NWCG Satellite Data Task Team

Report on Satellite Technology Requirements for Wildland Fire Services in the CONUS

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Report on Satellite Technology Requirements for Wildland Fire Services in the CONUS

Introductory Statement

The National Wildfire Coordinating Group (NWCG) Satellite Data Task Team, operated under the NWCG's Fire Environment Committee (FENC), investigated the current and rapidly evolving state of satellite-derived wildland fire data science and technology. Service gaps between current interagency wildland fire operations and newly supported capabilities, particularly those relevant to the lower 48 Contiguous United States (CONUS), were identified relative to advancements in satellite-based intelligence.

1. Objective & Scope

Deployment of new sensor technology onboard the National Oceanic and Atmospheric Association's (NOAA) Geostationary Environmental Satellites (GOES) 16/17 and Joint Polar Satellite System (JPSS) NOAA-20 has greatly increased the potential utility of satellite-derived data in wildland fire services. Infusion of these novel space-based capabilities in the operational environment has allowed practitioners from multiple fire-related service agencies to provide unprecedented wildland fire decision support. In most cases, innovative use of new satellite technology occurred to meet requests from partnering agencies as the potential benefits of these capabilities were realized.

> *"...innovation in the field is taking place faster than the organization can consider policies and guidance".*
>
> John Murphy
> National Weather Service (NWS) Chief Operating Officer

Screenshot from The Weather Channel segment titled "Do We Need A Fire Warning Protocol" which aired on the evening of 17 November 2018. During the segment, former NOAA officials advocated for the use of GOES-R-era technology as a technological impetus supporting reformation of wildland fire warning paradigms.

Outside of government, private industry is also innovating new ways to utilize emerging space-based technologies to improve public safety and for commercial use. Particularly, the unprecedented temporal

and improved spectral resolution offered by the GOES-R series is widely recognized as transformational and capable of revolutionizing warning processes for dangerous wildfire episodes. The debate about how to apply this new technology to improve warning paradigms is not confined to professional wildland fire and meteorological communities but is also being publicly advocated by media partners.

> *"Red flag warnings right now...we know the conditions are there that if a fire develops, it is going to be very bad, we can forecast that. What we can't forecast is where the fire is going to start, and that's really the key isn't it?...We are getting more and more technology that could enable us to determine when a fire has been ignited...One of those technologies is the new GOES-16[/17] satellite which gives us very high temporal resolution."*
>
> Chris Warren, Dr. Rick Knabb, and Tom Niziol
> The Weather Channel
> November 17, 2018

For this reason, the NWCG Satellite Data Task Team, convened by the NWCG FENC, was tasked to determine raw, algorithmic, and human-improved satellite data requirements for utility in wildland fire operations. The Task Team investigated ongoing prototype services and experimental pilot projects implemented by the represented agencies to fill growing service gaps with respect to fire related satellite services and the emerging technology, especially those relevant to operations in the contiguous 48 states. The scope of this task included current and anticipated future wildland fire utilities of satellite data including, but not limited to fire detections, burned area, fire progression and intensity, fire/burn perimeter, vegetation and weather intelligence, as well as smoke and air quality information. While the team's assigned tasking objective was to propose comprehensive interagency requirements for the delivery of satellite-based products and services that address the needs of the wildland fire community, to suggest, recommend, or otherwise determine roles of the represented agencies in meeting these requirements is beyond the scope of both the Task Team and this report.

> *"Wildland fire does not merely resemble a climatic or meteorological phenomenon; it results from them."*
>
> Dr. Stephen J. Pyne
> Fire in America: A Cultural History of Wildland and Rural Fire

Team Membership

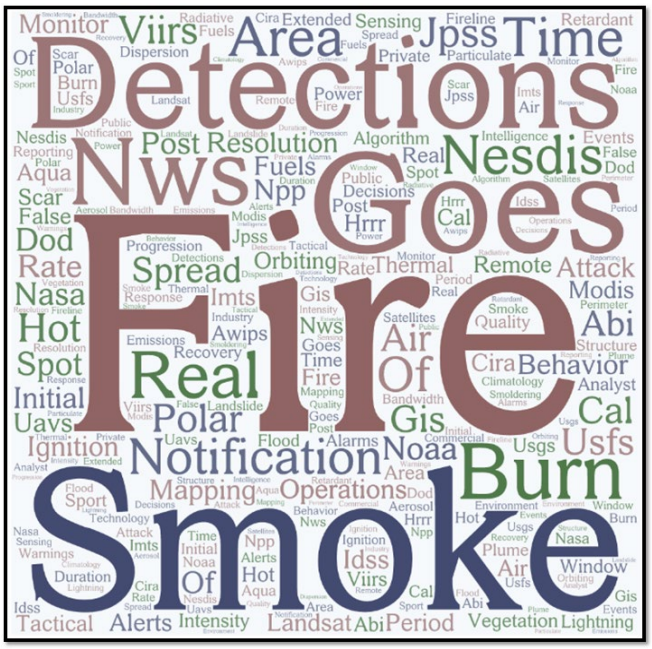
- Todd Lindley - NWS Weather Forecast Office Norman, Oklahoma, Chair
- Dr. Chad Gravelle - NWS Southern Region Headquarters, Fort Worth, Texas
- Dr. Susan O'Neill - USFS, Seattle, Washington
- Drew Daily - Oklahoma Forestry Services, Oklahoma City, Oklahoma
- Dr. Wilfrid Schroeder - NESDIS, College Park, Maryland
- Sean Triplett - NWCG Geospatial Subcommittee, Boise, Idaho
- Cole Belognie - NWCG Data Management Committee, Boise, Idaho
- Billy Gardunio - Predictive Services, Redding, California
- Craig Thompson - Office of Wildland Fire GIS, Boise, Idaho
- Hal Bromley - Bureau of Indian Affairs, Cody, Wyoming (self-recused March 2019)

Methodology

The panel of interdisciplinary subject matter experts convened for this Task Team conducted a thorough survey, when possible, of each representative agency's use of satellite data in wildland fire. Experimental uses, pilot projects, and service gaps were identified during the course of six virtual meetings between 8 November 2018 and 16 September 2019. The Task Team members then interviewed colleagues with similar or complementary expertise to gain a broader awareness of additional satellite-based needs or resources related to wildland fire. Subsequent input was solicited from stakeholders[1] including but not limited to:

- Local first responders (fire and emergency management)
- State forestry agencies
- Federal fire dispatchers
- Remote sensing and modeling experts
- Incident managers and fire behavior analysts
- NWS fire program managers and NOAA scientists
- Private sector meteorologists

Task Team meeting notes, emails, and stakeholder testimonials were consolidated to produce a prioritization of topics relevant to satellite-based information and partner agencies. While not a scientific survey of issues related to the use of satellite-based data in wildland fire, a word cloud of 458 key words/phrases from Task Team documents qualitatively indicates topics that dominated deliberations and priorities.



Word cloud showing the relative frequency of 458 key words/phrases as considered in Task Team documents.

The most common considerations indicated by the word cloud were identified as:

1. *Fire*
2. *Smoke*
3. *Detections*
4. *GOES (most referenced satellite)*
5. *Burn Area/Perimeter*
6. *NWS (most referenced partner agency)*

The Task Team was invited to present a progress report of its work at the International Association of Wildland Fire's (IAWF) 6th Fuels and Fire Behavior International Conference in Albuquerque, New Mexico, on 30 April 2019 titled "Deep Dive: Use of GOES-16/17 in Wildland Fire". Preliminary briefings on the Task

[1] *The term 'stakeholders' refers to wildland fire, emergency/land management, first responder professionals and affiliated partner agencies.*

Team's findings were delivered to the NWCG FENC on 17 October 2019, the Fire Behavior Sub-Committee on 13 November 2019, and the Office of Federal Coordinator for Meteorology on 29 January 2020. The Task Team additionally provided collaborative briefings with the Alaska Fire Science Consortium on 8 January 2020 and the NWS's Southern Region Science & Operations Continental West Group on 11 February 2020. A subsequent progress report was delivered to the NWCG FENC on 6 May 2020. A peer reviewed journal article documenting ground-based corroboration of GOES-17 fire detection capabilities resulted from the Task Team's work and was formally accepted on 27 July 2020 (publication pending). The Task Team presented their final briefing and written report to the FENC on 5 August 2020. Two major disruptions impacted the Task Team's workflow: the December 2018 to February 2019 Lapse in Appropriations (partial government shutdown) and the 2020 COVID-19 Pandemic.

Blog (wildfiretoday.com) coverage of the Task Team's presentation "Deep Dive: Use of GOES-16/17 in Wildland Fire" at the IAWF's 6th Fuels and Fire Behavior International Conference.

It is important to note that findings/recommendations provided herein are primarily focused on the use of satellite data in service of the wildland fire community across CONUS. The fire community in Alaska has independently innovated solutions to unique challenges of remote sensing for wildland fire at high latitudes, mostly through the use of low earth polar orbiting satellites due to their greater overhead pass frequency when compared to CONUS. Findings of the Task Team should by no means diminish or mitigate the necessity and utility of resources needed by stakeholders to address specific challenges in wildland fire operations at high latitude locations, such as Alaska.

2. Findings and Recommendations

The Task Team categorized key findings/recommendations in a manner that reflects the wildland fire incident response cycle as indicated in the table below.

2.1. Preparedness - training and operating procedures
2.2. Support of Initial Attack - timely interrogation and dissemination of remotely sensed fire detections that improves safety and mitigation in the response phase
2.3. Support of Extended Attack - fire-scale intelligence and data inventory that supports both ongoing firefighting efforts and future research, as well as real-time integration with ground-based remote sensing networks to detect the evolution of extreme fire episodes

2.4. Smoke Dispersion/Air Quality - improved sampling of plume, emission/trace gas, and particulate information for digitized model assimilation and analysis, including development/deployment of vertical cross-section capabilities
2.5. Recovery - burn intensity, vegetative rehabilitation, and hydrologic impacts

While this categorization is useful for presenting an orderly list, several findings/recommendations highlighted by this report span multiple categories in real-world operations. Some capabilities listed under Support of Extended Attack, would likewise also prove relevant in Support of Initial Attack and vice versa. The emphasis here is that findings/recommendations that fall under Support of Initial Attack and Extended Attack, as well as Smoke Dispersion/Air Quality (Section 2.2-2.4) are all based upon real-time detection and monitoring capabilities.

Executive Statement: Real-time detection and monitoring capabilities represent the core technological advances offered by modern satellite-based platforms and are the focus of evolving operational remote sensing utilities in wildland fire.

> *"Remote sensing tools…in the GOES-R [16/17] era and beyond…greatly increase the capabilities and role of fire meteorologists toward tactical IDSS (impact-based decision support services) in firefighting operations."*
>
> Lindley et al. 2016

> *"I have been in the fire service since 1974. During that time I have been blessed to see many new innovations that have greatly enhanced our operational effectiveness. One of the most impressive and useful tools I have seen developed during this time is the reporting system provided by your agency. These tools have proven to be accurate, dependable, and vital for our survival during wildfire season."*
>
> James Amerson, Randall County (Texas) Fire Chief
> Email reference to hotspot notifications provided by the NWS using GOES-16 data.
> 14 February 2018

Executive Finding: Modern satellite-based wildland fire detection capabilities, especially those provided by the GOES-R series, have the potential to revolutionize the provision of life saving warnings for both public and first responder safety during potentially dangerous wildfires. The GOES-16/17 Advanced Baseline Imagers (ABIs) have proven to be revolutionizing tools for the real-time detection and monitoring of wildland fire. The deployment of these spaceborne remote sensing platforms has been referred to as a "game-changer" for fire operations across multiple agencies.

Executive Recommendation: The NWCG should formally recognize the criticality of real-time wildfire detection and monitoring by modern satellite-derived platforms such as GOES-16/17 and JPSS NOAA-20. As such, NWCG should work directly with stakeholder policy makers to institute standards for the delivery of essential fire notifications, intelligence, and warnings based on the assimilation of all available space and ground-based remote sensing technologies to promote both first responder and public safety, while encouraging the development of future capabilities using satellite-based platforms. In addition, the NWCG should consider the appropriate roles of private versus public sector interests in the applications of such technologies.

The categorized findings and recommendations that follow, capture the Task Team's vision for how the collective wildland fire community can best leverage "game changing" space-based technology to improve fire operations across CONUS.

> *"The fact is, technology can enable but not advise, while science can advise but not decide. That synthesis belongs with politics."*
>
> Dr. Stephen J. Pyne
> *Tending Fire: Coping with America's Wildland Fires*

2.1 Preparedness

In order to fully leverage the technological advantages presented by modern satellite-based remote sensing of wildland fire, a degree of background preparatory actions must be taken through training and the establishment of guidance for operational logistics and infrastructure. This section highlights findings and recommendations in the preparedness phase of response to the implementation of advanced satellite capabilities in fire service operations.

Finding 1: There is a significant need for training on the use of satellite data in wildland fire within the professional meteorological and wildland fire communities.

Recommendation 1: The NWCG should support and actively promote the development of operationally-based training on remote sensing interpretation for wildland fire.

MetEd COMET has produced two training modules that serve as examples for the type of training that should be institutionalized in the wildland fire community. These include:

- *GOES-16/JPSS Case Exercise: Monitoring the Rhea Oklahoma Grass Fire*
- *GOES-R/JPSS Case Exercise: Detecting and Monitoring Western U.S. Wildfires*

Examples of two training modules produced by MetEd COMET on the use of satellite data in detecting and monitoring wildfires.

Finding 2: The aforementioned training modules, as well as many examples referenced throughout this report, demonstrate the criticality of real-time satellite-based detection and monitoring of wildland fire and its utility in impact mitigation.

Recommendation 2: The NWCG should emphasize to stakeholder policy makers the necessity of communicating real-time detections of newly ignited wildland fire and the role this information plays in successful mitigation.

Finding 3: Not all wildland fire detections by satellite-based remote sensing warrant reporting to the wildland fire community. Wildland fire is a natural feature of many ecosystems, and a majority of wildland fires are benign and result from intentional burning.

Recommendation 3: The NWCG should facilitate coordination between stakeholder agencies to establish pre-existing agreements on reportable wildland fire detections. In many cases, reporting criteria may be 'filtered' based upon fire environment conditions (weather and fuels), or incident response complexity, so as to reduce false alarm and/or non-actionable detections.

Finding 4: Initial 1-minute GOES-16/17 Mesoscale Domain Sector (MDS) operating plans for wildland fire support restricted the provision of timely decision support when pre-existing fire was absent and when red flag warnings were not in effect.

Stakeholder field experience has shown the availability of 1-minute satellite data is critical to fire/land/emergency management agency operations. Opportunities to leverage this technology and provide early detection for wildfire mitigation can exist in pre-fire environments, even when red flag warning criteria are not met and in the absence of ongoing fire. Such opportunities may occur when new wildland fire ignitions are anticipated to result in impacts to sensitive stakeholder operations, but when defined critical fire weather thresholds are not met and significant wildfire potential is low.

Real World Example

On 13 March 2019, a powerful midlatitude cyclone impacted the southern Great Plains and a high-impact gradient wind event ensued with occasional wind gusts that exceeded 70 mph and caused widespread damage. Given the previous night's rainfall and moist conditions, the threat of extreme fire behavior and resultant significant wildfires was low. However, a GOES-16 MDS was requested to monitor for potential fire starts due to anticipated damage to utility infrastructure from the high winds. A fire ignition was detected in rural parts of western Oklahoma 13 minutes prior to local emergency 911 calls. The early notification provided allowed first responders to quickly contain the fire before wind-driven flames could prompt a more significant incident. Drew Daily (Oklahoma Forestry Services) stated that the event was *"proof that merits innovative use of satellite data at hand - it paid off!"*. Under original NWS operating plans, however, the situation did not meet requirements for use of MDS in support of fire weather operations given that red flag warnings were not in effect and that ongoing fire was not occurring.

Recommendation 4: The NWCG should encourage partner agencies to implement policies and operational guidance that reflect the critical priority of real-time detection and monitoring of wildland fire. Such priorities should be well established and reflected in operating plans for GOES-16/17 MDS other components of service provisions.

2.2 Support of Initial Attack

A May 2019 integrated project team report by the Department of Homeland Security (DHS), the U.S. Fire Administration (USFA), and the Federal Emergency Management Administration (FEMA), made 53 references to the urgent need for utilization of satellite-based technology in mitigating public impacts from wildfires and emphasized:

> *"There exist available technologies (both government and commercial), which- if implemented- could immediately help emergency responders reduce the number of lives lost during WUI [wildland urban interface] fire incidents. In particular, these technologies could immediately support ignition detection, fire tracking, public information and warning, evacuation, and responder safety."*
>
> Dr. Geoffrey Berlin and Dr. Michael Hieb
> Wildland Urban Interface Fire Operational Requirements and Capability Analysis
> May 2019

Currently, the wildland fire community across CONUS is largely reliant on the National Infrared Operations Unit and Distributed Real Time Infrared fire imaging technology (Northwest Coordination Center 2018), which consists of only a few aircraft that identify, map, and monitor wildland fires. In order to supplement and enhance our capabilities to identify and provide timely initial attack on newly ignited fires, the Task Team sought answers to the following question:

"How do we use satellites to enhance detection capabilities and decrease response time over dispatch?"

During a 9 June 2020 Senate Committee on Energy and Natural Resources hearing on the state's preparedness for wildfires, U.S. Senator Maria Cantwell (D-WA) asked witnesses, *"The National Weather Service satellite technology can detect fires at an early stage, and so that's one of the ways…for us to find fire starts right away. Is the Forest Service and Department of the Interior aware of this Weather Service satellite technology, and are states using it? Is there something else that the Forest Service needs to take this technology and get it deployed for this fire season?".*

In response to the Senator's question, George Geissler, Washington State Forester and past President of the National Association of State Foresters, supported the importance of satellite and other technologies to assist wildland firefighters: *"That is actually a project very near and dear to my heart…it's being used very effectively with the Oklahoma Forest Service right now. It is technology whereby the weather service can detect the fires and notify the state fire folks where they're located, or where the potential is, and it happens every five minutes that they're looking at it."*

Finding 5: Experimental hotspot notifications were innovated by NWS forecasters in real-time at the request of core partner state forestry agencies as a means to provide GOES-R-era satellite-based fire detections to first responder agencies (Lindley et al. 2016). These notifications have been credited with saving lives and property in the spirit of the agency's mission and provision of impact-based decision support services (IDSS).

> *NOAA/NWS Mission Statement - "The **National Weather Service** (**NWS**) provides weather, water, and climate data, forecasts and warnings for the protection of life and property and enhancement of the national economy."*

Real World Example

On 6 March 2018, NWS Weather Forecast Office (WFO) Tulsa issued a hotspot notification for a large wildfire in Creek County, Oklahoma. When first responders arrived on the scene, the fire was immediately threatening to burn a home where a disabled elderly woman was found to be inside and was subsequently rescued. Covey Murray, the Creek County Emergency Manager, said *"the woman would have likely died without the hotspot notification"*, given that no 911 calls were received and the fire was otherwise never reported (NOAA 2018).

Recommendation 5: It is essential that hotspot notifications are issued from a trusted credible source agency with established deep core partnerships within the state and local first responder community.

Finding 6: The 1-minute temporal resolution of GOES-16/17 is paramount to early wildfire detection, as timely initial notifications of newly ignited fire provides the most value to the wildland fire community.

Recommendation 6: The cornerstone of any early wildfire detection operating plan needs to be based on the high-temporal resolution data from GOES-16/17.

Finding 7: The spatial resolution of JPSS NOAA-20 allows for detection of smaller wildland fires, but overpasses and data updates are infrequent (i.e., on the order of one observation every ~12h for CONUS). If overpasses are coincident with the early moments after fire ignition, then these detections also may be useful for early detection.

Important Service Gap: Improved latency and availability of polar orbiting data is needed in the operational environment, especially over CONUS.

Recommendation 7: The NWCG needs to promote and coordinate the use and integration of high-spatial resolution data from polar-orbiting satellites in all phases of the wildland fire incident response cycle.

Finding 8: The greatest and most urgent demand for satellite data by the wildland fire community (including local, state, federal, and commercial entities) is related to the provision of timely detection and notification of newly ignited wildfires within critical fire environments that support extreme fire behavior.

> *"Fact that never changes: the safest and least costly fires are the ones that receive strong initial attack and suppressed while still small."*
>
> Between Two Fires, 2015
> Dr. Stephen J. Pyne

Recommendation 8a: The NWCG should coordinate with partner federal agencies to define roles and jurisdiction for the operational issuance of accurate real-time hotspot notifications for newly ignited wildland fires that occur in critical fire environments based on GOES and JPSS data.

Recommendation 8b: Once agency roles and responsibilities are determined, NWCG should coordinate with stakeholders to establish appropriate and consistent operating plans governing the issuance of hotspot notifications.

Recommendation 8c: The NWCG should collaborate with partner agencies to ensure that designation of hotspot notification issuance responsibility aligns with expertise in remote sensing, message dissemination capabilities, and the provision of warnings for weather and climatic natural hazards.

Recommendation 8d: Effective hotspot notifications should minimally include the following information:

- ***Precise geolocation***
- ***A measure of confidence in the detection***
- ***Initial weather conditions***
- ***Direction of spread***

Recommendation 8e: Additional information that stakeholders indicate would increase the effectiveness of hotspot notifications should be considered, but require further development of ongoing experimental capabilities or are limited by the current state of science include satellite-based estimates of:

- ***Fire size and intensity***
- ***Fire perimeter mapping***
- ***Rate of spread***
- ***Involved fuel type - possibly cross referenced with LANDFIRE***
- ***Embedded fire detection satellite imagery***
- ***Assimilation of fire detection into coupled fire behavior models***

As an example, the Advanced Weather Interactive Processing System (AWIPS) Hotspot Notification Tool already provides base mapping that allows viewing of the general landscape characteristics of the satellite-detected fire area.

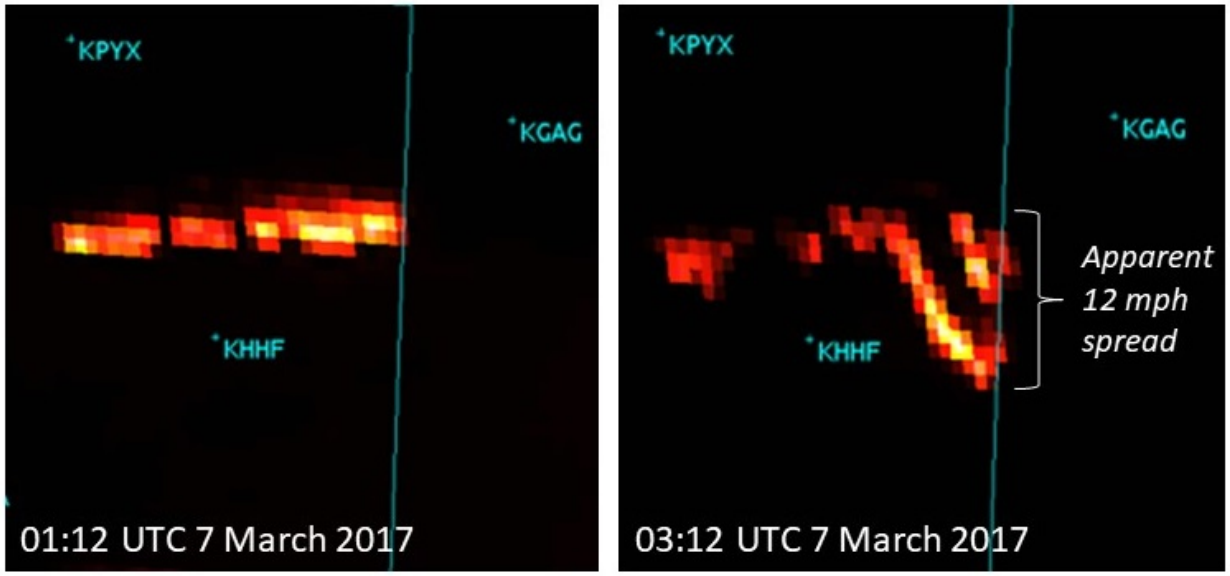
Example of terrain/fuel basemapping contained within the AWIPS Hotspot Notification Tool.

Real World Example

A 9 January 2020 email from Greenwood County, Kansas, Emergency Management Director, Levi Vinson, details a wildfire incident where a GOES-16 based hotspot notification was credited with saving two residences due to early dispatch. Director Vinson states: *"We have not had a failure with this product. It is so reliable that we dispatch fire units without confirmation of fire. [...] We have no doubt that it will continue to aid us in the identification of wildfires in sparsely populated areas that are often reported well after fires have become out of control."*

Finding 9: In order to support the needs of the wildland fire community, improved science is needed to correlate remotely sensed signals of wildland fire with surface fire characteristics and to incorporate these signals into other emerging observational and modeling platforms.

Recommendation 9: The NWCG, in coordination with partnering agencies and the research community, should actively support efforts to corroborate satellite-based remote sensing signals of wildland fire to wildfire structure and behavior. Such efforts may include observational field campaigns during both prescribed burns and wildfire events to improve scientific knowledge of remotely sensed fire signals that correlate to wildland fire structure and characteristics such as rate of spread, fireline intensity, and head fire identification.



GOES-16 remote sensing of the 6-7 March 2017 Perryton Fire (Texas) suggested an apparent rate of fire spread near 12 mph. Also, variations in the Fire Temperature RGB product appear to correlate to fire line intensity and wildland fire structure (i.e. flank versus head fire). Subsequent research is needed to corroborate these signals with observations of on-ground fire characteristics and behavior.

Finding 10: While a fine-scale geographic focus, as well as deeply trusted relationships with core partners and the local first responder community, is vital in the provision of timely and effective hotspot notifications, a regional and/or national scale summary of human-identified and/or algorithm-based fire detections is needed in a failsafe backup capacity.

Recommendation 10: The NWCG should coordinate with partner agencies to establish standards for the provision of regularly issued summary products that provide, at a minimum, aggregated

geolocations and times of near-real time fire detections emanating from all available space-based platforms. Given the time sensitive nature of this data, summary products should update every 5-30 minutes.

Finding 11: Current fire detection algorithms are insufficient to provide the vital timeliness needed to influence effective initial attack on many dangerously impactful wildfires through an automated process.

Recommendation 11: The NWCG should coordinate with partnering agencies and stakeholders, such as satellite algorithm developers at the University of Wisconsin Cooperative Institute of Meteorological Satellite Studies (UW-CIMSS) and the National Environmental Satellite, Data, and Information Service Center for Satellite Applications and Research (NESDIS/STAR), to improve the current Fire Detection Characteristics Algorithm (FDCA) and to ensure the development of more reliable future fire detection algorithms.

Finding 12: Manual human-based interpretation of raw satellite data provided by the GOES ABI, and in some cases JPSS, when performed by individuals well-versed in remote sensing, commonly result in earlier and more comprehensive fire identification than automated algorithm-derived fire detections. Improved fire detection algorithms are required before the process of fire detection notifications can be automated. In the meanwhile, provisions for human-based interpretation and at least partially manual notification processes should exist.

Recommendation 12: Pending the development of improved fire detection algorithms, the NWCG should request that efforts by partnering agencies to provide stakeholders with timely notification of new wildland fires are augmented by human interpretation, and not solely provided via automated means.

> *"The calibrated [GOES-16/17] data can be very revealing to the human eye, and is useful in cases where early detection is of prime importance. [...] The goal is to stop small fires before they become very large. NWS forecasters have learned how to exploit the remapping artifacts to improve the location of the hotspot to within less than half a pixel, visually identifying the centroid of the 2x2 pixel heat signature."*
>
> Chris Schmidt
> *Monitoring Fires with the GOES-R Series*

<u>Real World Example</u>

Evidence of value added IDSS provided by skillful human interpretation of GOES-16 ABI data over algorithmic automation was demonstrated on 6 March 2018 in Oklahoma. A forecaster at WFO Norman noted a small heat signature in GOES-16 MDS imagery that was approximately 1 K above the ambient background temperature and reported the hotspot to authorities. The signature was found to be an unreported house fire in a rural area near Drummright, Oklahoma, which escaped into the adjacent grasslands and was never detected by the FDCA.

<u>Real World Example</u>

The 23 October 2019 (local time) ignition of the Kincade Fire in northern California provided an ideal comparison of manual human-based interpretation of raw GOES ABI data versus FDCA, which was

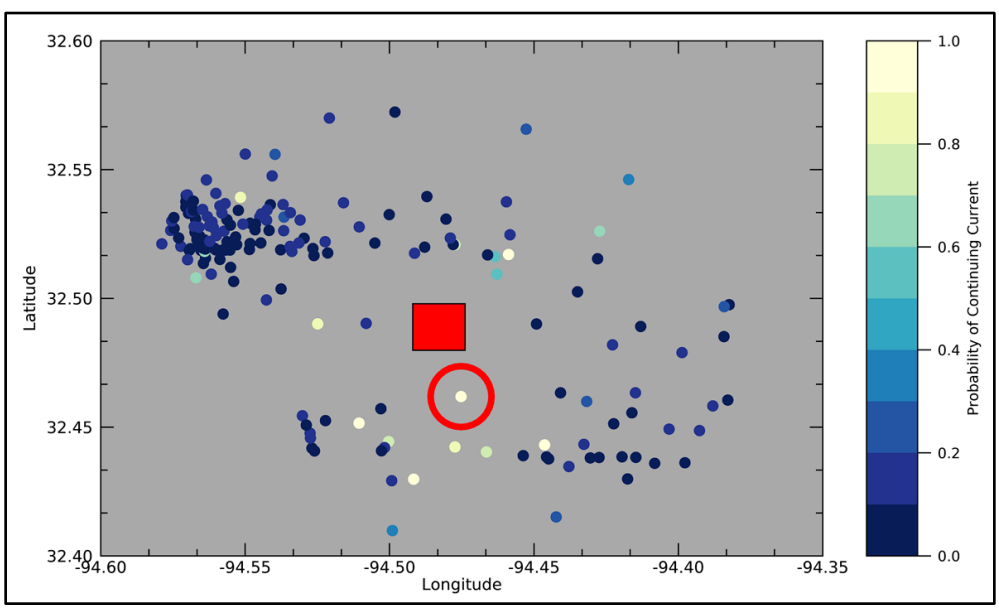
fortuitously corroborated by in situ ground-based ALERTWildfire observations, a near-IR camera network specifically designed to detect wildfire ignitions. The GOES-17 ABI's raw shortwave IR (3.9 μm, channel 7) first detected the Kincade Fire's heat signature 52 seconds after the ALERTWildfire's near-IR camera first indication of ignition. The various FDCA products began to register the fire between 5 and 10 minutes after ignition. *Note: the joint membership of this Task Team and the MetEd/COMET training module development team (previously mentioned in Section 2.1) have submitted a manuscript for consideration to the National Weather Association's Journal of Operational Meteorology to document this case in formal literature.*

Finding 13: The lack of GOES derived fire products for GOES-16/17 MDS (1-minute) data further reduces the timeliness of algorithm-derived wildland fire detections and the provision of automated notification processes.

Important Service Gap: GOES derived fire products, such as Fire Temperature, Fire Area, and Fire Power, are not currently available for MDS.

Recommendation 13: NWCG should coordinate with NOAA, NESDIS/STAR, UW-CIMSS, and other partnering agencies and stakeholders to ensure that derived fire products are implemented for MDS operations.

Finding 14: Preliminary research suggests GOES-16/17 Geostationary Lightning Mapper (GLM) data, integrated with various satellite and fuels data, can provide an initial estimation of the probability that lightning discharges will initiate a wildfire. This proposed concept is based on the remotely sensed identification of relatively long-lived "continuing current" lightning strikes that persist for tens or hundreds of milliseconds (Fairman and Bitzer 2019). This work has shown that new satellite-based wildland fire detections tend to occur around 4 days after, and within 7 km of, lightning strikes that have a high probability of continuing current pending background weather and fuel conditions.



Example of 826 GLM flash centroid locations color coded by probability of continuous current. The highest probability of continuous current flash (99%) is circled. A subsequent GOES ABI hotspot detection is shown by the red square.

Recommendation 14: The NWCG should support applied research by GLM developers, in partnership with interested stakeholders and the private industry, to ensure delivery of products to the wildland fire community that provide timestamped geolocations of continuing current lightning strikes. Such data could yield probabilities of ignition and locations of suspect strikes that would be closely monitored for the emergence of new wildland fires.

Finding 15: Coupled weather-fire behavior numerical models, such as the Coupled Atmosphere-Wildland Fire Environment (CAWFE) model, have shown an increased potential to predict complex and rapidly changing fire behavior (Coen et al. 2013, Coen 2013, Coen and Schroeder 2013, 2014 and 2017, Coen and Riggan 2014, Powers et al. 2016, Coen 2018, and Muńoz-Esparza et al. 2018).

Recommendation 15: The NWCG should promote coordinated scientific efforts to validate the assimilation of satellite-based detections for newly ignited wildland fire into atmosphere-fire behavior numerical models, such as but not limited to CAWFE and WRF-SFIRE (Mandel et al. 2011), to predict wildfire spread, behavior, and potential impacts.

Finding 16: There are growing calls by officials at all levels, from partnering federal agencies, to media, to private industry, to implement a "whole community" approach to wildfire warning dissemination that provides real-time public and first responder warnings of potentially dangerous wildfires. Such objectives have been established by high priority key findings in official reports and among various media outlets.

"The National Weather Service has satellites that can sense a developing "hot spot". With up-to-the-minute technology and rapid-refresh models that can anticipate what a fire will do next, meteorologists could alert folks downwind in the projected path." … [This] "Underscores the need for a short-fused Weather Service product – one that encompasses a small area, like a tornado warning, and elicits the same level of urgency through the EAS."

Matthew Cappucci
After the Fire Disaster in Paradise, Meteorologists Mull How to Improve Warning System
Capital Weather Gang - The Washington Post
28 November 2018

Recommendation 16: Pending scientific validation of data assimilation methods, a whole community warning system should be established that fully leverages satellite-based fire detections assimilated with fire-scale numerical atmosphere-fire behavior models to warn targeted populations and first responders of predicted extreme fire behavior and to inform emergency response actions such as preemptive public evacuations.

Finding 17: The concepts proposed in this report represent three out of seven key findings by the 2019 DHS/USFA/FEMA report:

- ***Key Finding 1: Implement and scale the use of state-of-the-art remote sensing assets to provide state and local stakeholders real-time, accurate, low-cost ignition detection and tracking information.***
- ***Key Finding 2: Improve the ability of available and adaptable public alert and warning technologies to deliver more targeted and effective messages across the whole community.***

- ***Key Finding 4: Support broader use of existing fire modeling and forecasting tools for pre-incident planning; while also advancing efforts to create high-confidence, timely WUI [wildland urban interface] fire-specific models that can be used to inform response tactics during extreme conditions.***

The report states that if these key findings are implemented, they could *"substantially improve immediate life-saving efforts during WUI fire incidents"*. Dr. Geoffrey Berlin and Dr. Michael Hieb, Wildland Urban Interface Fire Operational Requirements and Capability Analysis, May 2019.

Recommendation 17: The NWCG should coordinate with partner agencies and stakeholders to utilize modern satellite-based technologies in the adoption of DHS/USFA/FEMA report findings where scientifically and technologically feasible.

Finding 18: Experiments and retrospective proof-of-concept simulations have shown that meteorologists and fire behavior analysts can skillfully issue coordinated and targeted fire-scale warnings aimed to influence both public and first responder safety based on combined knowledge of the fire environment and GOES-R-era satellite-based remote sensing signals of extreme fire behavior (Lindley et al. 2019).

Real World Example

On 26 November 2019, a wildfire threatened the town of Fargo, Oklahoma. Based on satellite remote sensing signals associated with the fire, which was occurring within an environment known to support extreme fire behavior as indicated by experimental 2.5-km resolution gridded EnhancedFire Tool information, NWS forecasters at WFO Norman notified Oklahoma Forestry Services (OFS) of a "life threatening" fire northwest of Fargo at 15:06 LST. Subsequently, a period of complex interagency coordination between federal, state, and local partners ensued prior to the eventual issuance of a Fire Warning via request by local emergency management at 16:29 LST. This coordination is consistent with current agency policy. Yet, dissemination of critical fire location and evacuation information were delayed 83 minutes after combined fire environment and satellite-based signals of a life threatening situation, due to the complexities of multiagency coordination during chaotic incident initial attack response. Local authorities began evacuating Fargo residents at 16:07 LST, some 18 minutes prior to the official request for Fire Warning issuance. Had policies and procedures for proactive warning strategies based upon combined knowledge of the fire environment and satellite-based technologies been in place, public and local emergency officials could have been warned of the development of a "life threatening" wildfire incident at the time NWS meteorologists first informed OFS of the hazard, more than an hour earlier.

Recommendation 18: The NWCG should coordinate with partner agencies and stakeholders to adopt a targeted fire-scale whole community wildfire warning paradigm that fully utilizes satellite-based remote sensing along with coordinated interdisciplinary knowledge of the fire environment, and weather-fire behavior numerical weather prediction.

2.3 Support of Extended Attack

Beyond the urgent needs of the wildland fire community for timely and accurate detection notifications of newly ignited fire in support of initial attack, modern satellite technology additionally offers many capabilities that can be applied to prolonged wildfire incidents, or extended attack. During this phase of fire suppression activities, high spatial resolution data from low-earth polar satellites can provide essential intelligence on

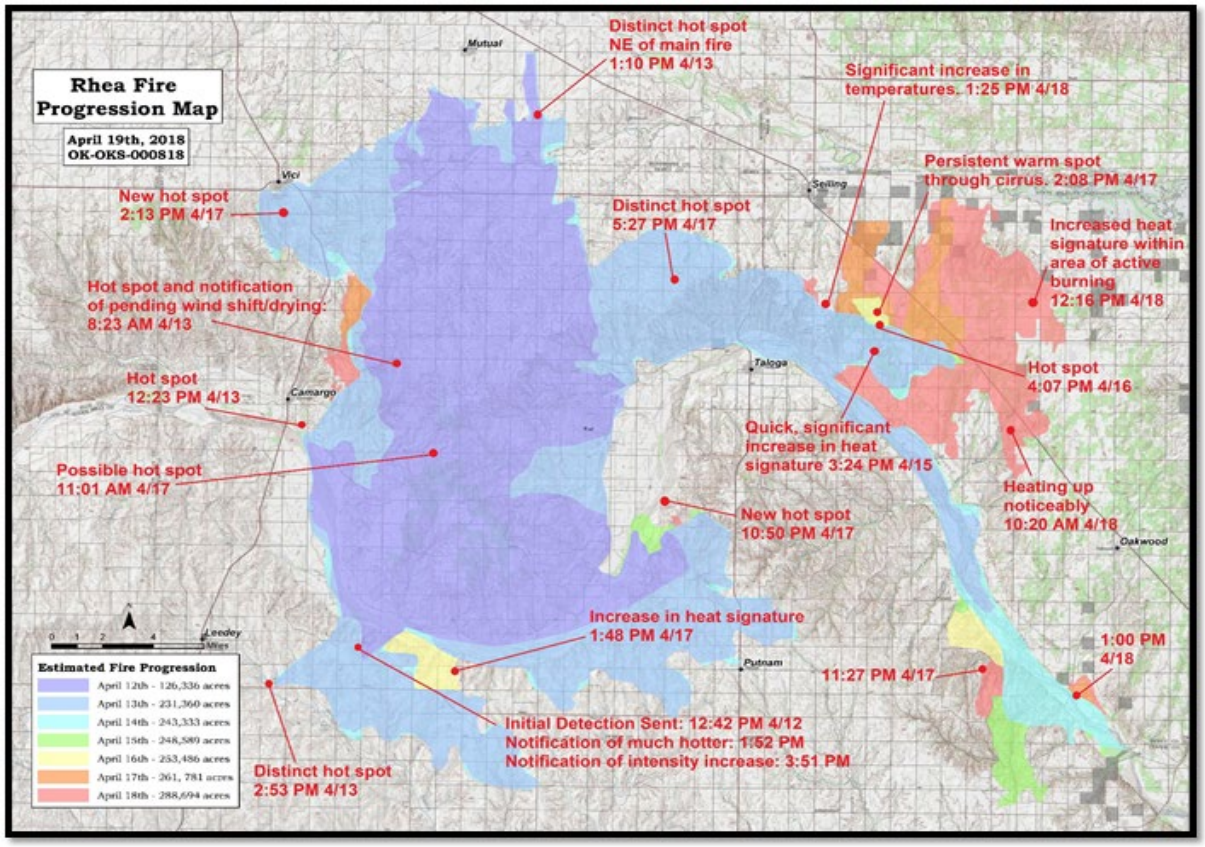
fire behavior and characteristics. This section will highlight community needs to fully leverage these and future capability development the Task Team proposed as priorities.

> *"Usage of the hotspot detection and actual high-resolution GOES-16/17 imagery from satellites depicting the near real-time spread of the fire was tremendous when it comes to [extended] response operations."*
>
> Michael Paddock
> Emergency Response Specialist
> NWS Liaison to FEMA National Incident Management Assistance Team West
> *November 2018 Camp Fire Service Assessment*

Finding 19: The wildland fire community would greatly benefit from remotely sensed information on changes in burn character/intensity and meteorological changes in the fire environment during extended attack. Such notifications have successfully provided tactical support to Incident Management Teams (IMTs) and firefighting officials during recent major fire incidents.

Real World Example

NWS forecasters leveraged the experimental AWIPS Hotspot Notification Tool to provide up to 20 real-time tactical updates to first responders and IMT commanders regarding changes in satellite depictions of burning and meteorological conditions during the 12-18 April 2018 Rhea Fire (Oklahoma). Many notifications provided authorities with precise and timely indications as active fire initiated in various sectors of the incident.



Rhea Fire (Oklahoma) progression map showing 20 tactical notifications of changes in the burn character and weather between 12-18 April 2018. Image credit: NOAA/NWS/WFO Norman.

"We...saw where a new fire had broken out north of the main area... I didn't believe it had been reported yet. I stopped to take a couple of photos, was about to call it into the office, when my phone went off showing a new hot spot...exactly where I was standing. I came back and explained to Field Operations how great it was to see hotspot working LIVE!".

Melissa Moore
Oklahoma Department of Emergency Management (ODEM)
Email correspondence on 19 April 2018

Recommendation 19: The NWCG should collaborate with partnering agencies to ensure that notifications are provided to the wildland fire community and incident commanders when satellite technologies remotely sense changes in fire character and behavior that are vital to support extended attack decisions. Guidance and operating plans should be established to support the operational implementation of such notifications.

Photo of newly active fire on the northern periphery of the Rhea Fire on 13 April 2018. This image and emergency manager account corresponds with the notification stating "Distinct hot spot NE of main fire" issued at "1:10 PM 4/13" as depicted in the progression/notification map shown above. Photo credit: Melissa Moore/ODEM.

Finding 20: There is a strong need for the regular issuance of operationally-relevant fire intelligence matrices and graphical products that communicate satellite-derived characteristics of ongoing wildland fires such as:

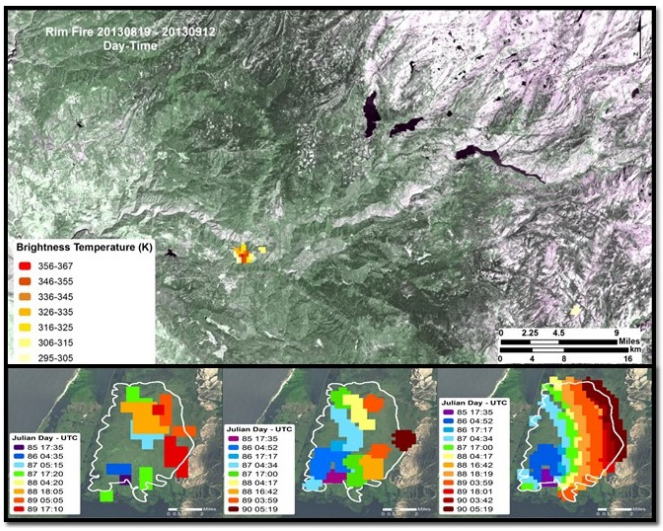
- ***Geolocation of wildland fire***
- ***Time of overpass/sampling***
- ***Rate of fire spread since previous overpass***

- ***Burn area/perimeter and associated changes since previous overpass***
- ***Fireline intensity/power***
- ***Fire temperature***

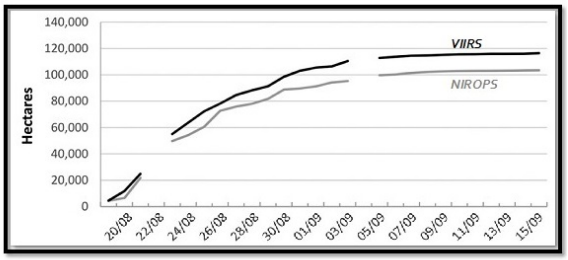
Recommendation 20a: The NWCG should work with partnering agencies to establish operating plans for the regular issuance of Fire Intelligence Matrices and standardized graphical products that summarize satellite-derived wildland fire intelligence across the CONUS in an operationally-supported product that is regularly updated. This function would be a powerful use of high spatial resolution low-earth polar-orbiting satellite platforms such as Visual Infrared Imaging Radiometer Suite (VIIRS) onboard the JPSS Suomi NPP and NOAA-20, if operational products were issued in a timely manner following each satellite overpass.

Recommendation 20b: The aforementioned proposed output should be assimilated into coupled fire-atmosphere numerical models to improve potential fire spread and behavior modelling that may influence IMT and Emergency Management decisions regarding suppression tactics and public evacuations.

GIS Mapping – Rim Fire
S-NPP/VIIRS 375 m- 12 h data



Daily Fire Growth – Rim Fire
S-NPP/VIIRS 375 m & NIROPS 10 m



Examples of currently produced satellite-derived data from high resolution polar orbiting satellites including GIS mapping and daily fire growth from the 375-m resolution Suomi VIIRS and 10-m resolution NIROPS for the 2013 Rim Fire (California). This information can be converted to operationally useful matrices and graphical products.

Finding 21: Current FDCA derived fire parameters, such as Fire Area and Fire Temperature, are approximations that do not produce realistic values representative of real-world fire characteristics.

> *"Fire Temperature and Fire Area are calculated using simultaneous equations and are dependent on one another. They represent a hypothetical heat source that would match the observed temperatures. Due to radiometric error, diffraction, and remapping of ABI data, the solutions are imprecise and primarily intended to be used in numerical models for aerosols and smoke. Therefore, Fire Temperature and Fire Area should not be taken as literal values representing the temperature and extent of wildland fire."*

Chris Schmidt
UW-CIMSS
Personal Communication

Recommendation 21: As part of the proposed NWCG's effort to collaborate with UW-CIMSS (Recommendation 11) to develop next-generation FDCA fire detection algorithms, an emphasis should be placed on ensuring that derived product output incorporates improved scientific techniques to result in more meaningful and representative parameters such as Fire Temperature, Fire Area, and Fire Radiative Power.

Finding 22: Anecdotal observations by operational practitioners suggest that satellite data, particularly high temporal resolution GOES-16/17 data, may be useful in monitoring the effectiveness of wildfire suppression activities.

Recommendation 22: The NWCG should encourage partnering agencies, stakeholders, and the research community to investigate the potential for satellite-derived data, including GOES-16/17 FDCA derived fire parameters, to be used in the monitoring of fire trends associated with suppression efforts, including aerial retardant drops.

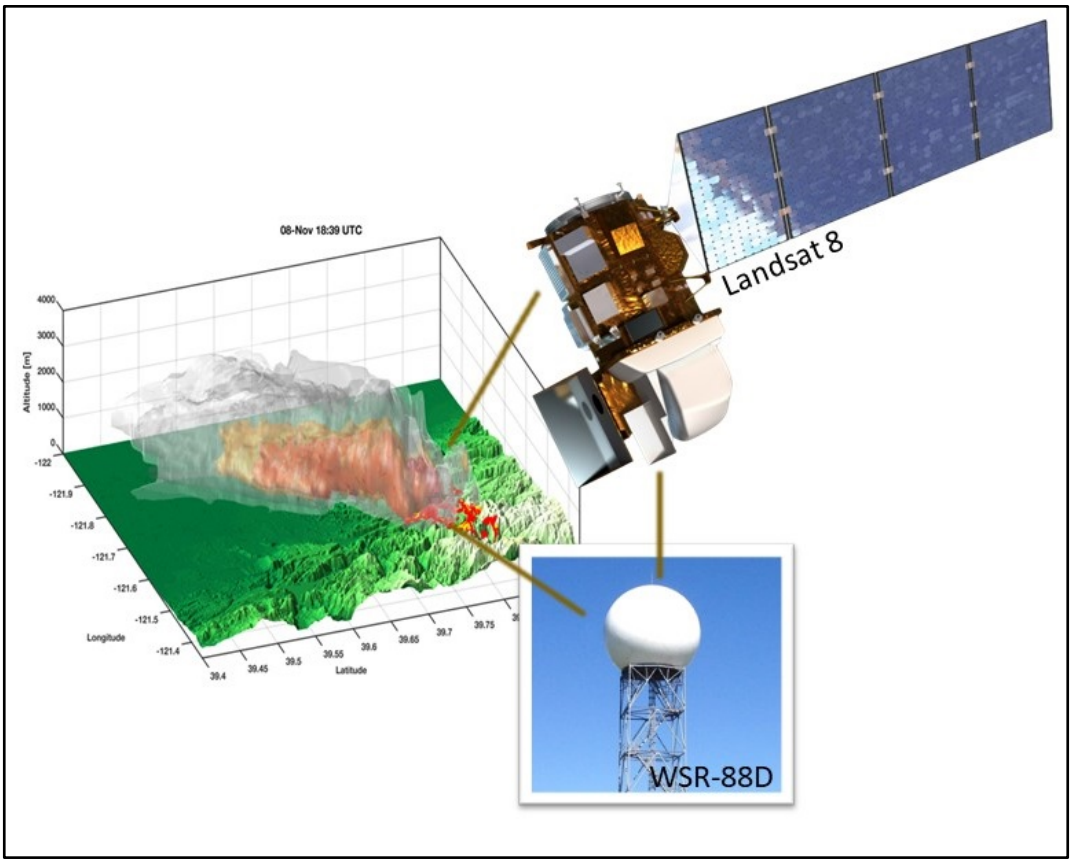
Finding 23: Research has shown that FDCA derived products, such as Fire Radiative Power and Fire Temperature, can be used to predict the development of pyro cumulonimbus (Tory 2019) associated with extreme fire behavior.

Recommendation 23: The NWCG should work with partnering agencies, stakeholders, and the research community to adopt methods using derived fire products, including Fire Radiative Power and Fire Temperature, to implement operational practices for the prediction of pyro cumulonimbus development, and avenues to communicate such predictions to the wildland fire community and incident commanders.

Finding 24: Proposed research suggests that composited satellite and ground-based radar data may reveal commonalities that quantify coupled fire-plume processes associated with extreme fire phenomena.

Recommendation 24a: The NWCG should work with partner agencies, stakeholders, and the research community to promote science focused on assimilation of multi-sensor (both space and ground-based) systems that may increase knowledge of extreme fire processes and reveal predictive indicators of their occurrence.

Recommendation 24b: The aforementioned scientific efforts should be encouraged to lead toward the use of Artificial Intelligence (AI) and machine learning probabilistic algorithms to be employed in wildland fire detection and volatility monitoring. Such systems are analogous to the ProbSevere products now integrated into the Multi-Radar/Multi-Sensor suite of products used in the NWS severe local storms warning program.



Example composited satellite (Landsat 8) and radar (WSR-88D) data revealing plume structure of the 2018 Camp Fire (California) (Neil Lareau, University of Nevada, Reno).

Finding 25: For the purpose of future research, and perhaps with some utility in operational fire prediction, it is important to develop satellite-based cataloged inventories of fire occurrence and associated burn periods. Such catalogs may be useful in persistence forecasting on prolonged incidents but would certainly be useful for climatological studies and related research.

Recommendation 25a: The NWCG should work with partnering agencies, stakeholders, and the academic research community to build satellite-derived databases of burn periods and associated fire activity that would include:

- ***Number of detectable active fires***
- ***Duration (in hours) of active burning as depicted by satellite***
- ***Magnitude of burning based on changes of burn area/perimeter and/or radiative fire power/fire line intensity***

Recommendation 25b: Burn period summary inventories should be finalized and transmitted to the wildland fire community/partner agencies at the end of each calendar day for use in operational planning.

Finding 26: There are numerous other governmental agencies operating satellites which have various degrees of utility in the detection and monitoring of wildland fire. Such entities including the U.S. Department of Defense, the European Space Agency (ESA), and even private sector organizations. Some of these earth observation platforms, such as the ESA's Sentinel-2, have optical resolution as low as 10 m, and have proven to offer unique satellite-based solutions to challenges faced by the wildland fire community at high latitude locations, such as Alaska.

Recommendation 26: The NWCG should work with partner agencies and stakeholders to further investigate the feasibility and possible advantages of obtaining access to these external sources of satellite data in application of wildland fire operations.

2.4 Smoke Dispersion/Air Quality

Second only to the urgent need for real-time fire detection information, the Task Team identified major service gaps in the wildland fire community's access to operationally relevant satellite-based data in support of smoke and air quality management decisions. Although current satellite technology is useful for monitoring smoke and some aspects of air quality, it would be more useful if practical upgrades and modifications to data assimilation and delivery are adopted. This component of the wildland fire community's use of satellite-derived data will likely require significant future technological advances to achieve operational objectives. The Task Team's findings and recommendations for the provision of satellite-based smoke and air quality information follows.

Finding 27: Wildland fire ignition and spread have direct implications for smoke plume development and transport. For example, within hours of ignition, the smoke plume from the 2018 Camp Fire stretched across northern California and millions of people were impacted by high particulate matter concentrations. Smoke forecasting systems failed to capture this.

Recommendation 27: Information from an assimilated real-time fire detection system (as recommended in Section 2.2) should be adapted/extended such that smoke/air quality prediction systems can initiate model runs. This can be as simple as ensuring the satellite-based notice of a wildland fire ignition be sent to agencies/groups conducting smoke modeling.

Example social media post using GOES-16 GeoColor imagery of smoke associated with the 2018 Camp Fire over northern California.

"GOES-16/17 satellite data was an excellent tool for both IMETs and Air Resource staff to evaluate smoke transport (track smoke plumes)."

Alex Hoon
NWS IMET
NOAA/NWS Camp Fire Service Assessment

Finding 28: Operational needs of the smoke and air quality segment of the wildland fire community require improved automated fire detection algorithms. For example, the FDCA derived Fire Radiative Power is used in the NOAA Smoke Forecast System to calculate plume rise and to estimate particulate matter emissions. Many of the findings in the Initial Attack and Extended Attack sections regarding fire detection algorithm improvements are also directly applicable to smoke.

Recommendation 28: The NWCG should collaborate with partner agencies, UW-CIMMS, and other stakeholders to improve satellite wildland fire detection algorithms that are needed to support enhanced smoke and air quality capabilities such as:

- ***Smoke prediction modeling***
- ***Plume rise calculations***
- ***Time profiles***
- ***Fire/particulate matter emission calculations***

Note: Often, remotely sensed based estimation methods are derived from global analyses that can mask the natural fuel heterogeneity. These calculations should be checked with local information from the Forest Land Managers or Fire Behavior Analyst and/or compared with ground-based emission estimates.

Examples of current fire detection systems (left) incorporated into smoke modeling such as HRRR-Smoke and BlueSky (right).

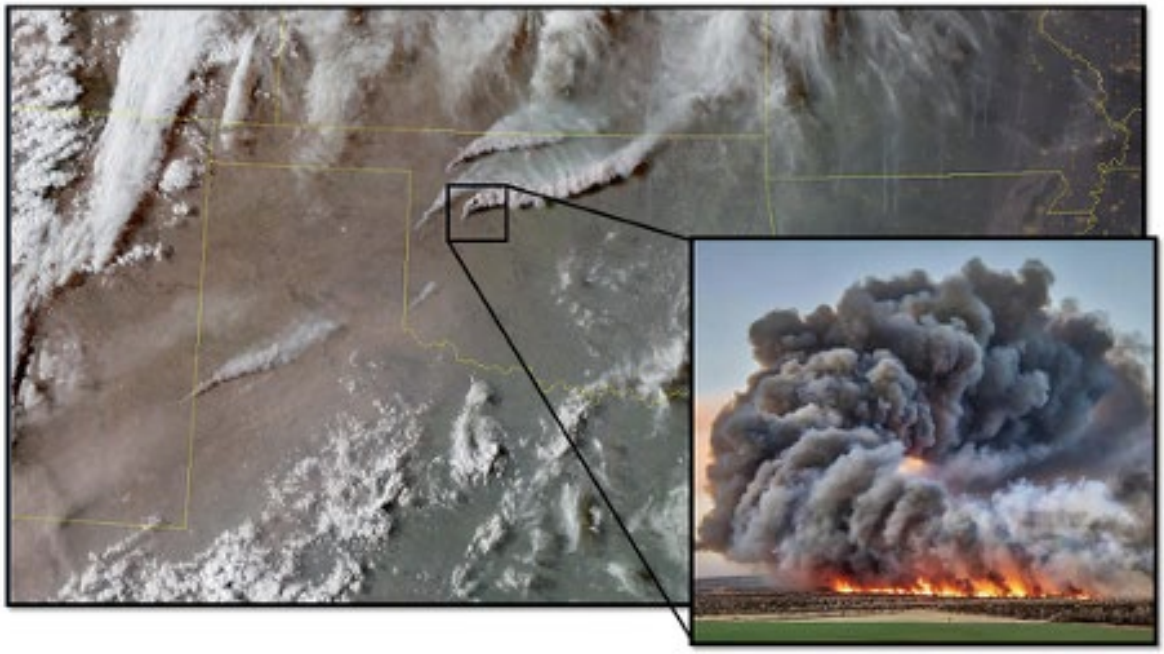
Finding 29: One of the most publicized advantages of the improved spatial, spectral, and temporal resolution of modern satellite technology has been the visualization of wildfire smoke. Visible and

composite visible-proxy (e.g., CIRA GeoColor) depictions of smoke are useful for public communication and messaging.

Recommendation 29: The NWCG should encourage partner agencies, stakeholders, and the research community to investigate science-based operational use of visible and composite visible-proxy depictions of smoke for decision support for remote-sensing interrogation of plume structure and area. For example, geo-rectified satellite-derived digitized smoke contours, depicting horizontal and vertical plume structures such as seen in the Rhea Fire (below), for assimilation in air quality models.

Finding 30: Internet access at IMT Incident Command Posts (ICPs) can be inconsistent, which can impact the latency of available satellite data in operations. Web-based resources such as the Cooperative Institute for Research in the Atmosphere (CIRA) SLIDER and NOAA AerosolWatch provide high-resolution visible satellite imagery that require a high bandwidth internet connection in order to display in a timely fashion.

Recommendation 30: Improved bandwidth is required for the stable use of satellite data in the operational ICP environment. This is a fundamental requirement needed to support all phases of wildland fire response but is particularly important when using satellite imagery products for smoke. The NWCG needs to ensure that sufficient bandwidth is available for all phases of wildland fire response.



GOES-16 GeoColor imagery of the Rhea Fire (Oklahoma) on 12 April 2018. Note the veering structure seen in the smoke column depicted by the satellite imagery compared to the same structure captured in ground-based photographs (inset photo credit: Matt Haney).

Finding 31: There is a strong need for smoke dispersion information to support local governments in the issuance of air quality/health alerts. These alerts are used to provide public and private entities information regarding the timing of smoke and air quality threats.

The Office of Wildland Fire GIS frequently responds to these requests, which are based on surface-based visibility observations. For example, a national hotel chain requested information on smoke dispersion data during the 2018 Camp Fire in California.

Recommendation 31: The NWCG should collaborate with the Interagency Wildland Fire Air Quality Response Program (IWFAQRP) to coordinate messaging of wildland fire smoke impacts. The IWFAQRP was created in 2011 and formally established by the 2019 Conservation, Management and Recreation Act (Senate Bill 47).

The IWFAQRP provides smoke messaging, monitoring and modeling tools and capabilities in response to smoke impacts from wildland fire. As part of the IWFAQRP, Air Resource Advisors (ARAs) are deployed with IMTs and/or GACCs to provide smoke forecasting expertise. Daily Smoke Outlooks are written and posted through the IMT Public Information Officer (PIO) trap lines, public bulletin boards, online smoke blogs, and sent to the local/regional air quality and health agencies. The ARAs also participate in public briefings and on daily regional smoke coordination conference calls. They use local knowledge of fuels and fire, measured observations of particulate matter, smoke prediction models, and satellite data to create smoke forecasts (e.g. Smoke Outlooks). They often work with the local community; people struggling to make business and public health decisions such as cancelling sporting events etc.

Finding 32: The Task Team supports Finding 4 from the NOAA/NWS Camp Fire Service Assessment which states: "There are inconsistencies within the NWS regarding what smoke transport guidance to use when providing IDSS".

Recommendation 32: The NWCG should collaborate with the NWS and IWFAQRP to determine the best smoke transport guidance for the NWS to use when providing impact-based decision support services.

Finding 33: Satellite products such as aerosol optical depth (AOD), visible or GeoColor images, aerosol index, and trace gases provide observations about the total atmospheric column or what the satellite sees from the viewpoint of the top of the atmosphere. This does not necessarily reflect smoke and air quality threats at the surface.

For example, the figure below illustrates the visible smoke plume from the Camp Fire at approximately 1300 local time. The circles are particulate matter measurement monitors. A green circle indicates a clean atmosphere at the surface and a red circle indicates an unhealthy atmosphere. Some monitors are measuring green/good conditions under the thickest smoke plume that indicate the smoke is aloft and not mixed to the surface.

Information about smoke in mid to upper levels of the atmosphere is important for both long-range transport issues and aviation needs in terms of both fire-fighting and commercial/private aviation. For example, in Alaska, Air Resource Advisors are often asked to provide upper-level smoke forecasts where air traffic typically fly. This is especially critical in rural Alaska where the only means in or out of some towns is by small aircraft.

The upcoming launch of the NASA Tropospheric Emissions: Monitoring of Pollution (TEMPO) geostationary mission will provide satellite measurements of lower tropospheric (0–2 km altitude), free tropospheric, and stratospheric ozone at resolutions between 2-4 km^2.

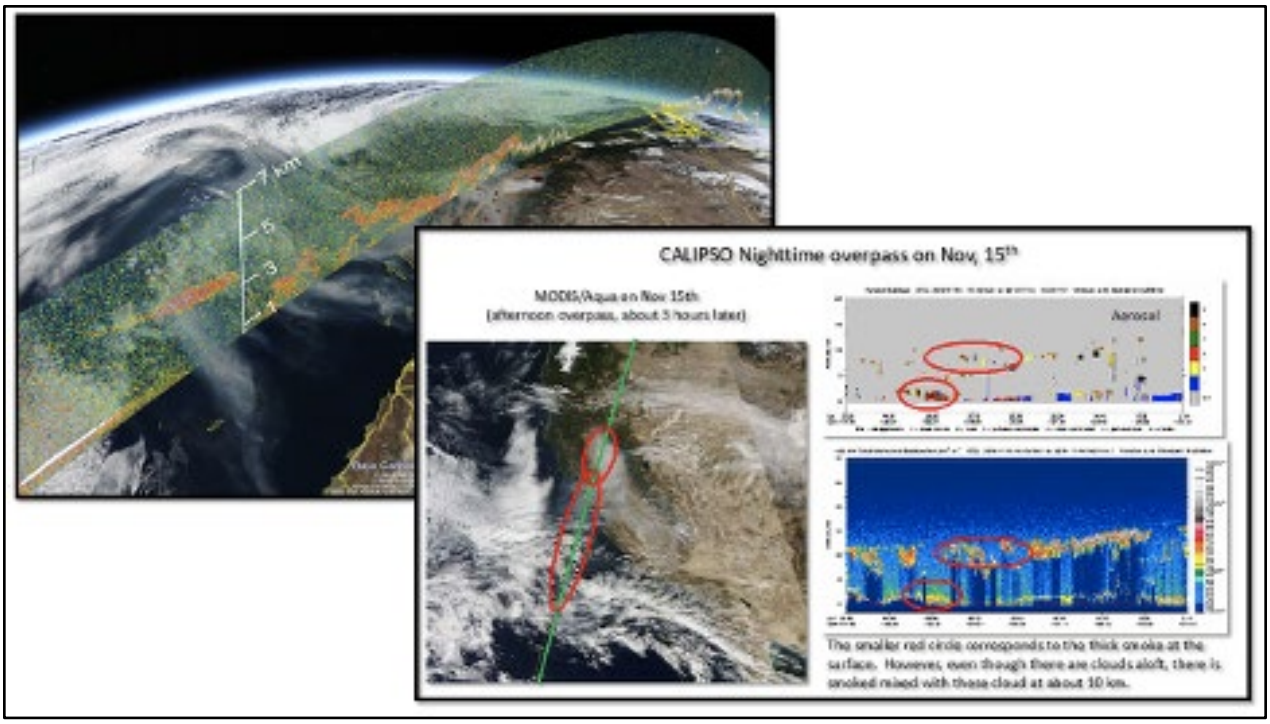
Recommendation 33: The NWCG needs to support the development of satellite missions and products that provide information about the vertical structure of smoke and aerosols.

Visible satellite imagery from GOES-16 at 1300 local time. Circles are 1-hr average particulate matter concentrations from the U.S. Environmental Protection Agency (EPA) AirNowTech system. Source: National Oceanic and Atmospheric Administration (NOAA) Aerosol Watch.

Finding 34: There is a lack of vertical smoke plume cross-section information for the wildland fire community. The vertical distribution of wildland fire emissions determines the transport paths smoke will take. Therefore, remote sensing and knowledge about the vertical distribution of smoke is vital for decision support services and data assimilation for smoke and air quality forecasts.

Current access to vertical plume cross-sections is only available via data from the joint NASA (U.S.) and CNES (France) operated Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite. The Laser Imaging Detection And Ranging (LIDAR) instrument data onboard CALIPSO is extremely limited due to a very narrow scanning window and effective overpass frequency of approximately once every 16 days.

Recommendation 34: The NWCG needs to advocate for the inclusion of LIDARs, and/or the development of other technologies capable of direct sampling or derivation of smoke height, onboard future spacecraft.



Example CALIPSO overpass data on vertical distribution of smoke associated with the November 2018 Camp Fire (California) shown relative to MODIS/Aqua visible imagery.

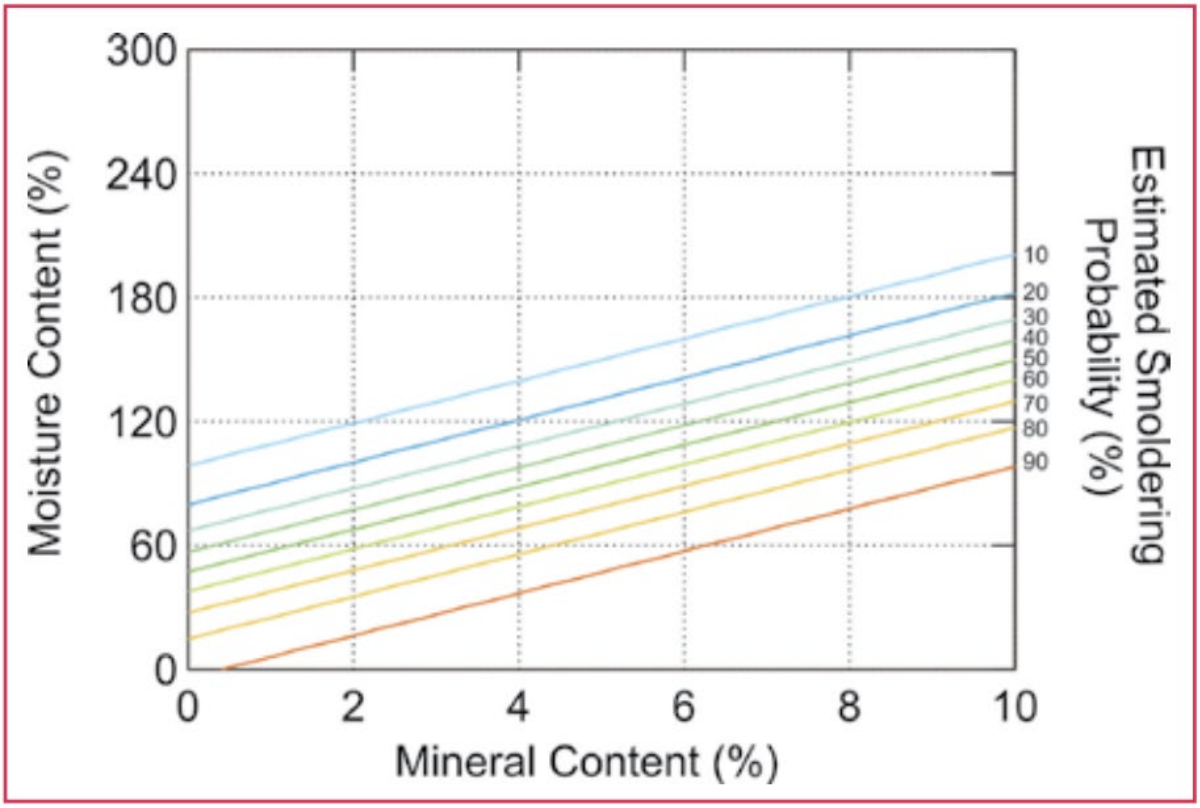
Finding 35: Wildland fires emit hundreds of trace gas and aerosol species and the complex chemistry within smoke plumes is poorly understood. This has implications for human health in terms of, for example, secondary processes producing ozone and additional particulate matter.

The Measurements of Pollution in The Troposphere (MOPITT) instrument onboard the Terra satellite and the Ozone Monitoring Instrument (OMI) aboard the Aura satellite provide information about species such as Ozone, CO, and nitrogen dioxide (NO2), however the resolution is coarse. The recent availability of high resolution (1-km) CO and NO2 from the TROPOspheric Monitoring Instrument (TROPOMI) instrument aboard the European Sentinel 5P satellite is new technology that is promising.

Recommendation 35: The NWCG should collaborate with agencies such as NOAA, NASA, and other partners to support the operational use of the current TROPOMI and upcoming TEMPO products.

Finding 36: Soil moisture is an important parameter in determining when ground fuel (e.g. duff, peat, organic soils) ignite, sustain smoldering combustion, and significantly contribute to particulate emissions. When ground fuels smolder they emit large quantities of smoke and can burn for many months. The figure below is an example of several feet of duff that burned in the 2008 Evans Road Wildfire in North Carolina and probable use of existing science.

Important Service Gap: The current state of ground fuel science is limited because of the lack of available remotely sensed ground monitoring stations and soil moisture data at large spatial scales over extended time periods. The NASA Soil Moisture Active Passive (SMAP) satellite was designed to provide mapped high-resolution soil freeze/thaw data and soil moisture of the top 3 feet (1 meter) of soil, every three days in 1000 km swaths, by combining measurements from instruments with resolutions of 1-10 km. However, instrument failures after launch terminated this project.



The estimated smoldering probability in root mat soils as a function of soil moisture and soil mineral content (U.S. Fish & Wildlife Service 2020).

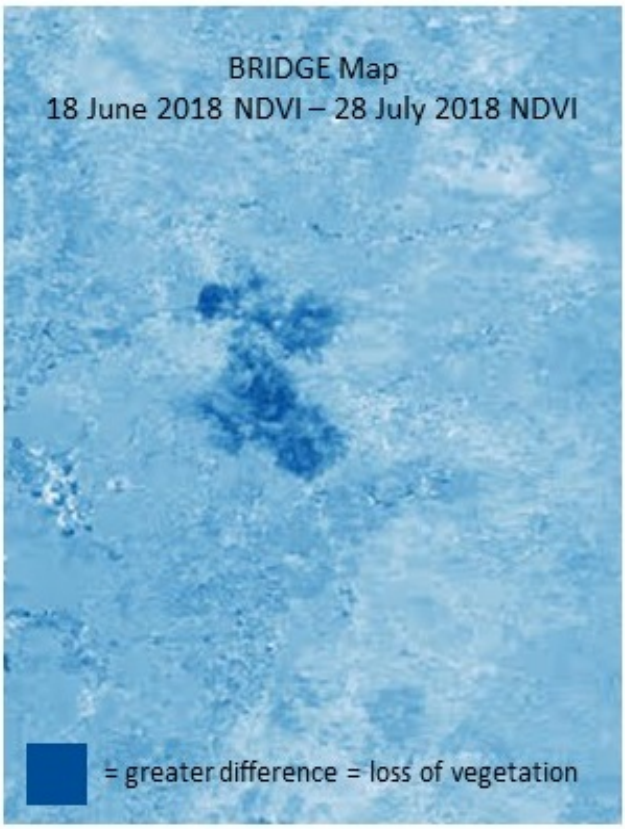
Stilted trees resulting from fire burning deep into the peat soils of the Pocosin Lakes National Wildlife Refuge remain as a visible reminder of the Evans Road Fire (U.S. Fish & Wildlife Service 2020).

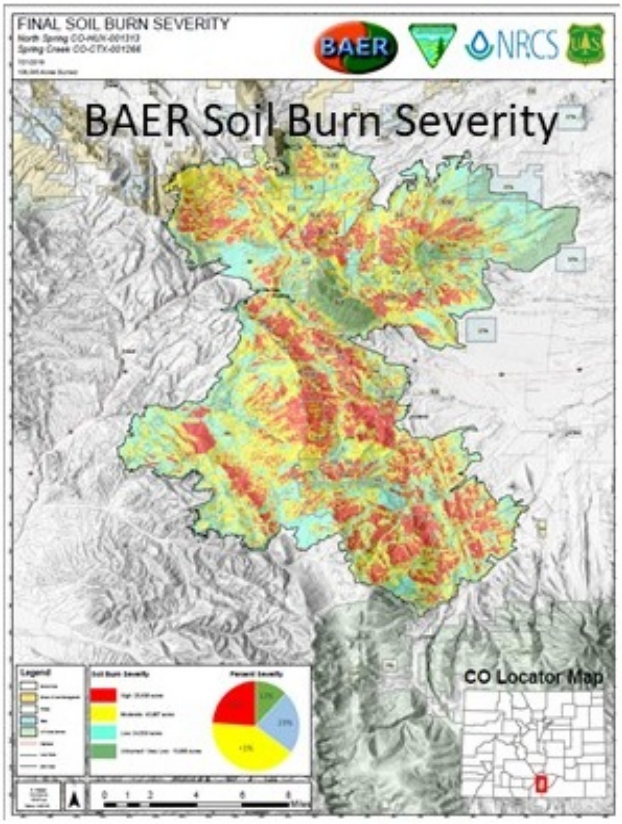
Recommendation 36: The NWCG needs to support and promote the development of satellite instruments and products that can provide the necessary information about soil moisture for ground fuels. This will allow shortcomings on ground fuel fires to be addressed as well as support surface fuel prescribed fire opportunities when ground fuel is present. Work on soil moisture benefits many programs that include fire weather, prescribed fire, wildfire, smoke management, and emission inventory.

2.5 Recovery

Numerous applications for satellite-based data exist in the post-fire recovery phase of wildland fire incidents. For example, satellite-based information may be useful to monitor the post-fire landscape before Burned Area Emergency Response (BAER) Teams can provide a detailed assessment of the burn scar. Satellite technology can also be applied to hotspot monitoring for residual burning and damage assessment efforts in the latter stages of incident management for impactful wildland fires prior to demobilization. Furthermore, assimilating satellite data with other emerging terrestrial datasets can enhance prediction of subsequent hydrologic episodes such as flash floods, mudslides, and debris flows. The Task Team's findings and recommendations for the provision of satellite-based recovery information follows.

Finding 37: The JPSS Burn Intensity Delta Greenness Estimate (BRIDGE) mapping tool for burn scar identification uses pre- and post-fire differenced VIIRS imagery to quantify changes to vegetation. The BRIDGE mapping product provides remotely sensed burn severity proxy data and is available almost immediately post-fire pending the next available unobstructed JPSS overpass (Batzli et al. 2018). Burn scar identification is important for monitoring flash flooding, mudslides, and debris flows.





Comparison of JPSS BRIDGE map produced via pre- and post-burn Normalized Difference Vegetation Index (NDVI) with BAER team assessment for the 2018 Spring Fire in Colorado (Line 2019).

Recommendation 37: The NWCG should coordinate with partnering agencies and stakeholders to streamline and ensure timely automated delivery of NWS/end-user BRIDGE mapping that would support improved burn scar recognition and supplement BAER surveys in the aftermath of damaging wildland fires (U.S. Forest Service, cited 2020).

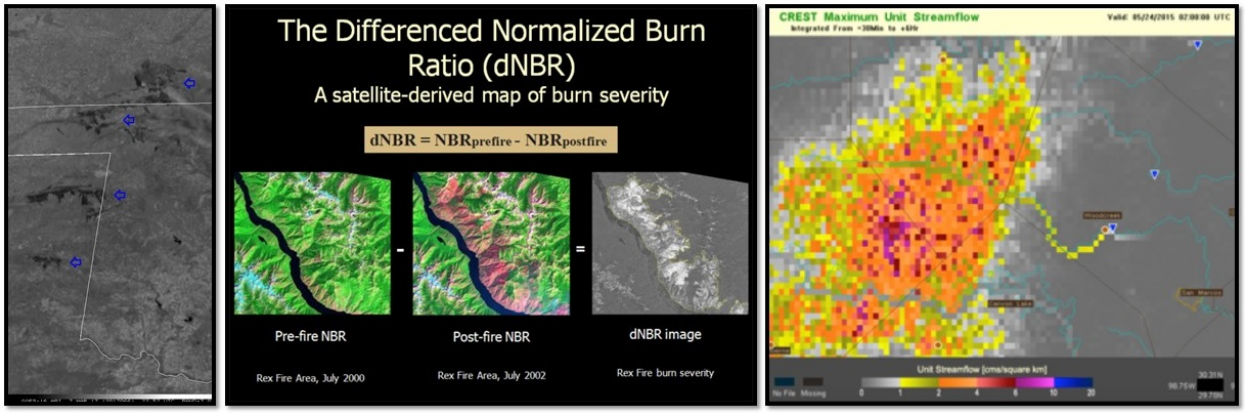
Finding 38: High spatial-resolution data from low-earth polar orbiting satellites, such as from JPSS's NOAA-20, are useful for post-fire surveillance of remnant interior hotspots and fire perimeter scouting to ensure containment.

Important Service Gap: Currently, polar satellite data useful for post-fire surveillance by incident management teams is not provided in the correct format for the NWS's decision-support platform (i.e., AWIPS).

Recommendation 38: The NWCG should coordinate with partnering agencies to ensure that raw polar orbiting satellite data is processed, packaged, and appropriately formatted for operational use by incident management teams.

Finding 39: Spaceborne surveillance of post-wildfire rehabilitation is needed up to, and potentially exceeding, one year following damaging wildland fire events. Post-fire recovery of vegetation cover and other landscape characteristics should be monitored for changes that would affect flash flooding, debris flows, and mudslides.

Recommendation 39: The NWCG should coordinate with partnering agencies and stakeholders to establish operating plans for post-fire surveillance of burn area recovery that leverage both existing and emerging satellite-based technology such as the NASA SPORT vegetation index, Landsat Differenced Normalized Burn Ratio (dNBR), and GOES ABI 0.86 μm (veggie band, channel 3).



Examples of GOES-16 ABI Veggie Band (0.86 μm) imagery of burn scars over Kansas, Oklahoma, and Texas in March 2017 (left), Landsat dNBR (middle), and FLASH (right). Assimilation of these capabilities has the potential to provide an improved provision of warnings for dangerous post-fire hydrologic.

Finding 40: There are existing and emerging combinations of satellite and terrestrial- based remote sensing networks that can be assimilated into hydrologic models to improve warning processes for wildland fire flash floods, mudslides, and debris flows.

Recommendation 40: The NWCG should coordinate with partner agencies, stakeholders, and the research community to support the assimilation of satellite-based post-fire surveillance data with

hydrologic models that are based on ground-based radar networks, such as Flooded Locations And Simulated Hydrographs (FLASH, Gourley et al. 2017).

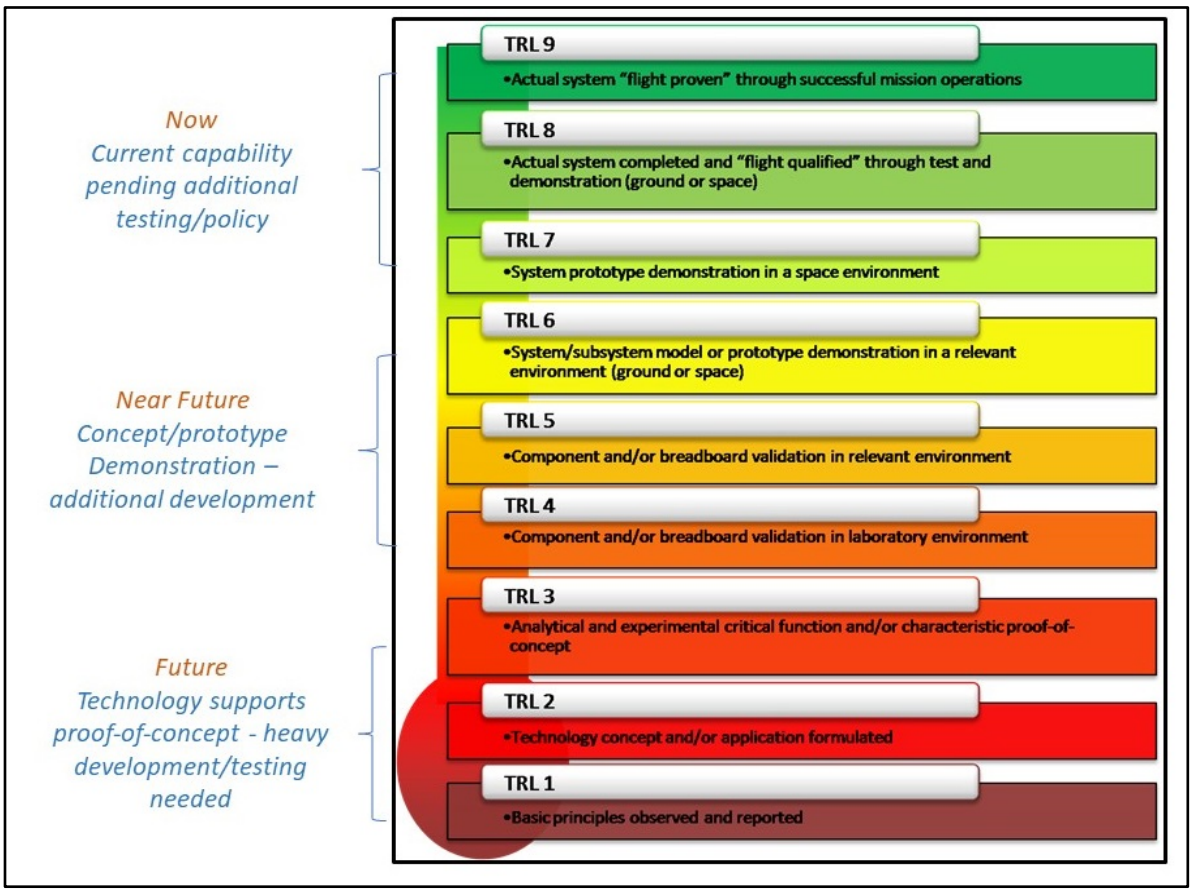
3. Summary of Key Task Team Recommendations

Summary of Key Task Team Recommendations
Section 2.1: Preparedness
● Support and promote the development of operationally relevant training on the use of satellite-based technologies in wildland fire services - Recommendation 1.
● Emphasize to policy makers the criticality of real-time satellite-based detection and monitoring of wildland fire in the mitigation of high-end public impacts and first responder safety - Recommendation 2.
● Coordinate guidance for reportable thresholds and criteria for satellite-detected wildland fire based upon fire environments supportive of extreme fire behavior - Recommendation 3.
● Ensure that partner agencies adopt policy and infrastructure to support the use of satellite-based fire detection and monitoring when it is needed most, including operating plans for GOES-16/17 MDS - Recommendation 4.
Section 2.2: Support of Initial Attack
● Coordinate partner agency roles and responsibilities for the issuance of accurate and timely notifications of newly ignited wildland fire in environments supportive of extreme fire behavior - Recommendation 5 and 8a.
● Establish operating plans for the issuance of hotspot notifications that provide the earliest possible notification of potentially problematic fire while reducing false alarms by implementing fire environment (weather and fuels) issuance criteria with discretion for complex incident management situations - Recommendations 8b-e.
● Support efforts to scientifically corroborate satellite-based remote sensing signals of wildland fire to wildland fire structure and behavioral characteristics - Recommendation 9.
● Advocate for regular and frequent issuances of aggregate satellite-based fire detection summary products - Recommendation 10.
● Support development of improved satellite fire detection algorithms and derived products on high-resolution data - Recommendation 11.
● Implement derived fire products on GOES-16/17 MDS (1-minute) data - Recommendation 13.
● Investigate the possibility of using GLM to identify lightning strikes that pose a high risk of wildland fire ignition - Recommendation 14.
● Satellite-based fire detections should be assimilated by coupled atmosphere-fire behavior models - Recommendation 15.
● Establish a whole community warning paradigm that leverages satellite-based remote sensing coupled with knowledge of the fire environment, possibly informed by coupled model predicted fire spread, as proposed by DHS/USFA/FEMA - Recommendations 16-18.
Section 2.3: Support of Extended Attack
● Develop guidance and operating plans for issuance of notifications for satellite-detected changes in

burn character or fire environment in tactical support of incident management - Recommendation 19.
● Develop guidance and operating plans for regular issuance of Fire Intelligence Matrices (or graphical products) that communicate remotely sensed fire behavior characteristics using high-resolution polar-orbiters - Recommendation 20a.
● Support scientific efforts to improve FDCA derived output and relate to monitoring the effectiveness of suppression, predicting pyrocumulonimbus development and other predictive signals for extreme fire behavior, and cataloging fire activity - Recommendations 21, 22, 23, 24a-b, and 25a-b.
Section 2.4: Smoke Dispersion/Air Quality
● Information from an assimilated real-time satellite-based fire detection and notification system should be adapted/extended such that smoke/air quality prediction systems can initiate model runs - Recommendation 27.
● Collaborate with partner agencies to improve satellite wildland fire detection algorithms that are needed to support enhanced smoke and air quality capabilities such as: smoke prediction modeling, plume rise calculations, time profiles, fire/particulate matter emission calculations – Recommendation 28.
● Collaborate with the Interagency Wildland Fire Air Quality Response Program (IWFAQRP) to coordinate messaging of wildland fire smoke impacts – Recommendations 31, 32.
● Support the development of satellite missions and products that provide information about the vertical structure of smoke plumes and information about trace gas and aerosols at multiple levels in the atmosphere – Recommendations 33, 34, 35.
● Support the development of satellite instruments and products that can provide information about soil moisture for ground fuels – Recommendation 36.
Section 2.5: Recovery
● Investigate use of JPSS VIIRS BRIDGE as rapid remote sensing proxy for burn severity mapping - Recommendation 37.
● Ensure availability of appropriately processed, packaged, and formatted polar orbiting satellite data for use by IMTs - Recommendation 38.
● Implement post-fire satellite surveillance of burn area recovery at various timescales ranging from 1 month to 3 years (or as needed) to monitor rehabilitation and flood, mud/landslide risks - Recommendation 39.
● Assimilate satellite-based measures of burn area post-fire surveillance with terrestrial radar network-based hydrologic models to implement improved flash flood, mud/landslide warnings - Recommendation 40.

Evaluating the operational readiness for all of the satellite-based capabilities discussed in this document, some of which are outside of the Task Team's areas of expertise, is beyond the scope of this report. However, the Task Team provided estimated Technology Readiness Levels (TRL; NASA 2007) as an overview assessment of the general operationality for capabilities within the five presented categories. The Task Team determined that capabilities described in the Preparedness and Support of Initial Attack categories (Sections 2.1 and 2.2) are generally current capabilities that could be implemented now pending additional testing and/or policy development. Satellite-based capabilities discussed in the Support of Extended Attack and Recovery categories (Sections 2.3 and 2.5) require additional conceptual development and prototyping but could be implemented in the near-future with proper collaboration and prioritization by the NWCG partnering agencies, stakeholders, and the research community. Notable

development needed in these categories include improved science relating remotely sensed signals of extreme fire behavior for use by machine learning (Recommendation 24a-b) for predictive algorithms and assimilation of existing combined terrestrial and space-based observing platforms to evaluate burn severity, rehabilitation, and hydrologic risks (Recommendations 39-40). Satellite capabilities that support the needs of the wildland fire community for smoke dispersion and air quality services (Section 2.4) are likely to require significant support, future development, testing, and proof-of-concepts for new technological deployments. These capabilities, likely to be realized in the future, may require significant upgrades to infrastructure (Recommendations 30) and the deployment of new satellite-base technologies (Recommendation 34). Even in this category of capabilities, the Task Team identified several individual commonsensical recommendations that if implemented, would immediately improve decision support services for smoke and air quality (Recommendation 31).



Generalized operational TRL Readiness Levels for capability categories.

The NWCG Satellite Data Task Team's Assessment by Capability Category:

2.1 Preparedness - ***Now***

2.2 Support of Initial Attack - ***Now***

2.3 Support of Extended Attack - ***Near Future***

2.4 Support of Smoke Dispersion Air Quality - ***Future***

2.5 Recovery - ***Near Future***

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