better informed of post-fire issues such as road closures, infrastructure damage, sensitive areas (keep out zones), and flood erosion potential areas. A public facing dashboard used in Florida helped communities recover and improve mitigation measures around their properties. Also, if parcel data is publicly shared, it could support fire management as well as rehabilitation of properties and road networks.

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[11] https://fsapps.nwcg.gov/baer/about-barc-faq

[12] The primary objective of the National Landslide Hazards Program is to reduce long-term losses from landslide hazards by improving our understanding of the causes of ground failure and suggesting mitigation strategies.

Participants noted that overall, with the changes in the FAA (e.g., getting emergency Certificates of Waiver or Authorization has been more efficient and effective), and now, with the potential for greater NASA involvement, there is opportunity to improve today's wildfire management operations.

Possible Next Steps

The Wildfire Management Workshop breakout sessions provided a wealth of information about the state of wildfire management and potential improvements. Much of the discussion focused not on better firefighting vehicles or tools but on creating useful data products that are delivered to front line personnel in a timely and effective manner. It is important to note that there was a recommendation to host another workshop with front line operational personnel to gather additional feedback from their perspective.

The subsequent possible next steps are derived from multiple facets of the Wildfire Management Assessment Activity, including the workshop discussions, Subject Matter Expert (SME) inputs, literature review, and RFI responses. They are classified into the following categories and aligned with NASA aeronautics capabilities. These are provided for further consideration by NASA and the broader wildfire community.

Comprehensive Concept of Operations, Systems Engineering Practice, and Transition to Reality

There is an opportunity to coordinate efforts to improve wildfire management. There could be great benefit in developing a multi-agency, unified concept of operations (ConOps) to align priorities, response strategies, information exchanges and integration, technologies and their interoperability requirements, and define a coordinated wildfire management approach. The ConOps could focus on near-term (about 3 years), mid-term (about 7 years), and longer-term activities (about 10 years).

Systems engineering rigor could be used to identify needs of multiple types of users, map those needs into functional requirements, and identify technology and procedure related considerations. This could result in a product roadmap that includes development of aircraft, airspace, communications, surveillance, and safety assurance technologies to ensure maximum impact for improving wildfire detection accuracy and timeliness, fire suppression effectiveness, and remedial efforts.

Transition from research and concepts into reality must be carefully planned. The users require mature, high technology readiness level products. If research and development are not sufficient, an approach must be created to support the transition of these efforts, culminating in useful products. This would require coordination, collaboration, and partnerships among multiple government agencies, industry, and philanthropic and non-profit organizations to successfully transition research results into reality at high technology readiness levels.

Leverage NASA Efforts and Programs

Both NASA's Science and Space Technology Mission Directorates have programs that have supported wildfire management efforts. NASA SMD, through the Earth Science Applied Sciences Disasters Program has access to and controls multiple data assets and tools that are beneficial to wildfire management. NASA SBIR and STTR have previously invested in technologies from small businesses that support of wildfire management efforts and could continue to be leveraged.

There could be benefit to collaboration among industry and other stakeholders in the development and ultimate production of technologies for use by firefighters. To that end, methods to incentivize industry could be beneficial. Other SBIR and STTR topics could encourage exploration of other concepts and technologies by small businesses and research institutions. STMD's Prizes and Challenges Program could be used to incentivize industry and the public to innovate in wildfire management topics. Examples of competitions could include reliable, omnipresent communication systems and more effective, cheaper, and environmentally friendly fire retardant. Additionally, NASA could consider partnering with government and industry through a small satellite constellation for surveillance program or the GoFly Wildfire Competition currently under consideration to be released later this year.

Data and Modeling

Data about wildfires comes from many sources including ground personnel, satellites, aircraft, and sUAS. Artificial intelligence (AI) and machine learning (ML) could be used in conjunction with the many data sources to produce effective data fusion. The data may not share a common format, which impedes processing. There is an array of modeling tools available to provide assessments and predictions of what a wildfire will do next. Improved projections using computational fluid dynamics, physics models, and supercomputers could greatly enhance the ability to anticipate and manage fires. This would make firefighting more efficient and help protect the safety of the firefighters, public, buildings, and infrastructure.

There could be benefit in conducting a comprehensive data and models inventory analysis to identify gaps and overlaps and review integration and interoperability considerations for multiple types of users. The purpose of this activity would be to maximize the value of information to the respective users at the time they need it the most. Existing modeling tools could be assessed, resulting in recommendations for improvements. The analysis could also cover how to increase the efficiency of processing data and running wildfire models. A goal would be to create integrated data collection and fire modeling systems that can be used for strategic analyses and fast-time tactical tools that provide information to firefighters on a 15- to 30-minute refresh cycle.

Furthermore, data and models must be easy to use and available at the locations where various wildfire fighting personnel have to operate.

Persistent Surveillance

Current surveillance of the fire regions could be enhanced from satellite-based (every 4 hours) to a combination of sensor data from satellite, small drones and High-Altitude Long Endurance (HALE) drone flights. There may be opportunities to augment and integrate SMD's data sets with additional surveillance means to provide greater capability.

Organizational Considerations

There are many federal, state, county, municipal, and private organizations involved in wildfire prevention and management. Research is carried out by a range of universities and government entities. Participants in the workshop spoke of the difficulties in coordinating among the various groups in terms of funding important research, the timeliness of research findings, accessing new sources of data, formatting data sets for wildfire models, and getting information and information technology tools to fire fighters and the public at the right time. Improved coordination and breaking down barriers that impede information flow could produce significant benefits.

There could be benefit in the establishment of a working group of representatives from the core wildfire organizations. The group could identify other key stakeholders and expand to include additional members, as needed. They would then address the perceived problems with coordination of data and resources that affect wildfire prevention and management. One solution could be to form a new national coordinating body (or expand an existing one) to facilitate wildfire management and channel funding for research.

Wildfire Management Aircraft

Aircraft are used in wildfire management with great effectiveness. However, the situation could be improved. Aircraft could be equipped with sensors that collect data about the fire while they are on a water or flame-retardant drop mission. GPS devices could be used to pinpoint where the drop was made. Better air traffic control and coordination would allow earlier access to the fire site by large and small aircraft and improve safety. The role of sUAS could be increased to collect data before, during, and after the fire at the micro and macro levels. For example, front line personnel could be assigned a few sUAS that would be dispatched to areas of interest and controlled from a tablet device. Additionally, UASs could be used for active fire suppression by converting existing large tankers to be remotely piloted or sufficiently automated to make piloting optional.

As the scope, intensity, locations, and impact of wildfires have increased in the past decade, it is important to assess the aircraft fleet, their capabilities, and associated technologies that will be most effective. Relevant use cases include surveillance, suppression, and remedial inspections. A team could be formed to review firefighting aircraft in current use and recommend future developments in airframes, sensors, and flight deck automation. Experience with UTM could provide tested solutions for deeper involvement of sUAS in wildfire work. Sensor packages from NASA Earth Sciences could be reviewed for application on firefighting and surveying aircraft. Flight deck automation could be specified to enable movement toward ground-piloted or autonomous tanker aircraft. The team could make recommendations, identify cutting-edge organizations, and locate potential funding sources.

Persistent Communication

Given that firefighters, incident commanders, and other personnel move around and operate in areas where current communications approaches are not always reliable, there could be benefits to developing concepts and technologies that will provide persistent communications. Both voice and data communications would benefit wildfire management personnel in the field. As previously discussed, these personnel would benefit from having access to multiple data sources. Moreover, having access to secure and reliable internet capable of supporting high resolution data would also be necessary. NASA's prior work in UAS Integration in the NAS project, and UAS Traffic Management (UTM) could be leveraged to develop requirements and technology options.

Cooperative Airspace Management for Manned and Unmanned Operations

A high workload activity during fire suppression is coordination of multiple types of manned and unmanned aircraft to ensure safe operations. NASA's UTM, Scalable Traffic Management of Emergency Response Operations (STEReO), and in-time safety assessment methods could be leveraged to develop a roadmap for automated (e.g., UTM-in-a-box) airspace management technology to reduce this workload and enhance safety. The roadmap could include common situation awareness capability as an early step and fully automated self-contained airspace operations as the end goal.

Wildfire Suppression Duration

Current practices largely confine the operations of helicopter and other aircraft to visual meteorological conditions, meaning that there is sufficient visibility for safe operations. There could be benefits to increase the suppression duration to as close to 24/7 as possible. Increasing the duration in day and night would likely require automated aircraft, automated airspace operations, and safety assurance methods to ensure persistent and safe operations.

Supporting Firefighting Personnel

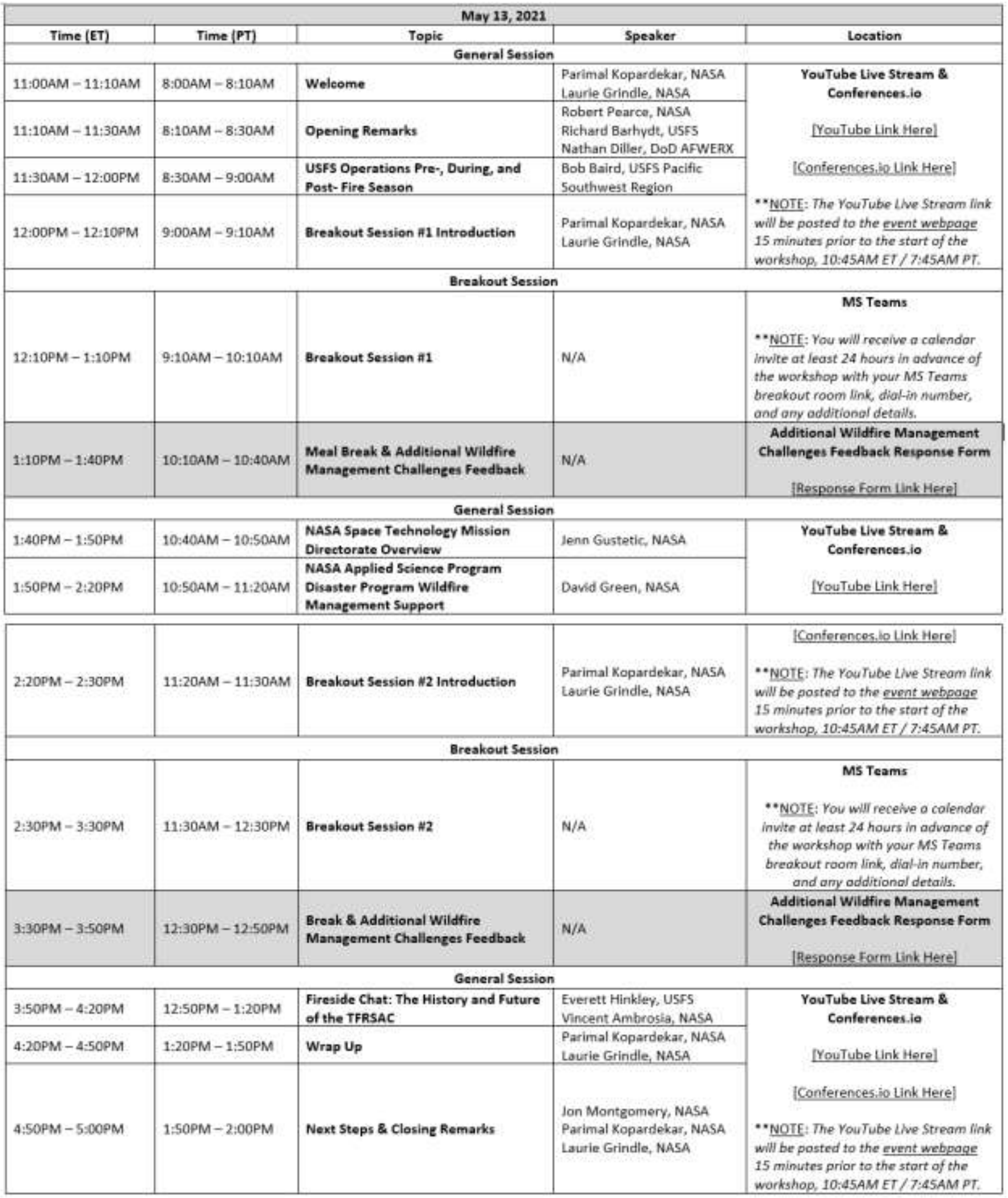
Wildfire Workshop participants articulated that the firefighters at the fire site need pertinent, easy to interpret, and timely information to stop a fire in its early stages and combat it effectively. This would also protect the lives of the firefighting crews and the public. Improvements in gathering data, running models, and collaborating between agencies could help in effective firefighting by providing the knowledge needed by the firefighters at the right place and time. Currently, information may not be available, be out of date, and/or not presented well. Cell phones and other networking tools often do not work in rural or forested areas.

A working group could be formed that includes project staff and representatives of front-line firefighter organizations to create analyses and recommendations to build an awareness of what is needed at the fire's edge. Sources for the critical information elements could be identified along with methods for communicating them such as HALE or new satellite constellations that offer Internet access. An early focus could be on assessing user needs and designing for the effective presentation of the data on hardened, portable devices.

Summary

This white paper captures highlights of the NASA ARMD Wildfire Management Workshop discussion and potential recommendations of capabilities to improve the state of the art. It is important to note that these recommendations are not considered prioritized or exhaustive, nor do they represent a consensus among participants. NASA looks forward to continued dialogue with the wildfire community on opportunities for collaboration.

Appendix A | NASA ARMD Wildfire Management Workshop Agenda



May 13, 2021				
Time (ET)	**Time (PT)**	**Topic**	**Speaker**	**Location**
General Session				
11:00AM – 11:10AM	8:00AM – 8:10AM	**Welcome**	Parimal Kopardekar, NASA Laurie Grindle, NASA	**YouTube Live Stream & Conferences.io** [YouTube Link Here] [Conferences.io Link Here] **NOTE: The YouTube Live Stream link will be posted to the event webpage 15 minutes prior to the start of the workshop, 10:45AM ET / 7:45AM PT.
11:10AM – 11:30AM	8:10AM – 8:30AM	**Opening Remarks**	Robert Pearce, NASA Richard Barhydt, USFS Nathan Diller, DoD AFWERX	
11:30AM – 12:00PM	8:30AM – 9:00AM	**USFS Operations Pre-, During, and Post- Fire Season**	Bob Baird, USFS Pacific Southwest Region	
12:00PM – 12:10PM	9:00AM – 9:10AM	**Breakout Session #1 Introduction**	Parimal Kopardekar, NASA Laurie Grindle, NASA	
Breakout Session				
12:10PM – 1:10PM	9:10AM – 10:10AM	**Breakout Session #1**	N/A	**MS Teams** **NOTE: You will receive a calendar invite at least 24 hours in advance of the workshop with your MS Teams breakout room link, dial-in number, and any additional details.
1:10PM – 1:40PM	10:10AM – 10:40AM	**Meal Break & Additional Wildfire Management Challenges Feedback**	N/A	**Additional Wildfire Management Challenges Feedback Response Form** [Response Form Link Here]
General Session				
1:40PM – 1:50PM	10:40AM – 10:50AM	**NASA Space Technology Mission Directorate Overview**	Jenn Gustetic, NASA	**YouTube Live Stream & Conferences.io** [YouTube Link Here]
1:50PM – 2:20PM	10:50AM – 11:20AM	**NASA Applied Science Program Disaster Program Wildfire Management Support**	David Green, NASA	
2:20PM – 2:30PM	11:20AM – 11:30AM	**Breakout Session #2 Introduction**	Parimal Kopardekar, NASA Laurie Grindle, NASA	[Conferences.io Link Here] **NOTE: The YouTube Live Stream link will be posted to the event webpage 15 minutes prior to the start of the workshop, 10:45AM ET / 7:45AM PT.
Breakout Session				
2:30PM – 3:30PM	11:30AM – 12:30PM	**Breakout Session #2**	N/A	**MS Teams** **NOTE: You will receive a calendar invite at least 24 hours in advance of the workshop with your MS Teams breakout room link, dial-in number, and any additional details.
3:30PM – 3:50PM	12:30PM – 12:50PM	**Break & Additional Wildfire Management Challenges Feedback**	N/A	**Additional Wildfire Management Challenges Feedback Response Form** [Response Form Link Here]
General Session				
3:50PM – 4:20PM	12:50PM – 1:20PM	**Fireside Chat: The History and Future of the TFRSAC**	Everett Hinkley, USFS Vincent Ambrosia, NASA	**YouTube Live Stream & Conferences.io** [YouTube Link Here] [Conferences.io Link Here] **NOTE: The YouTube Live Stream link will be posted to the event webpage 15 minutes prior to the start of the workshop, 10:45AM ET / 7:45AM PT.
4:20PM – 4:50PM	1:20PM – 1:50PM	**Wrap Up**	Parimal Kopardekar, NASA Laurie Grindle, NASA	
4:50PM – 5:00PM	1:50PM – 2:00PM	**Next Steps & Closing Remarks**	Jon Montgomery, NASA Parimal Kopardekar, NASA Laurie Grindle, NASA	

Appendix B | Breakout Groups' Questions

BREAKOUT SESSION 1

(Thursday, May 13, 2021 from 9:10AM – 10:10AM PT / 12:10PM – 1:10PM ET)

Planning for Fire Season (Group 1)
Breakout Questions:

- Data Management: What are the main uses of data during wildfire preparedness? What are the key challenges for data use in wildfire planning/pre-fire season?
- Indicate the source of data when answering the question. Data sources include airborne, satellite, and ground-based platforms.
- Is there a need for developing a standard for data and integration?

Planning for Fire Season (Group 2)
Breakout Questions:

- Agency Coordination: How are new technologies tested and introduced into pre-fire season/planning operations today and how might this be better supported in the future?
- Where are the opportunities to improve planning across multiple agencies?

Prediction Modeling and Challenges (Group 1)
Breakout Questions:

- Data Management: What are the main uses of data during wildfire prediction? What data is required to support modeling? What are the key challenges for data use in wildfire prediction and modeling?
- Indicate the source of data when answering the question. Data sources include airborne, satellite, and ground-based platforms.
- Is there a need for developing a standard for data and integration?

Prediction Modeling and Challenges (Group 2)
Breakout Questions:

- Agency Coordination: How are new prediction and modeling technologies tested and introduced into prediction and modeling operations today and how might this be better supported in the future?
- Round Robin - Everybody identifies 3 areas for improvement and where research and development is needed.

Aerial Fire Surveillance (Group 1)
Breakout Questions:

- What are typical challenges for aircraft that conduct fire surveillance operations? When is the aircraft surveillance better than satellite surveillance? Are there specific capabilities of aircraft and satellite you would like to have that don't exist today?

- What is the ideal range for aircraft for conducting surveillance of fires? What are the typical sensors (including their weight) installed on surveillance aircraft?
- Under what conditions (e.g., wind, visibility, day/night, altitude) do surveillance aircraft and their operations need to be conducted?

Suppression and Mitigation (Group 1)

Breakout Questions:

- Thinking through the process flow, where would a breakthrough make the greatest impact, e.g., around the clock operations capability, firefighters/personnel access to the fire, real-time information about heat detection and fire growth?
- What are current benchmark metrics (e.g., time to respond, time to put out fire, etc.)? What are barriers to meet those metrics and improve them?

Suppression and Mitigation (Group 2)

Breakout Questions:

- What are the key challenges for airspace and fleet operations management, e.g., aircraft, airfield, sensors, airspace?
- We have heard many cases where drones have caused stoppage of the aerial firefighting? What would you like to see changed so that wildfire aerial fighting is most effective?
- What are areas where research, development, testing, and aerial support could be improved? In what areas are research and development needed?

Suppression and Mitigation (Group 3)

Breakout Questions:

- Thinking specifically about aviation wildfire response, what limits the effort to suppress fire from the air?
- What types of aircraft are currently used in wildfire suppression and mitigation? What sensors are currently used on these aircraft and what types of sensors and aircraft are planned for use in the future?
- Do all firefighting locations have similar access to aerial firefighting resources? How are the decisions made about which aircraft to use?
- What are areas where research, development, testing, and aerial support could be improved? In what areas are research and development needed?

Post-Fire Remedial Efforts (Group 1)

Breakout Questions:

- What are typical activities conducted by following wildfire; why are they important? How can these activities of inspection, and analysis be improved?
- Agency Coordination: How are new technologies tested and introduced into post-wildfire operations today and how might this be better supported in the future?

Post-Fire Remedial Efforts (Group 2)
Breakout Questions:

- Data Management: What are the main uses of data during wildfire recovery, damage assessment, and remediation determination? What data is required to support remedial efforts? What are the key challenges for data use in post-wildfire damage assessment and stabilization?
- Should note the source of data when answering the question. Data sources include airborne, satellite, and ground-based platforms.
- Is there a need for developing a standard for data and integration?
- What are areas where research, development, testing, and aerial support could be improved? In what areas are research and development needed?

BREAKOUT SESSION 2

(Thursday, May 13, 2021 from 11:30AM – 12:30PM PT / 2:30PM – 3:30PM ET)

Planning for Fire Season (Group 1)
Breakout Questions:

- How are lessons learned from previous fire season identified and captured? What are the opportunities of improvement in the development of lessons learned from the previous fire season and their application to improve next season?
- Are lessons learned shared across the firefighting community? What are the barriers to sharing this information?

Planning for Fire Season (Group 2)
Breakout Questions:

- What are the most challenging/complex decision that wildfire management leaders must make? What makes them a challenge? What would be the most valuable type of support for these decisions (e.g., more/different data)?
- What are areas where research, development, testing, and aerial support could be improved? In what areas are research and development needed?

Prediction Modeling and Challenges (Group 1)
Breakout Questions:

- What are the key challenges in the prediction of fire hazards? What are the key challenges in the prediction of day-to-day wildfire suppression and mitigation operations?
- Round Robin - Everybody identifies 3 areas for improvement and where research and development is needed.

Prediction Modeling and Challenges (Group 2)
Breakout Questions:

- Identify data, analysis, and modeling needs by users/roles, e.g., researchers, planners, forecasters, firefighters, aerial firefighting pilots, incident commanders, virtual air boss, etc.
- What areas do you recommend for improvement as related to prediction models, data, analysis, and presentation?

Aerial Fire Surveillance (Group 1)
Breakout Questions:

- How are wildfires detected today; what are the methods of surveillance? What's the biggest challenge around detection, e.g., sensor fidelity/sensitivity, false positives/negatives, sensor size/weight/power/cost.
- What are different types of aircraft used in surveillance? How can that be improved?
- Would it be useful to use larger autonomous, unmanned, or remotely operated aircraft which can operate day and night, and under low visibility (e.g., instrument meteorological conditions)
- What are the opportunities to improve communication and coordination as the fire is detected during aerial flights? What type of communications and streaming capabilities are needed for surveillance aircraft?

Suppression and Mitigation (Group 1)
Breakout Questions:

- Communication: Describe the role of communication in wildfire response? What are the key challenges with respect to communication?
- Identify communication needs by users, e.g., firefighters, pilots, aerial observers, incident commanders, virtual air boss, etc. Where are opportunities to improve communications systems during firefighting?

Suppression and Mitigation (Group 2)
Breakout Questions:

- Data Management: What are the main uses of the data during wildfire response? What are the key challenges for data use in wildfire suppression and mitigation?
- Note the source of data when answering the question. Data sources include airborne, satellite, and ground-based platforms.
- Is there a need for developing a standard for data and integration?
- Round Robin - Everybody identifies 3 areas for improvement and where research and development is needed.

Suppression and Mitigation (Group 3)
Breakout Questions:

- What are limitations of current operations (e.g., visual conditions, wind, daytime only, etc.)?

- Would it be useful to use larger autonomous, unmanned, or remotely operated aircraft with retardant dropping capability which can operate day and night, and under low visibility (e.g., instrument meteorological conditions).
- What are barriers to 24/7 aerial firefighting?

Suppression and Mitigation (Group 4)
Breakout Questions:

- Agency Coordination: How are new technologies tested and introduced into suppression and mitigation operations today and how might this be better supported in the future?
- Do you see any opportunities to improve communication and coordination during firefighting based on multiple organizations and roles involved?
- Round Robin - Everybody identifies 3 areas for improvement and where research and development is needed.

Post-Fire Remedial Efforts (Group 1)
Breakout Questions:

- What types of aircraft are currently used post-fire season? What sensors are currently used on these aircraft and what types of sensors and aircraft are planned for use in the future?
- Round Robin - Everybody identifies 3 areas for improvement and where research and development is needed.

Appendix C | Breakout Groups' Top 3 Outcomes

BREAKOUT SESSION 1

(Thursday, May 13, 2021 from 9:10AM – 10:10AM PT / 12:10PM – 1:10PM ET)

Planning for Fire Season (Group 1)

Breakout Top 3 Outcomes:

1. Data sets that are sustainably updated are needed:
    - There are key types of data that are developed by third parties which do not guarantee persistence, commitment, and upkeep.
    - Cities, counties, state government, commercial, oil & gas pipelines, electric transmission lines, building footprints, maps of roads, structures, water/power infrastructure, fire weather, fuel moisture, vegetation.
2. Improved network models are needed to predict impacts and fire scenarios:
    - This would improve processes such as fire treatment planning, fire danger operating plans, and developing pre-planned fire scenarios for expected response.
    - Integrating these inputs with the Wildland Fire Decision Support System (WFDSS) would be very valuable.
3. Standards for data integration:
    - Quality of data sets vary wildly across the country impacting modeling/planning efforts (e.g., vector datasets), sustained collaboration among the research community outside the fire season (e.g., data users and data providers).
    - Teaming with the National Wildfire Coordinating Group (NWCG) is important here.

Planning for Fire Season (Group 2)

Breakout Top 3 Outcomes:

1. Establish an interagency process template for State and Federal entities:
    - Standardize rapid agreements and associated training/understanding to support wildfire activities.
    - CalFire processes were cited as a model for this.
2. DoD and NASA understand how to assess situations and develop tactics/strategies.
    - Neither are members of National Wildfire Coordinating Group so formalizing partnerships with them will be valuable.
    - Partnership will help collaboration on physics-based modeling, other advanced computing techniques, and data collection/distribution techniques.
3. Requirement for timely and actionable real-time information (real-time wind/weather predictions and detection, tracking, fire prediction):
    - Information collection could also include predictive efforts such as monitoring tree mortality.
    - Rothaermel model needs to be updated based on today's wildfire challenges.

  - Collaborate on data collection techniques and advanced computing techniques could be beneficial.
  - Consider leveraging other similar real-time processes and data solutions for disasters (e.g., volcanoes, earthquakes, floods, etc.).

Prediction Modeling and Challenges (Group 1)

Breakout Top 3 Outcomes:

1. Data Update Rate Difficulties:
    - Different time scales and density of data.
    - Especially for fuel and localized weather which are important for modeling and prediction.
2. Data and Model Processing Times:
    - Very computer intensive.
    - Need to find a way to decrease processing time and ways to use more automated data analytics.
    - Perhaps through data tagging and labelling.
3. Standardized Data Formats:
    - Need open format for data exchange and interoperability to aid in automated data ingestion.
    - There are too many sources that are proprietary (stove-piped data leads to login fatigue to get data to combine).

Prediction Modeling and Challenges (Group 2)

Breakout Top 3 Outcomes:

1. Modelers need access to the best data available to develop and validate predictive tools.
    - There is currently little coordination among modelers and data producers/providers.
    - It would be very helpful for a university or similar entity to conduct a comprehensive survey of data sources and modeling efforts and publish the results.
    - It would be even better if this could be repeated periodically and maintained, and perhaps turned into a portal for use by the model development community.
2. Modelers should carefully consider the needs of the model users in the way they present their results.
    - Users are often non-scientific and cannot easily use raw data (like smoke density in PPM) to make decisions.
    - If possible, data should be presented in terms of risk (i.e., likelihood of causing damage, injury, etc.) to help users make more informed operational decisions.
3. The current SOA in fire behavior modeling is non-spatial (i.e., localized).
    - There is a great potential to improve the predictive capabilities of fire behavior models through use of spatial modeling tools like CFD.

  - Computational power required will be high and will likely require the use of supercomputers.

Aerial Fire Surveillance (Group 1)

Breakout Top 3 Outcomes:

1. ML/AI solutions for differentiating fire and combining data sets for better/reliable information.
    - No or little AI/ML on camera collected information.
    - Operationalization capability is lacking (multi-view, multi-perspective).
2. Common operating picture (integrated information, intel operator to figure out who to send to, operationalization of the product, geospatial information integration).
    - Getting data off to users in real-time (amalgamation of concurrent systems).
    - Need a coalition of partners to ensure integrated data distribution.
    - Drop sensors, real time information flow is challenging (communications), policies, procedures, workflows don't exist (no storage, display, and integrated perspective).
3. Wide area surveillance damage assessment.
    - Aircraft offers advantage (getting under weather), small drones for surveillance (US made), most pyro luminous clouds, all weather conditions.
    - Systems engineering approach to recognize how to bring forward all aerial and space assets, hyperspectral/multi-spectral sensor, persistence (fire guard, long endurance, GOES – system of systems solutions).

Suppression and Mitigation (Group 1)

Breakout Top 3 Outcomes:

1. Timely anticipation technologies:
    - Provide rapid detection and situational awareness at decision scale with hourly or better updates toward near real time (with attention to specific actions e.g., morning and nighttime deployments).
    - For suppression logistics tailored to fuel environment and season.
2. Initial attack, helping local fire practitioners prioritize and be efficient with resources, including rapid intervention for extraction, deployment of retardants/water with autonomous aircraft and equipment.
3. Rapid modeling and simulation for effective mitigation (prescribed burns and breaks):
    - Supported by science imagery and analysis including for different fuel types and changing environmental conditions.

Suppression and Mitigation (Group 2)

Breakout Top 3 Outcomes:

1. Pilots in the airspace need to feel confident in the operators in the airspace.
    - UAS's need persistent communications to their ground operators.

- Currently if a UAS loses ground contact all operations are suspended or grounded till the contact can be re-established.

2. A persistent stare capability of <1m resolution is needed to provide knowledge at a human scale.
    - Informs the “boots on the ground” (absolute knowledge of the theater).
3. Data fusion and merge capabilities from various sources is needed.
    - Fast, responsive, low data demand, way to permit ground users, coordinators, and the response team access to the global situation.
    - More and more sensors are going into the air.

Suppression and Mitigation (Group 3)

Breakout Top 3 Outcomes:

1. Mapping and understanding the state of play.
    - Need: Night-time air tanker suppression activities (best time to fight a fire is when it's laying down).
    - Need: Persistent surveillance and real-time/near real-time data (large gap between the time when information is collected and when people go out to fight the fire).
    - Lots of opportunities for improvement with the frequency of fire mapping information and getting the info to the firefighters.
    - Too much can change in between data gathering times.
2. Different types of aircraft and usage techniques:
    - Very Large Air Tankers (VLAT) on the ridges are the best option for autonomous operations.
    - Need several size tankers (small for tight spots and larger for ridges).
    - Air tankers outfitted with thermal cameras would allow them to provide fire status information.
    - Tankers should also record where drops are made.
3. The USGEO (multi-agency) Innovation task team is looking at making connections between needs and capabilities.
    - Need cooperative public-private partnerships and straight forward/easy ways to work together (Same issues 7 years later).

Post-Fire Remedial Efforts (Group 1)

Breakout Top 3 Outcomes:

1. Post assessment reports such as the Burn Area Emergency Response (BAER) report are published within a few days requiring quick data acquisition and analysis.
    - Distillation and/or a deep learning/AI aspect would benefit cross agency users and learning for future incidents.
    - Sensors for high resolution optical imagery of burned areas are needed and LiDAR as well as hyper and multispectral data are desired.

    - Sensor data or remote assessment on hazards (chemicals, old mines, etc.) is also needed to determine what areas are safe to enter.
2. Need a digital infrastructure to support post fire response datasets and analysis for impacted people.
    - Use by multiple agencies and collaboration across gov levels, orgs.
    - It was also noted that comprehensive technology capability portfolios are lacking leading to a fractured focus on technology development and transition.
3. Enhanced data need--temporal as well as spatial.
    - Data acquisition also needed longer term on ground/space/aerial platforms to understand post incident impact on land/water rate of recovery.

Post-Fire Remedial Efforts (Group 2)
Breakout Top 3 Outcomes:

1. Fire Burn Severity layers are key.
    - BAER Teams to support recovery assessment and model debris flow probability layers to effect hazard notifications to region / communities.
    - These layers are derived from Earth Observation (EO) data (Landsat and Sentinel), but timeliness of both can be problematic given their orbit schedule and cloud cover issues.
    - Can we use other data to support those immediacy needs of data?
        - Contract aerial imagery services, other sensors with similar spectral bands to allow consistent Burn Severity algorithm development?
        - There need to be “standards” for airborne acquisition of Burned Area data, so that Landsat / Sentinel and other spectral data (aircraft-acquired) can be consistent.
2. Most post-fire assessment and remediation plans are distributed for fire management use.
    - Needs to be a public facing “dashboard” to allow communities to be informed of post-fire issues, such as road closures, damage to infrastructure, sensitive area (keep out zones), flood erosion potential areas, infrastructure damage.
    - This would allow fire-affected communities have a means to understand the recovery or mitigation plans underway that will affect them.
3. Each BAER team (from different agencies) provide their remediation/Burned Area Emergency Response (BAER) assessment reports to distributed service.
    - Need to coalesce those services for data continuity.

BREAKOUT SESSION 2

(Thursday, May 13. 2021 from 11:30AM – 12:30PM PT / 2:30PM – 3:30PM ET)

Planning for Fire Season (Group 1)
Breakout Top 3 Outcomes:

1. Lessons learned format:

  - Much is captured in paper form (e.g., Facilitated Learning Analysis, Incident Management Reports), but increasingly digital.
  - The opportunity is to increase digital capture, overcome barriers to sharing restricted digital data, and then utilize this for simulations and what-if learning for incident planning and management.
2. Lessons learned are largely retrospective.
   - Opportunities exist to be more anticipatory and pro-active, translating lessons into predictions while recognizing that that fires are now year around.
3. Lessons learned are being captured in part of the Wildfire Lesson Center over different time scales.
   - Including heterogeneous data.
   - Need to improve awareness to mobilize around improved plans, economic/financial impact, and incorporating earth systems, safety risk and loss assessments, and technology innovation for actionable plans.

Planning for Fire Season (Group 2)

Breakout Top 3 Outcomes:

1. Solutions are needed for Funding, Procurement, Data Merge / Operationalization, and Comms / distribution.
2. The Fire Fighting community needs the state of the art from 2010 to be an operational capability in 2021.
   - “The state of the art is useless when you're all alone digging a fire ditch, unless it's in your pocket or in your pack."
3. Community building and coalitions are needed to break barriers between state, government, and private bodies.
   - Need the players (those fighting the fires) connecting to the R&D for practical maturation of technology for real world use now and in the future.
   - The community is smaller than you expect and more distributed.
     - More community exchanges are needed to sit in a room and work out possible solutions.
     - More like this workshop where conversations are happening. We need operators to talk with short term technology infusers (12 - 24-month solutions) to work out how Commercial Off-The-Shelf (COTS) tools can be applied today.
     - If this was a requirement / listening workshop, another focused workshop on partnerships and problem solving would be good.

Prediction Modeling and Challenges (Group 1)

Breakout Top 3 Outcomes:

1. Analysis of large amount of data in short time:
   - May be able to benefit from Machine Learning (ML) algorithms for prediction modeling at various time scales.

2. Sustained engagement between end users and research and development community to match development efforts to prioritized user needs.
    - For example, morning session identified need for IR wildfire detection, tracking, and projection.
3. Delivering appropriate information to the right people at the right time given constraints such as bandwidth.
    - Communication very difficult in remote areas and extreme conditions.

Prediction Modeling and Challenges (Group 2)

Breakout Top 3 Outcomes:

1. Need data at a higher spatial and temporal resolution (100m, 15-30min update) to be relevant to fast moving fires.
    - Data needs to be integrated across sources and users.
2. Need to know where the fire is, where the firefighting assets are, and where the public is to be able to assess risks and make operational decisions.
    - However, there are privacy issues associated with using mobile-phone data or social media to determine where people are.
3. It is a challenge for modelers to understand the requirements of operational people and to get technology into field operations.
    - Researchers want to be able to validate their technology in real world conditions, but fire fighters are rightfully concerned about testing low Technology Readiness Level (TRL) technologies in life-threatening conditions.

Aerial Fire Surveillance (Group 1)

Breakout Top 3 Outcomes:

1. Detection:
    - Satellite, aircraft, and cameras (designing geostationary payload for school bus size detection) pixel dwell time.
2. King Air and Citation at National Infrared Operations (NIROPS) - 15000 ft and can see spot fire 8-inch diameter - not enough spatial resolution for mopup. It gets used for mopup, but that wasn’t what it was designed for.
    - Designed and targeted for moving fires.
    - Colorado multi mission a/c and others are also doing it – small UAS – need persistent surveillance. Small UAS would be good for mopup.
3. Small drones:
    - Integrated airspace operations are a challenge, people operating radios at different frequencies.

Suppression and Mitigation (Group 1)

Breakout Top 3 Outcomes:

1. Multiple data streams are being used to collect massive amount of data.

- Only enough data to make an informed decision (any additional data can become confusing).
- Can the computer/human interface be improved?
    - Maybe machine learning to parse through the data and display it in a useable manner.

2. Detect and mitigate drone interference with wildfire activities (e.g., rogue actors).
    - Smoke/fire are challenges.
    - What are the countermeasure technologies and implementation strategies that can be employed?
3. Can the communications between manned and unmanned assets be improved to allow for opportunities for collaboration across those assets?

Suppression and Mitigation (Group 2)
Breakout Top 3 Outcomes:

1. Primary use: protecting life and property; Primary challenge: connectivity.
2. Any collected data needs to be useful to the boots on the ground.
    - Additionally, in order to make collected data helpful to Geographic Information System (GIS) analysts and other uses, the research community needs to be properly educated/aligned with existing data standards (e.g., National Wildfire Coordination Group (NWCG)).
3. A challenging balancing act:
    - High quality and infrequent vs. Acceptable quality and timelier.
    - Both have advantages, but which to use when?
    - More discussion is needed with more users/stakeholders to understand other such ‘knobs’ that represent important tradeoffs.

Suppression and Mitigation (Group 3)
Breakout Top 3 Outcomes:

1. Current suppression mitigation operations (aerial) are limited by fire weather conditions (turbulence, visibility) and other elements (night / low-visibility flights, terrain, etc.); these necessitate improving developments of platforms and autonomous flight decision systems to allow 24/7 operations.
2. Since UAS fire suppression A/C may be of limited use now (due to platform design, build-out, and FAA certification time-lines), the team suggests a “spiral” development phase, where “augmented guidance (i.e., Heads-up displays for pilots) or optionally piloted (augmented flight ops) be the first stage of development (on manned platforms) while new UAS platforms are brought into operational context. These incremental technology developments on manned A/C can then be test-bedded and moved to autonomous ops in the spiral development stage.
3. Rather than focusing on “large” UAS Suppression (retardant drop) A/C, the focus can be on smaller platforms (rotorcraft (K-Max-class?) to support initial attack (IA) retardant

dropping. These platforms may be more maneuverable and provide more rapid support in those IA ops.

Suppression and Mitigation (Group 4)

Breakout Top 3 Outcomes:

1. New physics-based models are starting to come online.
    - Data intensive so data standardization and automated data input would be useful.
2. Need to get what is the most important data to the user based on the user's level.
    - Data for the Incident Command Center will be more detailed and broader than what the field operators need ("high tech" vs "low tech" e.g., color movies vs pdf).
    - This data needs to be communicated to the user just-in-time.
    - Communicating data is difficult, especially to field operators in remote areas with spotty cell coverage; so, asynchronous connectivity and communications interoperability are needed.
3. Most see disaster response as a government function.
    - Agencies must step up to support research, both private and public, in this area (DARPA for disaster response).
    - Technology may exist but the governmental bureaucracy / institutional inertia may prevent it from being field tested in a timely manner (e.g., small UAS).

Post-Fire Remedial Efforts (Group 1)

Breakout Top 3 Outcomes:

1. Great success with small off the shelf drones.
    - Looking at post-fire debris flows and flooding.
    - Mostly use satellite and airborne imagery from others when available to create the Burned Area Reflectance Classification (BARC) products and burn severity layer aircraft imagery for sediment level assessment, debris flows, and flooding.
    - But need high resolution aircraft imagery data to assess areas at risk in addition to the other items above.
2. Are there partnerships/sponsorships to provide access to state teams doing remediation efforts in addition to the federal agencies?
    - Is there a way for state entities to get access to federal agency data not currently accessible to them?
    - Better coordination is needed (federal, state, and city governments) for data sharing.
3. Sentinel is 10m resolution, but with large-scale fires need better computing solutions for modeling.
    - A better hyperspectral data map for the Burned Area Emergency Response (BAER) teams to know how much cover is left to protect soils, are soils

hydrophobic, and what type of storms are going to hit their watersheds during recovery.

- When is the watershed recovered? Could NASA resources (severity products) answer the question and assess the vegetation status?
  - Informs the communities how the risk level is reducing over time.

Appendix D |Possible Next Steps High-Level Descriptions

POSSIBLE NEXT STEP	HIGH-LEVEL DESCRIPTION
Comprehensive Concept of Operations, Systems Engineering Practice, and Transition to Reality	• Develop multi-agency unified concept of operations to align priorities, response strategies, information exchanges and integration, technologies and their interoperability requirements, and coordinated wildfire management approach to maximize the impact. • Use systems engineering approach to identify multiple types of users' needs, map the users' needs into functional requirements, and identify technology and procedure related considerations. This could result in a product roadmap for multiple users in the wildfire management community. • Develop an approach to transition research and concepts into reality. The users need mature high technology readiness level products. This will require coordination and collaboration among multiple government agencies, industry, and non-profit organizations.
Leverage NASA Efforts and Programs	• Collaborate with NASA STMD for wildfire focused competitions, prizes, and SBIR/STTR topics. • Partner with NASA SMD to leverage data assets and tools that are beneficial to wildfire management
Data and Modeling	• Conduct comprehensive data and models inventory analysis, identify gaps and overlaps, and identify integration and interoperability considerations for multiple types of users. This will maximize value of data and information to the respective users when they need it most.
Persistent Surveillance	• Improve the surveillance of the fire regions by using a combination of sensor data from satellite and High-Altitude Long Endurance (HALE) flights.
Organizational Considerations	• Improve coordination between federal, state, county, municipal, and private organizations involved in wildfire prevention and management, and break down barriers that impede information flow to produce significant benefits.
Wildfire Management Aircraft	• Assess the needed aircraft fleet, their capabilities, and associated technologies that will be most effective in wildfire management. Relevant use cases include surveillance, suppression, and remedial inspections.
Persistent Communication	• Develop concepts and technologies that will provide reliable, persistent communications (voice and data) in remote, hazardous areas.

POSSIBLE NEXT STEP	HIGH-LEVEL DESCRIPTION
Cooperative Airspace Management for Manned and Unmanned Operations	• Develop roadmap for automated (e.g., UTM-in-a-box) airspace management technology. The roadmap could include common situational awareness capability as an early step and fully automated self-contained airspace operations as the end goal.
Wildfire Suppression Duration	• Increase the suppression duration in day and night (24/7) through automated aircraft, automated airspace operations, and safety assurance methods to ensure persistent and safe operations.
Support Firefighting Personnel	• Provide the timely, accurate knowledge needed by the firefighters through improvements in gathering data, running models, and collaborating between agencies.

Appendix E | Breakout Groups' Top 3 Outcomes and Possible Next Steps Crosswalk

LEGEND: *(of Possible Next Steps shorthand)*

- Comprehensive Concept of Operations, Systems Engineering Practice, and Transition to Reality = *Crosscutting*
- Leverage NASA Efforts and Programs = *NASA*
- Data and Modeling = *Data*
- Persistent Surveillance = *Surveillance*
- Organizational Considerations = *Organizational*
- Wildfire Management Aircraft = *Aircraft*
- Persistent Communication = *Communication*
- Cooperative Airspace Management for Manned and Unmanned Operations = *Airspace*
- Wildfire Suppression Duration = *Suppression*
- Supporting Firefighting Personnel = *Personnel*

Planning for Fire Season (Session 1: Group 1)	
Top 3 Outcomes	**Possible Next Steps**
Data sets that are sustainably updated are needed: • There are key types of data that are developed by third parties which do not guarantee persistence, commitment, and upkeep. • Cities, counties, state government, commercial, oil & gas pipelines, electric transmission lines, building footprints, maps of roads, structures, water/power infrastructure, fire weather, fuel moisture, vegetation.	Data, Organizational, Aircraft, Personnel
Improved network models are needed to predict impacts and fire scenarios: • This would improve processes such as fire treatment planning, fire danger operating plans, and developing pre-planned fire scenarios for expected response. • Integrating these inputs with the Wildland Fire Decision Support System (WFDSS) would be very valuable.	Data, Personnel
Standards for data integration: • Quality of data sets vary wildly across the country impacting modeling/planning efforts (e.g., vector datasets), sustained collaboration among the research community outside the fire season (e.g., data users and data providers). • Teaming with the National Wildfire Coordinating Group (NWCG) is important here.	Data, Organizational

Planning for Fire Season (Session 1: Group 2)	
Top 3 Outcomes	**Possible Next Steps**
Establish an interagency process template for State and Federal entities: • Standardize rapid agreements and associated training/understanding to support wildfire activities. • CalFire processes were cited as a model for this.	Crosscutting, Organizational
DoD and NASA understand how to assess situations and develop tactics/strategies. • Neither are members of National Wildfire Coordinating Group so formalizing partnerships with them will be valuable. • Partnership will help collaboration on physics-based modeling, other advanced computing techniques, and data collection/distribution techniques.	Data, Organizational
Requirement for timely and actionable real-time information (real-time wind/weather predictions and detection, tracking, fire prediction): • Information collection could also include predictive efforts such as monitoring tree mortality. • Rothaermel model needs to be updated based on today's wildfire challenges. • Collaborate on data collection techniques and advanced computing techniques could be beneficial. • Consider leveraging other similar real-time processes and data solutions for disasters (e.g., volcanoes, earthquakes, floods, etc.).	Data, Surveillance, Organizational, NASA, Communication, Aircraft, Personnel

Planning for Fire Season (Session 2: Group 1)	
Top 3 Outcomes	**Possible Next Steps**
Lessons learned format: • Much is captured in paper form (e.g., Facilitated Learning Analysis, Incident Management Reports), but increasingly digital. • The opportunity is to increase digital capture, overcome barriers to sharing restricted digital data, and then utilize this for simulations and what-if learning for incident planning and management.	Crosscutting, Data, Organizational

Planning for Fire Season (Session 2: Group 1)	
Top 3 Outcomes	**Possible Next Steps**
Lessons learned are largely retrospective. • Opportunities exist to be more anticipatory and pro-active, translating lessons into predictions while recognizing that that fires are now year around.	Data, Organizational
Lessons learned are being captured in part of the Wildfire Lesson Center over different time scales. • Including heterogeneous data. • Need to improve awareness to mobilize around improved plans, economic/financial impact, and incorporating earth systems, safety risk and loss assessments, and technology innovation for actionable plans.	Crosscutting, Data, Organizational

Planning for Fire Season (Session 2: Group 2)	
Top 3 Outcomes	**Possible Next Steps**
Solutions are needed for Funding, Procurement, Data Merge / Operationalization, and Comms / distribution.	Crosscutting, Data, Surveillance, Organizational, Aircraft, Communication, Suppression, Personnel
The Fire Fighting community needs the state of the art from 2010 to be an operational capability in 2021. • “The state of the art is useless when you're all alone digging a fire ditch, unless it's in your pocket or in your pack.”	Crosscutting, Personnel

Planning for Fire Season (Session 2: Group 2)	
Top 3 Outcomes	**Possible Next Steps**
Community building and coalitions are needed to break barriers between state, government, and private bodies. • Need the players (those fighting the fires) connecting to the R&D for practical maturation of technology for real world use now and in the future. • The community is smaller than you expect and more distributed. • More community exchanges are needed to sit in a room and work out possible solutions. • More like this workshop where conversations are happening. We need operators to talk with short term technology infusers (12 - 24-month solutions) to work out how Commercial Off-The-Shelf (COTS) tools can be applied today. If this was a requirement / listening workshop, another focused workshop on partnerships and problem solving would be good.	Crosscutting, Organizational, Personnel

Prediction Modeling and Challenge (Session 1: Group 1)	
Top 3 Outcomes	**Possible Next Steps**
Data Update Rate Difficulties: • Different time scales and density of data. • Especially for fuel and localized weather which are important for modeling and prediction.	Data, Surveillance, Aircraft
Data and Model Processing Times: • Very computer intensive. • Need to find a way to decrease processing time and ways to use more automated data analytics. • Perhaps through data tagging and labelling.	Data
Standardized Data Formats: • Need open format for data exchange and interoperability to aid in automated data ingestion. • There are too many sources that are proprietary (stove-piped data leads to login fatigue to get data to combine).	Data, Organizational

Prediction Modeling and Challenges (Session 1: Group 2)	
Top 3 Outcomes	**Possible Next Steps**
Modelers need access to the best data available to develop and validate predictive tools: • There is currently little coordination among modelers and data producers/providers. • It would be very helpful for a university or similar entity to conduct a comprehensive survey of data sources and modeling efforts and publish the results. • It would be even better if this could be repeated periodically and maintained, and perhaps turned into a portal for use by the model development community.	Data
Modelers should carefully consider the needs of the model users in the way they present their results. • Users are often non-scientific and cannot easily use raw data (like smoke density in PPM) to make decisions. • If possible, data should be presented in terms of risk (i.e., likelihood of causing damage, injury, etc.) to help users make more informed operational decisions.	Data, Organizational, Personnel
The current SOA in fire behavior modeling is non-spatial (i.e., localized). • There is a great potential to improve the predictive capabilities of fire behavior models through use of spatial modeling tools like CFD. • Computational power required will be high and will likely require the use of supercomputers**.**	Data

Prediction Modeling and Challenges (Session 2: Group 1)	
Top 3 Outcomes	**Possible Next Steps**
Analysis of large amount of data in short time: • May be able to benefit from Machine Learning (ML) algorithms for prediction modeling at various time scales.	Crosscutting, Personnel

Prediction Modeling and Challenges (Session 2: Group 1)	
Top 3 Outcomes	**Possible Next Steps**
Sustained engagement between end users and research and development community to match development efforts to prioritized user needs. • For example, morning session identified need for IR wildfire detection, tracking, and projection.	Crosscutting, NASA, Data, Organizational, Personnel
Delivering appropriate information to the right people at the right time given constraints such as bandwidth. • Communication very difficult in remote areas and extreme conditions.	Organizational, Surveillance, Communication, Personnel

Prediction Modeling and Challenges (Session 2: Group 2)	
Top 3 Outcomes	**Possible Next Steps**
Need data at a higher spatial and temporal resolution (100m, 15-30min update) to be relevant to fast moving fires. • Data needs to be integrated across sources and users.	Data, Communication, Personnel
Need to know where the fire is, where the firefighting assets are, and where the public is to be able to assess risks and make operational decisions. • However, there are privacy issues associated with using mobile-phone data or social media to determine where people are.	Crosscutting, Surveillance, Aircraft, Communication, Organizational, Personnel
It is a challenge for modelers to understand the requirements of operational people and to get technology into field operations. • Researchers want to be able to validate their technology in real world conditions, but fire fighters are rightfully concerned about testing low Technology Readiness Level (TRL) technologies in life-threatening conditions.	Crosscutting, Data, Organizational, Personnel

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<tr><th>Top 3 Outcomes</th><th>Possible Next Steps</th></tr>
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• No or little AI/ML on camera collected information.
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• Getting data off to users in real-time (amalgamation of concurrent systems).
• Need a coalition of partners to ensure integrated data distribution.
• Drop sensors, real time information flow is challenging (communications), policies, procedures, workflows don’t exist (no storage, display, and integrated perspective).</td><td>Crosscutting, Surveillance, Organizational, Communication</td></tr>
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• Aircraft offers advantage (getting under weather), small drones for surveillance (US made), most pyro luminous clouds, all weather conditions.
• Systems engineering approach to recognize how to bring forward all aerial and space assets, hyperspectral/multi-spectral sensor, persistence (fire guard, long endurance, GOES – system of systems solutions).</td><td>Crosscutting, Surveillance, Aircraft</td></tr>
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• Satellite, aircraft, and cameras (designing geostationary payload for school bus size detection) pixel dwell time.</td><td>Surveillance, Aircraft</td></tr>
</table>

Aerial Fire Surveillance (Session 2: Group 1)	
Top 3 Outcomes	**Possible Next Steps**
King Air and Citation at National Infrared Operations (NIROPS) - 15000 ft and can see spot fire 8-inch diameter - not enough spatial resolution for mopup. It gets used for mopup, but that wasn't what it was designed for. • Designed and targeted for moving fires. • Colorado multi mission a/c and others are also doing it – small UAS – need persistent surveillance. Small UAS would be good for mopup.	Surveillance, Aircraft
Small drones: • Integrated airspace operations are a challenge, people operating radios at different frequencies.	Aircraft, Airspace, Communication

Suppression Mitigation (Session 1: Group 1)	
Top 3 Outcomes	**Possible Next Steps**
Timely anticipation technologies: • Provide rapid detection and situational awareness at decision scale with hourly or better updates toward near real time (with attention to specific actions e.g., morning and nighttime deployments). • For suppression logistics tailored to fuel environment and season.	Data, Surveillance, Communication, Suppression, Personnel
Initial attack, helping local fire practitioners prioritize and be efficient with resources, including rapid intervention for extraction, deployment of retardants/water with autonomous aircraft and equipment.	Organizational, Surveillance, NASA, Aircraft, Personnel
Rapid modeling and simulation for effective mitigation (prescribed burns and breaks): • Supported by science imagery and analysis including for different fuel types and changing environmental conditions	Data, Surveillance, NASA, Aircraft, Personnel

Suppression Mitigation (Session 1: Group 2)	
Top 3 Outcomes	**Possible Next Steps**
Pilots in the airspace need to feel confident in the operators in the airspace. • UAS’s need persistent communications to their ground operators. • Currently if a UAS loses ground contact all operations are suspended or grounded till the contact can be re-established.	Crosscutting, Data, Surveillance, Communication, Suppression, Personnel
A persistent stare capability of <1m resolution is needed to provide knowledge at a human scale. • Informs the “boots on the ground” (absolute knowledge of the theater).	Aircraft
Data fusion and merge capabilities from various sources is needed. • Fast, responsive, low data demand, way to permit ground users, coordinators, and the response team access to the global situation. • More and more sensors are going into the air.	Crosscutting, NASA, Organizational

Suppression Mitigation (Session 1: Group 3)	
Top 3 Outcomes	**Possible Next Steps**
Mapping and understanding the state of play. • Need: Night-time air tanker suppression activities (best time to fight a fire is when it's laying down). • Need: Persistent surveillance and real-time/near real-time data (large gap between the time when information is collected and when people go out to fight the fire). • Lots of opportunities for improvement with the frequency of fire mapping information and getting the info to the firefighters. • Too much can change in between data gathering times.	Crosscutting, NASA, Organizational

Suppression Mitigation (Session 1: Group 3)	
Top 3 Outcomes	**Possible Next Steps**
Different types of aircraft and usage techniques: • Very Large Air Tankers (VLAT) on the ridges are the best option for autonomous operations. • Need several size tankers (small for tight spots and larger for ridges). • Air tankers outfitted with thermal cameras would allow them to provide fire status information. Tankers should also record where drops are made.	Aircraft
The USGEO (multi-agency) Innovation task team is looking at making connections between needs and capabilities. • Need cooperative public-private partnerships and straight forward/easy ways to work together (Same issues 7 years later).	Crosscutting, NASA, Organizational

Suppression Mitigation (Session 2: Group 1)	
Top 3 Outcomes	**Possible Next Steps**
Multiple data streams are being used to collect massive amount of data. • Only enough data to make an informed decision (any additional data can become confusing). • Can the computer/human interface be improved? • Maybe machine learning to parse through the data and display it in a useable manner.	Data, Surveillance, Communication, Personnel
Detect and mitigate drone interference with wildfire activities (e.g., rogue actors). • Smoke/fire are challenges. • What are the countermeasure technologies and implementation strategies that can be employed?	Aircraft, Airspace
Can the communications between manned and unmanned assets be improved to allow for opportunities for collaboration across those assets?	Crosscutting, Aircraft, Communication

Suppression Mitigation (Session 2: Group 2)	
Top 3 Outcomes	**Possible Next Steps**
Primary use: protecting life and property; Primary challenge: connectivity.	Crosscutting, Communication, Personnel
Any collected data needs to be useful to the boots on the ground. • Additionally, in order to make collected data helpful to Geographic Information System (GIS) analysts and other uses, the research community needs to be properly educated/aligned with existing data standards (e.g., National Wildfire Coordination Group (NWCG)).	Data, Communication, Personnel
A challenging balancing act: • High quality and infrequent vs. Acceptable quality and timelier. • Both have advantages, but which to use when? • More discussion is needed with more users/stakeholders to understand other such ‘knobs’ that represent important tradeoffs.	Aircraft, Suppression, Personnel

Suppression Mitigation (Session 2: Group 3)	
Top 3 Outcomes	**Possible Next Steps**
Current suppression mitigation operations (aerial) are limited by fire weather conditions (turbulence, visibility) and other elements (night / low-visibility flights, terrain, etc.); these necessitate improving developments of platforms and autonomous flight decision systems to allow 24/7 operations.	Aircraft, Suppression, Personnel
Since UAS fire suppression A/C may be of limited use now (due to platform design, build-out, and FAA certification time-lines), the team suggests a “spiral” development phase, where “augmented guidance (i.e., Heads-up displays for pilots) or optionally piloted (augmented flight ops) be the first stage of development (on manned platforms) while new UAS platforms are brought into operational context. These incremental technology developments on manned A/C can then be test-bedded and moved to autonomous ops in the spiral development stage.	Crosscutting, Aircraft, Airspace

Suppression Mitigation (Session 2: Group 3)	
Top 3 Outcomes	**Possible Next Steps**
Rather than focusing on "large" UAS Suppression (retardant drop) A/C, the focus can be on smaller platforms (rotorcraft (K-Max-class?) to support initial attack (IA) retardant dropping. These platforms may be more maneuverable and provide more rapid support in those IA ops.	Data, Aircraft

Suppression Mitigation (Session 2: Group 4)	
Top 3 Outcomes	**Possible Next Steps**
New physics-based models are starting to come online. • Data intensive so data standardization and automated data input would be useful.	Data, Organizational
Need to get what is the most important data to the user based on the user's level. • Data for the Incident Command Center will be more detailed and broader than what the field operators need ("high tech" vs "low tech" e.g., color movies vs pdf). • This data needs to be communicated to the user just-in-time. • Communicating data is difficult, especially to field operators in remote areas with spotty cell coverage; so, asynchronous connectivity and communications interoperability are needed.	Data, Organizational, Communication, Personnel
Most see disaster response as a government function. • Agencies must step up to support research, both private and public, in this area (DARPA for disaster response). • Technology may exist but the governmental bureaucracy / institutional inertia may prevent it from being field tested in a timely manner (e.g., small UAS).	Crosscutting, Organizational, Personnel

Post-Fire Remedial Efforts (Session 1: Group 1)	
Top 3 Outcomes	**Possible Next Steps**
Post assessment reports such as the Burn Area Emergency Response (BAER) report are published within a few days requiring quick data acquisition and analysis. • Distillation and/or a deep learning/AI aspect would benefit cross agency users and learning for future incidents. • Sensors for high resolution optical imagery of burned areas are needed and LiDAR as well as hyper and multispectral data are desired. • Sensor data or remote assessment on hazards (chemicals, old mines, etc.) is also needed to determine what areas are safe to enter.	Data, Organizational
Need a digital infrastructure to support post fire response datasets and analysis for impacted people. • Use by multiple agencies and collaboration across gov levels, orgs. • It was also noted that comprehensive technology capability portfolios are lacking leading to a fractured focus on technology development and transition.	Crosscutting, NASA, Data, Organizational
Enhanced data need--temporal as well as spatial. • Data acquisition also needed longer term on ground/space/aerial platforms to understand post incident impact on land/water rate of recovery.	Data

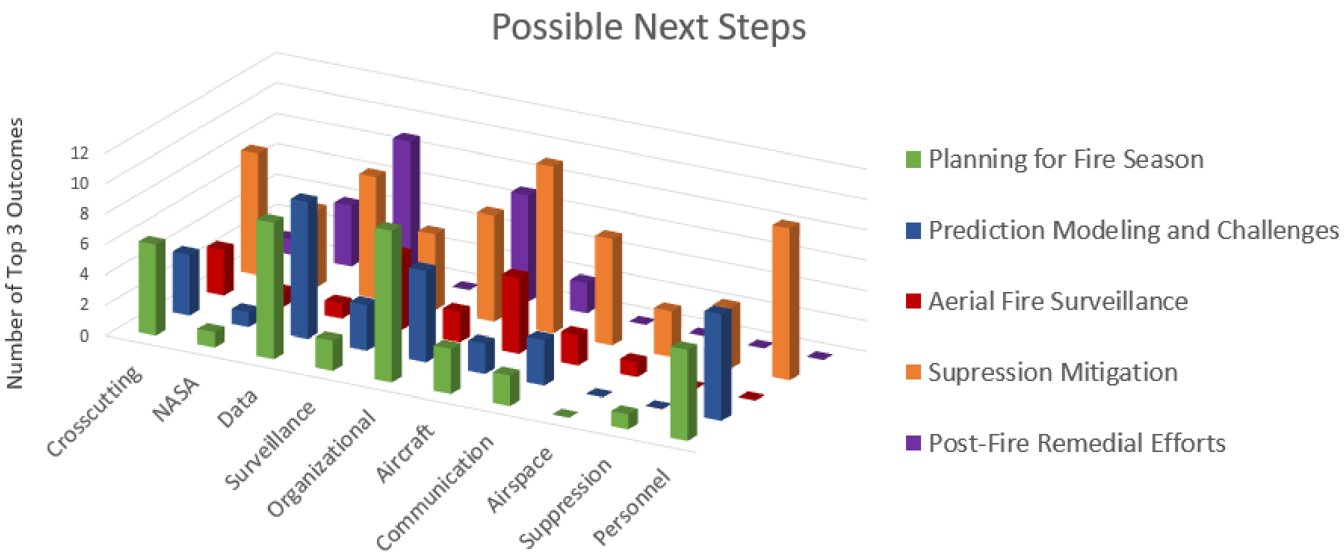
Post-Fire Remedial Efforts (Session 1: Group 2)	
Top 3 Outcomes	**Possible Next Steps**
Fire Burn Severity layers are key. • BAER Teams to support recovery assessment and model debris flow probability layers to effect hazard notifications to region / communities. • These layers are derived from Earth Observation (EO) data (Landsat and Sentinel), but timeliness of both can be problematic given their orbit schedule and cloud cover issues. • Can we use other data to support those immediacy needs of data? • Contract aerial imagery services, other sensors with similar spectral bands to allow consistent Burn Severity algorithm development? • There need to be "standards" for airborne acquisition of Burned Area data, so that Landsat / Sentinel and other spectral data (aircraft-acquired) can be consistent.	Data, NASA, Organizational, Aircraft
Most post-fire assessment and remediation plans are distributed for fire management use. • Needs to be a public facing "dashboard" to allow communities to be informed of post-fire issues, such as road closures, damage to infrastructure, sensitive area (keep out zones), flood erosion potential areas, infrastructure damage. • This would allow fire-affected communities have a means to understand the recovery or mitigation plans underway that will affect them.	Data, Organizational
Each BAER team (from different agencies) provide their remediation/Burned Area Emergency Response (BAER) assessment reports to distributed service. • Need to coalesce those services for data continuity.	Data, Organizational

Post Fire Remedial (Session 2: Group 1)	
Top 3 Outcomes	**Possible Next Steps**
Great success with small off the shelf drones. • Looking at post-fire debris flows and flooding. • Mostly use satellite and airborne imagery from others when available to create the Burned Area Reflectance Classification (BARC) products and burn severity layer aircraft imagery for sediment level assessment, debris flows, and flooding. • But need high resolution aircraft imagery data to assess areas at risk in addition to the other items above.	Data, Aircraft, Organizational
Are there partnerships/sponsorships to provide access to state teams doing remediation efforts in addition to the federal agencies? • Is there a way for state entities to get access to federal agency data not currently accessible to them? • Better coordination is needed (federal, state, and city governments) for data sharing.	NASA, Organizational, Data
Sentinel is 10m resolution, but with large-scale fires need better computing solutions for modeling. • A better hyperspectral data map for the Burned Area Emergency Response (BAER) teams to know how much cover is left to protect soils, are soils hydrophobic, and what type of storms are going to hit their watersheds during recovery. • When is the watershed recovered? Could NASA resources (severity products) answer the question and assess the vegetation status? • Informs the communities how the risk level is reducing over time.	NASA, Data

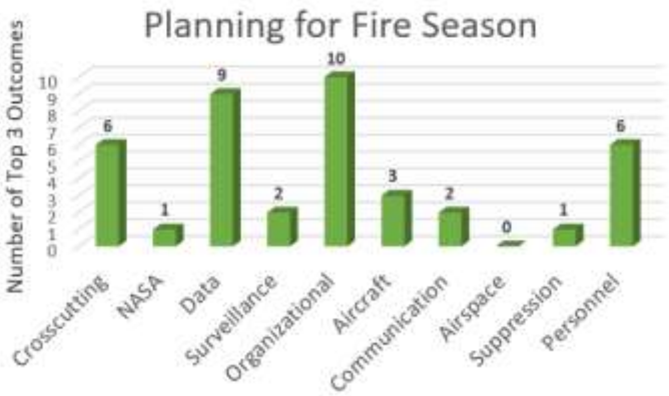
Appendix F | Breakout Groups’ Top 3 Outcomes and Possible Next Steps Crosswalk Plots

LEGEND: *(of Possible Next Steps shorthand)*

- Comprehensive Concept of Operations, Systems Engineering Practice, and Transition to Reality = *Crosscutting*
- Leverage NASA Efforts and Programs = *NASA*
- Data and Modeling = *Data*
- Persistent Surveillance = *Surveillance*
- Organizational Considerations = *Organizational*
- Wildfire Management Aircraft = *Aircraft*
- Persistent Communication = *Communication*
- Cooperative Airspace Management for Manned and Unmanned Operations = *Airspace*
- Wildfire Suppression Duration = *Suppression*
- Supporting Firefighting Personnel = *Personnel*



NOTE: This data is solely reflective of the Top 3 Outcomes received from the NASA ARMD Wildfire Management Workshop breakout participants on May 13, 2021.


Planning for Fire Season

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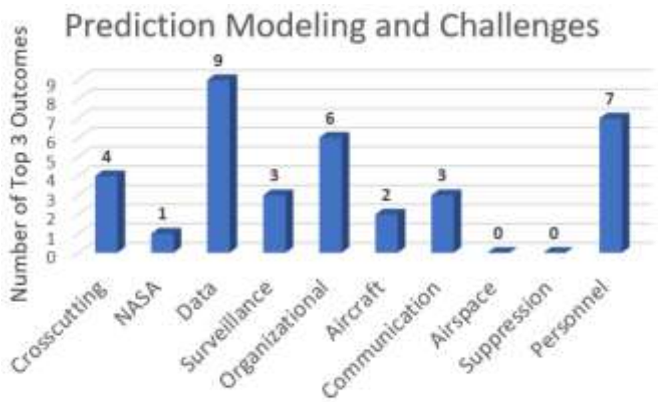
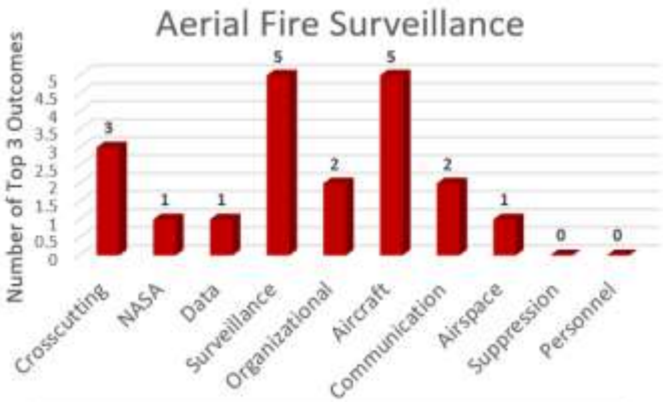
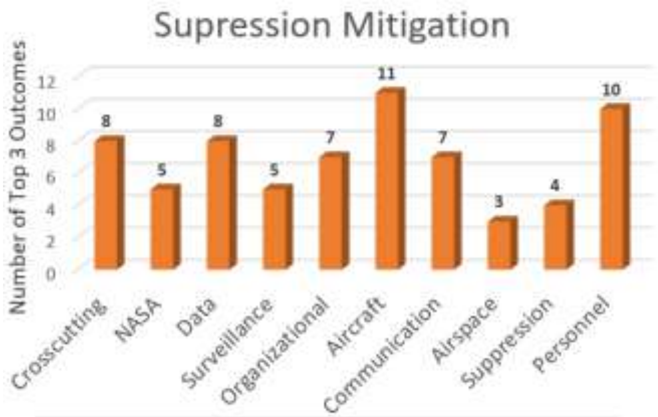

Prediction Modeling and Challenges

NOTE: This data is solely reflective of the Top 3 Outcomes received from the NASA ARMD Wildfire Management Workshop breakout participants on May 13, 2021.


Aerial Fire Surveillance

NOTE: This data is solely reflective of the Top 3 Outcomes received from the NASA ARMD Wildfire Management Workshop breakout participants on May 13, 2021.


Supression Mitigation

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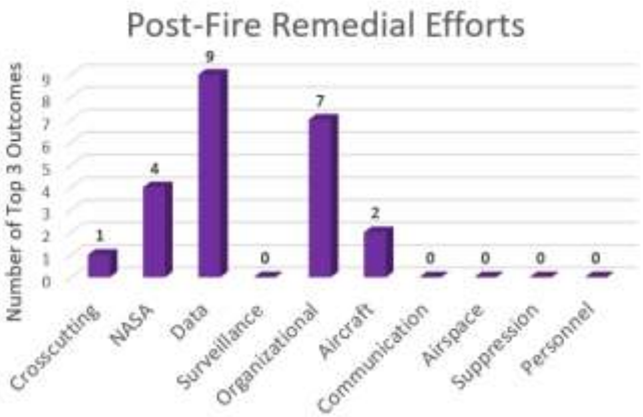
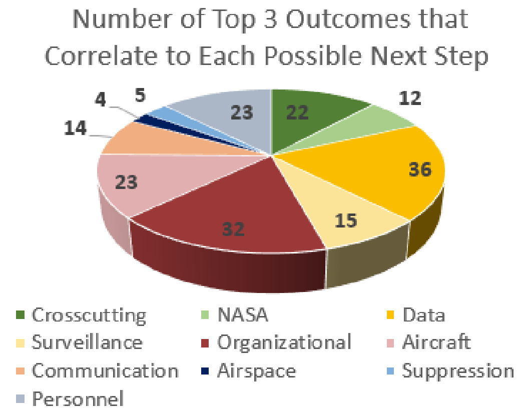

Post-Fire Remedial Efforts

NOTE: This data is solely reflective of the Top 3 Outcomes received from the NASA ARMD Wildfire Management Workshop breakout participants on May 13, 2021.


Number of Top 3 Outcomes that Correlate to Each Possible Next Step

NOTE: This data is solely reflective of the Top 3 Outcomes received from the NASA ARMD Wildfire Management Workshop breakout participants on May 13, 2021.