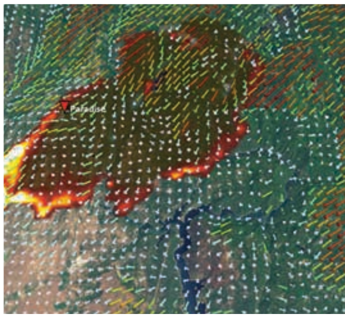
Fire Immediate Response System Workshop Report

APRIL 24-26, 2019



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EXECUTIVE SUMMARY

California's recent wildfires, exacerbated by extreme weather conditions, have focused the nation's attention on the problem of managing fire at the wildland urban interface. With the goal of understanding how new or re-imagined technologies could improve early fire detection and response, the Gordon and Betty Moore Foundation hosted a **"Fire Immediate Response System"** workshop (April 24 -26, 2019). Recognizing the broad and complex scope of fire management, the meeting focused on analyzing the systems and technologies employed during the first period of fire response — the 'Early Fire' phase (immediate pre-wildfire to 24 hours post-ignition) — when critical decisions are made that shape the growth, spread and impact of the fire. We focused on the tools and resources available for assessing Early Fire, including real-time detection of ignition and fire perimeter growth, rapid assessment (sizeup) methods, immediate response (initial attack) methods to extinguish/manage the wildfire, chains of command, and decision support tools.

The workshop brought together 40 stakeholders with a broad range of expertise, including representatives from fire management groups, federal and state government agencies, non-government organizations, universities, and the private and philanthropic sectors. Representatives from the firefighting community set the stage, providing insight into current fire response procedures and associated technology, and information and resource needs to support Early Fire assessment and response. Attendees then reviewed and evaluated current and planned capabilities for technology-based solutions including satellite, drone and ground-based fire detection.

A number of practical opportunities were identified for improving fire immediate response, involving some new technological and organizational capabilities including those in the private and defense sectors. Advances in data collection and numerical modeling were also identified that could enhance current assessments of fire risk and fire behavior. The group felt that much could be done to enhance fire immediate response with data and technology that are currently available but not yet harnessed.

With the pace of technological advancement (e.g., satellite, airborne and ground-based sensors, cloud computing, artificial intelligence and autonomous vehicles), it was recognized that the fire management community needs help determining operational suitability, reliability and readiness of new technologies to support real-time decision making.

The attendees identified fragmentation in how technological solutions are deployed in Early Fire and agreed that no one entity is entirely responsible for managing wildfire in California. Although there is a common goal of reducing loss of life and property, different stakeholder communities have differing views on how best to achieve that goal, which has resulted in technological fragmentation; different organizations use different tools. Technological fragmentation appears to manifest both institutionally, with expertise often constrained to a single department or research group, and spatially—firefighters in Northern and Southern California use different data to predict where and how a fire will burn. The workshop surfaced a pressing need for a common, operational intelligence platform to bring together disparate sources of data and model output in real-time to support fire immediate response decision-making.

Additionally, ingrained, habitual, and traditional thinking are at least as potent obstacles to radical improvement in fire management as are the technical issues, and a longer-term strategy is needed to change perspectives on fire, such as the commonly held perspective that every wildfire demands response. A more selective response strategy based on contemporary principles of forest management and models of risk could undergird a more selective, scaled and strategically effective response system.

A shared, interoperable data platform, fully leveraging the data and technology of the day, would improve wildfire operations intelligence and coordination within and across agencies and could support significant near-term improvement. However, the group identified knowledge and data gaps in how we characterize and predict the spread of wildfires. For example, the current network of weather sensors failed to capture how hot and fast winds would blow through the complex topography around Paradise during the Camp Fire, and the resulting predictions underestimated the rapid rate of spread. As a result, it's not yet clear that, even if there were clear communication between organizations, we currently understand fires well enough to stop the 5% of fires that are not contained.

How, then, can technological innovation fill these data, knowledge and institutional gaps to support the various organizations involved in immediate response? The workshop identified the following priorities and recommendations, which are described in detail in the report.

- Develop a shared, integrated platform for diverse sources of data, intelligence and information
- Conduct new wildfire risk assessments with high-resolution mapping technologies
- Improve scientific understanding of "megafires" through retrospective analysis
- Enhance fire behavior models and associated inputs for real-time prediction
- Perform a cost-benefit analysis of investment in solutions vs. reactive management
- Target investments in the development and adoption of new technologies
- Expand multi-stakeholder dialogue, collaboration and action

The goals of the recommendations above mirror those of fire management organizations: to preserve life and property, and to maintain healthy, resilient ecosystems. The current wildfire policy of extinguishing all fires allows fuels to accumulate. Along with a warming climate and inadequately scaled mitigation policies, the conditions are in place for repeated, severe and costly wildfires. The workshop elucidated the need to scale up preventative measures and to strike a new balance between resource allocation for near-term firefighting and long-term fuels management. Acting on the above priorities could help achieve these goals, supporting California's ongoing efforts to improve resilience in its ecosystems, institutions and communities.

1. BACKGROUND TO THE WORKSHOP

Managing fire in California is an extremely complex undertaking. The challenge of managing fire in the fire-adapted Mediterranean ecosystem is compounded by an expanding wildland - urban interface (WUI). The California Department of Forestry and Fire Protection (CALFIRE) is the best-resourced state fire management agency in the country. In 2018, CALFIRE responded to over 6000 wildfires. CALFIRE's goal is containment of fire growth to 10 acres and extinguishing every fire within 24 hours, with success at accomplishing this goal in 95% of all cases. However, the 5% of wildfire events that escape this control often occur under extreme fire weather conditions and can have catastrophic consequences, sometimes leading to loss of life, property and infrastructure. In 2018, the worst California fire year on record, 91 people lost their lives and over 18,000 properties were destroyed at the estimated cost of $3.5 billion. For 2017-2018, the expenditure of the California Emergency Fund for Fire Suppression alone was $947.7 million. In this context, the Moore Foundation organized a workshop to examine near-term opportunities to enhance Fire Immediate Response and identify longer-term imaginable solutions and potential areas for investment that could help with decision support and mitigate the harmful impacts of wildfire.

For this purpose, we parsed the problem of wildfire into four broad stages: (1) Pre-Fire, (2) Early Fire, (3) Mature Fire, and (4) Post-Fire. The **Pre-Fire stage** is the time for preparedness, prevention and ameliorative strategies. These include such measures as determining fire risk, implementing planned burns (prescription fires), fuel removal (ecologically selective tree harvesting and forest restoration;

Thomas Fire, Courtesy of Stuart Polley/US Forest Service.

clearing ladder-fuel brush and downed trees; etc.), housing codes (for fire-resistant construction), zoning (for location and distance from fuel), management of electrical transmission lines, firefighter training, evacuation planning and simulations and other community preparations. The **Early-Fire** stage extends from the time of ignition through the period (from minutes to hours) of linear extension and spatial growth of the fire. This phase was the focus for the workshop and is the phase of the fire where timely intelligence is needed but where critical information (e.g., updated fuels, fuel conditions and real-time wind, moisture, other crucial data) is lacking. The **Mature Wildfire** is one that has reached the scale and intensity where it is difficult or impossible to control. Such fires may ultimately result in loss of life, billions of dollars in damage, destruction of homes and communities, many tons of carbon emissions and damage to wildlife habitat and watersheds. Catastrophic wildfire calls on hundreds of heroic firefighters, emergency and disaster relief, and other support systems ranging from technology to monitor the fire in real time to public warning, managed evacuation, provision of food, water, clothing, shelter, medical care, counseling and social support. Wildfires can be regenerative for forests, but in 2% of cases, mature wildfires reach catastrophic scale, due to a "perfect storm" of wind, fuel and fire weather conditions. The **Post-Fire** stage can last from months to years and entails recovery, reconstruction and restoration. It includes such elements as insurance payments, disaster relief, post-trauma management, flood and water contamination mitigation, rebuilding and ecosystem restoration. A comprehensive wildfire prevention and management policy would encompass all four stages. In this workshop, we focused on Stage 2, Early Fire, where technological solutions may contribute and a concerted and coordinated strategy could dramatically diminish the burden and impact of wildfire.

We considered the Early Fire challenge in three parts: (1) Detection and location; (2) Assessment (of scale and risk, where scale includes potential size, direction and speed of spread, and risk includes location, potential severity and loss); and (3) Response (sufficiently rapid and effective quelling of the fire), along with early warning to facilitate deployment of resources, community alert and evacuation. The workshop discussion was organized around these three themes.

2. FIRE DETECTION

Fire immediate detection is the ability to detect the start of any wildfire, or at least any wildfire that can pose a risk to life or property. This has component parts of location, area (perimeter and coverage), sensor (types of detector), and communication (reporting how and to whom). The relevant approaches discussed included satellite sensors, sensors on piloted aircraft or "unmanned aerial vehicles" (UAVs) and drones, ground-based sensor networks (including ones strategically positioned along the powerline routes), and human visual or remote camera monitors from watch stations. The goal is to be able to detect in a matter of seconds to minutes the ignition of any wildfire, with sufficient locational accuracy to enable rapid response. It was noted that currently most fire reporting comes from 911 calls but these reports are not going into a unified system and usually lack the desired locational accuracy.

2A. SATELLITE-BASED FIRE DETECTION

Active fires can be identified by satellite sensors using different wavelengths in the Electromagnetic Spectrum, either by their temperature (radiance or brightness temperature) or by the presence of smoke plumes, once fire ignition occurs and the fire gets underway. Active fire detection is a function of fire size and temperature and the wavelength and spatial resolution of the sensor (Fig 1). The effectiveness of satellites for fire immediate response is determined by the timeliness of observation and the minimum detectable fire, which in general terms is .01-1.0% fire fractional cover area of the pixel size on the ground (GSD: ground sample distance). Geostationary satellite sensors (e.g., GOES-R Advanced Baseline Imager) provide a staring capability with repeat imaging every 5 minutes, or in special cases every minute, albeit with a minimum detection fire size of roughly half a football field (3,000-8,000m2 over California). Coarse spatial resolution (375m-1km) polar orbiting sensors (e.g., MODIS and VIIRS) are capable of detecting smaller fires, the size of a large bonfire but are limited by an observation frequency of 2-4 times per day. The current Landsat-class of sensors (e.g., NASA Landsat, ESA Sentinel 2) with moderate spatial resolution (10-30m) and shortwave infrared sensors, are capable of repeat coverage every 3-5 days and are capable of detecting smaller fires, the size of a very high temperature barbeque. A number of private companies are developing small low-cost, multi-satellite constellations, aimed at providing daily, fine spatial resolution optical imaging multiple times per-day, which would significantly increase satellite fire detection capability if they include calibrated shortwave, mid and longwave

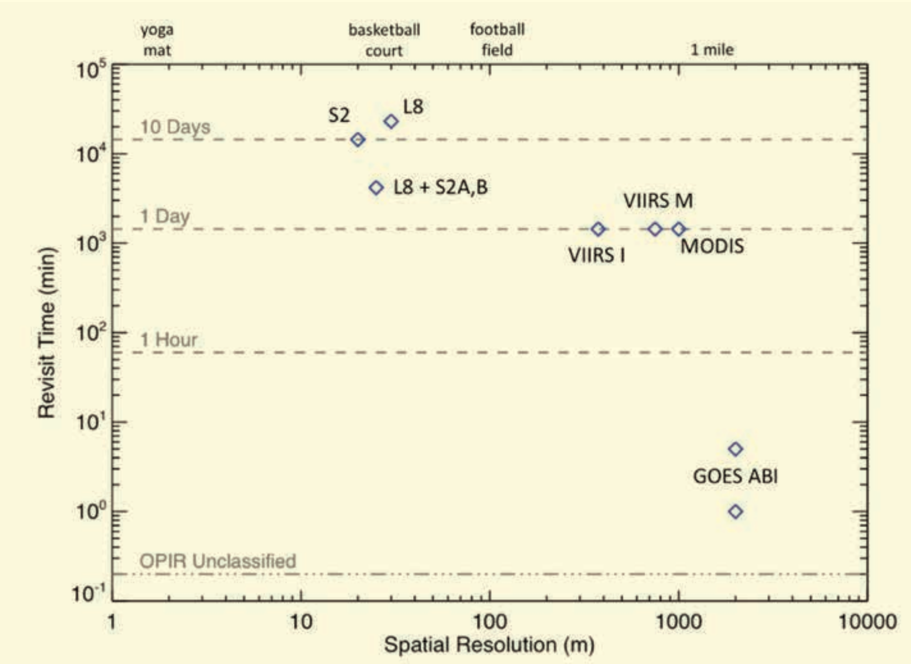
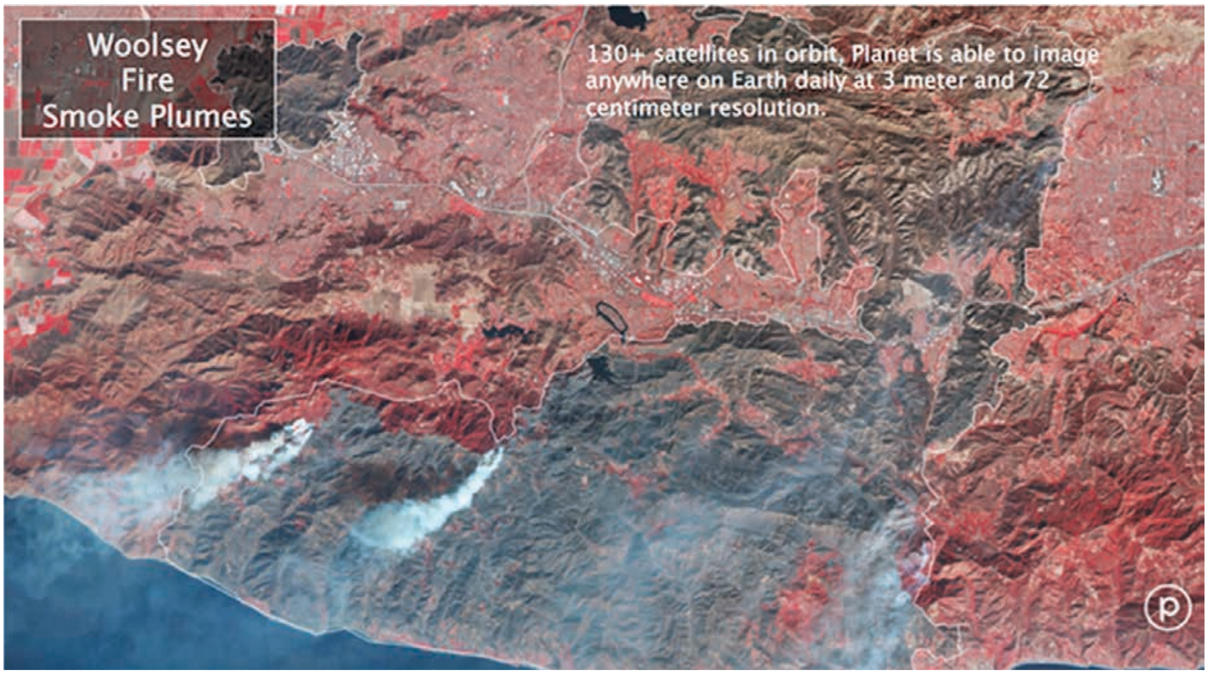


Figure 1. Current spaceborne assets useful for California fire detection.

The graph depicts the spatial resolutions and revisit times for the most common satellite sensors used to detect active fires (ESA Sentinel 2 (S2), USGS Landsat 8 (L8), the NASA/NOAA Visible and Infrared Imaging Radiometer Suite (VIIRS) Multispectral (M) and Imaging (I) bands, the NASA Moderate-resolution Imaging Spectroradiometer (MODIS) and the NOAA Geostationary Operational Environmental Satellite (GOES) Advanced Baseline Imager (ABI)), the USAF Overhead Persistent Infrared (OPIR) Mission . (Graph Courtesy Louis Giglio).



Courtesy of Planet.

infrared fire detection in their design. It should be noted that small ground fires can be obscured by closed tree canopy. A technological advance identified by the workshop that would significantly improve fire immediate response would be a geostationary sensor with fire detection capability at 500m spatial resolution (i.e., capable of detecting fires the size of half a basketball court or less (125-250m2) with 5-minute, round-the-clock observations. (China is currently operating such a system, Gaofen-4). It should also be noted that the presence of thick clouds or smoke can impede satellite active fire detection. Satellite-based, smoke plume detection currently relies heavily on visual image interpretation. Much less research has been done on fire identification by automated plume recognition, which could be improved through artificial intelligence, machine learning, and a better understanding of the relationship between the size of the plume and smoke dispersion, the size of the fire, and fuel consumed.

2B. AIRCRAFT-BASED FIRE DETECTION

Airborne imaging of fire perimeters has long been part of national fire management. With two manned aircraft with thermal and mid-IR sensors available on request for a targeted fire anywhere in the country (but primarily focused on missions in the western U.S.), the National Interagency Fire Center (NIFC) USDA Forest Service National Infrared Operations Platform Systems (NIROPS) can image once per day (night observations only), which falls short of the continuous real-time monitoring needed to support fire response. CALFIRE does not own any imaging aircraft of its own but tasks private aerial survey firms with fire mapping (thermal sensor) capabilities, on an event-by-event basis, to provide near real-time perimeter maps. Such aircraft flying relatively fast, relatively high, using either multispectral, multi-camera arrays or very fast and very stable step-stare and forward motion compensated mirror systems currently provide the most immediate and cost-effective solution for fire mapping. However, the number of aircraft available with experienced pilots and fire mapping capabilities are limited.

Investment to increase the number of manned aircraft and crews with the appropriate fire detection sensors is recommended. The California National Guard (CNG) can deploy large remotely piloted aircraft systems (RPAS: commonly known as drones) with full motion video to augment the mapping of fire perimeters by incident command. However, the CNG is rarely activated in the Early Fire Stage, as ordering CNG support is an involved process set in place once the Type 1 Incident Management Teams, working with Sacramento (Cal Fire HQ) or Vallejo (USFS Region 5 HQ), decide that they cannot muster enough resources internally, which takes time. The CNG currently operates a C-26 Metroliner manned aircraft which can be a fire imaging resource but the sensors are not optimized for georeferenced, wide area fire detection. During the discussion, the competition for aircraft during multiple fire events and the resulting shortage of aircraft assets was raised and the use of unmanned airborne systems was discussed. No UAV company presently fields or plans to field a UAV with the payload capacity sufficient to systematically map a large fast-moving fire. Small Unmanned Aircraft Systems (sUAS's) with cameras/sensors are not recommended for use in plume dominated environments due to platform instability in dynamic wind-plume environments, but the workshop attendees considered their potential use for initial fire assessment providing information on location, extent and behavior before fires grow too large; providing situational awareness and over-the-hill communications; and in support of fire-spot mop-up operations. Since the first responders on a fire scene are usually local fire department personnel, they may be good candidates for use of sUAS for immediate and improved situational awareness of the fire in its initial stages. A longer-term technological advance discussed at the workshop would be to establish persistent monitoring by medium or high-altitude long-endurance drones. High-altitude long-endurance platforms (>65,000 ft AGL) that can operate from days to months during high fire danger conditions as sub-orbital assets with "linger & stare" capabilities can also operate as mobile communications links, providing not only observations of the fire, but serving as a commlink (radio) relay (voice and data) between personnel on the fire front, and those at incident command in the management structure. Further dialogue with FAA on current flight rules would be required for drones to be used more extensively under different conditions, revisiting the UAV safe airspace restrictions. It was mentioned that improved legislation may be underway in this regard. The use of tethered Lighter Than Air (LTA) platforms with imaging and communication systems at a height of 500ft-5000ft was also briefly discussed. Higher altitude capable LTA UAS (those operating at altitudes up to 100,000 feet), and with flight endurances of days to months, are also an important platform consideration for long-term, persistent monitoring of an event or early fire detection over large areas. These high-altitude, long-endurance (HALE) LTA UAS should be available within 5 years and could prove to be a valuable sub-satellite observational platform for use on wildfire events, quickly and readily deployable to areas of high fire frequency during fire season.

2C. GROUND-BASED FIRE DETECTION

Fire lookout towers with human observers scanning for smoke plumes have been used for decades and there is a network of 77 towers distributed throughout California, which can triangulate fires. These have been recently augmented by automated time-lapse sensor/camera networks (> 200 cameras), the most sophisticated of which have automated smoke plume detection. A new low-power 2.4 GHz mesh network of ground sensors has been installed, tested and validated using controlled burns and

ALERTWidlfire camera at Pepperwood, Mayacamas Range, Northern California, courtesy of Lisa Micheli.

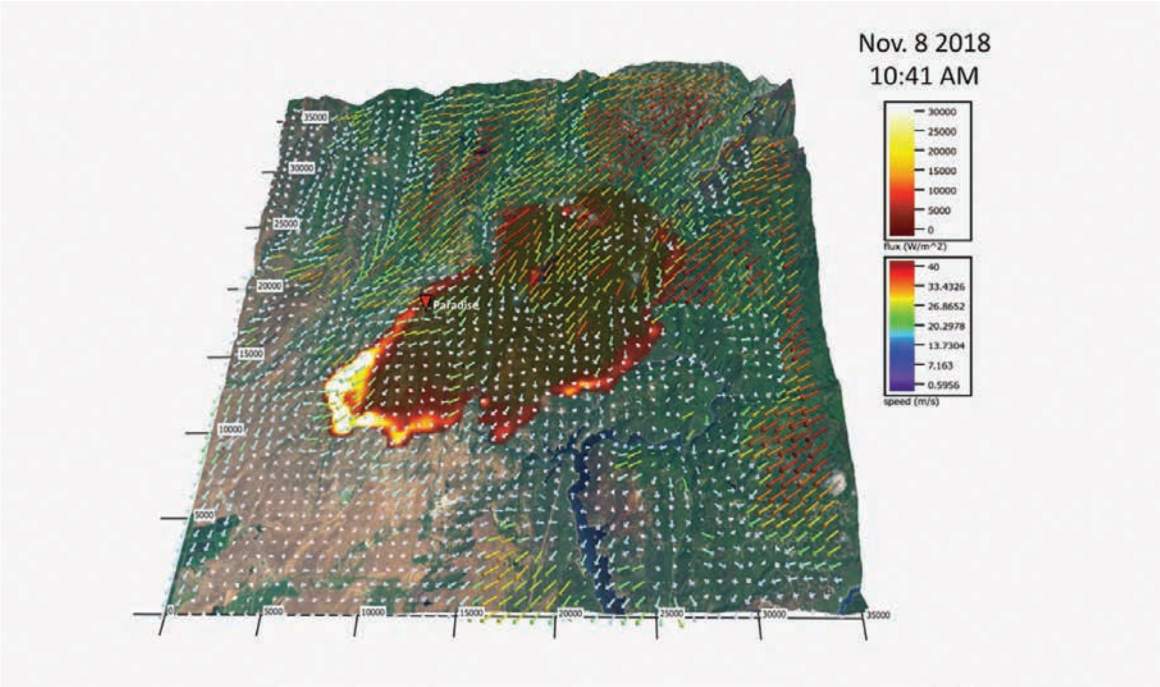
Summer 2019 controlled burn in Moraga Orinda Fire District to test ground-based sensors built by ADI, courtesy of Dave Winnacker.

is now deployed in a wildland urban interface in the Moraga Orinda Fire District. These sensors provide reliable ignition detection, and a paired autonomous evacuation decision support tool provides near real time evacuation recommendations, using current weather, projected fire spread, and existing fuel models to support first responder decision making during the critical initial period. Given that extreme wind conditions (e.g., Santa Ana winds in So. California, and Diablo Winds in No. California) can cause High Voltage Transmission Lines to arc and cause ignitions, there are efforts underway to place remote control camera systems on those towers at strategic points along the electric grid to identify problems / events as they happen. It was reported that Pacific Gas & Electric (PG& E) is in the process of installing a significant number of cameras and weather sensors associated with its power grid. The limitation of ground-based camera sensors is that they can primarily only provide daytime observations. To supplement daytime observations with night observations, deploying cameras with thermal imaging capability needs to be considered. With a large increase in the number of cameras and automated weather systems, we propose that the systems be sited based on scientific evidence of the most fire-prone areas or high-risk areas (e.g., at the WUI), or in high risk areas with complex microclimates and wind corridors. One suggested technological ground-based sensor solution included the use of autonomous vehicles with smoke detection systems patrolling high-risk areas at the WUI. Well-established ground-based systems that provide real-time detection of lightning strikes are already in place for parts of Northern California, delivering information on potential ignitions to help target fire detection.

In the various discussions, the need for integration of all satellite, aircraft, UAS (drone) and ground-based fire detection information with real-time intelligence and provision to fire teams in the field and incident command was raised. Considerable benefit could be gained from access to some of the 'battlesphere' capabilities developed and used by the DOD, or sensor-web concepts, where interconnected systems can cross-communicate and drive observations from adjunct systems to help validate a fire start or pinpoint a fire geo-position. It was assumed these would also be applicable to fire response, for example in providing attack-support to incident command and individual fire teams. The California National Guard already combines data from satellites and UAV assets and provides that to CALFIRE. A strengthening of that relationship and exploration of sharable DOD technology would be beneficial. Similarly, repurposing DOD surplus UAS for supporting fire management could be considered.

3. FIRE ASSESSMENT

By providing a determination of landscape-scale fire risk, Pre-Fire Assessment can, at a broad scale, help target areas for enhanced observations for potential fire outbreak and prioritize and design mitigation efforts. In 2007, CALFIRE developed a Fire Hazard Severity Map, which was a static assessment including fire management responsibility areas. A more spatially detailed, dynamic and real-time risk assessment is needed and could be used in assessing 'immediate fire risk' at the Early Fire stage. This would involve a current high spatial-resolution mapping of terrain and fuels, infrastructure (buildings, roads, powerlines), previous fire ignition points, water points, etc., sufficient for decision support with periodic updates. Identification of areas with 'weak infrastructure' in terms of fire prevention (weight-restricted and impassable logging roads) would be included.



CAWFE® (Couple Atmosphere Wildland Fire Environment) simulation, courtesy of Janice Coen.

The workshop noted a potential technological opportunity for using statewide lidar mapping of vegetation structure to give a better characterization of fuels (including ladder fuels) augmented with a regular update using satellite observations of vegetation condition changes; for example, identifying recently burned and regrowth areas. Essentially, assessment is a classification problem of a type familiar in many artificial intelligence (AI) applications but there is a need for significant technological applications development to use AI in fire assessment. In general terms, the assessment process gets underway during the fire season (Pre-Fire), with public updates using the traditional Fire Danger Rating system, or when weather conditions are of high enough risk to trigger a Fire Weather Watch (72 hours) or Red Flag Warning (24 hours). In such conditions CALFIRE currently prepositions firefighting assets. Pre-Fire identification of areas that are susceptible to high winds with assets and communities vulnerable to fire could be used to target heightened detection monitoring under Fire Weather Watch or Red-Flag conditions. More extensive, real-time reporting of humidity and fuel moisture status was suggested. Improved high resolution, spatially explicit modeling of pre-fire risk would help with preparation in advance of a fire event. Targeted prepositioning of assets based on a current pre-fire assessment of high-risk areas could also help reduce time to response.

Early Fire Assessment of the risks associated with a particular ignition is an integral part of initial attack ("size up") and response and an ongoing process as a fire evolves. Getting improved and timely (current) information to the first responders and the incident Command Team could aid in rapid and effective response, further reducing the expansion of small fires into larger, uncontrolled events. The initial fire assessment is currently undertaken by ground crews and airborne crews often in succession but generally independently. The initial assessment factors in the location of the fire, the local terrain, the fuels, proximities of infrastructure (i.e., the more static aspects identified in the detailed risk mapping mentioned above) and current conditions which are dynamic at different time scales (i.e., precipitation, fuel moisture content, relative humidity, temperature, wind direction, speed and variability). Wind conditions exhibit considerable local variability, often as a function of terrain, which necessitates updating on a continuous basis. Establishing a higher density of automated, networked wind measurements or remote automated weather stations (an effort already underway by utilities) and/or wind profile measurements in high risk areas, possibly involving citizen scientists, was identified as a possible technological enhancement. Currently, initial assessment relies heavily on expert knowledge and the experience the initial attack team leader or local expertise (forest ranger in National Forest lands, etc.). This on-site decision-making, associated with determining the appropriate response could be enhanced by the availability of real-time information about the extent and perimeter of the fire and the immediate conditions that would enable its growth.

Fire behavior models—some coupled with weather models that predict wind direction, speed and variability, temperature, relative humidity, and precipitation—that forecast the path and growth of a fire using various inputs such as fuel type and load, fuel moisture content, and terrain slope, are in development. Such models are used inconsistently as supplementary input for assessment of mature fires and need additional investment in their development. If the best of the current fire behavior models could be run in real-time and with sufficient fidelity, they could be applied at the early detection stage to predict the track of a maturing wildfire with different probabilities to help inform the fire immediate response and pre-positioning of resources to divert or suppress the projected path of the fire.

In the context of response, participants observed that there is a culture associated with immediate fire assessment that can result in conservative estimates of requested assets for the initial attack and a distrust of new technologies. This needs to be understood when developing decision-support tools.

4. RESPONSE

Immediate detection and rapid assessment are the foundation for an effective response. The incident command coordinates the delivery of retardant, water, human intervention or other means to extinguish the early wildfire. A key decision context is where to concentrate resources once a fire has been detected and the magnitude of the response. Accurate, early assessment could contribute to improved deployment of resources, more targeted community alerts, and protection of life and property.

Wildfire response is currently enabled by prepositioning of resources, however workshop attendees noted that there are too few airborne resources to handle multiple simultaneous fires resulting in triage, rather than proactive response. Suggestions were made on improving retardant delivery by developing the capability for night-time airborne tanker delivery, as well as delivery in smoke-obscured environments or in strong winds. The workshop also raised the issue of competition for resources, a decreasing labor force for firefighting and the time required for retardant pilot and dozer operator training, etc. It was noted, in the context of fire suppression, that better intelligence on forest and weather conditions could help inform fire management agencies as to when conditions were conducive to letting low-risk fires burn in order to reduce fuel loads and foster forest regeneration.

The discussion in the context of fire suppression included allowing the possibility of letting some fires run their course, based on the assessment of beneficial transformation of the vegetation community, where there is no risk to property or life; this is the current approach to fire management within the National Park System or Wilderness areas where there is no risk to property or life.

5. IMAGINED TECHNOLOGICAL SOLUTIONS TO FIRE IMMEDIATE RESPONSE CHALLENGES

The workshop included "blue skies" breakout discussions on imagined solutions and 'future-casting'. These are listed below.

- An 'authoritative platform' with an enterprise geospatial portal, integrating intelligence from all sources (public and private sector) relevant to fire detection, assessment, and response, providing real-time information for decision support to all fire management and response agencies. The platform should have interfaces customized for assessment and response use but also have a public facing component. It was noted that effort is needed to develop incentives for the private sector to share data in support of such a platform.
- A "California Forest Observatory" with high resolution and current mapping of fire risk, including high resolution, regularly updated determination of fuel loads, infrastructure, human population, high risk and vulnerable areas--with near-term (48-hour) and real-time information on both weather (temperature, humidity and wind) and soil/vegetation moisture status.
- A continuous monitoring of fire ignitions by a new geostationary satellite focused on California, with a 500m (or finer) spatial resolution. A discussion with NOAA management could elucidate plans, capabilities, and schedule for the next generation of geostationary sensors. Alternatively, high altitude (sub-orbital) UAVs could provide continuous fire detection during the fire season, with feasibility to be discussed with the California National Guard.
- Nighttime aircraft operations capability for perimeter mapping and pinpointed retardant delivery through darkness, smoke, and strong winds to decrease response time for large air tanker retardant drops, and, improve aircraft pre-position during Red Flag events for on-demand response closer to those potential fire areas. The former would need buy-in from the Federal Aviation Administration.
- Systematic use of sUAS low-altitude imaging for initial assessment, and UAS-enabled communication platforms to augment and allow communication amongst response and fire teams, where communications infrastructure may be damaged or non-existent (e.g., enabling WIFI for situation response). A suggestion was made to determine whether a fleet of UAS's delivering 30-gallon or smaller payloads could be used to extinguish spot fires.
- Expanded and strategically placed networks of automated ground-based data collection cameras and sensors for fire detection, microclimate, and wind data, with deployment of denser networks in areas of higher risk.
- Real-time, 3-D, hourly forecasts of fire behavior and fire spread, taking inputs from the 'authoritative platform' including up-to-date information on fuels and wind conditions.
- 'Heads-up' personal portable visualization system with real-time intelligence from the 'authoritative platform' to aid first responders in fire assessment and fire team leads for tactical firefighting. The DOD has such systems in operation for the battlefield.

Some of these suggestions were further developed in discussion, with the recognition that more in-depth feasibility and cost-benefit analysis is needed.

6. ELEMENTS OF A COMMUNITY RESEARCH AND DEVELOPMENT AGENDA

A number of areas were identified as requiring further research or development. The distinction was made between basic research and R&D needed to transition research products (e.g., tools and data products) into the operational domain. The latter is referred to as operational R&D.

6.1 FIRE BEHAVIOR MODELING

Fire behavior modeling is advancing to a point where improved models could be developed to support fire management decisions on mature wildfires. The research community is promoting a number of fire behavior models for fire management use, however, running models retrospectively and calibrating a model by changing inputs to obtain the desired output differs from running a model in real time, which is what is needed for operational use. Given the weather and fire behavioral complexity of recent events, the models should be as simple as possible but no simpler. There could be advantages to enabling models to use updated observations, as situations change during the modeling run. It is also important to understand that each model has uncertainty associated with its products. Better meteorological data are needed to characterize wind patterns, particularly in areas of complex terrain. For that reason, weather data collection networks could be supplemented based on detecting potential wind extrema, in addition to their original purpose.

Workshop participants agreed there would be value in an objective model cross-comparison analysis ("bake-off") over a range of scales and complexities, comparing predictions to observations, to determine the strengths and weaknesses of models for use in real-time applications, in the context of fire assessment and response. This comparison experiment should be designed with that use in mind and managed by a neutral party, with evaluation by independent scientists and fire managers, representing the needs of the operational community. The centroid of fire behavior modeling research has shifted academic disciplines from forestry to other scientific disciplines. Given the importance of being able to project the path and speed of a fire as it moves across the landscape, investment in parallel development of different models addressing the same objective, without monitored community objective model assessment and inter-comparison, as for example has been done for hurricane forecast models, dilutes the impact of scarce research funding.

Areas for growing model development include real-time integration of fire perimeter intelligence and modeling wind and plume-driven fires as they move across the landscape and through the Wildland-Urban Interface (WUI). An increase in micro-wind sensors in known high-risk areas and wind corridors would be beneficial. Modeling urban fire and fuel behavior is an area that could also benefit from increased research. There is likewise a need to identify what type of fire and landscape conditions (e.g., high wind areas or unique microclimates) require a more sophisticated or higher resolution modeling treatment or denser networks of ground-based observations. In addition, an effort to provide 3-D interactive model output in a format compatible with field and incident command decision-making would be beneficial. A related area of research associated with fire behavior concerns how fires can spread across the landscape beyond the main fire front. Fire spread under strong wind conditions can be caused by embers and spotting ahead of an advancing fire front. A better understanding of that process as a function of wind conditions and fire-created weather, and a system designed for real-time monitoring of spotting, would be an important improvement.

6.2 FUELS

There is a need for improved and up-to-date spatially explicit fuel type, fuel load and fuel moisture content information. Traditional methods rely on field data collection, aerial photography and in-situ weather station data. The California Interagency Fuel Mapping Group (CAIFMG) is currently developing surface fuel maps for the state that span jurisdictional boundaries. Fuels at the WUI need particular attention. Up-to-date mapping of vegetation and fuel types using the latest fine spatial resolution (<5m) multispectral satellite data is needed. Given the extent of recent fires and the associated regrowth, and the expansion of the WUI and fuel reduction initiatives, this mapping might need regular updating (e.g., on a three-year basis). The use of airborne lidar data for mapping vegetation forest structure (3-D) has increased in recent years and a number of private companies provide this service. A few research papers have developed the relationship between lidar data and surface fuels for different vegetation types, but further research will be needed to extract reliable fuel load information from lidar information for California ecosystems and the WUI and to understand the uncertainty in these measurements. Fuel moisture content estimation helps determine fire danger rating, and these rating systems are typically driven by available meteorological station data. The accuracy of the available, spatially explicit fuel moisture information versus what is needed for fire management decision-making requires further consideration. A denser network of automated weather stations will provide more representative conditions. Methods have been developed to generate spatially explicit estimates of live fuel moisture using soil moisture data and vegetation indices from polar orbiting satellites. An evaluation of the utility of and timeliness of such indices could augment the current fuel moisture reporting in the context of Fire Assessment. The development of these new information products and delivery systems should be co-developed with the intended users, to make sure the resulting information is tailored and useful for the intended decision-makers.

Once a body of research has led to the development of a tool, data product, or model that is determined to be application-ready, transitioning from research-to-operations may require parallel operation of both old and new or improved systems until confidence is gained by operational users. In this rapidly developing information technology environment, operational fire management agencies have limited resources or capacity to evaluate enhanced or new technologies. Currently, a single scientist in CALFIRE fills this role. Participants suggested that a fund be created for operational agencies to obtain help in technology evaluation from a pool of vetted, independent scientists or experts.

6.3 RETROSPECTIVE ANALYSIS OF RECENT CATASTROPHIC FIRES

A small percentage of fires escape initial attack, usually when weather conditions are extreme, ignitions are difficult to access, and/or multiple events happen concurrently and grow in size to become catastrophic megafires, often resulting in loss of life and property. However, with climate change and increasingly hazardous fuel conditions, this number is expected to grow. It was suggested that a retrospective analysis be undertaken on a number (25) of those fires that have occurred in the last decade in California, to identify any common attributes or characteristics, landscape location, weather conditions, fire behavior and propagation, or response procedures associated with the fires. The analysis would help with developing a collective set of lessons and provide insight into conditions that could result in future megafires and how to improve catastrophic fire assessment and response.

7. OTHER ISSUES RAISED

The discussion illustrated a difficulty in addressing parts of the fire-problem continuum in isolation. Workshop attendees wanted to broaden the discussion to include a broader context beyond the focus on Fire Immediate Response. For example, the need for a balance in emphasis and funding between fire prevention and suppression emerged as a recurrent theme. Increased forest and community resilience through locally sustaining sound actions in and around the WUI would buffer infrastructure and property and protect and enhance natural resource systems through science-based targeted actions. This included a discussion of new construction (better regulated to be fire resilient) vs. older properties (pre-1980's) that would benefit from retrofitting but doing so would be prohibitively costly. Regardless of the current housing crisis in California, restrictions on new buildings in high-risk locations at the WUI may be needed.

Fuels management at the WUI is also a priority intervention, as is general public education about the new normal of annual extreme fire events and a cultural shift to understand "good" and "bad" fire. In the meantime, the current 'no burn' policy exacerbates the problem of increased fuel loads, leading to more intense fires. CALFIRE needs the option to let a fire burn, when appropriate. But these changes in public attitudes take time, and careful messaging would be important to mainstream understanding of the need for increased controlled burning (with a resultant impact on local air quality) and reliance on community action before and during wildfire. Given the need to significantly increase fuels management (structural restoration) and controlled burning (process restoration), a severe shortage of trained staff and labor was noted.

While this workshop was focused on getting real-time intelligence to incident command, a simple authoritative outward-facing mobile application could also provide useful information to citizens (e.g., to contact every resident in harm's way, especially senior citizens and disabled residents; to engage with communities to plan and practice how to get out of fire-prone locations).

The question of sustained funding for fire management (e.g., public, private roles and responsibilities) was also raised, though likewise outside the scope of the workshop. Nevertheless, participants noted that in times of recession, available funds would likely decrease. Could a permanent funding stream be identified? Participants discussed "monetizing fire" such that citizens would be required to pay a modest annual fee for a mobile application that would help them understand the vulnerability of their property, receive near real-time updates on the current fire situation from an 'authoritative platform,' and access real-time, optimal evacuation routes and procedures, etc.

WORKSHOP RECOMMENDATIONS

Participants put forth recommended priorities for research, and several actionable near and longer-term steps that could be taken to mitigate the increased threats of wildfire. In addition to the imagined technology solutions identified in Section 5, seven broad recommendations were developed for further consideration.

1. DEVELOP A SHARED, INTEGRATED PLATFORM FOR DIVERSE SOURCES OF DATA, INTELLIGENCE AND INFORMATION

A needs assessment and landscape analysis of the relevant data and technologies that already exist and the data, tools and processes that different incident commanders currently use to make tough decisions would help identify what information is used, where it is found, what additional information is needed and how best to meet those needs. To make the information more accessible the group recommended a shared platform that can include multiple sources of distributed data and/or integrative models for relevant, synergistic decision support. Currently, navigating the multiple, different and sometimes conflicting sources and formats of data and information is a major challenge for the fire management agencies. A number of important elements for fire detection currently exist, however there has been little attention to their integration for easier access and use. Strategically placed networks of ground-based sensors, remote weather stations, camera networks, air-based (aircraft and RPAS) multi-waveband systems and satellite-based remote sensing could be integrated into a common system providing improved early-fire detection, assessment, monitoring and open-source modeling to support response decisions. However, it is imperative that the user-interfaces to such a system be co-developed by those who would be acting on the information provided (e.g., CALFIRE, USFS, individual fire districts). The platform could also enable information to be integrated into public early warnings and the data and information to be available to researchers. However, participants cautioned that much of what is already available would likely require a "reset" (to be optimized for operational tactics, rather than scientific research) and would need to be assimilated and accessible in a neutral, sustainable structure that includes both tailored and public-facing "dashboard" applications. Tools that are developed should ideally apply to as much of the fire continuum as possible, from "pre-fire" through "early-fire" and so on. A common, integrated and easy to use intelligence platform to bring together disparate sources of relevant data was the strongest recommendation for enhancing fire immediate response.

2. CONDUCT NEW WILDFIRE RISK ASSESSMENTS WITH HIGH RESOLUTION MAPPING TECHNOLOGIES

We are in need of a better understanding of wildfire risk—where and when are the next disasters most likely to happen, how big could a fire get, and what is the damage potential—informed by leveraging advances in remote sensing, artificial intelligence, real-time modeling, and cloud computing technologies to support dynamic and analytic risk mapping and response. In this way, with the benefit of a dynamic and sharpened focus, we could prioritize areas in greatest need of preventive measures, create a heightened pre-response, improve pre-detection capabilities, and more effectively pre-stage firefighters and firefighting assets. A better understanding of wildfire risk, as well as diagnostics and forecasting, e.g., models that reflect infrastructure and model the future path of wildfire on an hourly basis, could be integrated (in the common platform recommended above) to better target where to provide life-saving preventive forest management, pre-event deployment, and near real-time situational decision support.

3. IMPROVE SCIENTIFIC UNDERSTANDING OF "MEGAFIRES" THROUGH RETROSPECTIVE ANALYSIS

Fundamental uncertainty remains around what makes a fire large and severe—and retrospectively, why a megafire "did what it did." Winds contribute significantly, as do fuel loads and vegetation moisture content and terrain, but are there other factors and conditions? The facts and variables for the 25 most damaging fires of the last decade could be reviewed and analyzed (for a detailed assessment of weather and fuel conditions, response realities, etc.), to understand what the differentiators are for these devastating megafires. Gaps in our understanding could be explored by new data for future fires. For example, small anomalies (e.g., embers and spot fires) can be significant but may be impossible to capture in historical and retrospective analyses. The time and spatial scale needed for this kind of future data collection is likely to be an order of magnitude greater than what has been collected in the past.

4. ENHANCE FIRE BEHAVIOR MODELS AND ASSOCIATED INPUTS FOR REAL-TIME PREDICTION

Real-time fire behavior modeling could provide important information for fire managers by predicting the spread of the fire as it develops. The workshop attendees recommended an objective cross-comparison analysis of available models, over a range of scales and complexities, comparing predictions to observations, to determine the strengths and weaknesses of models for use in real-time applications. There is a need to identify what type of fire and landscape conditions require a more sophisticated or higher-resolution modeling treatment or denser networks of ground-based observations. An increase in micro-wind sensors in known high-risk areas and wind corridors would be beneficial and in general further research is needed in modeling the spread of urban fire and fuel.

5. PERFORM A COST-BENEFIT ANALYSIS OF INVESTMENT IN SOLUTIONS VS. REACTIVE MANAGEMENT

It would be beneficial to conduct an economic analysis of the costs of suppression and recovery from megafires versus investment in technologies that would offer improvement in prevention, early detection, assessment, and response. For example, how much more damage can we reduce or how much better would the prediction and management outcomes be in monetary terms and cost-benefit analysis versus the cost of solutions? What other data and analyses could help inform policy and build more public support? Within this context, the economic case should also incorporate the required resources and time, in years to decades, for preventive strategies (forest management, fuel reduction, prescribed and controlled burns, zoning, building codes, preparedness training, etc.).

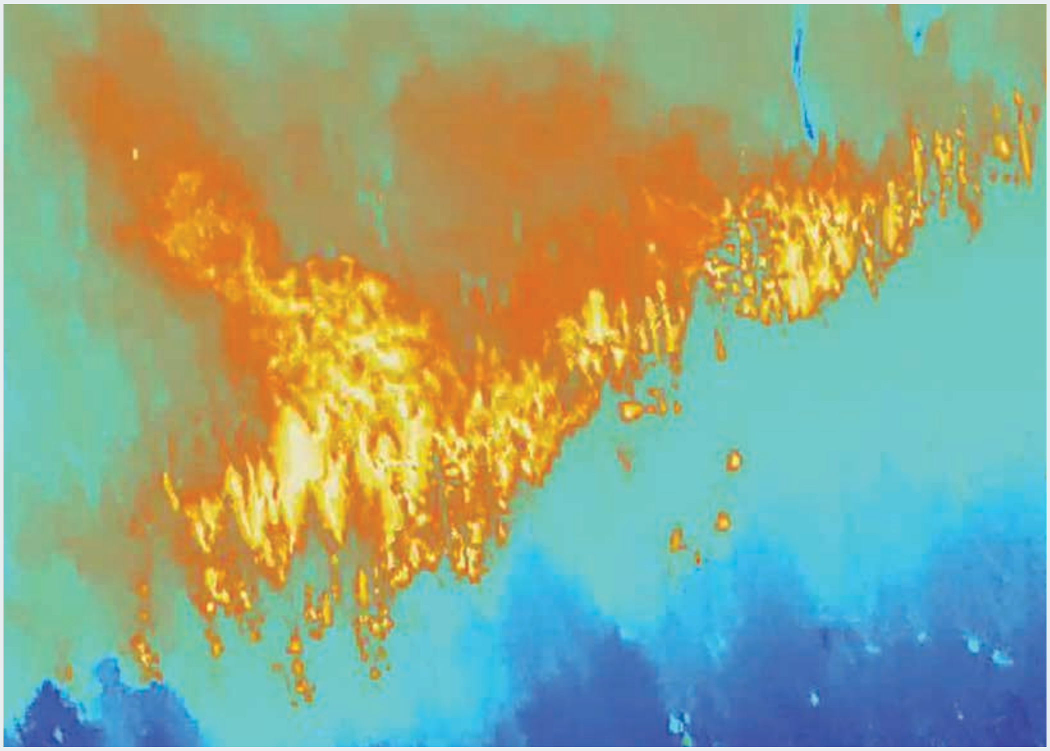
6. TARGET INVESTMENTS IN THE DEVELOPMENT AND ADOPTION OF NEW TECHNOLOGIES

Technological limitations inhibit our current ability to obtain and share timely and relevant information in the form needed to support real-time decisions and in-situ response. Increased research and development is needed and announcements like that of the rapid wildfire detection XPRIZE will encourage innovation, which should be guided by operational needs. The workshop identified a number of areas to be explored, including a higher spatial resolution geostationary satellite; high altitude long-endurance remote-piloted aircraft systems (RPAS) fire detection; and persistent high altitude lighter-than-air (LTA) platform sensor monitoring in high-risk areas during red flag "plus" conditions. While new technologies are being developed, an immediate investment is suggested to increase the availability and use of manned aircraft for rapid deployment, with currently available sensors designed for large area fire detection. The development of small RPAS for communication and assessment, in the early stage (fire development) and post fire stages (damage assessment) and autonomous air-based, RPAS retardant delivery (uninhibited by night, smoke, wind, scarce assets and competing demands) were also identified. At the same time, workshop attendees recognized that more technological capacity exists in the military and private sectors than is currently tapped for effective wildfire detection and response. A closer linkage between the military and civilian sector to help improve on-site fire-fighting decision support was encouraged. In the private sector, small-satellite capabilities are quickly maturing and technology is moving insurance and risk management from responding after losses to prediction and, ideally, to prevention. In the near-term, development is needed to synchronize ground, air and space data collection in all phases of fire to close existing gaps and avoid redundancy, ensuring that intelligence—including that which would be obtained from currently classified sources—could be more effectively and efficiently delivered to key decision makers. Likewise, it should be possible for wildfire response assets to be searchable and deployable through a dynamic database that would allow inputs (what is needed, where) and yield outputs of availability and dispatch orders—analogous to what has already been developed by the military for combat.

7. EXPAND MULTI-STAKEHOLDER DIALOGUE, COLLABORATION AND ACTION

The interdisciplinary composition of this workshop with fire managers, scientists, government and private sector stakeholders with a wide range of expertise and perspectives led to useful exchange of information and an extremely productive meeting. Given the complexity of the fire problem in California, it was suggested that a series of similar targeted workshops be held on different aspects of the fire problem, e.g., fuels management and controlled burning, community fire prevention, alert and evacuation, a common intelligence platform, and cost-benefit of interventions. Likewise, knowledge exchange with other states and countries would inform efforts in California and could help scale solutions more broadly.

The group acknowledged that governance and oversight of the totality of the wildfire challenge is complex. Nevertheless, a few critical investments to gather fundamental but lacking information and to bring together fragmented data and technologies could deliver significant near-term improvements, as well as a foundation upon which longer-term solutions could be soundly built.



APPENDIX 1

LIST OF WORKSHOP ATTENDEES

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Ilkay Altintas
University of California, San Diego

Vince Ambrosia
California State University, Monterey Bay

Christopher Anderson
Salo Sciences

Tim Ball
Fireball Intelligence

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Jupiter Intelligence

Megan Stromberg
California National Guard

Allison Wolff
Vibrant Planet

Brittany Zajic
Planet Labs

Tarek Zohdi
University of California, Berkeley

APPENDIX 2

WORKSHOP AGENDA

DAY 1. APRIL 24TH, 2019

9.00	Welcome and Focus for the Meeting – Harvey Fineberg
9.15	Synthesis of Submitted Materials – Chris Justice
	Plenary Discussion
10.30	Break
11.00	Breakout Session: Blue Skies Discussion on the Elements of Imaginable Solutions for a Fire Immediate Response System
12.30	Lunch
1.45	Report Back on Breakouts
2.15	Panel on Current Status of Operational Fire Detection and Response: Capabilities and Limitations
2.45	Breakout Session: Available Technologies and Imaginable Solutions to Fire Detection and Location
	· Satellite-based Fire Detection
	· Drone/Aircraft-based Fire Detection
	· Ground-based Fire Detection
3.30	Break
4.30	Report Back on Breakouts
	Discussion
5.00	Adjourn,

DAY 2. APRIL 25TH, 2019

8.30	Arrival
9.00	Summary of Day 1 Deliberations
9.20	Breakout Session: Available Technologies and Imaginable Solutions to Fire Assessment
	· Fuel and Weather Conditions
	· Post-detection Immediate Fire Assessment (location and terrain, size, speed/direction)
	· Fire Behavior Modeling
	· Risk (location, proximities)
	· Data Information Integration
10.30	Break
11.30	Report Back on Breakouts
12.30	Lunch
2:00	Breakout Session: Immediate Response and Implementation Issues
	· Fire Response to include quelling/containing the fire, airborne/ground-based approaches
3:30	Break
4.00	Report Back on Breakouts and Discussion
5.00	Adjourn

DAY 3. APRIL 26TH, 2019

8.30	Summary of Day 2 Deliberations
9.00	Plenary Session: Roundtable, Top Three Priorities
	· Most important actions to get to where we want to be in CA in 2030
	· Key questions to answer
	. Biggest challenge to overcome
	Discussion
11.00	Formulating Recommendations from the Workshop
12.00	Final Comments - Harvey Fineberg
	Adjourn

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