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Fire Weather Testbed Evaluations #002–004: An End-to-End Evaluation of NOAA's Emerging Wildland Fire Detection and Warning Capabilities

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / Office of Oceanic and Atmospheric Research

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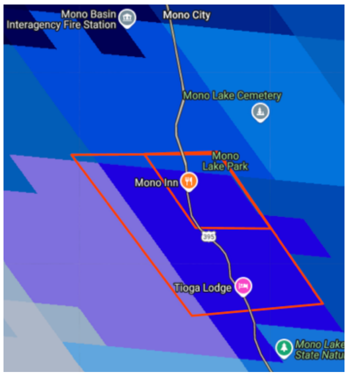


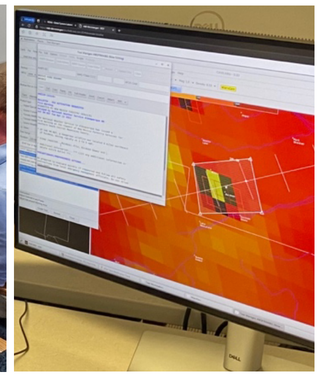

#002 Fire Detection and Dissemination: NESDIS Next Generation Fire System and NWS Hotspot Notification Tool

#003 Interagency Collaboration: Tactical Integrated Warning Team (IWT) for Wildland Fire Operations

#004 Fire Warnings: Tactical IWT Fire Warnings

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Executive Summary

BACKGROUND

Wildland fires are increasingly impacting communities with devastating outcomes. In the past decade, rapidly spreading wildfires have threatened communities with little to no warning, resulting in significant loss of life and destruction of property. Following the devastating 2018 Camp Fire in northern California, where 85 people lost their lives, the National Weather Service (NWS) in Norman, Oklahoma, pioneered a collaborative and innovative approach to interagency wildland fire response. They developed a new paradigm to collaboratively issue fire warnings between the NWS and their land management partners during conditions favorable for the rapid spread of wildland fires into populated areas.

From June 10-14th, 2024, the National Oceanic and Atmospheric Administration's (NOAA) newly established Fire Weather Testbed (FWT) conducted its first in-person evaluation of this collaborative approach as well as NOAA's emerging wildland fire detection and warning capabilities, specifically:

1) NESDIS Next Generation Fire System (NGFS) and NWS Hotspot Notification Tool (HSNT): The NGFS is a new satellite-based artificial intelligence (AI) algorithm utilizing geostationary and low Earth-orbiting NOAA Satellites to detect and monitor wildland fires, including a tool that highlights potential new wildfires. The NGFS is being developed in partnership between National Environmental Satellite, Data, and Information Service (NESDIS), the University of Wisconsin Space Science, and Engineering Center's (SSEC) Cooperative Institute for Meteorological Satellite Studies (CIMSS). While the prototype version of the NGFS was deployed in 2021, the system evolved significantly in the 2022–2024 timeframe. The HSNT, developed by NWS Norman, Oklahoma, is used to disseminate the geographic location of fire detections and weather forecasts from NWS Meteorologists to their land management partners via text messages or email notifications.

2) Tactical Integrated Warning Team (IWT) for Fire Operations: The NWS "Integrated Warning Teams" concept has been used for nearly two decades to improve communication and hazard warning messaging between NWS Meteorologists and core decision makers (state and local emergency managers and government officials). Lindley et al. (2024) adapted the IWT approach to specifically address rapidly growing wildland fire threats in the Southern Great Plains. This innovative approach, referred to here as the Tactical IWT for fire operations, adapts the IWT concept of multidisciplinary information exchange among multiple agencies with a shared mission to protect life and property. It enhances collaboration and communication by incorporating more tactical and fully integrated channels essential for understanding and predicting the evolution of wildland fire threats in real-time.

During the 2024 FWT evaluation, the Tactical IWT described in Lindley et al. (2024) was further adapted to highlight the new capabilities for fire detection, dissemination, and collaborative discussion with partners presented by the NGFS, HSNT, and the Tactical IWT workflow.

3) Fire Warnings Issued through the Tactical Integrated Warning Team Paradigm: Fire Warnings are officially issued by land or emergency management partners through the NWS alerting system. In the new paradigm evaluated in the FWT, land managers and meteorologists share information through the Tactical IWT process to quickly assess, request, and issue Fire Warnings to the public when fires threaten lives and property.

The Tactical IWT Fire Warning model, aligned with the NWS's "science first responder" vision (NOAA, 2023a), involves meteorologists and fire analysts assessing antecedent and current environmental conditions and remote sensing data to deliver early warnings through an interdisciplinary and collaborative approach.

EVALUATION OVERVIEW

The FWT invited NWS fire weather meteorologists and their high-level state land management partners from California, Kansas, North Carolina, and Florida to understand if and how these emerging technologies, products, and services could be implemented outside of the Southern Great Plains. Throughout the evaluation, pairs of meteorologists and fire managers were grouped by state to form four Tactical IWTs, representing regions with varying firefighting capabilities, fire ecologies, and population distributions.

These mock Tactical IWTs engaged in seven displaced real-time simulations of recent fire outbreaks. Each simulated IWT received new fire starts detected by the NGFS and sent through the HSNT. If and when the land managers decided to issue a Fire Warning, the meteorologist drew a polygon covering the area of Fire Warning issuance and issued the warning.

Data was gathered from participants via pre- and post-evaluation surveys and end-of-day roundtable discussions. At the end of the week, the FWT evaluators facilitated two private focus group discussions with participants–one for meteorologists and one for land managers–that were recorded, transcribed, and analyzed by the FWT. Findings from this evaluation are data-driven, while recommendations are both data-driven and informed/contextualized by FWT expertise.

FINDINGS & RECOMMENDATIONS

Overarching Evaluation Finding (NGFS, HSNT, IWT, and Fire Warnings) The Next Generation Fire System, Tactical Integrated Warning Team for Wildland Fire Operations, and IWT-derived Fire Warnings may be uniquely adapted to address local needs and resource capacities across regions. Throughout the FWT evaluation, the individual products demonstrated their potential to address information and communication gaps while also functioning effectively as an integrated system.

NESDIS Next Generation Fire System and NWS Hotspot Notification Tool

Finding: The publicly accessible NGFS provides utility as a tool for fire detection and monitoring. It enhances situational awareness and serves as a safety net for forecasters. By incorporating NGFS detections, the HSNT adds capabilities for the NWS to alert partner agencies. The NGFS and HSNT should integrate effectively into NWS operational environments.

Recommendations

- Integrate the NGFS into the NWS computer system (AWIPS) with user-customizable display capabilities to ensure smooth adoption into NWS operations. Expanding data access will also support integration into additional tools and common operating platforms.
- Develop training materials and documentation that explain the NGFS process, including how it detects fires, integrates known wildland fire information, and incorporates uncertainty to support validation with other sources.
- Add a mechanism for partner agencies to confirm receipt of NWS-provided hotspot notification(s) and ensure multiple communication pathways are available for agency partners to use as needed.

Tactical Integrated Warning Team (IWT) for Wildland Fire Operations

Finding: Participants believed the Tactical IWT approach to fire operations, both before and during wildland fire incidents, has the potential to improve communication, coordination, and situational awareness among meteorologists, land managers, and other fire/emergency response partners, thus enabling unified public messaging and coordinated response to wildland fire threats. Concerns from both groups centered around the challenges of building, implementing, and maintaining an IWT.

Recommendations

- Develop an NWS framework for implementing Tactical IWTs for Wildland Fire Operations in new service areas, modeled from the Southern Great Plains “Tactical IWT model” as an initial framework while ensuring scalability to meet varying regional needs.
- To implement the Tactical IWT, ensure consistent and ongoing local training with coordination between fire partners in consideration of local jurisdictions and partner bandwidth.

Tactical IWT-based Fire Warnings

Finding: Fire Warnings were perceived to be a valuable wildland fire alerting tool capable of relaying critical information from the NWS and land managers to other emergency management partners and the public when wildland fire poses an imminent threat to life and property. However, both land managers and NWS participants' concerns centered around determining warning authority and the potential public confusion with other products or directives (e.g., evacuation warnings and orders).

Recommendations:

- Explore transforming Fire Warnings from a "non-weather emergency" product into a standalone warning product with Wireless Emergency Alert (WEA) dissemination capability to more effectively communicate wildland fire hazard information to the public.
- Implement comprehensive Fire Warning training for the NWS personnel, land management agencies, emergency management agencies, and curate public education campaigns to increase effective Fire Warning implementation and response.
- Work with end-users to improve the Fire Warning product by exploring additional technological capabilities (e.g. Integrating in the NWS warning software (Hazard Services), incorporating fire spread modeling, and producing the capability to share polygons with external partners prior to issuance).
- Include explicit wording in Fire Warning products that highlights their co-creation and joint issuance by land managers and the NWS, emphasizing the collaborative effort involved so as to enhance public trust.
- Build Tactical IWTs to align with local and regional needs and resources, and clearly defining delegation authority, are crucial steps in issuing IWT-based Fire Warning.

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List of Acronyms

Advanced Weather Interactive Processing System (AWIPS)
Annual Operating Plan (AOP)
AWIPS Test Authorization Note (ATAN)
Bipartisan Infrastructure Law (BIL)
Continental United States (CONUS)
County Warning Area (CWA)
Energy Release Component (ERC)
Emergency Alert System (EAS)
Federal Emergency Management Agency (FEMA)
Fire Radiative Power (FRP)
Fire Weather Testbed (FWT)
Geostationary Operational Environment Satellites (GOES-R)
Global Systems Laboratory (GSL)
High Resolution Ensemble Forecast (HREF)
Hot Spot Notification Tool (HSNT)
Impact-Based Decision Support Services (IDSS)
Integrated Public Alert & Warning System (IPAWS)
Information Technology Officer (ITO)
Integrated Warning Team (IWT)
Land Manager (LM)
Moderate Resolution Imaging Spectroradiometer (MODIS)
National Environmental Satellite, Data, and Information Services (NESDIS)
National Digital Forecast Database (NDFD)
National Oceanic and Atmospheric Administration (NOAA)
National Severe Storms Laboratory (NSSL)
National Weather Service (NWS)
Next Generation Fire System (NGFS)
Non-Weather Emergency Messages (NWEMs)
Oklahoma Forestry Services (OFS)
Operations to Research to Operations (O2R2O)
Principal Investigator (PI)
Social and Behavioral Sciences Branch (SBS Branch)
Southern Great Plains Wildfire Outbreak (SGPWO)
Office of Science and Technology Integration (OSTI)
Texas A&M Forest Service (TFS)
Visible Infrared Imaging Radiometer Suite (VIIRS)
Warn-on-Forecast System (WoFS)
Weather Event Simulator (WES)
Weather Forecast Office (WFO)

1. Introduction

1.1 Motivation

The National Weather Service (NWS), firefighting, and emergency management (EM) agencies share the common mission of protecting life and property during wildland fire events. However, responding to wildland fire threats is a challenge due to the complex interaction of factors that span multiple scientific disciplines, such as human behavior, weather conditions, terrain, and fuels. Effective wildfire response requires coordinated efforts across agencies and disciplines. Meteorologists can provide crucial weather observations and forecasts, and land managers share insights into fuel, terrain, and fire behavior. Despite continued efforts, few standardized protocols exist for rapid communication across disciplines and agencies during evolving fire events, which can limit the abilities of agency officials to ensure public and first responder safety.

To enhance wildfire response, the NWS is leveraging advanced technologies such as the National Ocean and Atmospheric Administration's (NOAA) Geostationary Operational Environment Satellites (GOES-R), which provides high temporal resolution (60 seconds to 5 minutes over the CONUS, depending on scan mode) fire detection capabilities. The GOES-R satellites enable meteorologists to track fire activity and fire-relevant environmental conditions (e.g., smoke, land surface and atmospheric temperatures) in near-real-time (Lindley et al., 2016). The integration of satellite technology with fire detection algorithms and platforms, such as the Next Generation Fire System (NGFS) provides emergency response teams with information to mobilize resources and additional time to issue alerts and warnings (Lindley et al., 2020). While these technological innovations hold promise, the operational use of these tools continues to evolve with opportunities to standardize implementation procedures and related communication strategies to support decision-making.

The increasing frequency and severity of wildfires in recent years, exemplified by major incidents such as the 2017 Wine Country Fires (44 fatalities), 2018 Camp Fire (85 fatalities), 2020 Western U.S. Fire Siege (31 fatalities), the 2023 Lahaina Fire (101 fatalities), and the 2025 Palisades and Eaton Fires (29 fatalities) underscore the urgency of addressing gaps in wildfire communication and decision support (National Interagency Fire Center [NIFC], 2023). In such events, firefighting resources are often still mobilizing to the incident as fire behavior escalates, which makes timely and accurate warnings even more critical. Interagency fragmentation can hinder the efficiency and effectiveness of coordination and response efforts, emphasizing the need for tools that support collaboration and streamline communication across different agencies and communities (Wildland Fire Mitigation and Management Commission, 2023).

In response, a prototype Tactical Integrated Warning Team (IWT) for fire weather emerged at the NWS Norman, Oklahoma Weather Forecast Office (WFO) that involves the collaboration of multiple jurisdictions and disciplines across the Southern Great Plains region, including

NWS meteorologists and state forestry agency firefighters (Figure 1.1 left). This approach integrates satellite-based fire detection with information about the fire environment, fire intensity, local population, and proximity to critical assets. The Tactical IWT approach assesses current and predicted fire behavior, providing near real-time interagency situational awareness and decision support. Integrated meteorological and land management perspectives allow for unified tactics, responses, and messaging, including Fire Warning issuance when necessary. Following the NWS Norman Office's successful demonstration of the end-to-end fire detection, notification, and warning workflow, the NWS is exploring the expansion of Tactical IWT's across WFOs to improve the ability to issue timely warnings and support responders during wildfires, ensuring public and responder safety.

To assess the utility of and implementation pathways for these wildland fire detection and response products and services in other NWS WFOs, the NOAA Fire Weather Testbed (FWT) designed and conducted a week-long, in-person evaluation with NWS meteorologists and state land management partners. Specifically, the FWT evaluated the following products and services:

- #002 Fire Detection and Dissemination: NESDIS Next Generation Fire System and NWS Hotspot Notification Tool
- #003 Interagency Fire Environment Collaboration: Tactical Integrated Warning Team for Wildland Fire Operations
- #004 Fire Warnings: Collaborative Tactical IWT-driven Fire Warnings

For these evaluations, the FWT designed a quasi real-world operational environment for product end-users to learn about, practice using, and provide feedback regarding the evaluated products and services. The FWT collected and analyzed data from participating end-users, including their perceptions of product strengths, limitations, considerations, and opportunities for improved wildfire response and decision-making support.

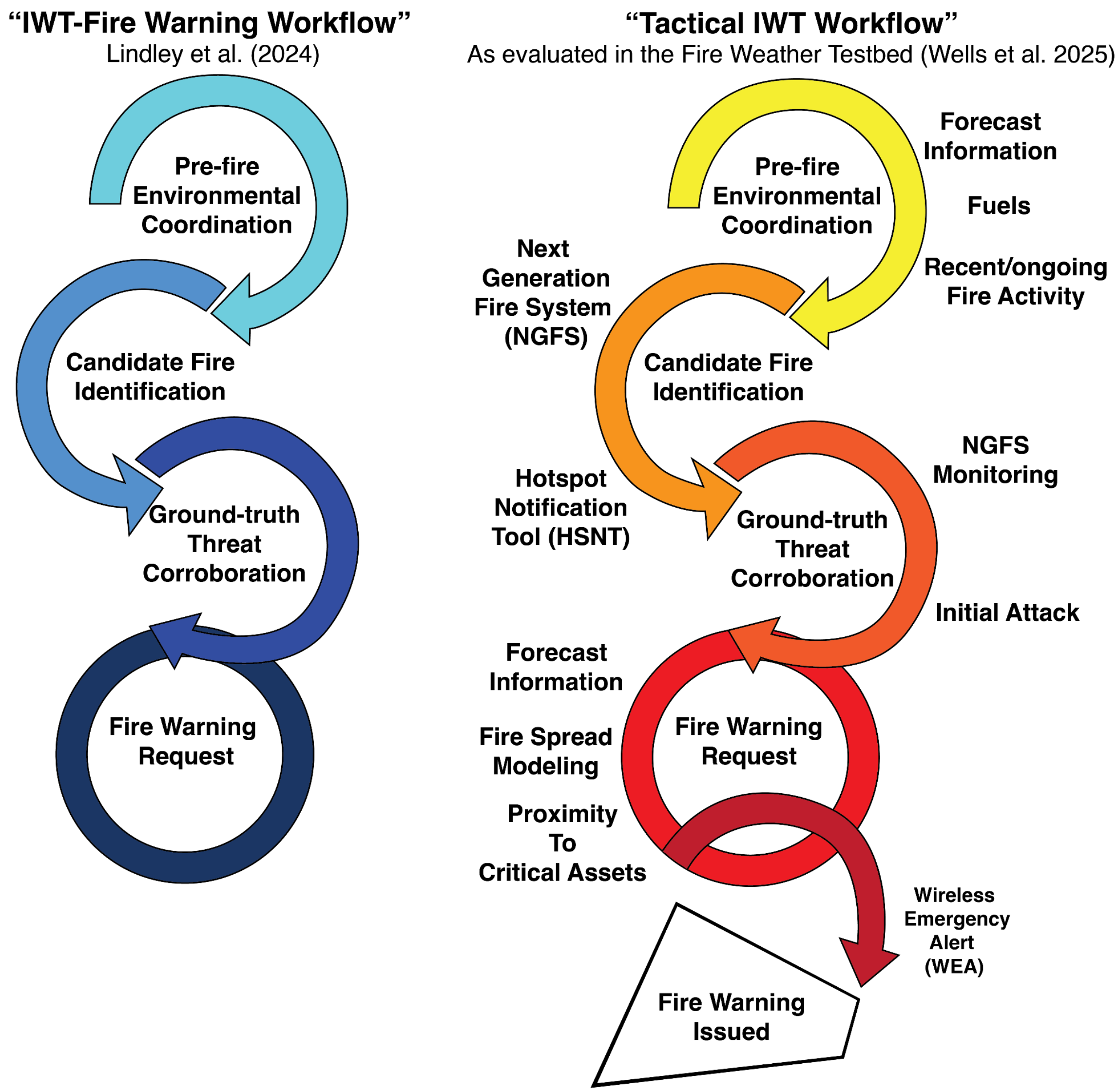


Figure 1.1: (left) Integrated Warning Team (IWT) for Fire Warnings process framework as developed by Lindley et al. (2024). (right) The adaptation of the Lindley et al. (2024) framework to a "Tactical IWT" workflow performed within the FWT's 2024 evaluations (Wells et al., 2025 and herein), showing specific information associated (i.e., discussed and/or evaluated) with each step in the process.

1.2 The Next Generation Fire System

The NGFS is a suite of artificial intelligence (AI) based algorithms and tools developed to detect and monitor wildland fires using satellite data. Designed to integrate seamlessly with a variety of satellites—including geostationary (GOES-R) and low-earth orbit platforms—NGFS emulates human expert analysis and is capable of detecting thermal anomalies indicative of fire ignition and spread, even in challenging weather conditions like cloud cover. To do so, the NGFS uses multispectral satellite measurements across visible, shortwave infrared, mid-wave infrared, and longwave infrared bands, combined with advanced spatial and temporal metrics (Pavolonis, 2025; Otkin et al., 2025). The system operates by combining satellite-based observations (1-5 minute temporal resolution and approximately 2 km spatial resolution) with other information including fire weather outlooks, current fire perimeters, fuel type information, and real-time meteorological data (Pavolonis, 20215; Otkin et al., 2025). In addition to near real-time detection, the NGFS is capable of monitoring wildland fire spread and intensity.

The NWS began experimentally utilizing the NGFS in 2023 to enhance situational awareness and support fire management partners. The NGFS mirrors the analytical process of human experts and is specifically designed to:

1. Provide satellite-derived information to reduce new fire incident response times
2. Enhance weather and fire monitoring in support of fire incident management
3. Enable improved fire emissions monitoring, smoke forecasts, and fire behavior/spread forecasts
4. Provide satellite-derived wildland fire analytics on a range of geographic and temporal scales
5. Simplify access to fire products and information

In preparation for the FWT evaluation, the NGFS was integrated into the Advanced Weather Interactive Processing System (AWIPS). AWIPS is used by NOAA/NWS meteorologists across the U.S. for processing, displaying, and communicating weather data to inform forecasts and issue weather warnings and advisories (Office of Central Processing, n.d.). Integrating the NGFS into AWIPS enabled evaluation participants to test it using displaced real-time simulations via the Warning Event Simulation (WES) software, critical for evaluating product functionality in an experimental setting.

1.3 Hot Spot Notification Tools

Rapid communication of fire location and intensity is crucial for ensuring an effective and timely wildfire response. While human reports of fire ignition (i.e., 911 calls) may precede satellite-based detection in more densely populated areas, satellite imagery may detect wildland fires earlier, particularly in more remote regions. The Information Technology Officer (ITO) at NWS Norman developed the Hot Spot Notification Tool (HSNT) to leverage NOAA satellite detections by alerting emergency responders of new wildland fire ignitions in real-time (Lindley et al., 2016).

The HSNT tool enables NWS meteorologists to issue targeted alerts to fire and emergency management partners via text message and/or email. The HSNT interface allows meteorologists to send the location of a fire, including information about its intensity and proximity to critical assets, along with essential weather forecast information in customizable alerts to core fire partners (e.g., fire agencies, land management agencies, and other emergency management agencies). By delivering timely and contextually-relevant notifications, the tool can facilitate situational awareness and emergency response, potentially reducing risks to life and property by increasing the time available to take protective actions and initiate fire suppression.

The integration of the HSNT with the NGFS offers promising opportunities to streamline communication between meteorologists and fire management partners. To fully understand its operational effectiveness, the FWT evaluation was designed to assess key aspects of the tool, including its performance in simulated fire events and the utility of the information provided for decision-making.

A second version of the HSNT, created by the NWS Central Region (CR), was designed as a stand-alone, web-based solution outside of the AWIPS framework. The evaluation plan included testing both tools to determine which version would be more effective for NWS operations. However, the CR HSNT could not be easily integrated into a displaced real-time simulation environment, making a direct comparison with the Norman version unfeasible. To address this limitation, the evaluation included a presentation and training session of the CR HSNT on the second day, providing participants with an overview of its capabilities. Ultimately, the Norman HSNT was the only version evaluated in simulated operational conditions.

1.4 Tactical Integrated Warning Teams (IWTs)

Within the "Weather-Ready Nation" initiative, the NWS emphasizes the importance of impact-based decision support services (IDSS) to improve preparedness and response to severe weather events, including wildfires (Hilderbrand, 2014; Uccellini & Ten Hoeve, 2019). Central to this initiative is the concept of Integrated Warning Teams (IWTs), which were originally designed to foster collaboration between NWS meteorologists, emergency management agencies, fire service personnel, and other partners. IWTs facilitate the exchange of information, enhance situational awareness, and ensure that decision-makers are equipped with the data needed to respond effectively to environmental threats. These collaborative interagency IWTs build the trust essential for effective warning partnership, enhance consistency, and improve dissemination of hazard messaging during critical incidents (Uccellini & Ten Hoeve, 2019).

Originally focused on severe weather, the IWT model has demonstrated its applicability and value in the context of wildland fire management. The IWT Fire Warning model, aligned with the NWS's "science first responder" vision (NWS, 2023a), involves meteorologists and fire analysts assessing environmental conditions and remote sensing data to deliver early warnings through an interdisciplinary approach. The IWT process seeks to minimize delays caused by decision-making uncertainty, expediting public awareness, to provide timely information to partners, and to encourage protective action such as evacuations (Mileti & Sorensen, 1990; Jauernic & Van Den Broeke, 2017; Lindley et al., 2024).

The multidisciplinary, multi-jurisdictional, and fast-moving nature of wildland fire involves tactical decisions that can be informed and supported by the IWT paradigm–herein referred to as the Tactical IWT for fire operations (Lindley et al., 2024; Wells et al., 2025). First implemented in the Southern Great Plains, the Tactical IWT for fire operations involves regular coordination and meetings between meteorologists and fire managers before and during wildland fire incidents to collaboratively assess fire risk, monitor ongoing fire activity, and when necessary, issue Fire Warnings (Fig. 1.1). Tactical IWT collaboration ensures that Fire Warnings are appropriately tailored to the specific needs of the region at risk.

Although the Tactical IWT approach has improved collaboration, situational awareness, and decision-making in the Southern Great Plains, understanding its full potential and broader applicability for wildfire response in other regions requires further study. Evaluation efforts should focus on assessing the Tactical IWT organizational structure, which and how fire weather products are integrated for decision support, and how interagency collaboration can enable more effective and efficient fire management (Lindley et al., 2024). Understanding how Tactical IWTs can optimize their roles in wildfire operations is a crucial step toward enhancing local, regional, state, and federal wildfire response capabilities.

1.5 Fire Warnings Issued through the Tactical IWT Paradigm

Rapidly spreading wildfires are increasingly common and have led to loss of life, especially for fires that become urban conflagrations. Fire Warnings are one mechanism to provide critical, time-sensitive information to the public when "...a spreading structural fire or wildfire… threatens a populated area. Evacuation of areas in the fire's path may be recommended by authorized officials according to state law or local ordinance" (NWS, 2021, pg. B-3).

Beginning in 2006, Fire Warnings were created and authorized as Non-Weather Emergency Messages (NWEMs) by federal, state, tribal, or local officials and disseminated through the NWS Emergency Alert System (EAS) to provide time-critical, life- or property-saving emergency information. In this original paradigm, which is still used in many areas today, Fire Warnings are issued sparingly and primarily to disseminate evacuation information from emergency managers. Unlike hazards such as tornadoes, wildland fire hazards require a multi-disciplinary understanding, and the NWS lacks the authority to directly issue Fire Warnings without requests from federal, state, Tribal, or local authorities (NWS, 2024; NWS, 2021). Instead, other agencies create and authorize Fire Warnings, which the NWS then disseminates through the EAS to television and radio stations.

To bridge agency disciplines and authorities, a new paradigm and prototype Fire Warning framework was developed in the Southern Great Plains through Tactical IWT collaboration between NWS Norman, Oklahoma Forestry Services (OFS), and the Texas A&M Forest Service (TFS). The framework integrates environmental and remote sensing data through meteorological and land management information exchange to identify fire detections and extreme fire behavior and provide timely Fire Warnings to the public and first responders (Lindley et al., 2019). While Fire Warnings in the Southern Great Plains are officially authorized by management agencies, Fire Warnings are jointly issued by NWS meteorologists and state fire partners through their Tactical IWT-driven approach.

The Tactical IWT approach is a significant evolution in Fire Warning issuance, promoting interagency situational awareness and collaborative workflows for dynamic decision-making and response to wildfire threats. The first Tactical IWT Fire Warning was issued during the 66 Fire in Mulhall, Oklahoma in March 2022, followed by a successful warning for the Hawkeye and Burnet 109 Fires in Texas in August 2023. The IWT's use of near real-time fire detection data from GOES satellites (recently improved by the NGFS), enhanced fire spread modeling, provided more accurate warning areas, and supported the coordination of frontline responders (Lindley et al., 2024).

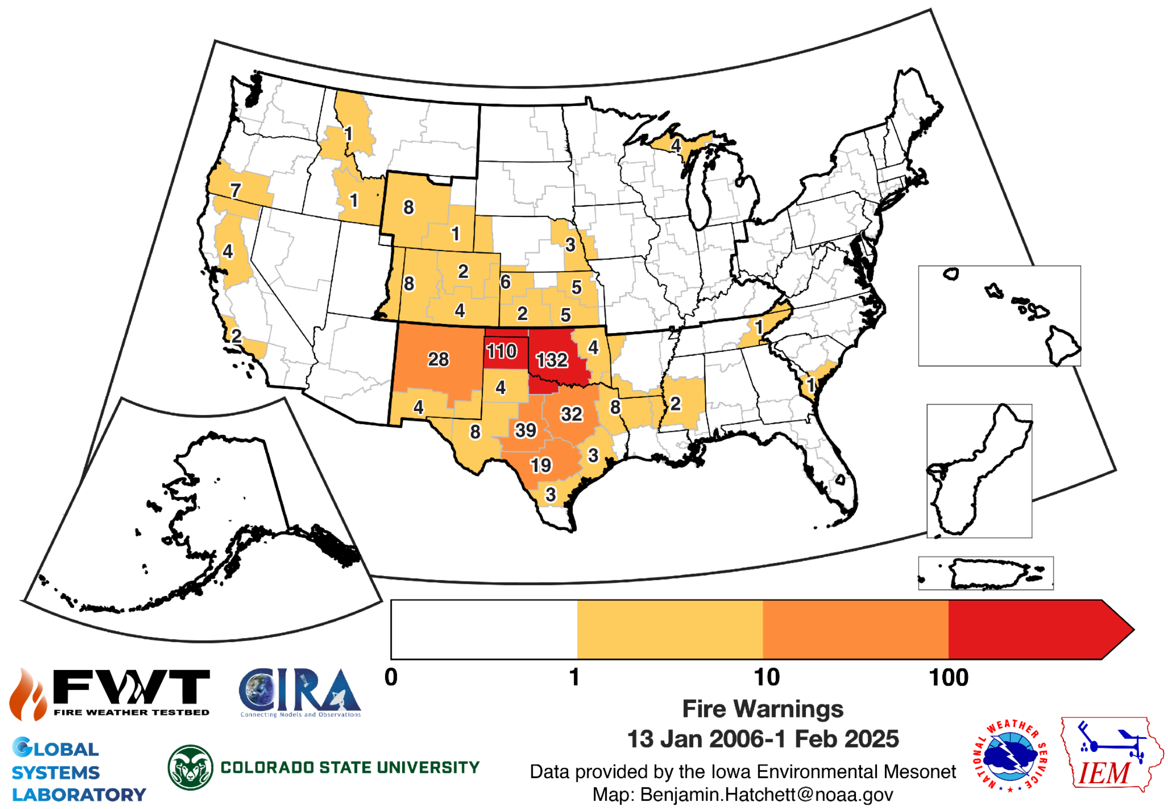


Figure 1.2: Number of IWT and non-IWT Fire Warnings (a total of 461) issued by National Weather Service County Warning Areas between 13 January 2006 and 1 February 2025. Data provided by the Iowa Environmental Mesonet.

Between 2022 and 2023, 12 IWT Fire Warnings were issued for nine wildfires across Oklahoma and Texas (NWS, 2023b). The February 2024 Texas Panhandle wildfires marked a milestone, with 20 IWT Fire Warnings issued across multiple NWS WFOs over two consecutive days, making these the most proactively warned fires in U.S. history. While unfortunately two lives were lost during the Texas Panhandle Fires, the increased coordination between NWS offices, emergency management, and fire agencies likely helped save lives, and officials attributed lives saved to the region's tactical coordination (Lindley et al., 2025). An examination of past wildfires suggest that the IWT-issued Fire Warning process could benefit different fire regimes (Lindley et al., 2024). However, there are several uncertainties that necessitate further Fire Warning research and evaluation, including how Fire Warnings influence partner and forecaster decision-making, how they can be integrated into operational workflows, and if and how they influence public perception and behavior.

This FWT evaluation examines the Fire Warning approach issued through the Tactical IWT process, acknowledging that Fire Warnings can and have been issued through other methods. Herein, all references to IWT-derived Fire Warnings or Fire Warnings specifically pertain to those issued via the Tactical IWT approach.

1.6 Fire Weather Testbed Role and Collaborative Approach

As part of a collaborative effort between NOAA's Global Systems Laboratory (GSL) under the Office of Oceanic and Atmospheric Research (OAR), NWS, and NESDIS, the FWT focuses on transitioning research-derived capabilities into operational settings. The FWT serves as a bridge between researchers, operational forecasters, and end-users (e.g., local, state, Tribal, and federal fire managers, planners, and practitioners) to advance fire weather forecasts, communications, and warning capabilities. Our role at the FWT is to integrate both social and physical sciences to address the technical and human aspects of fire weather challenges, ensuring that our evaluations and recommendations are scientifically rigorous, operationally actionable, and contextually appropriate (Section 2).

The FWT recognizes the complexity of bridging a range of end-user needs and the need to mitigate potential biases through diverse sampling strategies, interdisciplinary evaluation practices, and proactive end-user engagement. We utilize a deliberate transdisciplinary approach integrating extensive physical science research expertise, operational experience, and comprehensive social science research methodologies. By employing a range of qualitative and quantitative methods (Section 2.5), we ensure that our evaluations are both user-centered and technically sound. Transparent documentation and clear attribution of findings (i.e., whether results are from participants, FWT researchers, or a combination) are core to our processes. This approach is intended to result in actionable outcomes that meet end-user needs while enhancing the trustworthiness, integrity, and relevance of our evaluations, which is expanded upon in the overarching FWT findings and recommendations section (Section 5). Our commitment to rigor and continuous improvement, along with end-user engagement, supports the transition to effectively implementing fire weather innovations into operations.

1.7 Active Research to Operations: FWT's Role in Accelerating Innovation

The FWT, one of thirteen NOAA testbeds (NOAA, 2020), is a knowledge transfer platform (Lavis et al., 2006) whose main objective is to transition advanced technologies and new applications to operational platforms as quickly as possible (Wells et al., 2025). To accomplish this goal, the FWT actively engages in the Operations-to-Research-to-Operations development process when opportunities exist to optimize experimental products and assist in transitioning new tools and technology into operations to be used by end-users. Objectivity and scientific integrity are paramount in the FWT processes. When investing FWT time and resources to benefit tools in this way, the goal is to do so objectively, transparently, and with the immediate utility of our findings and recommendations at the forefront.

The FWT actively participated in the research-to-operations (R2O) process in this evaluation by using cloud development resources at NWS Office of Science and Technology Integration (OSTI) from the Bipartisan Infrastructure Law (BIL) funding to build an AWIPS plug-in for the NGFS. This enabled NWS meteorologists to visualize the NGFS data more effectively by including it within the NWS's internal native technology platform during the evaluation.

The result of this "active" R2O was twofold: 1) it enabled the use of the AWIPS Warning Event Simulator (WES) to create displaced real-time simulations of the NWS native computer environment to create a more realistic assessment of the NGFS in the evaluation, and 2) expedite the implementation of NOAA's new AI fire detection algorithm into NWS Operations.

The benefits of the FWT's active involvement–assisting with ingesting NGFS data into AWIPS–were experienced immediately. Prior to the evaluation, the developer of the NWS Norman HSNT quickly updated the tool to include the NGFS detections and provide a dashboard-like environment. Additionally, the NGFS AWIPS plug-in will be distributed to 10 NWS Forecast Offices for further testing through an AWIPS Test Authorization Note (ATAN). Additionally, the FWT created visualizations of antecedent fire weather and fuel conditions using gridded data (Section 2.3) to support this and future evaluations and research efforts.

The remainder of this report presents evaluation methodologies (Section 2), participant findings (Section 3), a discussion of key themes and implications arising from the evaluation (Section 4), and evidence-based recommendations for refining and implementing these systems more effectively in wildfire response operations (Section 5).

2. Evaluation Overview and Methods Used

2.1 Evaluation Overview

NOAA GSL's FWT assessed three experimental products and procedures during a week-long evaluation in Boulder, CO from 10-14 June 2024. The evaluation brought together NWS meteorologists and state fire management partners to evaluate the use and utility of (1) the NGFS accompanied with text message-based hotspot notifications via the HSNT (FWT Eval #002), (2) an extension of IWTs for wildland fire operations, referred to as "Tactical IWTs" (FWT Eval #003), and (3) the collaborative Tactical IWT approach for issuing Fire Warnings between NWS and land/emergency management partners (FWT Eval #004).

The evaluation team consisted of three meteorologists and three social scientists from GSL's FWT and Social Behavioral Sciences (SBS) Branch. The evaluation was supported by Oklahoma Forestry Services, NWS Norman WFO, NWS Warning Decision Training Division, NESDIS, the University of Wisconsin-Madison, and the Warn-On-Forecast team at the NOAA National Severe Storms Laboratory (NSSL). With this support, the FWT created real-time, displaced simulations using the WES, allowing participants to assume the roles of an NWS meteorologist and their fire management counterparts during a simulated wildland fire event. The principal investigators (PIs) of the evaluated products, tools, and procedures also conducted training sessions, offering insights into product functionality, potential workflows, and detailed accounts of past experiences to support participant learning.

Evaluation day one started with onboarding participants to the evaluation, including expectations and dissemination of a pre-evaluation survey to collect information about participants' current fire detection and interagency coordination processes and to establish a baseline perception of the evaluated tools (Appendix A). The FWT team members and PIs presented an overview of each new tool or product followed by a hands-on training exercise using a tutorial simulation (Section 2.4).

During evaluation days two through four, participants engaged in two displaced, real-time simulations of emerging wildland fires each day, one in the morning and another in the afternoon. These days included four supplemental presentations to acclimate participants to the products and procedures being evaluated: a demonstration of the NWS Central Region Hotspot Notification Tool; a demonstration of interagency collaboration used to produce probabilistic wildland fire forecasts for the Southern Great Plains; a walkthrough of a real-world example of how Tactical IWTs produced Fire Warnings during the Smokehouse Creek Wildland Fire Outbreak in February 2024; and a vision for a fully integrated fire detection and Fire Warning system.

Evaluation days two through four ended with a brief end-of-day survey and roundtable discussion concerning any questions, benefits, or challenges they experienced applying the evaluated products and processes during the simulated wildfire events. On the second day of the evaluation week, the FWT team coordinated an optional field trip to three sites in the 2021 Marshall Fire burn area, where local fire and emergency management agencies shared their experiences in responding to and recovering from the incident. On the final evaluation day five, participants completed a post-evaluation survey (Section 2.5), followed by private focus group discussions with FWT facilitators–one for meteorologists and one for land managers–that were recorded, transcribed, and analyzed (Section 3).

2.2 Participants

To evaluate these products and services in a setting that mirrored the participants' typical wildfire operational environment, we deliberately constructed an evaluation design that took into account the working relationships and collaboration needed between NWS and external land management partners. Therefore, in order to properly evaluate these products, we recruited NWS meteorologist and state forester/land manager (LM) pairs from the same operational areas.

A total of 9 participants represented North Carolina (n = 2), Florida (n = 2), Kansas (n = 2), and California (n = 3), with California sending two high-level personnel from CAL FIRE to participate in the evaluation. The recruited teams from North Carolina and California had a pre-established and trusted relationship ahead of the evaluation, which was desired as it was believed it would enhance the team's collaborative efforts and could be a useful comparison to the other paired teams. The different operational areas of the participants represented diversity in typical wildland fire behavior, regional ecologies (i.e., climate and fuels), land use, population densities, and firefighting infrastructure, resources, and tactics. This broad range of experience and working conditions helped to represent the wide range of environmental and logistical situations found across the country.

2.3 FWT Simulation Design and Tactical IWT Structure

To effectively test the operability of the products and ideas being evaluated, the FWT created seven displaced real-time simulations that were based on historical wildland fire incidents, enabling both parties to respond to developing incidents in a way that was authentic and unique to their respective positions.

Before each simulation, the FWT provided short briefings to participants that overviewed the forecast information and antecedent conditions for the simulated operational period as communicated ahead of the real-world event. These briefing packages included, but were not limited to, information regarding the operational area (including any ongoing fires), Fire Weather Products issued by the NWS at the time of the event (e.g., Red Flag Warnings, Fire Weather Outlooks, local Fire Weather Forecast), Warn-on-Forecast System (WoFS) forecast of Red Flag Threat Index (if available), and key messages and forecast information provided by the local WFO where the simulation was based. Participants were also given packets of information that detailed antecedent conditions of the operational region, including but not limited to maps of energy release component (ERC) percentiles, fuel moistures, precipitation anomalies, drought conditions, and MODIS- and VIIRS-based satellite fire detections for the three days leading up to the simulated event for operational and fire behavior context. An example of this material is shown in Figures 2.1 and 2.2 for the simulation based on the 2021 Marshall Fire.

During each simulation, meteorologists sat across from their land manager partners and each received role-specific information to aid in decision-making for operational response. The displaced real-time simulations played forward at the event's normal speed, allowing participants to experience the wildfire event in real-time while analyzing model forecasts, observational data, and information sourced from after-action reviews, news articles, and social media. This information was shared primarily through Google Chatrooms, with separate chatrooms dedicated to the meteorologists, the land managers, and each mock Tactical IWT. Meteorologists received weather updates and post-processed weather model information from facilitators, in addition to satellite and NGFS data via AWIPS in displaced real time. Land managers received updates of simulated ground activities and field reports of initial attacks from a team of FWT facilitators and PIs. Facilitators provided information that would simulate the operational fire environment to the extent possible, including the fire behavior and spread, ground response tactics, and risks to local populations, structures, and infrastructure. However, these simulations may not have replicated exactly how information would have been collected, shared or received in the operational context of rapidly-evolving wildfire events. Each participant received sets of information specific to their NWS/land management position, and paired participants collaborated within their respective Tactical IWT chatrooms to make informed decisions on how to effectively respond to the simulated wildland fire threats.

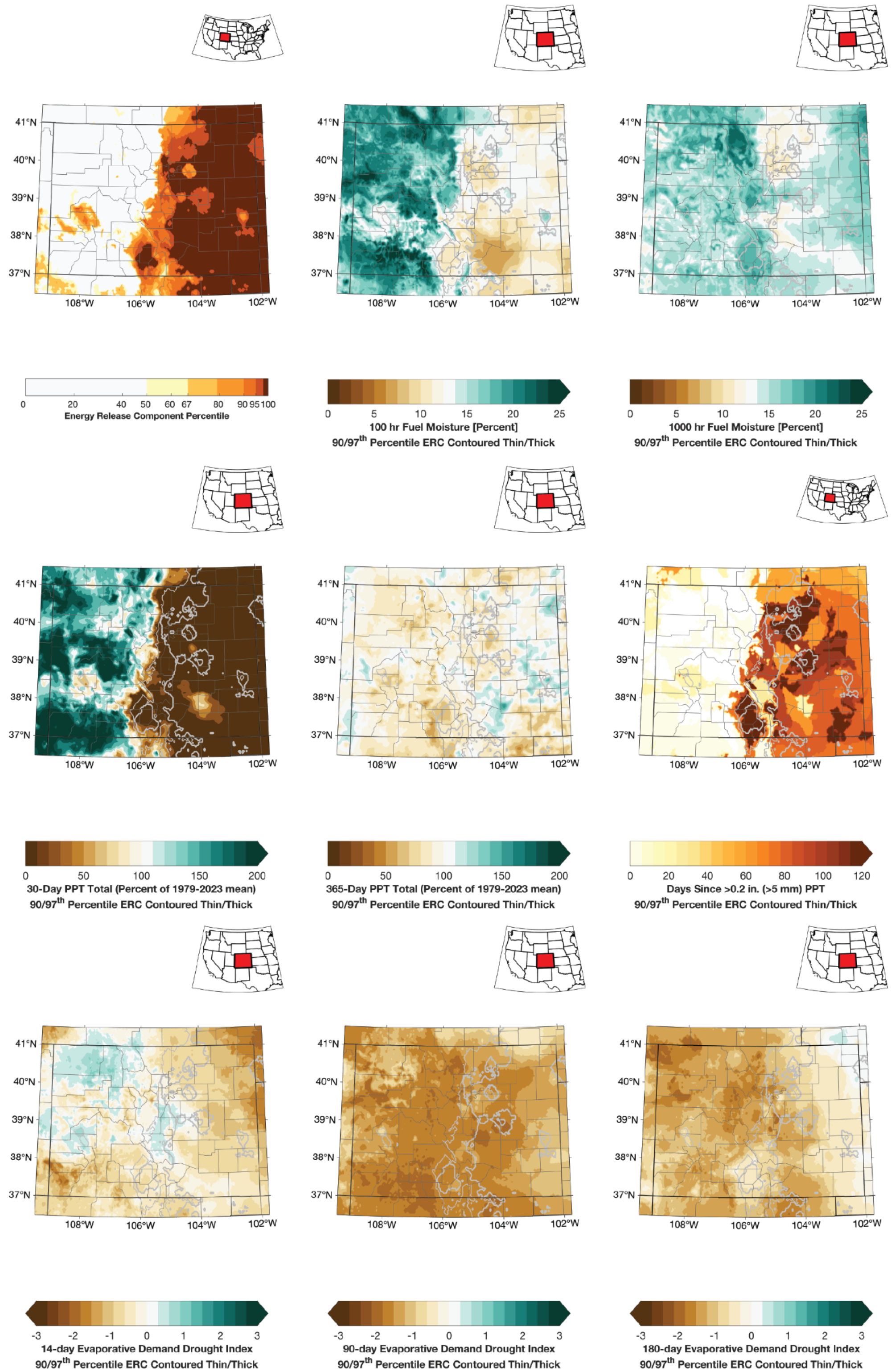


Figure 2.1: Regional maps of gridMET-based supplementary background information as provided to participants for the 2021 Marshall Fire wildfire event. Similar information was provided for each wildfire event.

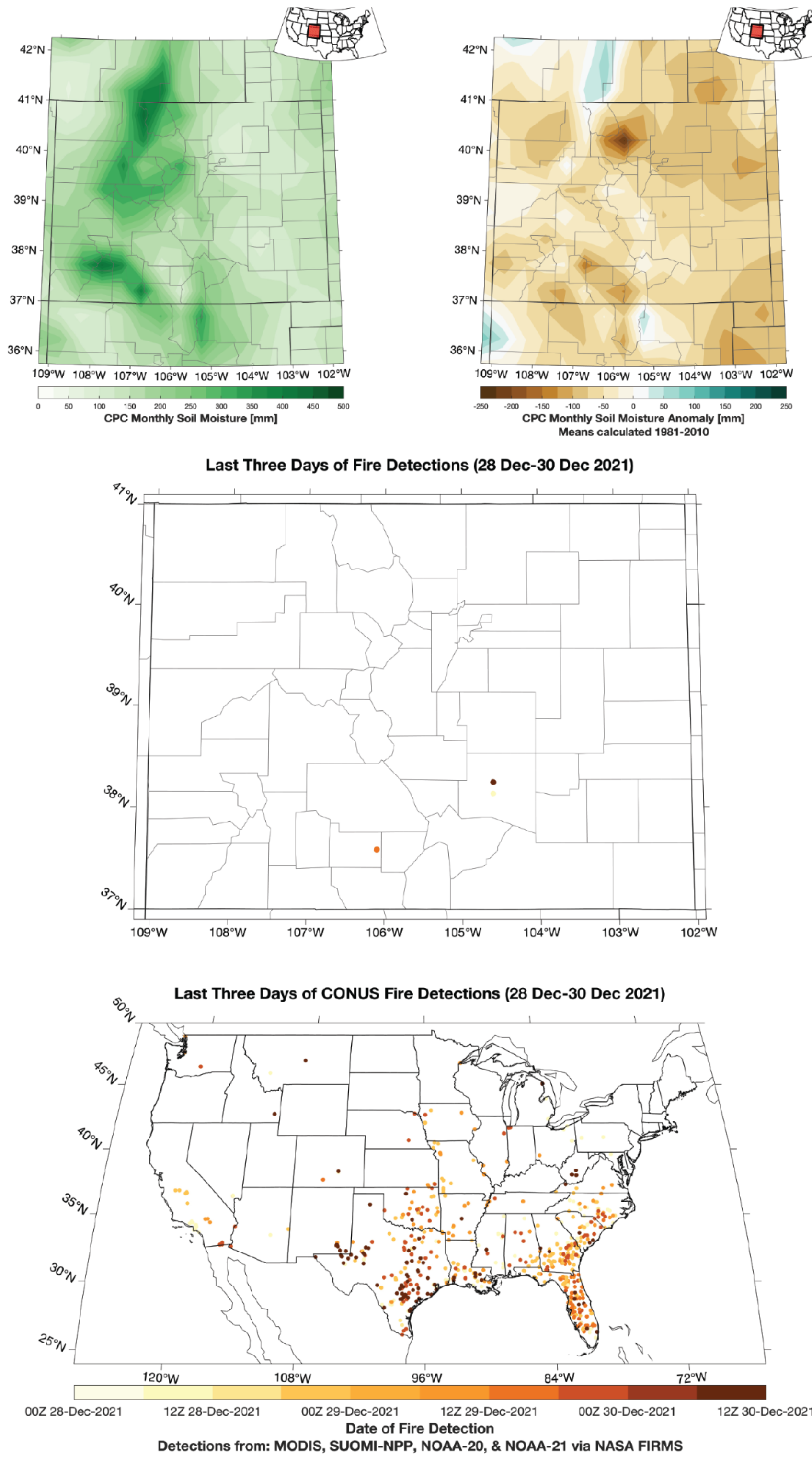


Figure 2.2: Regional maps of Climate Prediction Center-based supplementary background information and satellite remote sensing-based fire detections regionally and CONUS-wide as provided to participants for the 2021 Marshall Fire wildfire event. Similar information was provided for each wildfire event.

Meteorologists could access model output from the High Resolution Ensemble Forecast (HREF) and Warn-On-Forecast System (WoFS) with fire/smoke-based products, as well as archived weather observations through the Weather and Hazards Data Viewer. Land managers also had access to resources showing values at risk and community infrastructures within the operational area. When a wildland fire was detected by the NGFS, NWS meteorologists investigated the potential detection by comparing it with underlying concurrent satellite data, typically the 3.9 µm shortwave infrared band or fire temperature RGB imagery. If verified, meteorologists relayed information pertaining to the emerging wildland fire to land managers via the HSNT. Land managers received the HSNT notification via text message including fire location information (e.g., fire weather level, detection method, weather forecast, and comments specific to the fire). Land managers then received simulated information from the FWT facilitators about the candidate fire's behavior as if it had been relayed by local firefighters during an initial attack, which helped them determine the threat posed by the wildland fire. Meanwhile, NWS meteorologists continued to monitor the candidate fire's activity through satellite observations.

By receiving distinct yet complementary information, both meteorologists and land managers leveraged their respective expertise to analyze the data, coordinate, and make informed decisions regarding candidate fires. While land managers had the authority to issue IWT Fire Warnings at any time, NWS meteorologists continuously monitored fire activity and intensity using the NGFS. If satellite observations indicated that a candidate fire had reached the threshold intensity of previous high-impact wildland fires in the region, meteorologists could issue a secondary hotspot notification, designating the fire as a "Potentially Dangerous Fire" and proactively recommending the issuance of an IWT-derived Fire Warning. If the Tactical IWTs decided to issue a Fire Warning, they would then collaborate to define the warning area and craft the message content. In some scenarios, fire spread models were provided to participants to support their decision-making process. This procedure was repeated as needed for all wildland fires within the simulations.

2.4 Wildfire Events Evaluated

The seven displaced real-time simulations of wildfire events used in this evaluation occurred between 2020 and 2024 across a variety of fuelscapes. Events were intentionally selected to represent high-end to unprecedented (i.e., 'career') cases. Locations included Colorado (2021 Marshall Fire), Kansas (2021 Four County Fire), Oregon (2020 Lionshead Fire), Washington (2023 Gray Fire), Oklahoma (2023 Simpson Road Fire), Texas (2024 Texas Panhandle/Smokehouse Creek Fires), and New Mexico (2022 McBride Fire) (Table 2.1).

To evaluate the collaborative detection-to-warning process, simulated wildfire events were selected that occurred under fire environments with receptive fuels, elevated suppression difficulty, and population centers and other critical assets under threat due to rapid fire spread and extreme fire behavior. Events included some combination of higher wind speeds (all), elevated temperatures, lower relative humidities, and lower fuel moistures resulting from both ongoing critical fire weather conditions and anomalously dry, long-term hydroclimate conditions. Fire ignition sources varied and included lightning, trees falling on power lines, arcing and downed power lines, and an escaped burn pile. Fuel types were generally grass but also timber and shrublands. Appendix B provides additional details on each fire, and Table 2.1 describes the simulated operational time period of each fire covered during the evaluation.

FWT Evaluation #002-004 Displaced Real-time Simulations						
Simulation Number	Event Name	Date	Operational Period	State	WFO	Available Satellite Imagery
Simulation #1	Marshall Fire	12/30/2021	1800-1915 UTC	Colorado	BOU	ECONUS, WMESO-1
Simulation #2	Gray Fire	8/18/2023	1900-2200 UTC	Washington	SPO	WCONUS, WMESO-2
Simulation #3	McBride Fire	4/12/2022	1945-2100 UTC	New Mexico	ABQ	ECONUS, WCONUS, WMESO-1
Simulation #4	Smokehouse Creek Fire	2/27/2024	2130-2300 UTC	Texas	AMA	ECONUS, EMESO-2, WMESO-1
Simulation #5	Labor Day Fires	9/8/2020	0445-0630 UTC	Oregon	PQR	WCONUS, WMESO-1
Simulation #6	Simpsons Road Fire	3/31/2023	1830-2000 UTC	Oklahoma	OUN	EMESO-2
Simulation #7	Four County Fire	12/15/2021	2015-2215 UTC	Kansas	DDC	ECONUS, EMESO-1, EMESO-2

Table 2.1: Listing of the displaced real-time simulations used in FWT Evaluation #002-004. Simulations are listed in the order they were given to the participants with information on the operational area of responsibility and time frames used.

2.5 Evaluation Methods

Following participation in the simulations described in Table 2.1 and Appendix B, this evaluation aimed to identify and understand participants feedback for each product involved in the detection-to-warning process (the NGFS/HSNT, Tactical IWTs, and Fire Warnings), including perceived utility and usability, opportunities for implementation, as well as considerations and concerns for product/process use and implementation. The evaluation employed a mixed methods approach, combining surveys, roundtable discussions, and focus groups to gather comprehensive qualitative and quantitative data on participant experiences and perspectives. These evaluation materials were developed by the SBS team, led by Drs. Emily Wells, Stephanie Hoekstra, and Jamie Vickery, with input and feedback provided by the broader FWT team. Colorado State University's Institutional Review Board determined this research qualified for exempt status and was approved on May 9, 2024 (#5711), ensuring that the evaluation adhered to ethical guidelines for human subjects research.

Data collection included pre- and post-evaluation surveys to gauge initial and evolving perceptions of the evaluated products, as well as daily surveys centered on product use and utility specific to each simulation. At the close of each day, informal, unrecorded roundtable discussions were facilitated by the FWT and attended by developers, participants, and evaluators, fostering collaborative dialogue and immediate feedback. The week concluded with formal, recorded focus groups, attended only by FWT facilitators and participants to promote open, participant-driven discussion and to limit potential biases, helping to ensure participants felt comfortable sharing their insights freely and confidentially.

Focus Groups

The FWT-facilitated participant focus groups lasted approximately 2.5 hours each. At the start of each focus group, facilitators obtained verbal consent from each participant before starting the discussion, including permission to record the conversation for transcription purposes. The focus group guide (Appendix C) aimed to explore the potential strengths of, opportunities for, and concerns associated with each product's use and utility based on participant evaluation experience. These open-ended focus group questions first focused on each evaluated product individually, and then transitioned to how the products were used together throughout the evaluation simulations. Additionally, focus group questions addressed if and how each product might be implemented in the participants' home offices/agencies, including potential barriers to implementation.

Drs. Emily Wells and Benjamin Hatchett facilitated the land manager focus group, while Dr. Stephanie Hoekstra and Kyle Thiem facilitated the meteorologists' focus group. These focus group discussions were recorded to ensure accurate data capture. While the recorded focus groups took place, Zach Tolby and Dr. Jamie Vickery co-led an informal discussion with developers to gather their feedback and perceptions on the week-long evaluation, including identification of reasonable next steps and opportunities for improvement for the evaluation process.

Focus group recordings were transcribed, de-identified, and then underwent in-depth analysis of recurring themes and unique insights (Braun & Clarke, 2006; Galvin et al., 2015; Massey, 2011). Using a thematic analysis approach, qualitative interview data were inductively coded by two coders (AT and JV). We first generated initial codes across the two focus group transcripts by interview question and determined themes based on the frequency in which they were mentioned and by the number of participants who aligned with each theme. We then presented the initial themes by code to the co-facilitators (BH, SH, KT, and EW) of each focus group for review and feedback. After this round of review and iteration, we shared themes from the focus groups with the broader FWT team, which resulted in another round of refinement before finalizing findings from the focus groups (Braun & Clarke, 2006; Galvin et al., 2015, Massey, 2011). This approach ensures methodological rigor in interpreting participants' experiences through iterative analysis that ensures that data were interpreted similarly across the evaluation team. Evaluation findings presented within this report are primarily derived from the participant focus group data and augmented by the survey results and roundtable discussions.

Pre- and Post-Evaluation and Daily Surveys

Pre- and post-evaluation and daily surveys were distributed to each participant via Qualtrics online software. Surveys included a mix of closed- and open-ended questions related to the perceived need for and the accessibility, usability, and utility of each product. Participants took approximately 11 to 23 minutes to complete the pre-evaluation survey and 10.5 to 21.5 minutes to complete the post-evaluation survey. We analyzed the survey data using the R software package to produce descriptive statistical results, which we used to triangulate the qualitative focus group findings.

Roundtable Discussions

In addition to the formal focus groups, we held informal, unrecorded roundtable discussions at the end of each day of the evaluation in which members of the FWT and SBS teams took detailed notes. These discussions captured initial feedback from participating meteorologists and land managers, as well as conversations and points of clarification between participants and product developers. Detailed notes from each roundtable discussion, taken by at least two FWT/SBS employees, were thematically coded using MAXQDA to identify and organize key themes and topics.

3. Focus Group and Survey Findings

This section details findings from data collection activities carried out throughout the week-long evaluation, including the end-of-week focus groups with land managers and NWS meteorologists and pre-and post-evaluation surveys administered to all participants (n = 9). We divide the following subsections according to the three core elements of NOAA's end-to-end workflow for fire detection and warning systems at the center of the evaluation: NESDIS' NGFS and the Norman WFO HSNT, the Tactical IWT for fire operations, and Tactical IWT-issued Fire Warnings (see Figure 1.1). Throughout each of these subsections, we highlight themes pertaining to opportunities, considerations, and potential or experienced concerns for operational use as reported by each interviewee group. While we use quotes to illustrate these themes, we do not assign state identifiers so as to protect participant confidentiality. Select results from the pre- and post-evaluation surveys complement the focus group findings. Finally, at the end of each subsection specific to each product, we summarize visually key findings along with synthesized recommendations by meteorologist and land manager participant group (Figures 3.2, 3.4, 3.6). Many of the roundtable discussion insights echoed the identified focus group themes. Any comments that were unique to the roundtable discussions are highlighted throughout this section.

3.1 Next Generation Fire System and Hotspot Notification Tool

Throughout the following subsections we do our best to distinguish feedback specific to the NGFS and the HSNT; however, in this evaluation the NGFS, HSNT, and IWT were used in combination and therefore feedback was at times difficult to disentangle. Importantly, focus group and informal discussion questions regarding the NGFS and HSNT often treated these distinct elements as part of a unified detection and notification system. NWS meteorologist participants, compared to land managers, engaged directly with the NGFS interface and were able to speak distinctly about the two, while land managers were only exposed to NGFS-derived fire detection information via HSNT during simulations. As such, we frame the land manager subsection as "NGFS-Derived HSNT in Practice" and note clearly areas of feedback specific to the NGFS.

NWS Meteorologists

NGFS and HSNT in Practice: Identified Benefits and Opportunities for Use in Operational Settings

To begin the focus group interviews, facilitators asked participants to share what seemed to work well when using the NGFS and/or HSNT, prompting them to consider any NGFS features or output that were particularly helpful during the evaluation or could be helpful to their home WFO. Themes coalesced across three "strengths" or ways that the NGFS helped them in their role as a meteorologist, including: 1) the ability to detect new and emerging fires, 2) the potential for NGFS to act as a "safety net", and 3) its ability to build situational awareness.

First, NWS participants reported that the NGFS seemed to work well for detecting new and emerging fires during the evaluation. As one meteorologist shared:

> *I liked it for new fires. So one of the ways that I found it very useful was like the simulation yesterday in the last one, when there's an area that you're focused on, you don't have to worry about areas like yesterday with the clouds and dust. So I was really concerned about that one area, and I let it cover the rest of the area where I knew it would perform well. (Met 1)*

A second related theme from the NWS meteorologist focus group regarding NGFS strengths was that many considered the hotspot monitoring aspect of the NGFS platform to act as a **"safety net,**" and allowed them to not feel "overloaded" or risk missing hotspot detections: *"I would say when it comes to fire detection, the NGFS is a time saving tool that has a great safety net as well." (Met 2)* Relatedly, as a result of the automated monitoring aspect of NGFS, participants noted the potential for the NGFS to **mitigate extra workload on forecasters** by helping to reduce the attention dedicated to hotspot detections in operational settings. One participant shared that it would be particularly helpful *"on those days where maybe the day overachieved, so we weren't anticipating the need to watch for hotspots, so we didn't staff accordingly. And to have that tool in the absence of that staffing I think would be extremely helpful." (Met 3)*

A third and final theme, which is inherent throughout the previous themes, is that the NGFS allows for **situational awareness-building** in an operational setting. An NWS participant summarized this aspect of the tool, explaining:

> *I think it's a very good situational awareness tool…If there is an elevated day or there's a red flag day, that is going to be a crucial piece and it's going to alleviate some of that overload…situational awareness is a huge thing. Especially amid other weather phenomena that we're also trying to keep track of and communicate at the same time. (Met 1)*

Considerations and Concerns about Operational Use of NGFS and HSNT

We also asked participants what did not seem to work well (and why) when using the NGFS and HSNT during the week-long evaluation. The responses by NWS participants converged around three themes, which included challenges they experienced during the evaluation as well as anticipated or potential challenges to using NGFS and HSNT in an operational setting, including: 1) concern about overwhelming their land management partners with hotspot notifications; 2) feeling inundated with information and notifications; and 3) constraints with the communication mechanism used during the evaluation for disseminating hot spot notifications.

A potential concern that NWS meteorologists may experience when using the HSNT to notify partners about possible hotspots is they felt uncomfortable issuing multiple notifications - not wanting to inconvenience their partner. In line with this theme, one participant noted concerns of overwhelming their land manager partner with information:

> *I think there was some feelings of overwhelm. I can feel the overwhelm from his side because especially when we were in outbreak mode…as far as I could tell, I could feel it across from him that he was like trying to keep up by chatting with me…And then I felt that I was like, am I overloading him…? So I don't know if that's awkwardness or just kind of like the delicate balance of understanding and being empathetic of the other person on the other side. (Met 4)*

Although NWS meteorologist participants expressed concerns about sending hotspot notifications to fire partners, this issue may be less related to the specific use of NGFS/HSNT and more indicative of the challenges posed by rapidly changing and extreme fire conditions. This could be remedied through consistent partnership/collaboration building and identification of preferred communication styles and frequency determined by local IWT policies.

Second, multiple NWS meteorologist participants felt that they received a substantial number of notifications through NGFS on these active wildfire days- potentially compounding the existing NWS notifications they already receive. A concern they shared, and also related to a recommendation, is that the most pressing notifications from NGFS were not necessarily listed at the top of the HSNT. This is exemplified by the following quotes shared by two NWS meteorologists: "*We get bannered to death as it is"* and *"You go numb to it. You will. And that is a concern." (Met 4)*

A third and final concern reported by NWS meteorologists regarding the NGFS/HSNT pertains to the communication mechanism used for transmitting hotspot notifications to their partners during the evaluation. Participants found the delivery of hotspot notifications through the HSNT as text messages challenging or cumbersome in simulations involving a large number of wildland fires, prompting them to suggest alternative or supplementary communication methods. The HSNT also has the capability to distribute hotspot notifications via email, and several participants suggested that this approach could be more effective in specific scenarios and improve the organization of hotspot notifications for their partners. This underscores that communication practices may achieve optimal effectiveness when aligned with the infrastructure, preferences, and capabilities of land and emergency management partners.

Land Managers

NGFS-Derived HSNT in Practice: Identified Benefits and Opportunities for Use in Operational Settings

In our evaluation and in real-world operations, land managers receiving hotspot notifications ultimately experience a combination of NGFS-derived information, relayed by the HSNT, and communication procedures set up by their IWT. Therefore these cannot be completely disentangled to perfectly delineate between them. Thus, we include feedback in this section as NGFS-derived HSNT strengths and potential applications of NGFS-derived HSNT, as reported by land manager participants. This feedback converged around three themes that largely overlapped or complemented those reported by NWS participants. NWS policy has been proposed for this novel approach which allows forecast offices to deliver satellite-derived data of emerging fires to their land management partners. Regarding communication mechanisms for hotspot notifications, land managers reported text messaging was an appropriate way to communicate this information while out in the field responding to fires or hotspots, though they also mentioned the need for multiple mechanisms to ensure that these notifications reach everyone they are intended to reach. This is a feature of the current HSNT, although it was not presented as such in the evaluation since only one land manager was being alerted per NWS meteorologist in the controlled evaluation setting. As one participant explained:

> *And it [hotspot notifications] has to be multiple [communication channels] because I can see, for instance, you know, that the operations center that they don't want, they wouldn't want at all the text message per se, they want it on email. But..that is the commander of that, that area ranger he would want on text message because he's in the field and I would want my area ranger or my county ranger to be able to have that. I wouldn't want that operation center to be able to confirm that.* ***I would want that county ranger within that county to be able to confirm whether or not it's an actual on the ground fire*** *(LM 2)*

Second, they shared that the NGFS allows for situational awareness and persistent coverage of hot spots and fires. Specifically, they mentioned the benefit of being able to see “heat” move across the landscape at higher temporal frequency compared to other remote-sensing products - and therefore being able to track heat signatures over space and time - was a considerable strength and value of the NGFS tool. Inherent within this is the value for monitoring and validating hotspots. As one participant explained:

> *I think that NGFS is great. We just need to add more to it…the fire radiated power for meteorologists to sit there and say, “Oh that hit at 95 Celsius. Oh it just spiked at 122 Celsius”. And now he's got other collection things that are there. The FireGuard, the spot reports are being populated in there as well. So then it really gives that person really that validation…That persistent coverage and the ability to see that heat as it moves across the landscape is great. (LM 2)*

Relatedly, some land manager participants noted the possible use of NGFS for monitoring prescribed burns. Specifically, they referenced the potential usefulness of this tool to quickly capture any instances where prescribed burns may have escaped (e.g., in instances where a prescribed burn heat signature increases, especially after the specified burn period).

A third notable finding and aspect of the NGFS as reported by land manager participants and exemplified via the following quotes is that the tool is freely accessible and is not resource or labor intensive. This is a significant consideration for states with fewer resources for tracking and alerting potential hot spots to those in the field:

> *So in the meantime, you know, for the smaller programs like [State] and for the medium programs like [State], is the NGFS program a suitable program? I think it is. You know, is there room for improvement? Yes, surely. (LM 2)*

This exchange between land managers highlights the value of NGFS for such programs:

> *For my programs, simple is better at this point. Really, because I just don't have the staff to do the other things that we're talking about. I don't have the technology staff. I don't have the science folks, with the background to do the things that we're doing. (LM 5)*
>
> *It's already there, though. All you have to do is consume it. It's already, it's already a polished product for you to actually consume. There's nothing else that you would have to labor your staff with other than signing up for it and then just receiving. (LM 3)*

Considerations and Concerns about Operational Use of NGFS and HSNT

Similar to NWS meteorologists, land managers reported both perceived and experienced barriers or challenges to using the NGFS and implementing the NGFS-derived HSNT that centered around communication frequency and communication mechanism(s), perceived concerns about false positives, and potential redundancy with other products and services that effectively meet their needs or provide advantages compared to what is offered via NGFS.

First, the text message notification mechanism, as shared by some land manager participants, limits those who use landlines or who may be operating within an office setting. Of note, however, is that the HSNT allows for multiple communication mechanisms (e.g., text messages, emails), although it was not presented as such in the evaluation given the controlled nature of the evaluation format and the fact that there were only one to two land managers per NWS meteorologist (thus not perfectly reflecting an operational environment that would necessitate multiple communication methods). Nonetheless, they shared that text messaging may not always be the most appropriate mechanism for being notified about hotspots. During the roundtable discussion, they also mentioned email as another useful mechanism. Email allows users to easily see which notifications are the newest and can provide consistent knowledge exchange and situational awareness when employee shifts change, such as within local dispatch offices. As one land manager explained:

> *There's got to be some other communication we need to put in there.. i.e., emails because* ***my local dispatch office has one email set up so that every email, every person***

> ***in that office goes to one email, but everybody gets it. So even if they're not on there, it would be in their inbox. But the person on duty would see it. Text message is not doing it.*** *(LM 4)*

Relatedly, the frequency at which land managers received hotspot notifications during some of the simulations was overwhelming, which speaks to more of a procedural and/or relationship-derived issue as opposed to an inherent characteristic of the NGFS-derived HSNT. Establishment of communication preferences for hotspot notifications, including mechanisms and frequency, is an essential component of NGFS-derived HSNT implementation. This could be addressed in the process of building a regional IWT or similar program. A sentiment shared by NWS meteorologists, land managers expressed challenges in deciphering new and evolving information from "white noise" (LM 1) upon receiving text message notifications during the evaluation, which they expressed could be an operational concern. Regardless of the NGFS/HSNT notifications, it would be expected that a high volume of fire notifications would be received by managers whether from HSNT or from other sources such as dispatch, phone calls, or texts.

Indeed, the amount of notifications made it difficult for land managers to keep track of and determine which was the most recent notification. Land manager participants generally agreed that "*The other thing that needs to be built into the system is a confirmation tool that it [the hotspot notification] has been received [by land managers]" (LM 4)* - reflecting a desire for more seamless two-way communication. They described how this confirmation would facilitate more efficient hotspot notification confirmations and contribute to situational awareness for both land managers and NWS colleagues: "*That way, you know, it's two fold: it's we're closing the loop on our end, and then we're also kind of closing the loop on the Weather Service's end"* (LM 2). Also related to communication preferences, land manager participants expressed frustration in receiving a notification and then having to enter a location via latitude and longitude coordinates into a computer, which would be challenging in the field. This highlights the importance of customizing hotspot notification messaging and processes to fit local needs, preferences, and ideally, could integrate into their existing IT infrastructure. Doing so could better serve land managers by accommodating the diverse locations where they may be stationed and their varying communication infrastructures.

Other perceived barriers to implementing NGFS and NGFS-derived HSNT involved concerns about receiving false positive notifications, which could have the effect of eroding trust and confidence in hotspot detections. The detections by the NGFS, generated through artificial intelligence, raised concerns regarding expenditure of time and resources in response to potential false positive detections. This highlights the importance of human interpretation of NGFS detections. This evaluation involved a NWS Meteorologist with expertise in satellite observations interpreting NGFS fire detections to assess their validity prior to issuing hotspot notifications to land managers. Nonetheless, like any system, there exists a possibility for misinterpretion, especially by users without expertise in satellite analysis. The concern about false positives varied somewhat by region, particularly in the southeast where, as one participant explained:

> *And you can pull up the viewers of MODIS any day and see a bunch of red dots all over the southeast. I mean, so there's there's a potential for a whole lot of false positives in the southeast. Not just [State], but just all over the southeast. People love to burn in the South. We burn everything. We burn leaves, we burn debris, we burn… so… and it could be a small brush pile. It could be a brush pile three times the size of this room. So and I mean, if you burn a brush pile three times size room, I guarantee you it's going to give off a hit. (LM 2)*

Other concerns about implementation of NGFS-derived HSNT and the potential for false positives centered around putting lives and resources at risk when responding to false positive detections that may take away from areas requiring attention and the need for a reliable tool to garner support for implementation. As one land manager explained:

> *False positives - whether it's Cal Fire or whether it's Nebraska, it doesn't matter how many resources you have. You are now putting people at risk by going out to those fires. And you are taking that element that's available and making them unavailable to go on a wild goose chase. And that's something that we just can't afford. Our false positive detections have to be absolutely minuscule, because no one can afford to send resources to something that doesn't exist. (LM 1)*

Although participants highlighted such concerns about false positives, no false positives were detected or incorporated throughout the evaluation simulations.

Finally, a reported constraint to using NGFS for some locales with existing fire detection systems and high population density allowing for rapid 911 call identification is that the NGFS "derived satellite is antiquated" (LM 3), with some participants noting other fire detection products, such as FireGuard[1] and live cameras that effectively meet their needs:

> *That's the hard part because [NGFS is] competing against 54 million cell phones, the anomalies that we're getting from our cameras, and FireGuard. So the space that NGFS is doing for detections is a pretty small, slim window; by the time they actually start seeing something flickering and actually do that human interaction and actually push that out to a very, very small space, actually fill that gap, that's not really a bottleneck that we are seeing in [State]. (LM 3)*

Survey Results: NGFS and Hotspot Notification Tool

To complement the focus group discussion findings, we administered pre- and post-evaluation surveys to all participants (n = 9), wherein they were asked to rate their agreement with

[1] FireGuard is a fire detection product using military capabilities to detect wildfires and notify authorities. More information about FireGuard can be found here: https://www.nationalguard.mil/News/Article-View/Article/3223104/fireguard-program-enhances-national-guard-wildfire-fighting/

statements regarding technical and workflow features of satellite-based fire detection. Pre- and post-survey results shown in Figure 3.1 compare participants' level of agreement with various statements on the functionality, utility, and need for improvement of existing satellite-based fire detection tools (Appendices D1-2) in relation to NGFS/HSNT (Appendix D3). Comparative results show participant perceptions of existing satellite fire detection (pre-evaluation survey) relative to their perceptions of the NGFS/HSNT based on their testbed experience (post-evaluation survey).

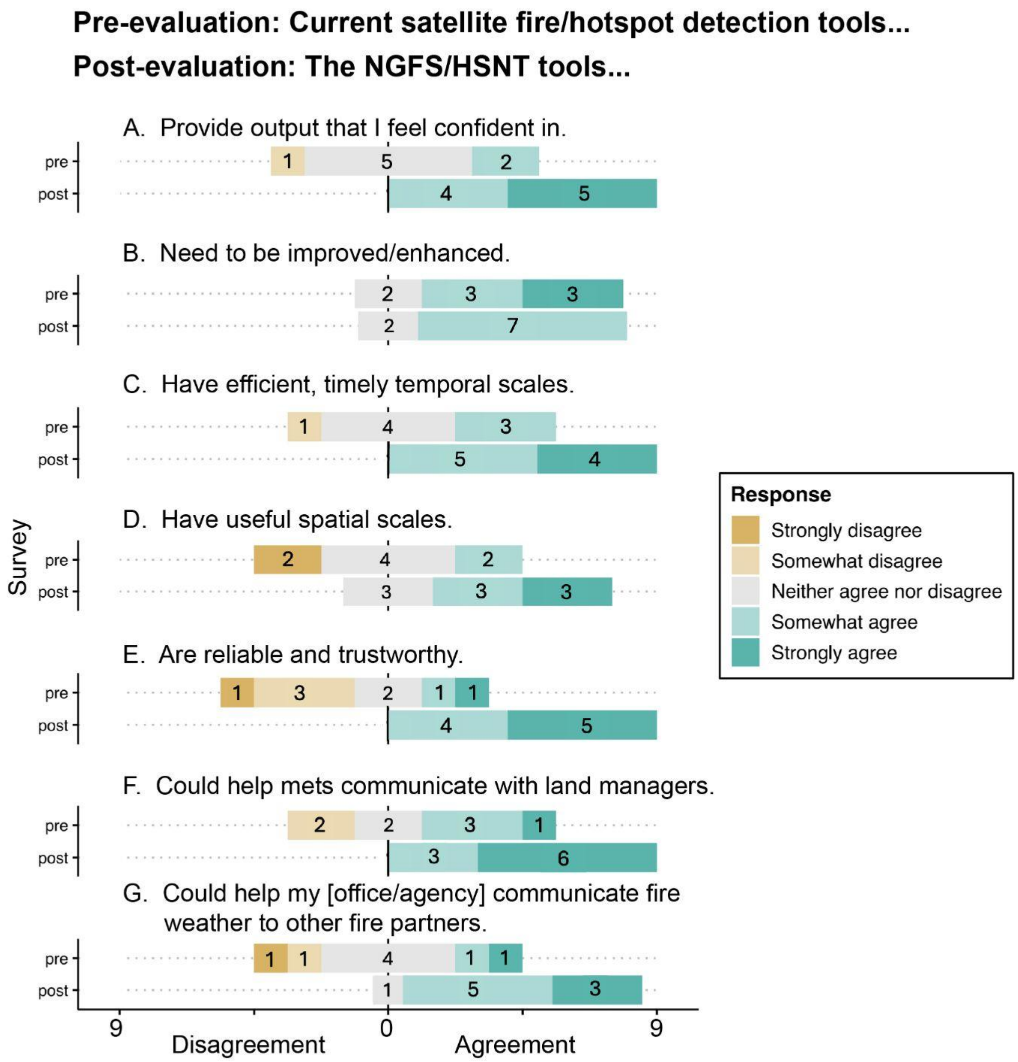


Figure 3.1: Number of total participants (N = 9) who indicated their level of agreement with various statements related to satellite-based fire detection tools along a 5-point Likert scale (1 = Strongly disagree to 5 = Strongly agree). In the pre-evaluation survey, participants were asked their level of agreement in relation to existing satellite-based fire detection tools. In the post-evaluation survey, participants indicated their level of agreement with the same statements, now reframed specifically for the NGFS and HSNT.

The survey results generally mirror focus group findings related to the NGFS and supporting hotspot notification system (HSNT). Broadly, Figure 3.1 shows that participants indicated stronger agreement with positive attributes of the NGFS/HSNT assessed in the post-evaluation survey relative to existing satellite-based fire detection tools assessed in the pre-evaluation survey. The NGFS appeared to bolster confidence and trust, relative to existing satellite-based fire detection / hotspot notification systems, as indicated by participants selecting that they somewhat (n = 4) or strongly (n = 5) agreed that they felt the NGFS/HSNT provided output they were confident in (Figure 3.1A) and by selecting that they somewhat (n = 4) or strongly (n = 5) agreed that the NGFS was more reliable and trustworthy (Figure 3.1E). Participants indicated that they somewhat (n = 5) or strongly (n = 4) agreed that the NGFS provided efficient, timely temporal scales (Figure 3.1C) and, to a lesser degree, useful spatial scales (n = 3 somewhat agreed and n = 3 strongly agreed) (Figure 3.1D) relative to existing satellite-based fire detection tools. Further, participants indicated that they somewhat (n = 3) or strongly (n = 6) agreed that the HSNT-improved communications between meteorologists and land management partners (Figure 3.1F), as well as with other fire partners (n = 5 somewhat agreed and n = 3 strongly agreed) (Figure 3.1G). However, despite these positive attributes of the NGFS/hotspot notification tools, most participants (n = 7) indicated that they somewhat agreed that the HSNT needs to be improved or enhanced (Figure 3.1B). This complements the barriers expressed during the focus group discussions, such as the need for hotspot receipt confirmation and improvements in communicating hotspot notifications, which could be added to these emerging tools.

In the pre-evaluation survey, all four meteorologists reported barriers and challenges to fire detection. These barriers and challenges ranged from a limited need/scope for satellite detection given the size and geography of the County Warning Area (CWA), cell phone carrier limitations (delayed notification and spam-filtered messages) for effectively notifying detected potential fires/hot spots, to high staff turnover and limited staff capacity for detecting fires. Other barriers mentioned included concerns about false detections and contact management issues, including how meteorologists contact their partners.

When land managers were asked in the pre-evaluation survey about challenges and/or barriers to fire detection, all five responded with different examples of potential or experienced challenges, including: 1) a scalable solution for detection areas has not been created to tailor management and resource coordination; 2) there is limited remote fire detection use in their state and that they only respond when a hot spot has been verified by a human given staffing constraints; 3) that there is no "one-stop-shop" for fire-related products and that "combining so all of the info is in one location and simple to use will benefit fire managers and operational personnel."; 4) concerns about false positives; and 5) how to message to the public so as to not contribute to "white noise" or potential panic.

In the post-evaluation survey, when asked "in what types of fire environments was the NGFS (hotspot) tool *most useful* during your FWT evaluation experience," all four meteorologists responded with examples of how the NGFS-derived HSNT was useful. In particular, two reported that the HSNT was most useful during "significant" events and "high impact" fire environment days, with other examples suggesting it helps to reduce forecaster workload and feelings of being overwhelmed. One participant shared:

> *I found it most useful during intermittent cloud cover or blowing dust when the hotspot signal was muted on satellite imagery. It was also useful during periods when we had rapid hotspot development with numerous hotspots in a short period of time, it allowed me not to feel overwhelmed. (Met survey response)*

When land managers were asked the same question, all five respondents shared examples of when the NGFS-derived HSNT was most useful to them during the evaluation. We list their responses verbatim:

- *During all simulations the tool was useful. It allowed us to identify hotspots and then make a determination based on weather and values at risk. It can also help prioritize the movement of resources to specific incidents that are occurring.*
- *At this point I believe the ability for the met to analyze the hot spot compared to the current hot spot tool we use will be of benefit to us*
- *In high fire threat weather events. It provides a persistent coverage and identifies FRP to quickly identify possible damaging fire.*
- *I think the tool is most useful in critical fire weather environments when life and property are threatened and time is of the essence. This tool when used, can help land managers spread the word about the dangerous conditions of a wildfire to the affected public and assist the responding resources with preconditioning the public if further action is needed to be taken*
- *When the lack of ground truthing and intel flowing into the areas, this was an invaluable tool to assist in making decisions. When combined with other remote automated intel coming in, through other networks, I could see a synergistic effect and a built in redundancy. Having a second set of eyes looking at a data set was also nice so that it freed up my time to do verifications and or communication with other partners about what we were seeing*

Participant Recommendations for NGFS Developers

Figure 3.2 synthesizes key findings across participant groups pertaining to the NGFS and HSNT, including participant-provided insights and suggestions for improving the NGFS and HSNT to better meet their operational needs during high fire danger or active fire days. These were collected through focus groups and daily group discussions.

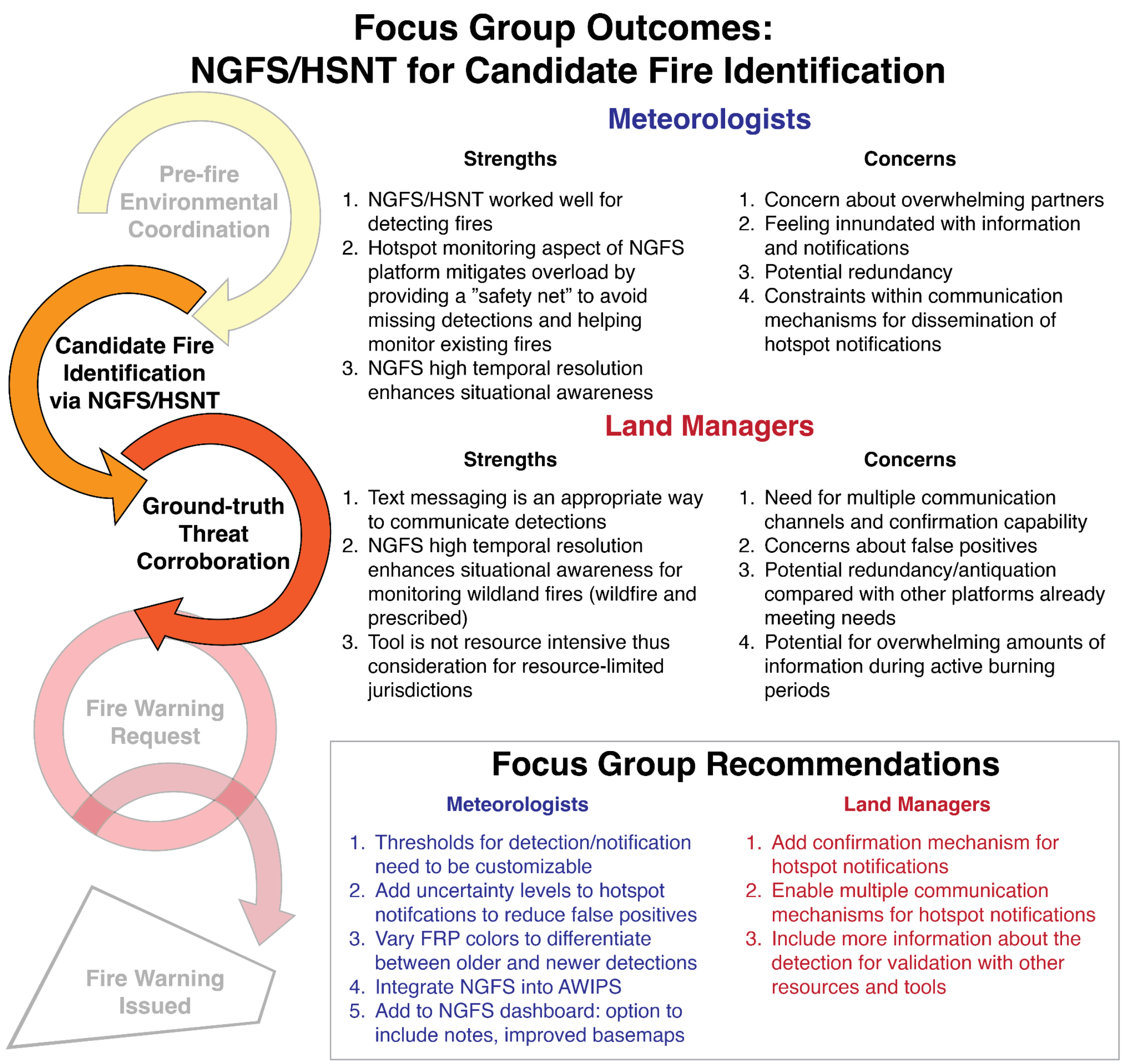


Figure 3.2: Summary diagram showing focus group findings and recommendations for meteorologists and land managers for the candidate fire identification step using the Next Generation Fire System (NGFS) and Hotspot notification tool (HSNT) in the tactical IWT workflow.

3.2 Tactical IWT for Fire Operations

The Tactical Integrated Warning Team (IWT) approach for fire operations was well received by both NWS meteorologist and land manager participants, though this was not without some concerns or potential barriers to implementation.

NWS Meteorologists

Tactical IWT for Fire Operations in Practice: Identified Benefits and Opportunities for Use in Operational Settings

NWS meteorologists expressed that they found value in the real-time communication element of the IWT approach, along with it being a mechanism for bringing core partners together and building rapport. Both NWS and land manager participants reported trust as a critical factor for the success of IWTs and response to fire weather more broadly. Through relationship development via trust, IWTs for fire operations could effectively validate and strengthen decisions regarding Fire Warnings and bolster communication across agencies and with the public, making IWTs a "force multiplier" as one NWS meteorologist suggested. Another echoed this sentiment, sharing:

> *…it makes the process more robust and it adds integrity. But like when you, when you finally do decide to put out a warning, it comes out from not just one entity, it's from multiple entities. Well that support has more weight. (Met 2)*

Considerations and Concerns about Operational Use of IWTs for Fire Operations

Reported barriers or considerations to the use of IWTs for Fire Warnings centered around 1) the applicability of the Norman "Tactical IWT model " for meteorologists in other regions; 2) how to determine who should be on an IWT; and 3) confronting staffing and bandwidth shortages for IWT participation.

First, while the IWT for fire operations is intended to be adaptable and scalable, some participants still expressed hesitation and concern with the approach's applicability to their respective jurisdictions. In particular, they cautioned that without redundancy and clear roles across members of an IWT, this could run the risk of failure if it is reliant on a handful of individuals who have other responsibilities outside of fire weather operations. While the model highlighted out of the Norman WFO provides an exemplar of how IWTs for fire operations could operate, participants recognized the role of a few key individuals in Oklahoma who carried this model forward - which may not be readily replicated elsewhere.

A second and related consideration shared by NWS met participants involved how to identify who should be included in an IWT and whether/how this can be formally instituted (e.g., via an Annual Operating Plan (AOP)). Given varying geographies, resources, operating procedures, and populations across the U.S., partner involvement would likely (and necessarily) vary. If IWT members were to be outlined in an AOP, for example, participants agreed that it would have to be described based upon role rather than specific names if a person is not available.

A final overarching barrier or concern among NWS participants, echoing previous concerns, pertains to staffing shortages and bandwidth considerations that may inhibit active participation in building and implementing an IWT for fire operations. Given the existing strain on WFOs, some grappled with how they would be able to effectively maintain an IWT for wildland fire operations - compounded with the fact that some offices encounter fire weather conditions less frequently than others, necessitating routine (e.g., annual or bi-annual) "refresher training" for IWT for fire operations.

Land Managers

Tactical IWT for Fire Operations in Practice: Identified Benefits and Opportunities for Use in Operational Settings

Land manager participants overwhelmingly highlighted that a core strength of the IWT approach to fire operations was the collaborative design aspect in that it brings together partners in fire weather and establishes these connections before an event occurs. As one land manager expressed:

> *I really like the concept of IWTs, especially for the fire notification system because when everyone's on that same page and they're actually working towards that goal and actually looking for it. So at that point, everyone's on board, everyone's talking about it. We need that verification piece there. In our world, we would be like to send, the, the meteorologist a model of where we want the fire to go, whether it's in 4 hours or 8 hours, to actually tailor that polygon, and actually potentially make it smaller or bigger, depending on how that model comes out. And it gives them more information, gets the better part out out to the public. (LM 1)*

Another explained that the concept of IWTs are beneficial for keeping everyone on the "same page" in terms of response, roles, and responsibilities through communication and trust building:

> *I think that's where the importance of the Integrated Working Team, or Warning Team, is going to come into play where we just can't throw this together. You know, I can't just… throw it together and be done without actually coming together, meeting, talking, doing a little bit of training together, building that confidence, building that trust. And and not only doing that initially, but continuing to do it that…. So there has to be that continual, you know, team thing where we're still talking, working, communicating. All that stuff happens where we still have that trust and confidence in each other. You can't just up and do an initial and then leave it. (LM 2)*

> *I like the "working" [name] because he's 100% right, it helps you build those relationships, not just for the fire side, but for the other issues that can go on. If that relationship is built there, if that communication system is already built up… some of our units don't have that close relationship with our WFOs, some of the other units do, but sort of brings them into that direct communication with the WFOs (LM 1)*

> *I came in with a kind of an open mind into the IWT and it was kind of, like the gentleman in the middle [LM 4] said, you know, this is kind of the way we should be doing things (LM 2)*

Much like traditional IWTs currently in widespread operations and based on participants' evaluation experiences, regular training and meetings between NWS, land management, and other fire partners within an IWT can foster trust and confidence needed ahead of fire events.

For some locales, the sort of partnership and coordination established within IWTs was perceived as being in place already, validating their current partnerships: "*I think for us specifically, it has validated the work we're doing already. Right? This communication is already going on in our state. So, I didn't really learn anything new, just to continue doing what we're doing" (LM 5).* Thus, some land management participants suggested that they will continue to engage in inter-agency partnerships, with opportunities to expand towards more formalized IWT structures.

Considerations and Concerns about Operational Use of IWTs for Fire Operations

Similar to NWS meteorologist participants, land managers also had reservations about the ability to implement IWTs based upon capacity concerns. One land manager illustrated this potential constraint:

> *…we are understaffed, overworked, and very underpaid. So I'm not saying this is a, this is actually a very easy program with minimal work to implement. It really is, honestly… but I'm going to take this program back and I'm going to talk about it and the first thing people are going to say is, "There's more work. This is more work." However easy the work is, and I mean, how often is it really going to affect their day job? Not much at all. But they're going to see it as more work. We're already… add it to the fact that we're already overworked (LM 2)*

Despite the perceived feasibility of IWTs for fire operations, they went on to explain the need for acquiring "buy-in" from core partners including those with "boots on the ground" and the importance of demonstrating IWTs' value.

> *I think I can get the management team to buy in, and now we're just really going to have to get the boots on the ground to buy in. And I think once they see it and I think I'm thinking of a couple instances now where, if they if we had it back then, they were like, "yeah, this would have been great". You know, I think we can get buy in, so… But that's going to be the biggest issue. It's just convincing folks that this is worth their time and effort. (LM 2)*

Another land manager echoed these sentiments, describing the need to "sell the why" behind IWT implementation:

> ***…****As the folks sitting in this room, we have got to sell the "why" to our folks. We don't sell the "why", sell it right, then it's not going there. You know? And it kind of goes back to keeping it simple. False positives can kill this program, and making it too difficult, "You've got to do this site, this site, this site, and this site"... In the spur of the moment, I need quick feedback so I can make quick, decisive actions...It's not going to be on the National Weather Service. We got to take it back to our folks and sell it. (LM 4)*

Survey Results: Tactical IWT for Fire Operations

Figure 3.3 shows the corresponding post-evaluation survey results on participant's indicated level of agreement with various features and qualities related to the functionality, utility, and feasibility of IWT for fire operations. The post-evaluation survey results are broken down by the meteorologist and land manager participant groups. Note that only post-evaluation survey results are shown here, as IWTs for fire operations are relatively emergent and participants had not previously engaged in them.

All four participating meteorologists indicated that they somewhat (n = 2) or strongly (n = 2) agreed that IWTs for fire operations could improve operational timeliness (Figure 3.3C) and situational awareness (Figure 3.3D). Generally, participating land managers agreed, in that all but one indicated that they somewhat (n = 2) or strongly (n = 2) agreed that IWTs for fire operations could improve operational timeliness (Figure 3.3C). Survey findings of improved operational timeliness and situational awareness align with focus group findings in that Tactical IWTs were described by NWS meteorologists to be a "force multiplier" due to the collaborative design, which LMs described as a way to strengthen fire response more broadly.

The post-evaluation survey results complemented focus group findings in that IWTs for fire operations could support enhanced communication between meteorologists and land managers. Figure 3.3E shows that all four meteorologists strongly agreed that IWTs for fire operations could help them in communicating with land managers, and all five land managers somewhat or strongly agreed that IWTs for fire operations could help them communicate with local meteorologists. Further, all participants somewhat or strongly agreed that the IWTs for fire operations would help their office or agency communicate with the public (Figure 3.3F) and with other fire partners (Figure 3.3G). These survey findings were corroborated by focus group findings, including NWS meteorologists' perceptions that Tactical IWTs can help build rapport and trust between agencies and by LMs expressing that Tactical IWTs can help keep collaborating agencies on the same page.

Post-evaluation survey results show that all five land managers somewhat (n = 3) or strongly (n = 2) agreed that IWTs for fire operations would be *feasible* for their agency. Of the meteorologists, most (n = 3) agreed that IWTs for fire operations would be feasible for their office, with one participant indicating that they neither agreed nor disagreed (Figure 3.3A). All participants indicated that they somewhat agreed (n = 8) or strongly agreed (n = 1) that IWTs could be adapted to their respective agency or office and their fire partners (Figure 3.3B), though all somewhat agreed (n = 3) or strongly agreed (n = 6) that regular training or education for their agency or office would be required for Tactical IWT adoption and implementation (Figure 3.3I).

Perhaps related to training and educational needs, both NWS meteorologist and LM participants were less agreeable in terms of whether they felt their agency or office and associated fire partners would implement and use the Tactical IWT process (Figure 3.3H).

These results align with focus group findings in terms of the potential challenges in implementing Tactical IWTs for fire operations. Accordingly, six of the nine participants strongly agreed that implementing IWTs for fire operations would require training for their agency or office, aligning with focus group findings about the need for consistent training and flexibility and scalability of the IWT for fire operations structure. Thus, while the Tactical IWTs were perceived to offer various operational benefits, implementation challenges were recognized by participants, as they were in the focus group discussions.

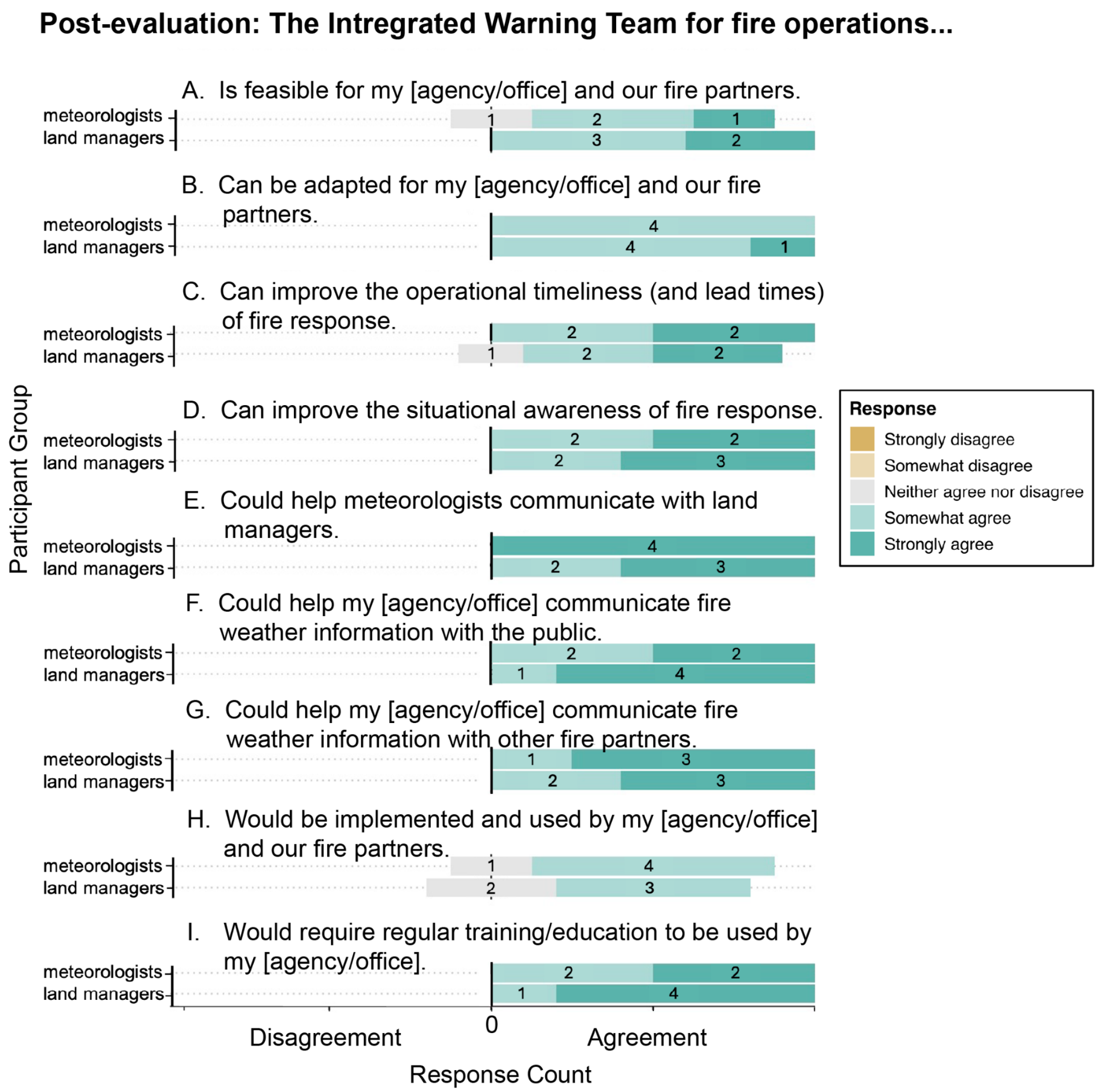


Figure 3.3: Post-evaluation survey results on participant's indicated level of agreement with various features and qualities related to the functionality, utility, and feasibility of **Tactical Integrated Warning Teams for Fire Operations,** as measured along a 5-point Likert scale (1 = Strongly disagree to 5 = Strongly agree). The results are broken down by the meteorologist (top) and land manager (bottom) participant groups.

Participant Recommendations for IWT for Fire Operations

The following recommendations and synthesized findings (Figure 3.4) represent participant-provided insights and suggestions for improving the process and composition of the IWT for fire operations to better meet their and the public's needs. We indicate meteorologist- or land manager-specific recommendations; however, many of these recommendations overlap or are related.

Figure 3.4: Summary diagram showing focus group findings and recommendations for meteorologists and land managers for the Tactical Integrated Warning Team for Fire Operations workflow as a complete process.

3.3 Fire Warnings

Fire Warnings, as mentioned earlier in the report (Section 1.5), are currently pass-through non-weather emergency messages requested and written by land/emergency managers and disseminated through the NWS messaging infrastructure. However, a new experimental approach to Fire Warnings, which have been utilized within Oklahoma and the Texas panhandle, established a collaborative approach to issuing Fire Warnings between NWS Meteorologists and state forestry or local EMs/firefighters. This promotes a more proactive approach to warning on threats posed by wildland fires by employing the end-to-end workflow of Tactical IWTs for Fire Operations (Figure 3.5). The testbed environment enabled a unique opportunity to evaluate the process of meteorologists and land managers to collaboratively determine whether to issue Fire Warnings and where to draw the warning polygons in the context of Tactical IWT Fire Warnings. During the end-of-week focus group discussions, both NWS meteorologist and land manager participants were asked to share their thoughts on the utility of Fire Warnings as well as barriers to issuing them in their respective offices/agencies. Like the previous section, focus group findings regarding Fire Warnings are divided by each participant group, with strengths and concerns thematically presented throughout. At the conclusion of this subsection, we provide participant-identified recommendations regarding the use and issuance of Fire Warnings.

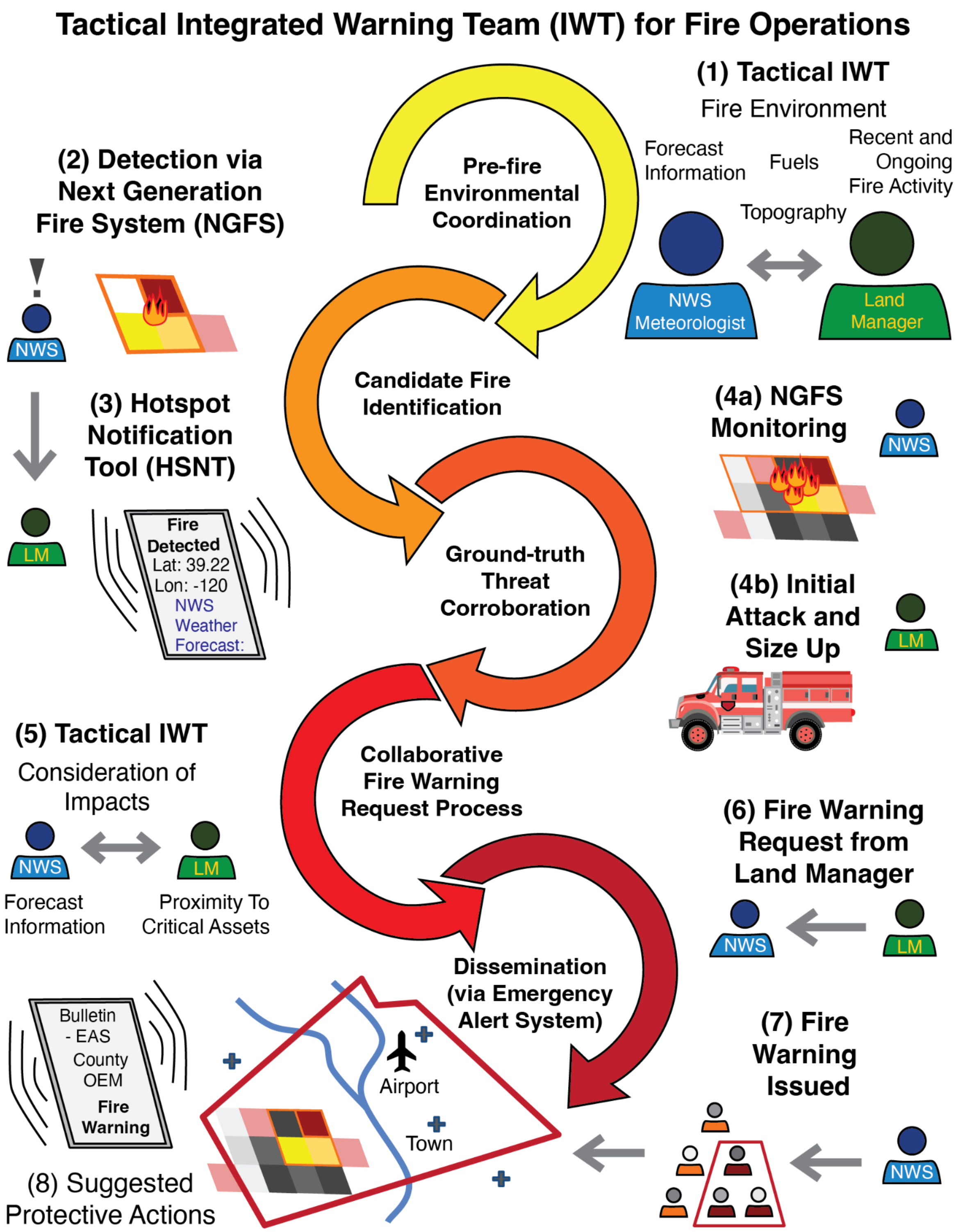


Figure 3.5: Schematic of the workflow involved in issuing fire warnings using a Tactical Integrated Warning Team for Fire Operations. Steps 1-7 were evaluated by the NOAA Fire Weather Testbed and are bolded; suggested protective actions (Step 8) was not evaluated. Figure from Wells et al. (2025).

NWS Meteorologists

Fire Warnings in Practice: Identified Benefits and Opportunities for Use in Operational Settings

When asked about their thoughts on issuing Fire Warnings in collaboration with land manager partners, one theme in particular rose to the top of the discussion. NWS meteorologist participants believed that Fire Warnings could be a powerful risk communication tool primarily designed for the public. The utility and potential impact of Fire Warnings issued in coordination between NWS WFOs and land management agencies could bolster the messaging provided to the public for awareness building and action for wildfires that threaten lives and property. As one meteorologist explained:

> *And if the public knows and the media knows that it's being issued not just by the Weather Service, but by land managers or emergency management in conjunction with the weather service, I feel that makes the warning stronger.* (Met 2)

Another shared that:

> *The Fire Warning is a tool that fire officials, land managers, emergency managers need to have in their toolbox so that we can prevent future loss of life or fire, similar to the Camp Fire or the Lahaina Fire, to provide lifesaving information to the public.* (Met 1)

All NWS participants saw value in the use of Fire Warnings, explaining that it not only provides another "tool in the toolbox" (Met 1), but that it is aligned with the NWS mission of protecting life and property. This extends not only to the general public, but for warning fire fighters and operational teams of the changing weather that can impact their operations and safety. The following quotes illustrate this sentiment:

> *I definitely leave here at the end of the week that it's a the fire warning is like a tool in the toolbox that I think we need if our mission is life and property, and I actually see it more so at a level below Cal Fire in my state, meaning my emergency managers, my local fire chiefs, so on and so forth. Where like I said yesterday, super rare scenario. But that they could call up and be like "Hey, Monterey forecaster, could you please issue this Fire Warning?"* (Met 1)

> *...it's 100% necessary for what we do and to meet our mission...I don't have to worry if there's a fire that it's racing towards a community in my area that we can at least get some notification on, and nothing to prevent as much as we can the loss of life or property.* (Met 4)

> *I think that there are probably a lot of roadblocks that we're going to have to smash through, both in our agency and in our partner agencies. And it will probably take a bit of time. I think it's [Fire Warnings are] worth pursuing it 100%...if you had that warning and it could be WEAed and it was just for that area, then the firefighters*

they're going to get that on their phone. And so I don't have to, like I felt helpless during that, I'm like these firefighters, I know they're out there. I know they know this but still there ended up being groups of firefighters that were stuck on some of the highways as this fire went around them. I saw some amazing pictures, but I might have been able to prevent that. So even not just the public, but as an IMET so I've. So I think it's certainly something we need to do. (Met 2)

According to NWS meteorologists, and as exemplified above, Fire Warnings seem especially appropriate for the public's consumption, and there is added value to the IWT approach to Fire Warnings given that it would be a collaborative issuance - which may increase public trust in the warning.

Considerations and Concerns about Fire Warnings in Operations

NWS meteorologist participants reported three overarching concerns and issues (both experienced and perceived potential issues) to determining and issuing Fire Warnings: 1) difficulty determining where to warn as well as how to integrate "buffer zones" that may not be considered or deemed critical by land management partners; 2) a general sense of hesitation in trusting their gut around suggesting the need to issue Fire Warnings or not, while acknowledging that they are not experts at fire behavior; and finally, 3) determining who will make the decision(s) to issue/not issue Fire Warnings.

Some NWS participants expressed difficulty they experienced in determining where to warn, including how to integrate "buffer zones" in collaboration with their land manager partners. This is evidenced by the fact that different paired "teams" during the evaluation had different descriptors/communication styles for how and why to outline a warning polygon a certain way. In one state team, the meteorologist provided descriptive information about the speed, direction, etc. of a simulated fire that would directly inform the polygon. A meteorologist belonging to another team, by comparison, was receiving and acting upon "bounds" provided by their land manager partner to create fire warning polygons.

Just like any other warning. Tornado warning, hurricane warnings that the risk. How's the risk? Right. And then we went with land managers and decision makers on evacuations, they're thinking, all right, where were the bounds of our evacuations? That's where we want to warn versus we need that buffer zone because we don't I mean, there's there's some things that just aren't predictable. (Met 4)

While land managers were requesting more precise polygons around an active fire, meteorologist participants - in other warning contexts - are accustomed to "buffering" a warning polygon. Buffering means making the polygon larger on a side (or sides) than explicitly provided by model and/or forecaster guidance to account for inherent forecast uncertainty and expected storm motion. Here, buffering pertains to the expected and/or simulated fire spread.

Relatedly, and also centered around the importance of trust and familiarity with their land management partners, NWS participants reported hesitation and a sense of unease in terms of trusting their gut when issuing Fire Warnings in a real-world setting. Indeed, they had difficulty determining where to warn, which required contact with land managers to determine. This experience differed from typical "warned" events that they commonly issue. Some acknowledged that since they are not the experts in fire behavior, it required them to work closely with their land management partners. To create and maintain close working relationships with the appropriate land managers requires time and commitment, especially in areas that do not already have relationships established.

Finally, and embedded throughout many of the previous concerns, is determining who/what entity is responsible for issuing Fire Warnings. Some participants shared concerns about delineation of boundaries and responsibilities depending on where a fire is occurring and the potential for power struggles as to who ultimately gives final approval (e.g., on Federal or State lands v. non-Federal/county-specific lands).

> *So in my area I think that if [..] we didn't have the emergency manager being an approving source, they would not appreciate that specifically. They would feel like they're being blocked out, from something that they should not be…because if they're the ones they like to call their evacuations, right?… But ultimately they're…not a lot of them know about…wildland fire. So I know if I'm talking about a federal forest, a national forest, they're going to want to make that decision for their fire, you know, or for whatever's going on. But I think it's a group. I think there's a group there that is going to want to be involved (Met 4)*

Land Managers

Fire Warnings in Practice: Identified Benefits and Opportunities for Use in Operational Settings

Similar to NWS meteorologist participants, land manager participants during the end-of-week focus group shared that a key strength of Fire Warnings is that they can serve as a public communication tool. Additionally, Fire Warnings were often discussed in the context of the IWT system as a whole, with some participants explicitly expressing that they would like to issue Fire Warnings: *"I'm on a five-year plan. I hope to issue a Fire Warning in the next five years."* (LM 2) Another explained that:

> *Our partnerships are already in place. We communicate regularly, frequently. So I think we just have to come together and define the process for the Fire Warnings…So I think it's going to be relatively easy for us to implement. I don't see any stumbles at all. Everything's in place, all the, all the lines of communication…if we decide to do it with the state, it will be an easy, easy toggle to turn on for us.* (LM 5)
>
> ***I think the public, particularly in [State], the public is looking for it. Like there's social media sites now that have hundreds of thousands of viewers and people that***

> ***log in, just to look up where the fires are, what they're doing, what do they need to be prepared for? So I think there's an appetite that's already there by the public, and I think we, are leaning forward to try to figure something out. So I think that this [NWS Fire Warnings] would be accepted by us.*** *It would have to be like [LM 1] had said, this guy…**it would have to be socialized quite a bit.*** (LM 3)

> *Yeah, I think it would be accepted. I think the folks that would like it are not only like our [operations] folks of just identifying areas of potential hazard for that warning, but also our [communications] folks. So all of our PR wise push it out on social media and getting that so…We still have large areas of populations…that are very sparse…So to get it out to them, we're not we're not telling you to evacuate. What we're telling you is that there's a [Fire] Warning here…you need to be aware that there's a fire on the other side of the hill. And I think our [communications] folks would appreciate that portion of it.* (LM 3)

Considerations and Concerns about Fire Warnings in Operations

While land managers who participated in the evaluation generally see value in the use of Fire Warnings, they shared notable caveats about their implementation. Land manager participants expressed both experienced and perceived or anticipated barriers to issuing Fire Warnings. First, there was a general consensus that some members of the public may be unfamiliar with local fire culture and that Fire Warnings may not be taken seriously, which could be amplified when Fire Warnings are not issued intentionally or are issued too often: *"I want to use [Fire Warnings] so sparingly that when the public does receive a fire warning, they're like 'Oh my god, I got one…I don't ever get these.'" (LM 2)* Relatedly, and along the lines of public risk communication, all participants expressed or supported concerns that the public may confuse Fire Warnings with other fire weather products and directives, such as Red Flag Warnings and evacuation orders:

> *My only caveat to the whole thing is…is how the public is going to react to that Fire Warning and make that differentiation between a Warning versus an evacuation. I think some of the IWT stuff that goes on and the coordination piece before that button gets hit, can smooth that out.* (LM 1)

> *I want to emphasize the language piece on the whole thing. So like fire weather forecast and all that language that comes out of NWS, it's very, very standard. It's very, very canned. So everyone knows what it means. If we were sending out messaging to the public and they are wandering around during the summer going camping, and the message is different from something they're used to, they're going to react.* (LM 1)

Further, warning authorities and bureaucracies in place at the state-level for coordinating and issuing a Fire Warning can be complex, with differences across states for disseminating what would ultimately be a Fire Warning. For example, the authority to issue an evacuation warning varies by state, and that may not be the same authority who could issue a Fire Warning (e.g., Governors, state emergency management agencies, or local officials like the county Sheriff's office). In the roundtable discussion, participants noted that coordination would be difficult, as the IWT process could vary across regions, with one participant asking, "*Who is going to be a part of that working team?*" and expressing concern that many different stakeholders may want to be involved.

> *There's six levels…state government wise, that it would be the local jurisdiction and then it would be the local law enforcement, and then it would be, the State Operations Center EOC person to say, 'Yes…I think it's doable'. But we'd have to bring all of those players in to say, just like [LM 4] said, like, give us that roadmap, that presentation, so that we can bring all those folks in to say, 'Hey, this is something that we want to put out for the public'. Or, we don't say anything to them, and you all [NWS] just start doing it. And then eventually the state will have to accept it, adapt to it. (LM 2)*

Beyond local and state jurisdictional involvement, there was an expressed need to involve federal partners "*…even if it's just an informational campaign or something, you're going to have to include federal partners in this if it's going to be used in incident management teams" (LM 2).*

Land manager participants viewed the current restrictions on issuing Fire Warnings as a significant barrier, noting that the NWS requires secondary permission or approval to issue such warnings. They argued that, like flash floods, fires are directly influenced by weather, and therefore the NWS should be empowered to issue Fire Warnings without external authorization. As one participant put it, "*A fire would not happen without weather, just as a flash flood would not. So I think, you know, there needs to be some kind of policy change that says, 'Hey, this is a fire emergency'. You [NWS] should be able to punch the button and issue it.*"

On the other hand, NWS participants generally felt it was important to consult land management partners before issuing a Fire Warning, recognizing them as the experts in fire behavior. Despite this difference in opinion, both groups highlighted the bureaucratic processes involved at the state or local levels could slow or complicate Fire Warning implementation. For example, in the roundtable discussion, land managers expressed strong views on the current classification of Fire Warnings as non-weather products, which prevents their dissemination through the Wireless Emergency Alert (WEA) system. Many considered this policy outdated and a hindrance to effectively reaching the public in urgent situations. One participant questioned, "*How is a flash flood a weather emergency and a fire is not?*" and others noted that fires are often weather-driven. Many advocated for reclassifying Fire Warnings as weather products, which would allow for their delivery through WEA, ultimately enhancing public reach and impact.

Survey Results: Fire Warnings

Echoing the general favorability of Fire Warnings in focus group findings, all nine participants indicated in the post-evaluation survey that they strongly agreed that the Fire Warnings would be useful for communicating risk to the public (Figure 3.6B) and would be a beneficial addition to the fire weather suite (Figure 3.6C). Nearly all participants strongly (n = 8) agreed that Fire Warnings would help improve situational awareness of emerging fire incidents (Figure 3.6F). However, and as explained during focus group discussions, most participants were neutral (n = 1 land manager) or somewhat agreeable (n = 3 meteorologists and n=3 land managers) on the ease of implementation of Fire Warnings for their office or agency (Figure 3.6D). Similar to implementing Tactical IWTs for Fire Operations, all participants somewhat or strongly agreed that issuing Fire Warnings would require regular training for their office/agency (Figure 3.6E). Focus group findings echoed this in that participants recommended public education campaigns as well as training on approaches to jointly issuing Fire Warnings between NWS meteorologists and land managers.

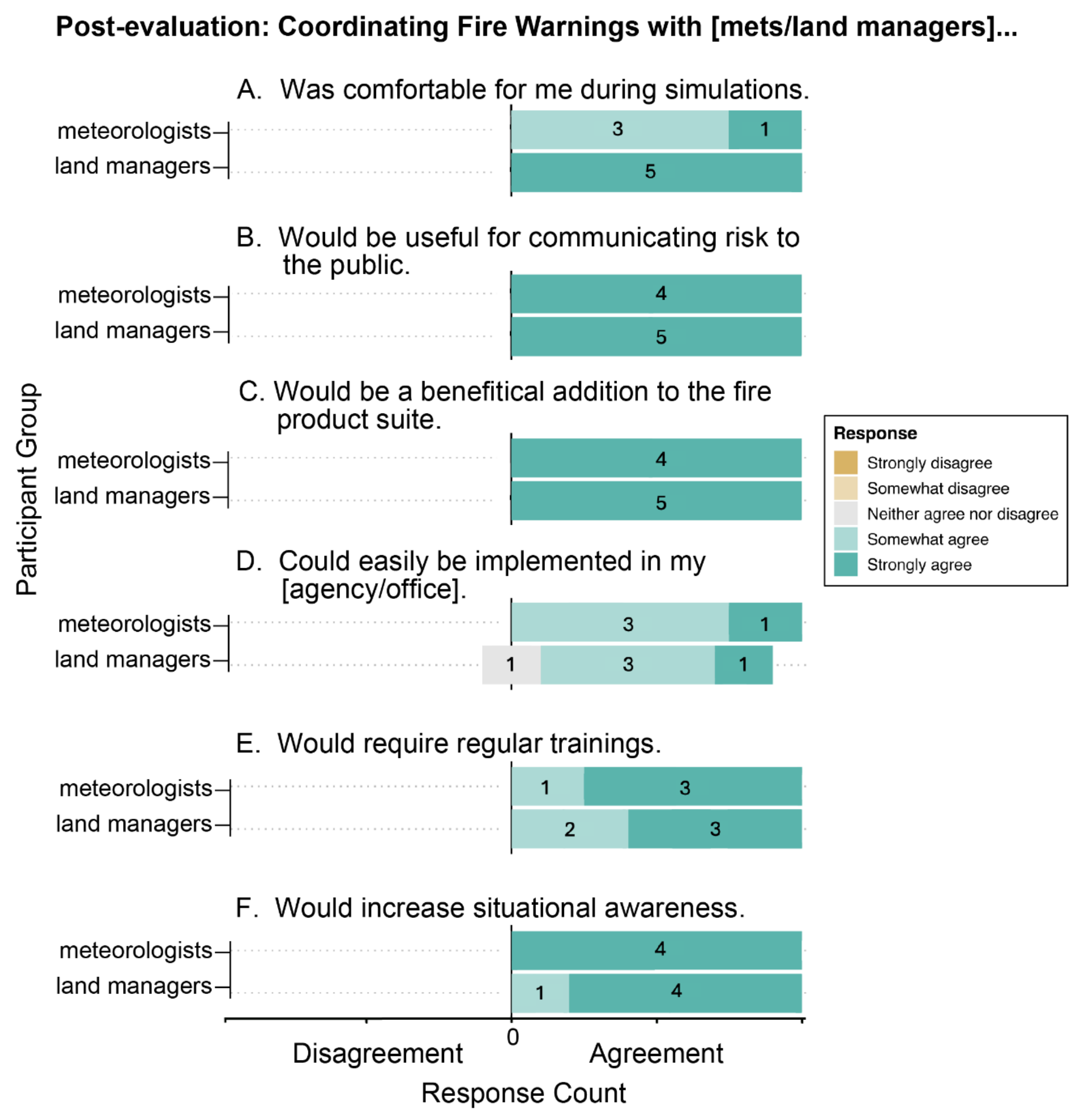


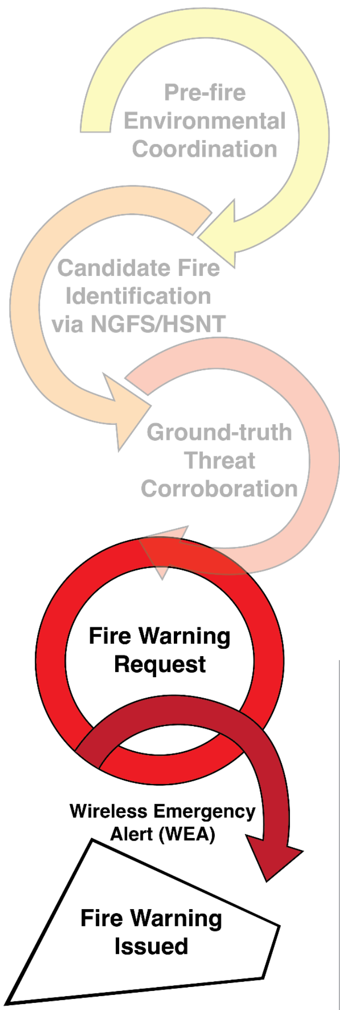
Figure 3.6: Post-evaluation survey results on participant's indicated level of agreement with various features and qualities related to the functionality, utility, and feasibility of NWS Fire Warnings, as measured along a 5-point Likert scale (1 = Strongly disagree to 5 = Strongly agree). The results are broken down by the meteorologist (top) and land manager (bottom) participant groups.

In the pre-evaluation survey, two meteorologists explained barriers to issuing Fire Warnings involving in part a lack of familiarity or a lack of guidance around the Fire Warning issuance process as well as complications or lack of clarity around who ultimately has the authority to issue Fire Warnings. This is further compounded by the fact that, for one meteorologist's particular CWA, instances where Fire Warnings may apply are rather rare events and could lead to media scrutiny or parent agency ramifications. Three meteorologist participants expanded upon their previous survey responses about potential barriers and challenges to issuing Fire Warnings that "the lack of an event would be the largest barrier" along with "determining real-time intel of the fire" and whether a threat truly exists, and the lack of training, workflow, and processes or policies for issuing Fire Warnings.

Participant Recommendations for Fire Warnings

The following recommendations (Figure 3.7) represent participant-provided insights and suggestions for improving the process and composition of Fire Warnings to better meet their operational needs, separated by participant group.

Focus Group Outcomes: Fire Warnings



Meteorologists

Strengths

1. Powerful risk communication tool to bolster awareness and protective action
2. Aligns with NWS mission to protect life and property
3. Very appropriate for public consumption, especially given collaborative issuance with land managers

Concerns

1. Delays in satellite data availability
2. Unsure who will make final decision(s) to issue warning; power struggle potential
3. Difficulty in determining warning polygon (i.e., adding a buffer zone)
4. Hesitation of 'gut instincts' to suggest warning need (or not) given lack of fire behavior expertise

Land Managers

Strengths

1. Serve as useful public communication tool
2. Desired tool to have as part of IWT system as a whole

Concerns

1. Public may confuse with other NWS fire products such as fire weather watches and red flag warnings
2. Public may confuse with evacuation warnings and orders
3. Complexities in delegating authorities and bureaucracies could slow process
4. Need for NWS to have land manager approval to issue warning

Focus Group Recommendations

Meteorologists

1. Training needed for NWS mets that emphasizes collaborative process for issuing FRW and fire behavior
2. Training needed for public to discern among other fire products
3. Integrate FRW into Hazard Service

Land Managers

1. FRW disseminated through WEA as well as other mechanisms
2. Allow NWS to issue FRW without secondary permission/input of LM
3. Capability to tailor FRW to specific area rather than county-wide
4. Insert FRW into NWS outreach and training
5. Link to information sources as part of FRW
6. Ability for land managers and mets to view a proposed warning area

Figure 3.7: Summary diagram showing focus group findings and recommendations for meteorologists and land managers for the fire warning step in the Tactical IWT for Fire Operations workflow.

3.4 Integrated Fire Operations

The final section of the focus group interview guide for both NWS meteorologists and land managers asked, "Did you find that the integrated NGFS and Tactical IWT for fire operations system felt cohesive, like they belong together? Why or Why not?" with additional sub questions regarding whether it is necessary for the NGFS tool to be a part of the IWT fire operations process and if they envision these being easily integrated into existing workflows.

Rather than breaking out this section into strengths and barriers across interviewee groups, we present key themes in a combined fashion - noting instances where land managers or NWS meteorologists shared additional feedback.

Both NWS meteorologists and land manager participants reported that while the NGFS and Tactical IWT approach *could* be implemented separately, they work well together. For instance, at least three land managers agreed that:

> *I don't think any of them [the evaluated products] are mutually inclusive. I think they play well together in some instances, but I don't think you have to have it. It's not all or none, right, and so okay I think they're modularized and you can use them to your benefit (LM 2).*

Several NWS meteorologists echoed this sentiment, one expressing that "They [IWTs and NGFS] can be implemented separately, but they're better together" (Met 1). While land manager participants discussed regional considerations for the use of NGFS, particularly in California, they saw value in implementing IWTs and Fire Warnings:

> *[State] is sort of a unique case, I can't speak for other systems, but like for the NGFS, there was limited value for that in [State]. But the IWT's and the Fire Warnings, there's definitely value with those. So, well, granted they can be linked together, but where we're at in our detection side, the NGFS has limited applicability (LM 1).*

Throughout both focus group interviews participants either explicitly or implicitly referred to the importance of trust and relationship development for these processes to be effective. From one meteorologist's perspective, they used the example of feeling comfortable "pushing back" on fire warning polygon outlines, and how an established relationship with their land manager partners is necessary to have these types of conversations. Further, and similar to their feedback on Fire Warnings, land management participants expressed a need for *"...coming together, meeting, talking, doing a little bit of training together, building that confidence, building that trust. And and not only doing that initially, but continuing to do that."* They went on to explain that, *"You can't, I can't come and meet you, have a little bit of training, go our separate ways, and be done…. So I don't want me and you coming together, meeting initially, going our separate ways, and then five years later, we have a huge outbreak (LM 2).* Thus, fostering trust and confidence between NWS and land management partners in issuing Fire Warnings might involve regular training and meetings based on evaluation experiences.

Whether as a standalone approach or in connection with NGFS, land manager participants highlighted the importance of coordination across state lines, suggesting somewhat of a regional approach to IWTs based on climate, fuels, and sociopolitical factors. We include the exchange below between two land managers to illustrate:

> *Well, and like I said, I really like the idea of the Southern Great Plains because they have common fuels, you guys have common fuels. Common weather. (LM 2)*

> *Common political, social issues… (LM 5)*
>
> *Yeah, and so I was thinking the same way with the [Region] is, just common fuels, common political, common weather patterns that cause fire. And, you know, it'd be nice to throw up a, "hey, you know, we have, you know, a high probability" … not necessarily of severe fire, but a high probability of ignitions today, you know, or whatever. (LM 2)*
>
> *And the benefit of those, right, is, well you can always throw lines on a map, the benefit of these Southern Great Plains and what, what the colleague at the end of the table [LM 2] is recommending is that it raises the GACC boundaries. Right. Because we we tend to put these little boundaries, little fences up, and we tend to want to play within them. But but I have more in common with the [other GACC A] and [other GACC B] than I do the [assigned GACC]] that I sit in, that my state sits in, right, so. And, to me, my relationship with the states to the south of me is closer to my reality than the states that I'm lumped in with. (LM 5)*

Such feedback makes central the perspective that no one tool, technique, or model will likely address *all* weather information needs leading up to and during wildfire threats; however, identifying ways to improve coordination and collaboration will enhance the overall mission toward protecting lives and property by bringing together various disciplines and agencies needed for understanding and responding to often complex wildfire events.

4. FWT Discussion

Throughout the evaluation, participants shared detailed feedback, preferences, and recommendations on the products and processes being assessed during challenging, high-end wildfire outbreak scenarios. Many of the scenarios could be, or are (e.g., Marshall Fire, Smokehouse Creek Fire, and Lionshead Fire), considered as 'career' defining due to the number of ignitions, rapid rates of fire growth, and immediate threats posed to life and property This section synthesizes key themes from focus group data, highlighting significant challenges and contextualizing participants' feedback. By examining these themes, we gained a deeper understanding of the logistical and operational complexities participants' faced. This analysis was essential in shaping our overarching findings and actionable recommendations presented in Section 5.

4.1 Challenges and Considerations for Building Effective Tactical IWTs

Throughout the evaluation, participants actively shared comments, posed questions, and suggested ways to assemble Tactical IWTs within their home operational environments. As discussions progressed, the complexities of constructing effective Tactical IWTs became apparent, particularly regarding which agencies should be included in the warning decision process and how official warning authority should be delegated.

Participants agreed that the IWT for fire operations model established in the NWS Norman operational area seemed well-suited for the Southern Great Plains' agency partnerships and wildland fire environment. However, they highlighted that land management needs, resources, and capacity vary substantially across different regions and states. For example, California employs over 12,000 state-level firefighters, while Kansas has fewer than 10, relying more on local jurisdictions and regional/national support. Fire detection capabilities also vary by region— some states use advanced technological systems like the U.S. National Guard's FireGuard fire detections (now available over the CONUS), while others rely more heavily on population density and ground reports. These variations could influence how Tactical IWTs integrate the NGFS and HSNT into their workflows.

While this evaluation primarily focused on land managers in state forestry agencies, participants raised questions about the potential role of local emergency managers (EMs) in the Fire Warning process. EMs serve as key partners to local NWS WFOs, working closely with local first responders possessing valuable knowledge of their communities, infrastructure, and evacuation authorities. While they may not be experts in fire behavior, participants pointed out that emergency managers in rural jurisdictions are sometimes part-time and, during emergencies, may face resource limitations and challenges in coordinating with external organizations. While the involvement of local emergency management in the Tactical IWT process may vary by situation or jurisdiction, participants generally agreed that their inclusion would be beneficial.

Participants also posed questions about the potential role of Incident Management Teams (IMTs) in Tactical IWT decision-making. IMTs oversee all facets of a wildland fire response, have greater fire suppression resources, and possess extensive incident management experience. However, IMTs may not engage in regular communication with the local NWS WFO, except to request forecast information. If a NWS IMET is deployed to a fire, they could potentially serve as a liaison between the IMT and the local NWS WFO, facilitating better communication. However, once IMTs are deployed and established at a fire scene, evacuation orders may already be in place, reducing the urgency of issuing Fire Warnings. Participants indicated that if fire conditions unexpectedly worsened beyond initial forecasts, closer collaboration between IMTs, Tactical IWTs, and local NWS WFOs would be critical to adjust response efforts in real time.

As jurisdictions consider the integration of Tactical IWTs into fire operations, several additional factors should be addressed to ensure their effectiveness. Variability in jurisdictional policy, differing organizational and operational objectives, available resources presents challenges in standardizing Tactical IWT implementation across different regions. Additionally, interagency collaboration remains a critical component, and relationship-building between NWS WFOs and other partner agencies may be needed in some areas.

4.2 Interpretation and Potential Utilization of Tactical IWT-driven Fire Warnings

Throughout the evaluation, the mock Tactical IWTs made decisions to issue Fire Warnings in the context of alerting areas under threat of swift-moving wildland fires that threatened local communities, with a potential need for evacuations. Some participants, primarily land managers with experience serving as Incident Commanders for IMTs, identified other potential applications of Fire Warnings. One participant suggested Fire Warnings be treated as pre-evacuation warnings, another suggested that a Fire Warning could serve as the final alert for a wildland fire pushing into a community, following the issuance of an evacuation warning rather than preceding it. However, these suggestions indicate multiple, possibly conflicting, interpretations of the Fire Warning product in addition to possible conflation with other fire and evacuation alerts that can influence decision making.

Some land manager participants proposed that the authority to issue Fire Warnings be granted exclusively to NWS meteorologists, eliminating the requirement for authorization from land managers. Notably, this suggestion came from land managers with close, pre-existing relationships with their local NWS IMETs and Fire Weather Program Leaders, and as such, this sentiment highlights the high level of trust between coordinating NWS and state land management agencies. However, meteorologist participants noted that essential fire behavior expertise and on-the-ground intelligence reside outside of the NWS.

4.3 Simulated Fire Warning Issuance during the FWT Evaluation

Since the introduction of the Fire Warning as a non-weather emergency, pass-through product by the NWS in 2006, a total of 461 warnings have been issued through the year 2024 (Figure 1.2). It is estimated that at least 36 of these Fire Warnings were collaborated through local IWTs.[2] During the seven displaced real-time simulations that were executed during our evaluation, participants issued 74 IWT-driven Fire Warnings, more than double the number to have been issued in actual operational contexts. The precise count of real-world Fire Warnings issued through the IWT framework is unclear, as it is challenging to determine whether these warnings are issued collaboratively or exclusively by the direction of emergency management.

Notably our participants, primarily land managers, were fairly trepidatious about the concept of Fire Warnings at the start of the evaluation, raising legitimate concerns about their use, implementation, and public reaction. By the end of the week, after significant exposure to the IWT-driven warning process and testimonials from developers of this comprehensive approach, nearly all participants recognized the advantages of having the Fire Warning as a valuable tool for alerting the public about rapidly spreading wildland fires that pose risks to life and property.

In the simulation of the Simpson Road Fire, occurring on 31 March 2023 in north-central Oklahoma, we analyzed the simulated Fire Warnings issued by our participants alongside those issued during the wildland fire outbreak by NWS Norman (Figure 4.2). Visual inspection revealed consistency between participants' simulated Fire Warnings and the Fire Warnings issued during the event by NWS Norman. The warnings issued look to be of comparable sizes, with similar buffering to account for potential uncertainty. Simulated Fire Warnings did extend further northward, but that was likely due to the provided fire spread model showing a similar bias. These findings suggest that the simulated Fire Warnings accurately reflected the real-world issuance, demonstrating that, with appropriate models and input data, participants' predictions could align with operational decision-making during actual wildfire events. This consistency highlights the potential of using such simulations as valuable training materials for issuing IWT-driven Fire Warnings.

[2] The NWS does not differentiate between IWT-driven and non-IWT-driven fire warnings, making them difficult to track.

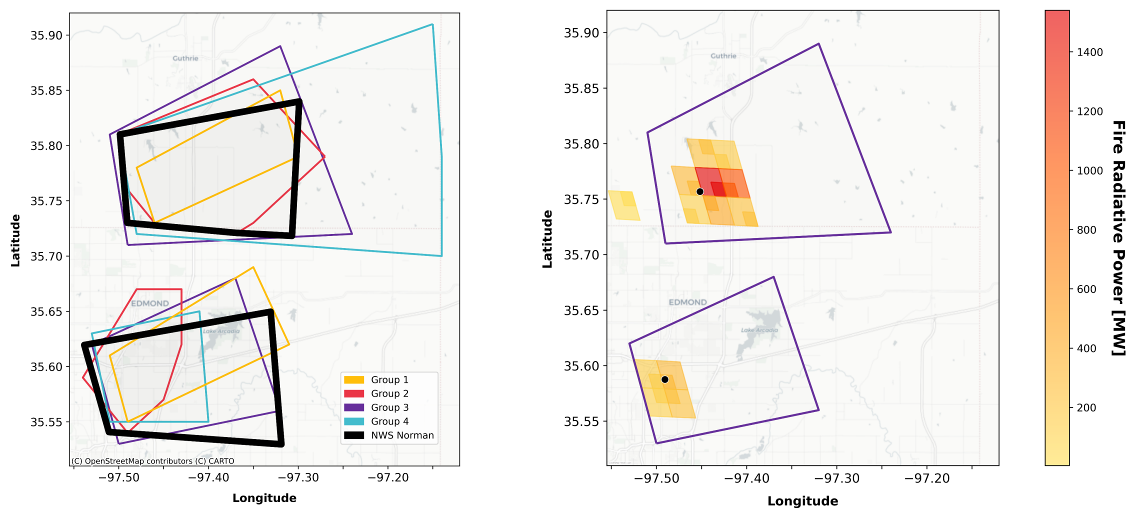


Figure 4.2: (left) A comparison between the Fire Warnings issued during the Simpson Road Fire by Oklahoma Forestry Services and the NWS Norman (bold, black boxes), and the four mock Tactical IWTs in the FWT evaluation (thin, multicolored boxes.) (right) An example of the Fire Warnings issued by one of the paired teams, alongside calculations of Fire Radiative Power (warm colored boxes) provided by the NGFS and the locations of distributed Hotspot Notifications (black dots) during the evaluation.

5. Overarching FWT Findings and Recommendations

The overarching findings and recommendations presented here are a culmination of feedback and recommendations provided by our participants, facilitators' experiences during the evaluation, as well as applied operational and institutional knowledge from the scientists at the FWT and SBS Branch of NOAA's Global Systems Laboratory (See FWT Role and Collaborative Approach in Section 1.6).

> **Overarching Evaluation Finding (NGFS, HSNT, IWT, and Fire Warnings):** *The Next Generation Fire System, Tactical Integrated Warning Team for Wildland Fire Operations, and IWT-derived Fire Warnings may be uniquely adapted to address local needs and resource capacities across regions. Throughout the FWT evaluation, the individual products demonstrated their potential to address information and communication gaps while also functioning effectively as an integrated system.*

5.1 Fire Detection and Notification: NESDIS Next Generation Fire System and NWS Hotspot Notification Tool

> **Overarching Finding (NGFS and HSNT):** *The publicly accessible NGFS provides utility as a tool for fire detection and monitoring. It enhances situational awareness and serves as a safety net for forecasters. By incorporating NGFS detections, the HSNT adds capabilities for the NWS to alert partner agencies. The NGFS and HSNT should integrate effectively into NWS operational environments.*

NWS meteorologists expressed trust in the NGFS, and some participants recognized its potential to fill knowledge gaps in fire detection, particularly in remote or sparsely observed areas where emerging fires might otherwise go unreported for extended periods of time. Participants noted NGFS' utility for monitoring wildland fire spread under fire weather conditions.

Land managers also saw potential applications for the NGFS during prescribed fire operations. Specifically, NGFS could be used to monitor prescribed burns in real time, ensuring fire activity remains within planned boundaries. Additionally, Fire Radiative Power (FRP) data could help detect unexpected flare-ups early. The NGFS's ability to consolidate fire intensity into a single FRP metric makes it useful for prioritizing ongoing wildland fire response and monitoring of wildland fires.

Meteorologist participants noted that the NGFS could function as a "safety net," enhancing situational awareness and reducing workloads in WFOs. By automating the initial detection of emerging wildland fires, the NGFS would free up forecasters to focus on other mission-critical tasks. Additionally, land managers appreciated having publicly available fire detection and monitoring as an alternative to paid commercial products. It was pointed out that land management agencies with limited resources would particularly benefit from freely available NGFS data.

While participants were generally favorable toward the NGFS, they stressed the importance of usability. That is, if the tool is difficult to implement or ”doesn’t work well out of the box,” integration into operational workflows could be hindered. The following recommendations address these concerns, incorporating both participant feedback and additional insights derived from their input.

5.1.1 Overarching Recommendation (NGFS, Data Access, and Display): Integrate the NGFS into the NWS computer system (AWIPS) with user-customizable display capabilities to ensure smooth adoption into NWS operations. Expanding data access will also support integration into additional tools and common operating platforms.

Meteorologists who used AWIPS to view NGFS data in simulations found it instrumental for their operational workflows. Displaying NGFS fire detections over satellite data in AWIPS allowed forecasters to quickly verify emerging wildland fires, accelerating alerts to land management partners. Some forecasters even relied on the NGFS as a “safety net,” letting it handle the bulk of fire detections while they focused on partner collaboration or more challenging satellite interrogation.

Land management participants also expressed a need to see weather observations near fire detections. However, in areas with complex terrain, the closest weather observation may not be representative of the weather impacting the fire.

Customizable AWIPS displays were a key priority for forecasters. The ability to overlay the NGFS detections, the base satellite data the NGFS is derived from, along with meteorological or geographical data, would provide essential context to accurately interpret conditions of the wildland fire environment. Some NWS participants also recommended integrating the NGFS into existing situational awareness displays within their WFOs to enhance fire tracking in their local regions.

Because the NGFS is publicly available, it has multiple potential applications. Land management agencies could integrate it into their own operational environments or GIS platforms, while new tools such as the NWS Norman HSNT could also incorporate NGFS detections.

Participants provided several recommendations for improving AWIPS and NGFS displays to enhance usability in an operational settings:

- *Differentiate newer detections from older ones.* While FRP values were color-coded by magnitude, forecasters suggested desaturating or increasing the transparency of bounding boxes based on detection age.
- *Provide more user control over AWIPS displays.* Participants desired customization options, including an optional table format to view detections.

Ultimately, forecasters preferred flexibility in the AWIPS NGFS display while preserving the NGFS's core capabilities. More user control over how the NGFS data are presented could facilitate smoother integration into pre-existing NWS workflows.

5.1.2 Overarching Recommendation (NGFS, Training, and Documentation): Develop training materials and documentation that explain the NGFS process, including how it detects fires, integrates known wildland fire information, and incorporates uncertainty to support validation with other sources.

While most participants found the NGFS detections useful, a recurring concern throughout the evaluation was the potential for "false positive" detections. Although no false positive detections were simulated during the evaluation, participants repeatedly raised concerns that incorrect detections could hamper ground operations and erode land management agencies' trust in the NGFS. To mitigate this perceived risk, participants suggested incorporating uncertainty information alongside detections to help users gauge confidence in reported hotspots. However, it is unknown if confidence levels are inherently available or feasible to calculate within the NGFS. This concern could be addressed by establishing activation thresholds tailored to the local wildland fire environment. This method could assist in identifying prescribed or controlled burns from unplanned wildland fires, which can rapidly escalate into threats to nearby communities and infrastructure during critical fire weather conditions. Therefore, it would not be an intrinsic barrier to the NGFS, but rather a question of how it is operationalized.

Both meteorologists and land managers expressed a strong need for comprehensive and transparent training materials on how best to use NGFS data. Enhancing transparency and providing guidance on interpreting detections, validating NGFS with other sources, and understanding potential uncertainties may boost end-user trust and confidence, ultimately leading to better operational decision-making. By equipping forecasters and land management agencies with key knowledge, NGFS training and documentation would support more effective fire detection and response.

5.1.3 Overarching Recommendation (HSNT and Partner Communication): Add a mechanism for partner agencies to confirm receipt of NWS-provided hotspot notification(s) and ensure multiple communication pathways are available for agency partners to use as needed.

In the mock environment, the HSNT quickly and effectively communicated emerging wildland fire threats. Participants generally agreed that it was a useful communication tool for potential wildfire detection. Land managers found that receiving text notifications while in the field was a useful way to relay fire information to operational firefighters and emergency response personnel. However, several meteorologist and land manager participants noted that having the ability to distribute information through multiple communication channels (e.g., text, email, chat, etc) would be necessary, because the best method would vary depending on different factors. For example, several land managers noted that local dispatch centers typically would want to receive fire information via email rather than text, making this an important pathway for integration. While the evaluated version of the HSNT already supports email, this capability was not tested during simulations due to the absence of a mock dispatch center.

Despite the HSNT's benefits, participants expressed concern over excessive notifications:

- NWS meteorologists were concerned about receiving too many alerts from the NGFS
- Land managers expressed concern about an overload of notifications from the NWS sometimes regarding prescribed fires, known incidents, or false alarms.

To address these concerns, it is essential to establish notification thresholds based on agreed-upon environmental conditions during the formation of local IWTs.

All participants agreed that the HSNT would be improved by adding a confirmation mechanism to "close the loop" between forecasters and land managers. Doing so would (1) ensure meteorologists know when notifications are received and acted upon, (2) reduce the need for follow-up communication via alternative channels, and (3) minimize concerns that critical alerts are being missed during busy operational activities. By implementing a confirmation feature and refining notification thresholds, the HSNT could enhance efficiency while reducing communication burdens for both NWS meteorologists and land managers.

5.2 Tactical Integrated Warning Team for Fire Operations

> **Overarching Finding (Tactical IWTs for Fire Operations):** *Participants believed the Tactical IWT approach to fire operations, both before and during wildland fire incidents, has the potential to improve communication, coordination, and situational awareness among meteorologists, land managers, and other fire/emergency response partners, thus enabling unified public messaging and coordinated response to wildland fire threats. Concerns from both groups centered around the challenges of building, implementing, and maintaining an IWT.*

5.2.1 Overarching Recommendation (Framework): Develop an NWS framework for implementing Tactical IWTs for Wildland Fire Operations in new service areas, modeled from the Southern Great Plains "Tactical IWT model" as an initial framework while ensuring scalability to meet varying regional needs.

Throughout the evaluation, participants identified several challenges related to the structure and implementation of the Tactical IWTs. A recurring concern was role confusion, as participants were uncertain about the particular roles and responsibilities of Tactical IWT partners. While some of this uncertainty may have stemmed from differences between the simulated evaluation environment and real-world operations, the feedback highlighted a clear need for an implementation framework. Participants requested a framework for developing and executing Tactical IWTs for fire operations at the local or state level, including defined roles and responsibilities, clear delineation of authority, and customization options to fit the needs and meet the objectives of local and/or regional partners. Participants recommended using the Southern Great Plains Tactical IWT model as a starting template while ensuring scalability to meet varying regional needs. Showcasing real-world examples and best practices of developed Tactical IWTs implemented across the NWS would further support this effort, providing actionable recommendations for new adopters.

Participants agreed that the Tactical IWTs for fire operations formed in the NWS Norman's operational area seemed to work well for their partnership agencies and the Southern Great Plain's wildland fire environment. However, they pointed out that the real-world implementation of Tactical IWTs would vary regional and state differences in land management agency needs, resources, and capacities. Some regions or states may have more limited capacity and bandwidth to form, maintain, and implement Tactical IWTs for fire operations, requiring a scalable and flexible approach. Framework development should consider localized capacity and offer implementation strategies for varying levels of partner engagement. Further, Tactical IWTs should be framed as flexible decision support and situational awareness tools that best fit partner needs, capacities, and workflows. Positioning Tactical IWTs in this way could help address a key perceived barrier presented by land managers: securing "buy-in" from various core partners, especially in resource-limited locations.

Participants connected the need for Tactical IWT flexibility and scalability to the National Incident Management System's (NIMS) Incident Command System (ICS) and expressed the need for IWTs to fit into those established systems. It would be advantageous to clearly establish representatives from all involved agencies comprising a Tactical IWT within the state's Annual Operations Plan (AOPs). This would have multiple benefits, including clear definitions of each organization's roles and responsibilities within the Tactical IWTs, sharing updated contact information between organizations, and establishing dependable, overarching sources for incident information and Fire Warning authority in the event an urgent decision is required during life-threatening incidents.

5.2.2 Overarching Recommendation (Training and Coordination): To implement the Tactical IWT, ensure consistent and ongoing local training with coordination between fire partners in consideration of local jurisdictions and partner bandwidth.

Land manager and NWS Meteorologist participants emphasized the need for training and coordination in establishing and maintaining an effective Tactical IWT in their respective regions. Participants emphasised trusted relationships and operational procedures need to be established before interagency collaboration is required during an incident. Participants expressed that operational procedures and trust could be established through training exercises, consistent communication, and a mutual understanding of each agency's roles, capabilities, responsibilities, and objectives. Land managers noted working in similar, collaborative team structures within their current operations, indicating familiarity with traditional IWT concepts that could help implement Tactical IWTs with their local NWS

WFOs. Furthermore, as land managers desired timely and accurate meteorological information to support operational emergency response, planning, and preparedness decision-making, the interagency relationships established through Tactical IWTs could fill existing information gaps. Participants in areas less prone to wildfire outbreaks proposed labeling IWTs as Integrated "Working" Teams to add to their potential applications and value beyond the Fire Warning process and wildfire response operations.

5.3 Tactical IWT-based Fire Warnings

> ***Overarching Finding (IWT Fire Warnings):*** *Fire Warnings were perceived to be a valuable wildland fire alerting tool capable of relaying critical information from the NWS and land managers to other emergency management partners and the public when wildland fire poses an imminent threat to life and property. However, both land managers and NWS participants' concerns centered around determining warning authority and the potential public confusion with other products or directives (e.g., evacuation warnings and orders).*

5.3.1 Overarching Recommendation (Wireless Emergency Alerts): Explore transforming Fire Warnings from a "non-weather emergency" product into a standalone warning product with Wireless Emergency Alert (WEA) dissemination capability to more effectively communicate wildland fire hazard information to the public.

Non-Weather Emergency Messages (NWEMs) are disseminated through the Emergency Alert System (EAS), which broadcasts to television and radio stations. NWEMs are not disseminated through the WEA system, which sends alerts directly to mobile devices like a Tornado or Flash Flood Warning. Land management participants were surprised to learn that Fire Warnings are considered NWEMs since, as they explained, "a fire would not happen without weather." Current operational WEA dissemination of IWT Fire Warnings requires additional coordination with local emergency management offices/departments, which can slow down the dissemination of life-saving alerts and information.

Non-IWT Fire Warnings, which are issued directly by emergency managers through the Federal Emergency Management Agency (FEMA) Integrated Public Alert & Warning System (IPAWS), can be disseminated using the WEA system. Unfortunately, Fire Warnings issued this way do not benefit from IWT coordination, are not always geo-targeted and can alert an entire county. NWS and land manager participants expressed concern about county-level warnings as they would inherently over-alert areas that are not in immediate danger.

The prototype Fire Warnings demonstrated in this evaluation were unique. They were designed, messaged, and disseminated similarly to other short-fuse NWS warning products (e.g., Tornado Warnings and Flash Flood Warnings). Additionally, they include geo-targeted warning polygons that delineate the threat by specific area rather than by county, and they provide a structured messaging format including what, when, where, and precautionary/preparedness action information. In the Tactical IWT model, the Fire Warning still officially comes from a partner agency (e.g., state or local fire agency) but employs an approach that creates a geo-targeted, collaborative warning message.

For IWT-driven Fire Warnings to successfully alert the public of rapidly evolving wildfires that threaten lives and property, they should inherently be geo-targeted and employ the WEA system.

5.3.2 Overarching Recommendation (Training): Implement comprehensive Fire Warning training for the NWS personnel, land management agencies, emergency management agencies, and curate public education campaigns to increase effective Fire Warning implementation and response.

Throughout the evaluation, participants interpreted the purpose of Fire Warnings in different ways. Some saw them as pre-evacuation alerts or general hazard messages, while others viewed them as tools for delivering information or instructions to targeted instruction for those within Fire Warning areas. FWT facilitators observed that land managers struggled to separate these ideas, which highlights the need to clearly articulate the product's purpose. NWS meteorologists stressed the need for training NWS WFO personnel to adopt and implement the collaborative Fire Warning process, because these novel, short-fuse NWS warnings require external coordination—a practice that differs from usual operations. Participants also noted public confusion between Fire Warnings and other fire-related products (e.g. Red Flag Warnings, Fire Weather Watches, and Evacuation Warnings/Orders) could be reduced through a well-designed education and outreach campaign that clearly explains the purpose of Fire Warnings and prompts the appropriate protective actions.

5.3.3 Overarching Recommendation (Technology): Work with end-users to improve the Fire Warning product by exploring additional technological capabilities (e.g. Integrating in the NWS warning software (Hazard Services), incorporating fire spread modeling, and producing the capability to share polygons with external partners prior to issuance).

Meteorologists agreed that Fire Warnings should be integrated within Hazard Services (the NWS' newest warning software) (Schlie et al. 2025), using a template that aligns with the updated NWS warning methodology. Land managers stressed that including links to local informational sources, such as available evacuation information, would support situational awareness. They also pointed out that the current collaboration and approval process for issuing Fire Warnings presented barriers to effectively and efficiently sharing and deciding upon Fire Warning polygon bounds. As such, participants asked for the ability to share proposed Fire Warning polygons with outside partners prior to issuance.

While not evaluated here, participants responded positively to the possibility of including fire spread modeling capabilities within AWIPS Hazard Services to assist in drawing the Fire Warning polygon. If implemented, this could save time and resources for land and emergency managers who typically provide fire spread information to the NWS, and it could help meteorologists construct more optimal warnings.

Although fire spread modeling is not yet integrated into NOAA or NWS operational systems, its addition could enhance the NWS proactive IDSS approach. However, integrating this feature would require significant initial development, training, and validation in collaboration with fire partners and fire behavior modeling experts.

5.3.4 Overarching Recommendation (Communication): Include explicit wording in Fire Warning products that highlights their co-creation and joint issuance by land managers and the NWS, emphasizing the collaborative effort involved so as to enhance public trust.

Participants described the multidisciplinary nature of the Fire Warning as a "force multiplier" that can encourage protective mitigation actions and strengthen public trust. The expressed concerns that the public might confuse Fire Warning with Evacuation Warnings/Orders if the messaging is unclear. To address these issues, the language in Fire Warnings should be organized, purposeful, and explicit about the collaborative nature of the product. In addition to building trust between agencies, this approach will help ensure that the public understands that the warnings are co-produced by both land managers and the NWS. Unified messaging can build trust to motivate the public to follow prescribed precautionary and preparedness actions while they await or seek out further guidance from emergency management sources.

5.3.5 Overarching Recommendation (Build IWTs): Build Tactical IWTs to align with local and regional needs and resources, and clearly defining delegation authority, are crucial steps in issuing IWT-based Fire Warnings.

Current policy restricts the NWS from unilaterally issuing Fire Warnings for new or spreading fires (NWS, 2021). Unlike most weather hazards, wildland fire impacts can be strongly influenced by fire suppression strategies and tactics, local topography, and the spatial distribution of composition and fuels—information that lies outside NWS expertise and observational capabilities. Local land and emergency management agencies, however, do possess this critical expertise and access to this data. Therefore, developing Tactical IWTs that integrate weather information from the NWS with topographical and fuels data from local agencies is essential. Such coordinated, multidisciplinary teams will enhance decision-making for issuing Fire Warnings and ensure that authority is clearly delegated among partners.

6. Reflections: Limitations and Participant Feedback

6.1 Limitations

Evaluation Design

The FWT purposely sampled participants and designed the evaluation to mimic operational wildland fire environments; however, there are some inherent limitations that warrant consideration when interpreting our findings. First, our efforts to maintain a manageable participant group size—driven by facility constraints and evaluation design—resulted in the underrepresentation of NWS WFOs, varied geographies, and diverse wildland fire regimes across the U.S. Consequently, these findings may not fully capture the perspectives of all U.S. NWS WFOs or state land management agencies. After future development of the Tactical IWT framework, additional research including a broader range of meteorologists and state land management personnel may offer usability, utility, and implementation insights on the evaluated products.

While our evaluation design aimed to replicate realistic operational conditions, some factors may have influenced participant responses. The weeklong, in-person training attended by PIs and developers provided a controlled and intensive environment that likely differs from real-world training and implementation. We note that this controlled training environment was necessary to isolate product performance and manage the evaluation effectively. However, it is important to acknowledge that our approach was a deliberate trade-off—we prioritized gathering initial, focused feedback in a controlled setting over replicating the complexities of operational reality. Further research should assess participant perceptions under training durations and formats that more closely reflect operational realities (Hoekstra, 2024). Moreover, participants' prior familiarity with some of the archived case simulations may have influenced how participants engaged with and perceived the evaluated products. Although we intentionally selected archived cases (simulations) from locations outside of participants' home states to minimize any 'home field advantage,' we could not control for the extent of their prior knowledge. Finally, the cases were intentionally selected to encompass characteristically extreme events which may have biased participant experiences and feedback compared to more typical day-to-day operations of fire detection and response.

Not all participants knew their Tactical IWT partner prior to the evaluation, which may have affected the frequency and style of communication and overall knowledge exchange during evaluation simulations. Although familiarity with archived simulations and/or Tactical IWT partners might have influenced decision making during simulations, we do not believe it impacted participants' perceptions of the products themselves.

Several technical constraints may have influenced the evaluation findings. For instance, while the FWT collaborated with NWS STI and WDTD to build the NGFS into AWIPS for the evaluation, information provided through the NGFS Dashboard (Cooperative Institute for

Meteorological Satellite Studies, n.d.) specific to the archived cases was accessible but archived display of the NGFS Dashboard itself was not viewable. This limited evaluation feedback on the NGFS Dashboard, specifically, though we were able to assess the use of NGFS in AWIPS and for hotspot notifications. Additionally, Google Chat and text messaging were used as the primary tools for meteorologist and land manager communication throughout the evaluation, though in a real-world operational context, alternative or additional communication channels may be used. Participants also mentioned that because they had access to other participant Google Chat messages, they were occasionally prompted to take actions or make decisions during the evaluation simulations, a potential source of conformity bias (Wisdom et al., 2013; Padalia, 2014).

Focus Group and Group Discussion Limitations

Participant insights elicited during end-of-day roundtable discussions may have been influenced by social desirability bias given the presence of product developers during these discussions. To mitigate this potential bias, we conducted formal focus groups without developers present, and we used the resulting data to generate findings and inform recommendations (Krueger and Casey, 2015). We acknowledge the potential limitations and constraints of using a focus group method, such as the lack of anonymity among participants that may affect the willingness to share views openly (Krueger and Casey 2015). To encourage candid discussions, we also separated participants into distinct focus groups for NWS meteorologists and land managers.

Another significant challenge arose in parsing feedback—especially from land managers—related to the NGFS, HSNT, and IWT, as they were often conflated. The FWT and SBS teams collaborated closely to disentangle complex overlaps and consolidate participant comments and recommendations into overarching findings and recommendations for developers and decision-makers at NESDIS and the NWS.

Constraints Evaluating the Tactical IWT for Fire Operations

The evaluation of the Tactical IWT presented multiple challenges because it is a collaborative *process* rather than a stand-alone tool that can be easily replicated in an evaluation environment. Many participants were already familiar with the IWT concept from existing NWS practices, and land managers used a similar process through the NIMS. However, interdisciplinary collaboration at the level of the NWS Norman Tactical IWT Model remains largely undocumented outside of the Southern Great Plains Wildfire Outbreak (SGPWO) Working Group, which has developed its collaborative approach over more than 15 years. As a result, significant training on the Tactical IWT for Fire Warnings may be required to fully demonstrate its utility and address fire managers' concerns about adding another product to the existing suite of NWS fire watches and warnings.

6.2 Participant Feedback on the FWT Evaluation Design

During the focus groups and the post-evaluation survey, we invited and encouraged feedback on the evaluation process, including what worked well and what could be improved (see Appendix D.3). Post-evaluation survey responses provided valuable insights into how we can enhance future participant experiences and refine evaluation designs. A notable area for improvement was striking the right balance between training, simulation walk-throughs and exercises, and group discussions. For example, one meteorologist and four land managers desired additional training and walk-throughs to better clarify participant roles, objectives, and expectations before and during the simulation. Other specific recommendations included:

- Improving clarity on Google Chat communication
- Incorporating additional role playing demonstrations
- Adding more Incident Commander and/or emergency manager role players
- Swapping meteorologist and land manager roles to foster a better understanding of each other’s role
- Limiting the number of testbed observers during evaluations to reduce distractions and noise.

On the technical side , participants suggested adding landmarks (e.g., highways, county boundary lines) to simulation maps and including more fire-specific information during briefings to complement the predominantly weather-related information. Feedback from this first in-person FWT evaluation will guide future evaluation designs. In upcoming evaluations, we plan to provide additional training and walk-throughs early in the process to clearly define participant roles and objectives. We will also continue to require observers to watch remotely via a live video feed to create a more focused testbed experience.

Despite the challenges of being the first large-scale, in-person evaluation conducted by the newly established FWT— while still hiring, renovating physical space, and building out policies and procedures—participants, PIs, and observers shared many positive comments. In closing, some participants offered the following feedback on their experience during the evaluation week, as collected in the post-evaluation survey:

- “Kudos to Kyle for keeping things on track and Alex for all the background tech support with WES. The simulations were clearly thought out. I really give the whole team credit for pulling this off the way they did, I know it's no small feat. It was nice to have the social science people around as well.” (Met)
- “A big learning experience!” (LM)
- “The experience exceeded my expectations.” (LM)

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Appendix A: Evaluation Agenda

MONDAY - DAY ONE:

- Check in
- Group introductions and FWT introduction
- Evaluation overview and expectations
- Pre-evaluation survey
- Introducing the NGFS (Conceptual training)
- Introducing IWT Fire Warnings (Conceptual training)
- Introducing and Configuring the AWIPS Hot Spot Notification Tool (Tutorial)
- Case Demonstration: Marshall Fire
  - Brief/setup (15 mins)
  - Hands-on tutorial/training (75 mins)
  - Debrief (15 mins)
- Roundtable Discussion (30 mins)
- End-of-Day Survey (15 mins)

TUESDAY - DAY TWO:

- Case #1: McBride Fire
  - Brief/setup (15 mins)
  - Simulation (2 hours 30 mins)
  - Debrief (15 mins)
- Introducing the Central Region Hot Spot Notification Tool (15 mins)
- Case #2: Grey Fire
  - Brief/setup (15 mins)
  - Simulation (1 hour 30 mins)
  - Debrief (15 mins)
- End-of-Day Survey (15 mins)
- Roundtable Discussion (60 mins)
- Optional Marshall Fire Field Tour (1 hour 30 mins)

WEDNESDAY - DAY THREE:

- Case #3: Smokehouse Creek Fire Day 1
  - Brief/setup (15 mins)
  - Simulation (2 hours 30 mins)
  - Debrief (15 mins)
- IWT Showcase (Smokehouse Creek Day 2 Walkthrough) (75 ins)
- Case #4: Lionshead Fire
  - Brief/setup (15 mins)
  - Simulation (1 hour 15 mins)

    - Debrief (15 mins)
- End-of-Day Survey (15 mins)
- Roundtable Discussion (60 mins)

THURSDAY - DAY FOUR:

- Case #5: Simpson Road Fire
    - Brief/setup (15 mins)
    - Simulation (2 hours 30 mins)
    - Debrief (15 mins)
- Southern Great Plains Working Group Probabilistic Forecast (Conceptual Training) (75 mins)
- Case #6: Four County Fire
    - Simulation walk through (2 hours 15 mins)
    - Vision for a fully integrated system presentation (15 mins)
    - Debrief (15 mins)
- End-of-Day Survey (15 mins)
- Roundtable Discussion (60 mins)

FRIDAY - DAY FIVE:

- Post-evaluation survey (15 mins)
- Focus group discussions (private, recorded) (2 hours 30 mins)
- Roundtable Discussion with PIs and observers (2 hours 30 mins)
- End of Week Wrap Up and Awards (60 mins)

Appendix B: Description of Evaluation Case Studies

B.1 2021 Marshall Fire (Colorado; Demonstration Event)

The 2021 Marshall Fire ignited in the late morning (first reported at 1010 local time) of 30 December 2021 in Boulder County, Colorado near Marshall Road northwest of Superior, Colorado, during a downslope wind event that preceded a strong winter season cold front. A high wind warning was in effect for the area, which initiated a county-wide burn ban. The wildfire had two sources of ignition, an escaped holdover burn pile and disconnected and arcing powerlines. These separate fires later merged into a single fire. The Marshall Fire burned an estimated 6,000 ac. The fire demonstrated extreme rates of spread due to extraordinarily high winds, anomalously dry and snow-free conditions, and historically dry (and thus receptive) fuels following a wet spring driving fine fuel growth. The fire began as a wildland fire in grass fuels with an average rate of spread of 2.1 mi/hr that initially burned structures in the wildland-urban intermix but later transitioned into an urban conflagration with structure-to-structure spread. Pure structure rates of spread were estimated at 6,000 ft/hr. Evacuations were first ordered at 1147 local time. A total of 1,084 homes were destroyed, 149 damaged, and an estimated 2,663 were exposed either directly or indirectly. Seven commercial structures were destroyed and 30 damaged. Unfortunately, two fatalities resulted and many animals were killed.

B.2 2023 Gray Fire (Washington; Test Case #1)

The Gray Fire was first reported at 12:24 local time on 18 August 2023 as a late summer cold front moved through northeastern Washington. While the frontal system brought a slight respite from the previous four days of extreme (>100°F) heat, it was associated with moderately strong winds (20-30 mph, gusts to 40 mph) and very dry air (6% relative humidity. The fire was ignited by a faulty outdoor light owned by Inland Power in a wheatfield and ran quickly across the highly receptive grass fuel types (tall and cured wheat fields) and hilly terrain of the eastern Washington steppe landscape, making a 6.7 mile eastward run in the first two and a half hours, burning an estimated 3,000 ac. This rapid growth and extreme fire behavior (reported 30-40 ft flame lengths) quickly overwhelmed the regional response and evacuation notices were issued for numerous communities including Gray Road, Clear Lake, Medical Lake, and Silver Lake. The major interstate, I-90, was closed eight hours after ignition, limiting regional commerce. The fire burned 10,085 ac, destroyed 240 structures, and resulted in one fatality.

B.3 2022 McBride Fire (New Mexico; Test Case #2)

The McBride Fire ignited around 14:30 local time in Ruidoso, New Mexico on 12 April 2022. The ignition occurred when a drought-stressed tree fell onto power lines during a spring downslope wind event as a region of low pressure moved into the southwestern U.S. A red flag warning was in effect during this time. According to the 12 April 2022 update from the US Drought Monitor, 100% of New Mexico was experiencing abnormally dry to exceptional drought with over 50% of the state in extreme to exceptional drought conditions following an anomalously dry and low snow winter. Sustained winds of 50-60 mph with gusts reaching 80 mph limited aircraft-based initial attack. The winds and low relative humidities (<20%) promoted rapid fire spread and extreme fire behavior (crowning and spotting) in drought-stressed timber fuels and seasonally dry grass fuels within a wildland-urban intermix fuelscape. Two fatalities occurred and 207 structures were destroyed. The fire burned 6,159 ac (2,492 ha) and was contained on 7 May 2022.

B.4 2024 Smokehouse Creek Fire (Texas; Test Case #3)

The Smokehouse Creek Fire was one of numerous wildland fires comprising the greater Texas Panhandle Wildfire Outbreak of 26-28 February 2024. Record late winter heat (highs exceeding 80°F), strong winds, and inadequately forecast rapid-onset dry conditions associated with a newly-recognized-but-classic critical fire weather pattern in the Southern Great Plains (called a low level thermal ridge with overspreading strong winds; Lindley et al. 2019) produced an extremely favorable fire environment, especially for heavy accumulations of 1 and 10 hr fuels. Minimal nocturnal relative humidity recoveries favored a near-continuous burning period for existing fires. The second day of the event (the time period of the FWT evaluation) began with 30-40 mph westerly pre-frontal winds that later shifted with cold frontal passage to become northerly. Frontal passage accelerated winds to sustained 45 mph (gusts to 65 mph). Strong and gusty winds and dry air (relative humidities initially in the 15-20% range) contributed to rapid southward growth along the well-established and extensive (approaching 30 miles) right flanks of many fires. The combination of fire sizes, numbers of fires, fuel loading, and weather combined with accessibility challenges due to complex terrain made for a situation of substantial suppression difficulty (fire behavior exceeding suppression capability). Ignition sources included power lines (Smokehouse Creek) and other human activities. Multiple Fire Warnings were issued throughout the event beginning in the afternoon of 26 February, many by WFO Amarillo, Texas, who had completed training, outreach and adoption of the IWT Fire Warnings the previous week. (Lindley, 2024). Despite two lives lost, the 1,058,482 ac (1,654 sq mi; 428,352 ha; contained 14 March 2024) of burned area highlighted the potential capability of Fire Warnings at prompting people in the area to take rapid protective actions including evacuations and sheltering-in-place. At least 130 homes were lost.

B.5 2020 Lionshead Fire (Oregon; Test Case #4)

The 2020 Lionshead Fire was initially ignited by lightning during a major western US-wide lightning bust where 46,000–66,000 cloud-to-ground strokes were observed between 14-20 August 2020. Ignition coincided with extreme drought conditions and near record-high energy release components (Hatchett et al. 2024). First reported on 16 August 2020, the Lionshead fire grew slowly until a historic easterly downslope windstorm with continued extremely hot and dry conditions caused it to make a rapid westward run through numerous communities on 7 September. The FWT evaluation focused on this period of rapid growth. During this run it merged with the P-515 Fire to the south and later the Beachie Creek Fire to the west (both of which also started during the lightning bust) to form the Santiam Fire. The Santiam Fire burned a total of 402,274 ac (162,795 ha) and at least 1,500 structures. Once the easterly winds subsided and onshore (westerly) flow returned, the wind shift caused the fire to reverse its direction and spread eastward. The Santiam Fire was contained on 10 December 2020.

B.6 2023 Simpson Road (Oklahoma; Test Case #5)

Arcing powerlines during a damaging high wind event (gusts nearing 80 mph) in Logan County of north central Oklahoma were identified as the ignition source of the Simpson Road Fire on the morning of 31 March 2023. Despite an approximate ignition time of 18:40Z/13:40 local time, strong winds and extremely dry air (relative humidities into the single digits) created a favorable environment for ignition and rapid spread. The Simpson Road fire burned eastwards across the north-south oriented I-35 interstate highway. An estimated 100 structures were destroyed before the fire was fully contained on 6 April 2023. The fire burned an estimated 3,000 ac. Fire Warnings were issued for both the Hefner Road fire and the Simpson Road fire.

B.7 2021 Four County Fire (Kansas; Test Case #6)

Multiple wildfires, dust storms, and tornados during mid-December 2021 resulted from a widespread derecho event generated by rapid lee cyclogenesis within a negatively tilted shortwave trough and subsequent cold frontal passage in the Great Plains and upper Midwest. Extreme (>100 mph) winds caused numerous negative outcomes, from dust storms to downed trees and powerlines to property damage and road closures. In addition to reductions in visibility due to dust, extremely dry fuels following prolonged rainfall deficits during November and December (conditions from abnormally dry to severe drought characterized western and central Kansas) created highly receptive fuelbeds for downed powerlines to cause ignition and allow rapid spread of wildfires in the dry grass. At least 16 starts were observed with two of the largest merging into what became the “Four County Fire” spanning Ellis, Osborne, Rooks, and Russell counties. Strong winds gusting upwards of 80 mph limited air operations during the event with the exception of National Guard Blackhawks. The Four County fire prompted evaluations of hundreds of residents and ultimately burned 121,622 ac (49,219 ha) before being contained on 23 December 2021. Two people were killed, three hospitalized, and over 42 structures were destroyed in the Four County Fire.

Appendix C: Focus Group Questionnaires

For Appendices C.1 - C.2, bolded questions were asked by the FWT evaluators during focus group discussions and questions unbolded were planned for focus group discussions, though not directly asked, often because participants' responses to other questions addressed them.

C.1 Focus Group Questionnaire for Meteorologists

NGFS (30 to 45 mins)

1. **Based on your use of the NGFS throughout this evaluation, what seemed to work well?**
    a. **Are there any NGFS features or output that you feel would be particularly helpful for your office? Why or why not?**
    b. **Does the NGFS fill any gaps that you encounter in your office?**
2. **Based on your use of the NGFS through this evaluation, what didn't seem to work so well? Why?**
    a. **Would you need this barrier to be solved before you could implement the IWT process?**
3. **How do you think your fire partners liked the hot spot notifications?**
4. **Did you feel like your hot spot notifications were well received or respected by your fire partners?**
5. How, if at all, did information provided by the NGFS change your fire detection operations during the case studies?
    a. [If yes] Do you believe it influenced fire detection outcomes at all? Why or why not?
6. How will it interact or conflict with current programs or processes that you have in place for alerting your partners about fire(s)?
7. Generally, did you feel confident in using the NGFS?
8. **Did you feel confident in the service it provides your partners? Do you feel it is helping them?**
9. **Considering everything, would you want to integrate the NGFS into your office's fire detection operations?**
    a. [If yes] How would your office need to change to implement the NGFS tool, if at all?
        i. Could these changes be reasonably implemented in the short-term (define)? Long-term (define)?
        ii. [If no] Why not?
            1. What potential challenges or barriers do you foresee in implementing NGFS in your office? What complications may arise?

Fire Warnings (15-30 mins)

10. **What are your thoughts on your office issuing Fire Warnings in partnership with your partners?**
11. **Do Fire Warnings fill an important communication gap in your office? Do you feel the current fire weather product suite is lacking? Why or why not?**
12. **How do you think the widespread adoption of Fire Warnings would change your current practices/procedures?**
13. **What barriers do you see to issuing Fire Warnings in your office?**

Tactical IWT for Fire Operations (30-45 mins)

14. **Has your understanding or perception of an IWT changed throughout the week?**

15. **Based on your use of the IWT for fire operations throughout this evaluation, what seemed to work well?**
16. **Are there any IWT system features, processes, or output that you feel would be particularly helpful for your office ? Why or why not?**
    a. **Does the IWT seem to fill any gaps that you encounter in your office?**
17. **Based on your use of the IWT process through this evaluation, what didn't seem to work so well? Why?**
    a. **Would you need this barrier to be remedied before you could implement the IWT process?**
18. How, if at all, did the IWT system change how you made fire warning decisions or initiated fire warning conversations during the case studies?
    a. [If yes] Do you believe it influenced fire operations outcomes at all? Why or why not?
19. **Do you think it is feasible to issue Fire Warnings through an IWT partnership between mets and fire analysts?**
20. **If you were to adopt the IWT process, what would it look like? How would the IWT idea translate to the realities of your unique situation? (political, resource, social, enviro)**
    a. **Who would be on it?**
    b. **How big do you think it should be? (Thoughts on Norman size of 2)**
        i. **What is too small? What is too big?**
21. **As presented, the Norman IWT model requires equal partnership between foresters and mets. In your reality, do you believe your counterpart will pull their weight?**
22. **Would you want to integrate the IWT process into your office's fire detection operations?**
    a. **[If yes] Do you think that your office can feasibly implement or integrate this process? Why or why not?**
        i. How would your office need to change to implement the IWT process, if at all?
            1. Could these changes be reasonably implemented in the short-term (define)? Long-term (define)?
        ii. [If no] Why not?
            1. What potential challenges or barriers do you foresee in implementing the IWT process in your office? What complications may arise?
            2. Do you use other processes/systems for issuing Fire Warnings? If so, which?

Together: NGFS + IWT for Fire Operations System (15 mins)

23. **Did you find that the integrated NGFS and IWT for fire operations system felt cohesive, like they belong together? Why or why not?**
    a. **Do you think using the NGFS tool is necessary for the IWT fire operations process? Do they need to be adopted together?**
    b. Do you envision one being more easily integrated into your workflow?
24. Please finish this sentence: For the NGFS and the IWT fire operations system to be integrated and implemented in my office, these systems would need to __________.

C.2 Focus Group Questionnaire for Land Managers

NGFS/Hotspot Notification Tool (30 to 45 mins)

1. **Based on your experience receiving the Next Generation Fire System derived hotspot notifications throughout this evaluation, what seemed to work well?**

   a. **Are there any NGFS features or output that you feel would be particularly helpful for your state? Why or why not?**
   b. **Does the NGFS fill any gaps that you encounter in your state?**
2. **What potential challenges or barriers do you foresee in implementing NGFS-derived hotspot notifications in your state? What complications may arise?**
   a. **Would you need X barrier to be remedied/solved before you could implement the NGFS/hotspot?**
3. How will NGFS-derived hotspot notifications interact with existing tools, technologies, processes for fire detection in your state?
4. How, if at all, did NGFS-derived hotspot notification change your fire operations and response?
   a. **Generally, did you feel confident in interpreting the NGFS-derived hotspot notifications?**
   b. Do you believe it influenced fire response outcomes at all? Why or why not?
   c. When you receive a hotspot notification from your forecaster, how did the notification using NGFS compare to a typical notification that you would receive?
   d. **Did you prefer this information that you were receiving over other detection sources? Who do you think should receive it?**
5. **Would you want to integrate the NGFS and related hotspot notifications into your state's fire detection operations?**
6. **The NGFS Dashboard will be available in the future; will this be of use to you at all? How might you use it?**

Fire Warnings (~15-30 minutes)

7. **What are your thoughts on your office issuing Fire Warnings in partnership with your partners?**
8. **Do Fire Warnings fill an important communication gap in your agency? Why or why not?**
9. **How do you think the national, widespread adoption of Fire Warnings would change your current practices/procedures?**
10. **What barriers do you see in issuing Fire Warnings in your state?**

Tactical IWT for Fire Operations (45 to 60 mins)

11. **Has your perception of the IWT process changed throughout the week?**
    a. **Based on your IWT partnerships throughout this evaluation, what seemed to work well?**
    b. **What IWT features or processes that you feel would be particularly helpful for your state? Why would they be helpful?**
    c. **Does the IWT seem to fill any gaps that you encounter in your state?**
12. **Based on your use of the IWT process through this evaluation, what didn't seem to work so well? Why?**
    a. Would you need X barrier to be remedied before you could implement the IWT?
13. **What potential challenges or barriers do you foresee in implementing the IWT process in your state? What complications may arise?**
14. How, if at all, did the IWT system change your fire response during the case studies? Do you think that, without the IWT, your response would have been different during the simulations?

a. **Do you think the IWT process would fit with your existing fire response/operations workflow? Why or why not?**

15. **If you were to adopt the IWT process, what would it look like? How would the IWT idea translate to the realities of your unique situation?**
    a. **Who would be on it? How big do you think it should be?**
    b. **Thoughts on the relatively small number on the Norman IWT? What number is too small, what number is too big? Mets-only? IMET or FM?**
    c. **As presented, the Norman IWT model requires equal partnership between foresters and mets. In your reality, do you believe your counterpart [would pull their weight]?**
16. Do you want to integrate the IWT process into your state's fire operations?
    a. Do you think that your state can feasibly implement or integrate this process? Why or why not?
    b. How would your state need to change to implement the IWT process, if at all?
        i. Could these changes be reasonably implemented in the short-term (define)? Long-term (define)?
        ii. Who else would you bring in?
    c. [If no] Why not?
        i. What potential challenges or barriers do you foresee in implementing the IWT process in your state? What complications may arise?
        ii. Do you use other processes/systems for issuing Fire Warnings? If so, which?
        iii. What would it need to change for you to feel comfortable implementing it?

Together: NGFS + IWT for Fire Operations System (30 mins)

17. Did you and your team feel confident in your role in issuing Fire Warnings by using the NGFS and IWTs? Why or why not?
18. **Did you find that the integrated NGFS/HS and IWT system felt cohesive, like they belong together? Why or why not?**
19. **Do you think using the NGFS/HS tool is necessary in the IWT process? Do they need to be adopted together?**
20. Do you envision one being more easily integrated into your workflow?
21. Please finish this sentence: For the NGFS/HS and the IWT fire operations system to be integrated and implemented in my state, these systems would need to _________.

Appendix D: Pre- and Post-Evaluation Surveys

D.1 Pre-Evaluation Survey - Meteorologists

1. What is your 4-digit personal identification number?
2. What region do you currently work in? *(Select one: Alaska, Central, Eastern, Pacific, Southern, Western*)
3. Approximately how long have you worked in operational fire or fire weather? *(Select one: <1 year, 1 - 4 years, 5 - 9 years, 10 - 19 years, 20 - 29 years, 30+ years)*
4. Who does your office communicate, coordinate, and/or partner with related to wildland fire and fire weather? *(Please select all that apply: Local land management agencies, State land management agencies, Tribal agencies/partners, Local emergency response organizations/agencies, State hazard*

management organizations/agencies, Community-based organizations (e.g., NGOs, not-for-profit), Public, Broadcasters, We do not have wildland fire partners, Other [fill in])

5. Please indicate your level of agreement with the following statements related to **your job role and functions** *(Select from 5-point Likert Scale from 1 = Strongly disagree to 5 = Strong agree)*:
    a. I need an updated fire detection tool.
    b. I need stronger collaboration/coordination with land management partners.
    c. I need an updated approach to issuing Fire Warnings.
6. Please indicate your level of agreement with the following statements related to **your office** *(Select from 5-point Likert Scale from 1 = Strongly disagree to 5 = Strong agree)*: :
    a. My office needs an updated fire detection tool.
    b. My office needs stronger collaboration/coordination with weather partners.
    c. My office needs an updated approach to issuing Fire Warnings.
7. To your knowledge, has your office ever disseminated a **fire/hotspot detection** to your fire partners? (*Select one: 'Yes', 'No', 'Not Sure')*
8. [If 'Yes' to #7] Please select each of the data, information sources, tools, or products that your office uses for **fire detection** *(Select one: 'Yes, we use this', 'No, we do not use this', 'Not sure'):*
    a. Satellite and remote sensing
    b. FireGuard
    c. Spot forecast requests
    d. Highway patrol
    e. Camera networks
    f. Partner notifications
    g. Private services
    h. Other
9. [If 'Yes' to #7] Approximately how many times per year does your office disseminate fire/hotspot detections to your fire partners? (*Select one: '1 time per year', '2 - 5 times per year', 6 - 10 times per year', 10+ times per year')*
10. [If 'Yes' to #7] How, and to whom, does your office currently disseminate fire/hotspot detections? *(Open response)*
11. [If 'No' to #7] Are you familiar with any satellite fire detection tools or products? *(Select one: 'Yes', 'No', 'Not sure')*
12. [If 'Yes' to #7 AND 'Yes, we use satellite and remote sensing' to #8 OR if 'No' or 'Not sure' to #7 AND 'Yes, we use satellite and remote sensing' to #8] Current satellite/hotspot detection tools… *(Select from 5-point Likert Scale from 1 = Strongly disagree to 5 = Strong agree)*:
    a. are unfamiliar to me – I rarely if ever use them.
    b. are accessible.
    c. provide output that I feel confident in.
    d. need to be improved/enhanced.
    e. have efficient, timely temporal scales.
    f. have useful spatial scales.
    g. are reliable and trustworthy.
    h. are well understood and implemented within my office.
    i. help meteorologists communicate with land managers.
    j. help my office communicate fire weather information with the public.
    k. help my office communicate fire weather information with other fire partners.
13. Briefly describe the current **barriers to and/or challenges** in **fire detection** within your office. Please consider barriers in data, information, modeling, tools, coordination, communication, policy, etc. *(Open response)*
14. How familiar with the Next Generation Fire System were you before today? *(Select one: Not familiar at all (never heard of it), 'Slightly familiar (was introduced to it through this evaluation)', 'Moderately familiar (heard of it before this evaluation)', 'Very familiar (learned how to use it before this evaluation)', 'Extremely familiar (used it before this evaluation)')*

15. To your knowledge, does your National Weather Service office help issue Fire Warnings? *(Select one: 'Yes', 'No', 'Not sure')*
16. [If 'Yes' to #14] Approximately how many times per year do you estimate that your office issues Fire Warnings?
17. [If 'Yes' to #14] **How does your office currently issue Fire Warnings?** Who are the players involved in this process and what roles do they play? What was that process like for you?
18. [If 'Yes' to #14] Briefly describe your office's current **barriers to and/or challenges** in issuing Fire Warnings. Please consider barriers in data, information, modeling, tools, coordination, communication, policy, etc. *(Open response)*
19. [If 'No' or 'Not sure' to #14] Briefly describe why your office **has not** issued Fire Warnings. *(Open response)*
20. How familiar were you with the National Weather Service's process for issuing Fire Warnings before today? *(Select one: Not familiar at all (never heard of it), 'Slightly familiar (was introduced to it through this evaluation)', 'Moderately familiar (heard of it before this evaluation)', 'Very familiar (learned how to use it before this evaluation)', 'Extremely familiar (used it before this evaluation)')*
21. [If 'No' or 'Not sure' to #15 AND 'Moderately familiar' OR 'Very familiar' OR 'Extremely familiar' to #20] Briefly describe any other potential **barriers** to your office **issuing Fire Warnings**, based on what you currently know. Please consider barriers in data, information, modeling, tools, coordination, communication, policy, etc.
22. How familiar were you with the **Integrated Warning Team for fire operations** before today? *(Select one: Not familiar at all (never heard of it), 'Slightly familiar (was introduced to it through this evaluation)', 'Moderately familiar (heard of it before this evaluation)', 'Very familiar (learned how to use it before this evaluation)', 'Extremely familiar (used it before this evaluation)')*
23. ['Moderately familiar' OR 'Very familiar' OR 'Extremely familiar' to #22] Briefly describe the potentia**l barriers to and/or challenges** in implementing or using the **Integrated Warning Team for fire operations** system within your office, based on what you currently know. Please consider barriers in data, information, modeling, tools, coordination, communication, policy, etc. *(Open response)*

D.2 Pre-Evaluation Survey - Land Managers

1. What is your 4-digit personal identification number?
2. What region do you currently work in? *(Select one: Alaska, Central, Eastern, Pacific, Southern, Western*)
3. Approximately how long have you worked in operational fire or fire weather? *(Select one: <1 year, 1 - 4 years, 5 - 9 years, 10 - 19 years, 20 - 29 years, 30+ years)*
4. What partnerships and/or information sources do you use for fire weather forecasting and/or decision support? Please select each that your agency uses, to your knowledge. *(Select all that apply: NWS Weather Forecast Offices, NICC Predictive Services, NOAA/NWS Storm Prediction*

Center forecasts, NICC seasonal outlooks, Tribal agencies/partners, Non-federal forecasts, Private services, Other [fill in])

5. Please indicate your level of agreement with the following statements related to your job role and functions *(Select from 5 point Likert scale from 1 = Strongly disagree to 5 = Strongly agree)*:
    a. I need an updated fire detection tool
    b. I need strong collaboration/coordination with weather partners
    c. I need an updated approach to issuing Fire Warnings
6. Please indicate your level of agreement with the following statements related to your agency *(Select from 5 point Likert scale from 1 = Strongly disagree to 5 = Strongly agree)*:
    a. My agency needs an updated fire detection tool
    b. My agency needs stronger collaboration/coordination with weather partners
    c. My agency needs an updated approach to issuing Fire Warnings
7. Please select each of the data, information sources, tools, or products that your agency uses for fire detection (*Select from 'Yes, we use this', 'No, we do not use this', or 'Not sure')*:
    a. Satellite and remote sensing
    b. NWS alerts (e.g., Fire Weather Watch, Red Flag Warning)
    c. FireGuard
    d. Camera networks
    e. Field personnel communications
    f. Social media
    g. Public reports (e.g., 911 calls)
    h. Private services
    i. Partner agencies
    j. Other
8. To your knowledge, has your agency ever received a National Weather Service fire/hotspot detection? (*Select from 'Yes', 'No', or 'Not sure')*
9. [If 'Yes' to #8] Approximately how many times per year does your agency receive NWS fire/hotspot detection notifications? (*Select from '1 per year', '2-5 per year', '6-10 per year', or 10+ per year')*
10. [If 'Yes' to #8] How does your agency currently use NWS fire/hotspot detections? (*Open response*)
11. [If 'No' or 'Not sure' to #8] Are you familiar with any satellite fire/hotspot detection tools or products? (*Select from 'Yes', 'No', 'Not sure'*)
12. [If 'Yes' to #8 AND 'Yes, we use satellite and remote sensing' to #7 OR if 'No' or 'Not sure' to #8 AND 'Yes' to #11] Current satellite fire/hotspot detection tools… (*Select from 5 point Likert scale from 1 = Strongly disagree to 5 = Strongly agree)*:
    a. Are unfamiliar to me – I rarely if ever use them
    b. Are accessible
    c. Provide output that I feel confident in
    d. Need to be improved/enhanced
    e. Have efficient, timely temporal scales
    f. Have useful spatial scales
    g. Are reliable and trustworthy
    h. Are well understood and implemented within my agency
    i. Help meteorologists communicate with land managers
    j. Help my agency communicate fire weather information with the public
    k. Help my agency communicate fire weather information with other fire partners
13. Briefly describe the current barriers to and/or challenges in fire detection within your state. Please consider barriers in data, information, modeling, tools, coordination, communication, policy, etc. (*Open response*)

14. How familiar with the Next Generation Fire System were you before today? (*Select from 'Not familiar at all (never heard of it)', 'Slightly familiar (was introduced to it through this evaluation)', 'Moderately familiar (heard of it before this evaluation)', 'Very familiar (learned how to use it before this evaluation)', or 'Extremely familiar (used it before this evaluation)')*
15. To your knowledge, has your state ever issued a Fire Warning through the NWS? (*Select from 'Yes', 'No', or 'Not sure')*
16. How familiar were you with the National Weather Service's process for issuing Fire Warnings before today? (*Select from 'Not familiar at all (never heard of it)', 'Slightly familiar (was introduced to it through this evaluation)', 'Moderately familiar (heard of it before this evaluation)', 'Very familiar (learned how to use it before this evaluation)', or 'Extremely familiar (used it before this evaluation)')*
17. [If 'Yes' to #14] Approximately how many times per year do you estimate that your state issues Fire Warnings through the National Weather Service? (*Select from '1 per year', '2-5 per year', '6-10 per year', or 10+ per year')*
18. [If 'Yes' to #14] Briefly describe current barriers to and/or challenges in issuing Fire Warnings through your local NWS WFO. Please consider barriers in data, information, modeling, tools, coordination, communication, policy, etc. (*Open response*)
19. [If 'Yes' to #14] Briefly describe what worked well when issuing Fire Warnings through your local NWS WFO. Please consider barriers in data, information, modeling, tools, coordination, communication, policy, etc. (*Open response*)
20. [If 'No' or 'Not sure' to #14] Briefly describe why your agency has not collaborated/coordinated with your local NWS WFO on issuing Fire Warnings. (*Open response*)
21. [If 'No' or 'Not sure' to #14 AND 'Moderately familiar' OR 'Very familiar' OR 'Extremely familiar' to #16] Briefly describe any other potential barriers to your agency issuing Fire Warnings with your local NWS WFO, based on what you currently know. Please consider barriers in data, information, modeling, tools, coordination, communication, policy, etc. (*Open response*)
22. How familiar were you with the Integrated Warnings Team for fire operations before today? (*Select from 'Not familiar at all (never heard of it)', 'Slightly familiar (was introduced to it through this evaluation)', 'Moderately familiar (heard of it before this evaluation)', 'Very familiar (learned how to use it before this evaluation)', or 'Extremely familiar (used it before this evaluation)')*
23. [If 'Moderately familiar', Very familiar', OR 'Extremely familiar' to #22] Briefly describe the potential barriers to and/or challenges in implementing or using the Integrated Warning Team for fire operations system within your state, based on what you currently know. Please consider

barriers in data, information, modeling, tools, coordination, communication, policy, etc. (*Open response*)

D.3 Post-Evaluation Survey: Meteorologists and Land Managers

1. After learning more about these tools/processes, please indicate your level of agreement with the following statements related to **your job role and functions** (*Select from 5 point Likert scale from 1 = Strongly disagree to 5 = Strongly agree)*:
    a. I need an updated fire detection tool.
    b. I need stronger collaboration/coordination with land management partners.
    c. I need an updated approach to issuing Fire Warnings.
2. After learning more about these tools/processes, please indicate your level of agreement with the following statements related to **your agency** (*Select from 5 point Likert scale from 1 = Strongly disagree to 5 = Strongly agree)*:
    a. My office needs an updated fire detection tool.
    b. My office needs stronger collaboration/coordination with weather partners.
    c. My office needs an updated approach to issuing Fire Warnings.
3. In what types of fire environments was the NGFS (hotspot) tool most useful during your Fire Weather Testbed evaluation experience? Why? (*Open response*)
4. The NGFS tool… (*Select from 5 point Likert scale from 1 = Strongly disagree to 5 = Strongly agree)*:
    a. provides output that I feel confident in.
    b. needs to be improved/enhanced.
    c. has efficient, timely temporal scales.
    d. has useful spatial scales.
    e. is reliable and trustworthy.
    f. could help meteorologists communicate with land managers.
    g. could help my agency communicate fire weather information with other fire partners.
    h. would be implemented and used by my agency if available to us.
    i. would fit into my agency's workflow.
    j. would require significant training/education to be used by my agency.
    k. provides strategically useful information. *(asked of land managers only)*
    l. provides tactically useful information. *(asked of land managers only)*
    m. brings my attention to detections I might otherwise miss.
    n. has a useful automation feature.
5. The IWTs… (*Select from 5 point Likert scale from 1 = Strongly disagree to 5 = Strongly agree)*:
    a. are feasible for my agency and our fire partners.
    b. can be adapted for my agency and our fire partners.
    c. can improve the operational timeliness (lead time) of fire response.
    d. can improve the situational awareness of fire response.
    e. could help meteorologists communicate with land managers.
    f. could help my agency communicate fire weather information with the public.
    g. could help my agency communicate fire weather information with other fire partners.
    h. would be implemented and used by my agency and our fire partners.
    i. would require regular training/education to be used by my agency.
    j. provide strategically useful information. *(asked of land managers only)*
    k. provide tactically useful information. *(asked of land managers only)*
6. Issuing NWS Fire Warnings… (*Select from 5 point Likert scale from 1 = Strongly disagree to 5 = Strongly agree)*:
    a. was comfortable for me during simulations.
    b. would be useful for communicating risk to the public.
    c. would be a beneficial addition to the fire product suite.
    d. could easily be implemented in my agency.

    e. would require regular training.
    f. would increase situational awareness.

7. Please indicate your level of agreement with the following statements about your Fire Weather Testbed experience (*Select from 5 point Likert scale from 1 = Strongly disagree to 5 = Strongly agree)*:
    a. The pre-arrival information and communication was clear and adequate.
    b. Generally, the evaluation simulation exercises resembled real-world operational environments.
    c. The Day 1 orientation and training was adequate.
    d. The testbed room was comfortable.
    e. Before the Smokehouse Creek Fire Day 2 walkthrough, I understood my role during simulations.
    f. After the Smokehouse Creek Fire Day 2 walkthrough, I understood my role during simulations.
    g. I felt like my voice was heard and can help improve the evaluated products/processes.
    h. I felt like my career experience and opinions were valued.
    i. I learned new things, including some that I would like to adopt at my home WFO.
    j. The Marshall Fire tour was a good use of my time.
    k. The experience was fun.
    l. The daily workload was manageable.
8. Do you have any recommendations for us to improve future Fire Weather Testbed simulations or exercises? (*Open response*)
9. Do you have any recommendations for us to improve future Fire Weather Testbed logistics (e.g., travel, coordination, break times)? (*Open response*)
10. What was your biggest takeaway in one sentence? (*Open response*)

Appendix E: Shareable Executive Summary

The version of the executive summary on the subsequent pages is intended for broader dissemination as a standalone document. Note the page numbers restart.

FWT

FIRE WEATHER TESTBED

An End-to-End Evaluation of NOAA's Emerging Wildland Fire Detection and Warning Capabilities

Executive Summary

NOAA

Fire Detection and Dissemination: NESDIS Next Generation Fire System and NWS Hotspot Notification Tool

Interagency Collaboration: Tactical Integrated Warning Team (IWT) for Wildland Fire Operations

Fire Warnings: Tactical IWT-based Fire Warnings

Full report: NOAA Fire Weather Testbed, Baring, A., Hatchett, B.J., Hoekstra, S., McMeeking, L., Thiem, K., Tolby, Z., Vickery, J., Wells, E.M., 2025: Fire Weather Testbed Evaluations #002–004: An End-to-End Evaluation of NOAA's Emerging Wildland Fire Detection and Warning Capabilities. NOAA Technical Memorandum OAR GSL-71, https://doi.org/10.25923/4pqf-7g49

Background

Photo credit: ***Lauren Lipuma***

Wildland fires are increasingly impacting communities with devastating outcomes. In the past decade, rapidly spreading wildfires have threatened communities with little to no warning, resulting in significant loss of life and destruction of property. Following the devastating 2018 Camp Fire in northern California, where 85 people lost their lives, the National Weather Service (NWS) in Norman, Oklahoma, pioneered a collaborative and innovative approach to interagency wildland fire response. They developed a new paradigm to collaboratively issue fire warnings between the NWS and their land management partners during conditions favorable for the rapid spread of wildland fires into populated areas.

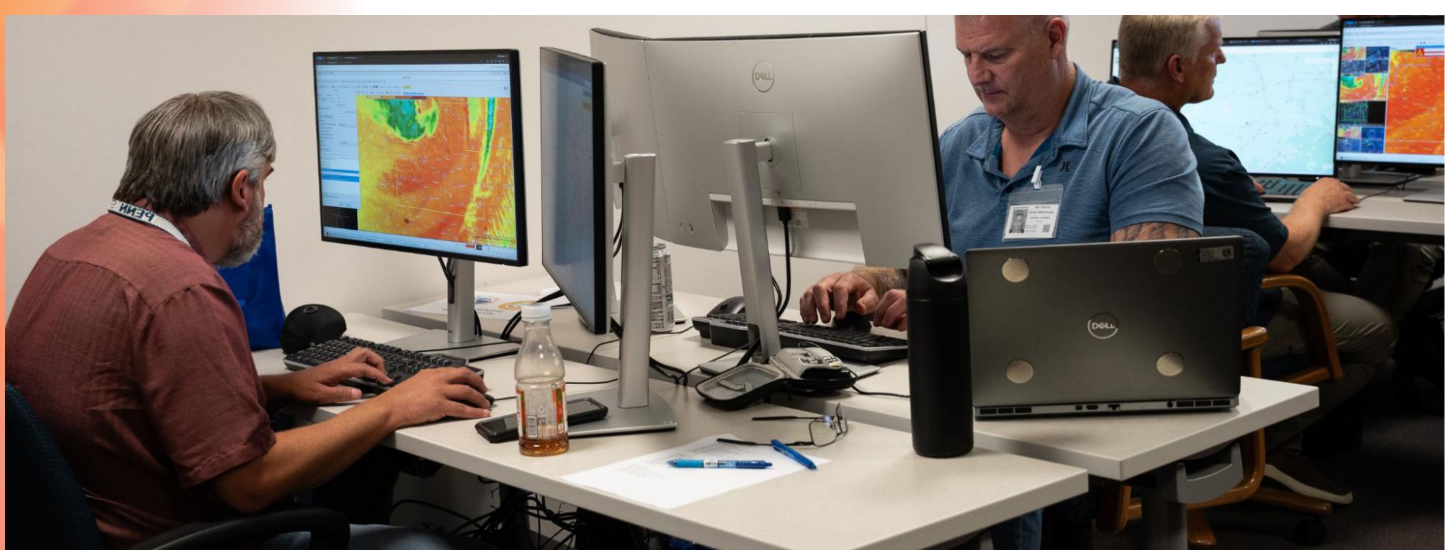
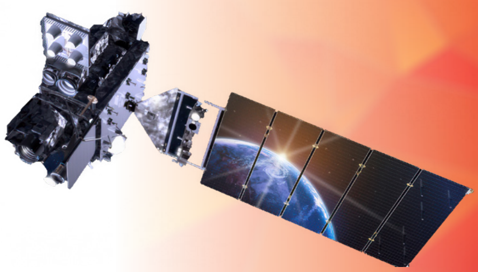


Photo credit: ***Lauren Lipuma***

From June 10-14th, 2024, the National Oceanic and Atmospheric Administration's (NOAA) newly established Fire Weather Testbed (FWT) conducted its first in-person evaluation of this collaborative approach as well as NOAA's emerging wildland fire detection and warning capabilities, specifically:

NESDIS Next Generation Fire System and NWS Hotspot Notification Tool (HSNT)



The NGFS is a new satellite-based AI algorithm utilizing geostationary and low Earth-orbiting NOAA Satellites to detect and monitor wildland fires, including a tool that highlights potential new wildfires. The NGFS is being developed in partnership between National Environmental Satellite, Data, and Information Service (NESDIS), the University of Wisconsin Space Science, and Engineering Center's (SSEC) Cooperative Institute for Meteorological Satellite Studies (CIMSS). While the prototype version of the NGFS was deployed in 2021, the system evolved significantly in the 2022 - 2024 timeframe. The HSNT, developed by NWS Norman, Oklahoma, is used to disseminate the geographic location of fire detections and weather forecasts from NWS Meteorologists to their land management partners via text messages or email notifications.

Tactical Integrated Warning Team (IWT) for Fire Operations

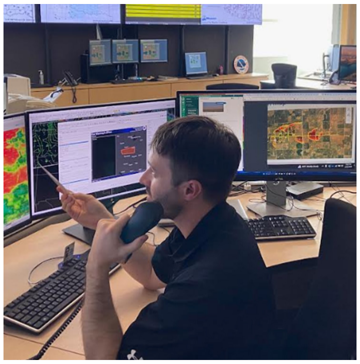


Photo credit: ***Todd Lindley***

"Tactical Integrated Warning Teams" concept has been used for nearly two decades to improve communication and hazard warning messaging between NWS Meteorologists and core decision makers (state and local emergency managers and government officials). Lindley et al. (2024) adapted the IWT approach to specifically address rapidly growing wildland fire threats in the Southern Great Plains. This innovative approach, referred to here as the Tactical IWT for fire operations, adapts the IWT concept of multidisciplinary information exchange among multiple agencies with a shared mission to protect life and property. It enhances collaboration and communication by incorporating more tactical and fully integrated channels essential for understanding and predicting the evolution of wildland fire threats in real-time.

During the 2024 FWT evaluation, the Tactical IWT described in Lindley et al. (2024) was further adapted to highlight the new capabilities for fire detection, dissemination, and collaborative discussion with partners presented by the NGFS, HSNT, and the Tactical IWT workflow.

Fire Warnings Issued through the Tactical Integrated Warning Team Paradigm

Fire Warnings are officially issued by land or emergency management partners through the NWS alerting system. In the new paradigm evaluated in the FWT, land managers and meteorologists share information through the Tactical IWT process to quickly assess, request, and issue Fire Warnings to the public when fires threaten lives and property.

The Tactical IWT Fire Warning model, aligned with the NWS's "science first responder" vision (NOAA, 2023a), involves meteorologists and fire analysts assessing antecedent and current environmental conditions and remote sensing data to deliver early warnings through an interdisciplinary and collaborative approach.

Evaluation Overview

Photo credit: ***Zach Tolby***

The FWT invited NWS fire weather meteorologists and their high-level state land management partners from California, Kansas, North Carolina, and Florida to understand if and how these emerging technologies, products, and services could be implemented outside of the Southern Great Plains. Throughout the evaluation, pairs of meteorologists and fire managers were grouped by state to form four Tactical IWTs, representing regions with varying firefighting capabilities, fire ecologies, and population distributions.

These mock Tactical IWTs engaged in seven displaced real-time simulations of recent fire outbreaks. Each simulated IWT received new fire starts detected by the NGFS and sent through the HSNT. If and when the land managers decided to issue a Fire Warning, the meteorologist drew a polygon covering the area of Fire Warning issuance and issued the warning.

Data was gathered from participants via pre- and post-evaluation surveys and end-of-day roundtable discussions. At the end of the week, the FWT evaluators facilitated two private focus group discussions with participants–one for meteorologists and one for land managers–that were recorded, transcribed, and analyzed by the FWT. Findings from this evaluation are data-driven, while recommendations are both data-driven and informed by FWT expertise.

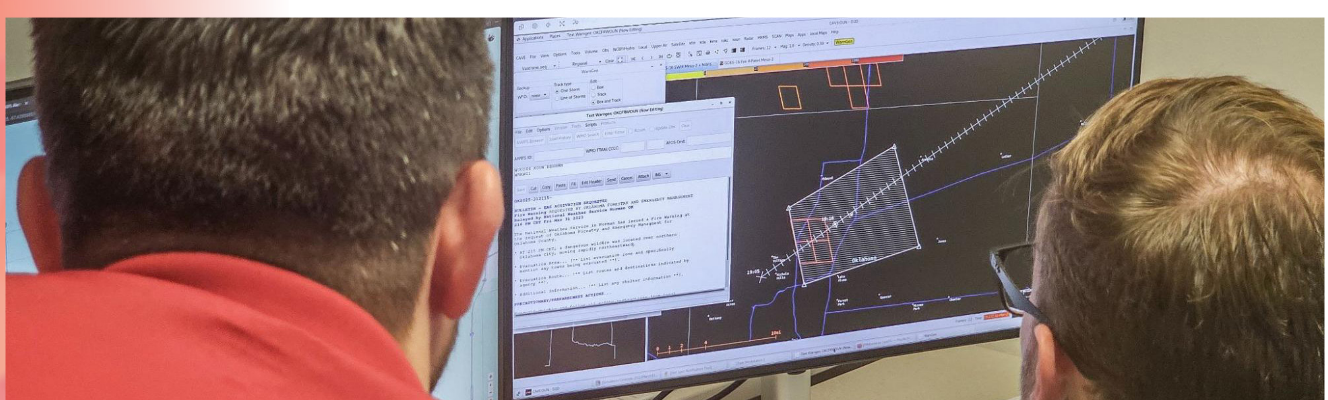


Photo credit: ***Zach Tolby***

Findings and Recommendations

Overarching Evaluation Finding (NGFS, HSNT, IWT, and Fire Warnings)

The Next Generation Fire System, Tactical Integrated Warning Team for Wildland Fire Operations, and IWT-derived Fire Warnings may be uniquely adapted to address local needs and resource capacities across regions. Throughout the FWT evaluation, the individual products demonstrated their potential to address information and communication gaps while also functioning effectively as an integrated system.

NESDIS Next Generation Fire System and NWS Hotspot Notification Tool (HSNT)

Finding

The publicly accessible NGFS provides utility as a tool for fire detection and monitoring. It enhances situational awareness and serves as a safety net for forecasters. By incorporating NGFS detections, the HSNT adds capabilities for the NWS to alert partner agencies. The NGFS and HSNT should integrate effectively into NWS operational environments.

Recommendations

- Integrate the NGFS into the NWS computer system (AWIPS) with user-customizable display capabilities to ensure smooth adoption into NWS operations. Expanding data access will also support integration into additional tools and common operating platforms.
- Develop training materials and documentation that explain the NGFS process, including how it detects fires, integrates known wildland fire information, and incorporates uncertainty to support validation with other sources.
- Add a mechanism for partner agencies to confirm receipt of NWS-provided hotspot notification(s) and ensure multiple communication pathways are available for agency partners to use as needed.

Tactical Integrated Warning Team (IWT) for Wildland Fire Operations

Finding

Participants believed the Tactical IWT approach for fire operations, both before and during wildland fire incidents, has the potential to improve communication, coordination, and situational awareness among meteorologists, land managers, and other fire/emergency response partners, thus enabling unified public messaging and coordinated response to wildland fire threats. Concerns from both groups centered around the challenges of building, implementing, and maintaining an IWT.

Recommendations

- Develop an NWS framework for implementing Tactical IWTs for Wildland Fire Operations in new service areas, modeled from the Southern Great Plains "Tactical IWT model" as an initial framework while ensuring scalability to meet varying regional needs.
- To implement the Tactical IWT, ensure consistent and ongoing local training with coordination between fire partners in consideration of local jurisdictions and partner bandwidth.

Findings and Recommendations
continued

Tactical IWT-based Fire Warnings

Finding

Fire Warnings were perceived to be a valuable wildland fire alerting tool capable of relaying critical information from the NWS and land managers to other emergency management partners and the public when wildland fire poses an imminent threat to life and property. However, both land managers and NWS participants' concerns centered around determining warning authority and the potential public confusion with other products or directives (e.g., evacuation warnings and orders).

Recommendations

- Explore transforming Fire Warnings from a "non-weather emergency" product into a standalone warning product with Wireless Emergency Alert (WEA) dissemination capability to more effectively communicate wildland fire hazard information to the public.
- Implement comprehensive Fire Warning training for the NWS personnel, land management agencies, emergency management agencies, and curate public education campaigns to increase effective Fire Warning implementation and response.
- Work with end-users to improve the Fire Warning product by exploring additional technological capabilities (e.g. Integrating in the NWS warning software (Hazard Services), incorporating fire spread modeling, and producing the capability to share polygons with external partners prior to issuance).
- Include explicit wording in Fire Warning products that highlights their co-creation and joint issuance by land managers and the NWS, emphasizing the collaborative effort involved so as to enhance public trust.
- Build Tactical IWTs to align with local and regional needs and resources, and clearly defining delegation authority, are crucial steps in issuing IWT-based Fire Warnings.

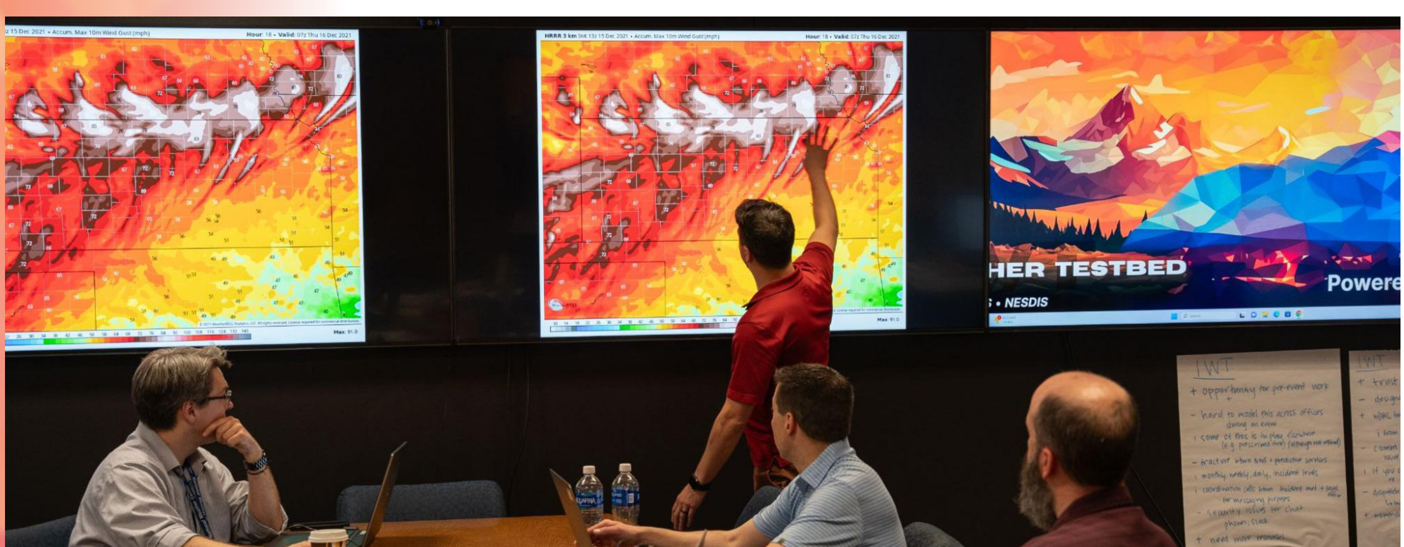


Photo credit: ***Lauren Lipuma***

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