PROPOSED IMPLEMENTATION OF WARN-ON-DETECTION FIRE WARNINGS FOR PUBLIC AND FIREFIGHTER SAFETY

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1. INTRODUCTION

The lack of fire-specific warning protocols to influence public and firefighter safety has garnered widespread attention following recent national wildfire disasters. Meanwhile, both scientific knowledge of dangerous wildfire environments and the technology to remotely detect wildland fire ignition and behavior, have dramatically improved. Deployment of GOES-16/17, and their Advanced Baseline Imagers has revolutionized operational wildland fire detection and monitoring capabilities. National Weather Service (NWS) forecasters have leveraged GOES-16/17 era technology to provide real-time notifications of wildfires since 2016 (Lindley et al. 2016). In many cases, hot spot notifications are received prior to emergency 911 calls and have facilitated rapid response to fires that saved lives and property (NOAA 2018).

By applying combined knowledge of fire environments that support particularly dangerous wildfires with expertise in high-resolution meteorological remote sensing technology to detect extreme fire behavior, and the means to disseminate existing hazard messaging, NWS meteorologists and state forestry fire analysts in Oklahoma and Texas jointly propose implementation of experimental warn-on-detection fire warnings. The proposed warnings communicate text and polygon messages that identify potentially dangerous wildfires similar to tornado, severe thunderstorm, and flash flood warnings for broadcast via the Emergency Alert System (EAS), and perhaps eventually via Wireless Emergency Alerts (WEA).

This paper documents a collaborative process with forestry/fire/emergency agencies, as well as the development of warning decision aids and forecaster training which demonstrate a proposed path toward implementing warn-on-detection fire warnings. Forecaster decision making based upon satellite-derived signals of extreme fire behavior during fire warning simulations is evaluated. This process may serve as a prototype for future phenomenon-based fire warnings that modernize the current red flag warning program toward an impacts-based paradigm.

2. BACKGROUND & PRESIDENCE

Fire warning (FRW) is an existing NWS product governed by Directive NWSI 10-518 B.4.9 as *"a warning of a spreading structural fire or wildfire that threatens a populated area"*. The directive further states *"evacuation of areas in the fire's path may be recommended by authorized officials according to state law or local ordinance"* (NOAA, cited 2019). In

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operational practice, the NWS has only utilized FRWs at the request of local officials as a means to disseminate active evacuation information via the EAS. Since FRW implementation in 2006, a total of 350 warnings have been issued by 16 NWS Weather Forecast Offices (WFOs) through 2018 (Fig. 1). To-date, 89% (313) of all FRWs have been issued by WFOs that service Oklahoma and Texas.

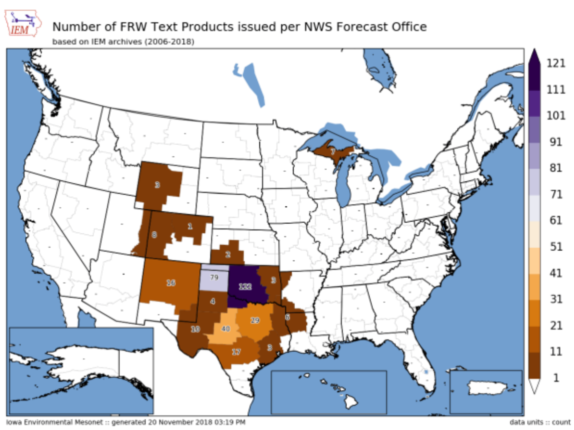


Figure 1: Map showing the number of FRWs issued per WFO between 2006 and 2018.

3. PROPOSED FRWs

Recent interdisciplinary innovation in wildland fire has shown that tactical warnings for extreme fire behavior are possible (Lindley et al. 2018). Such capabilities exist in the operational environment where meteorologists possess unique data sets and quantifiable knowledge of:

- environmental parameters supportive of dangerous wildfire occurrence,
- high-resolution remote sensing technology capable of detecting wildland fire ignition and extreme behavior, and
- existing means and templates to disseminate hazard messages (FRW).

Foundational to the validity of proposed FRWs is a mutual respect for the expertise and core capabilities of partner agencies (NOAA 2013). A multiagency agreement on science-based methods for assessment of the fire environment combined with timely interpretation of remotely sensed signals of extreme wildland fire behavior by operational meteorologists was achieved. The proposed FRWs would be issued for potentially dangerous wildfires that present an immediate threat to life and property. These warnings would supplement (not replace) legacy FRWs that traditionally communicate evacuation information at the request of local officials. The prototype warn-on-detection FRWs would be issued based upon predetermined satellite-inferred signals of extreme wildland fire behavior that occur within specified environmental parameters known to support damaging and life-threatening wildfires.

a. Coordination, criteria, & logistics

Extensive multiagency coordination occurred in proposal of warn-on-detection FRWs (Fig. 2a-h). Proof-of-concept tests were originally discussed with NWS regional administration during a series of meetings between WFO Norman management and NWS Southern Region Headquarters (SRH) between 7-17 December 2018. Oklahoma Forestry Services (OFS) and Texas A&M Forest Service (TAMFS) fire analysts convened at WFO Norman to evaluate proposed environmental and remote sensing criteria and to test warning issuance procedures via a displaced real-time Weather Event Simulator (WES) on 31 January and 1 February 2019. The simulations concluded with a joint NWS/OFS/TAMFS meeting (with SRH representation) to establish a framework for multiagency agreement. A joint briefing to the Oklahoma State Forester was conducted on 4 February 2019. Warn-on-detection and messaging concepts were then collaborated with the Oklahoma Department of Emergency Management (OEM) during subsequent simulations on 20 February 2019. WFO Norman and OEM representatives then co-developed technical solutions for polygon dissemination, and began preliminary discussion of future WEA activation for FRWs through the state operations center. Live demonstrations of FRW capabilities for local emergency managers began on 6 March 2019. Additional live demonstrations were conducted for NWS officials including the National Fire Weather Program Leader and NWS Headquarters AFS Severe, Fire, and Winter Weather Branch Chief on 25 April 2019. To test operational readiness, one-on-one training and forecaster warning decision evaluations were conducted at WFO Norman between 28 January and 14 May 2019. These simulations focused on diagnosing extreme wildland fire behavior using GOES-16/17.

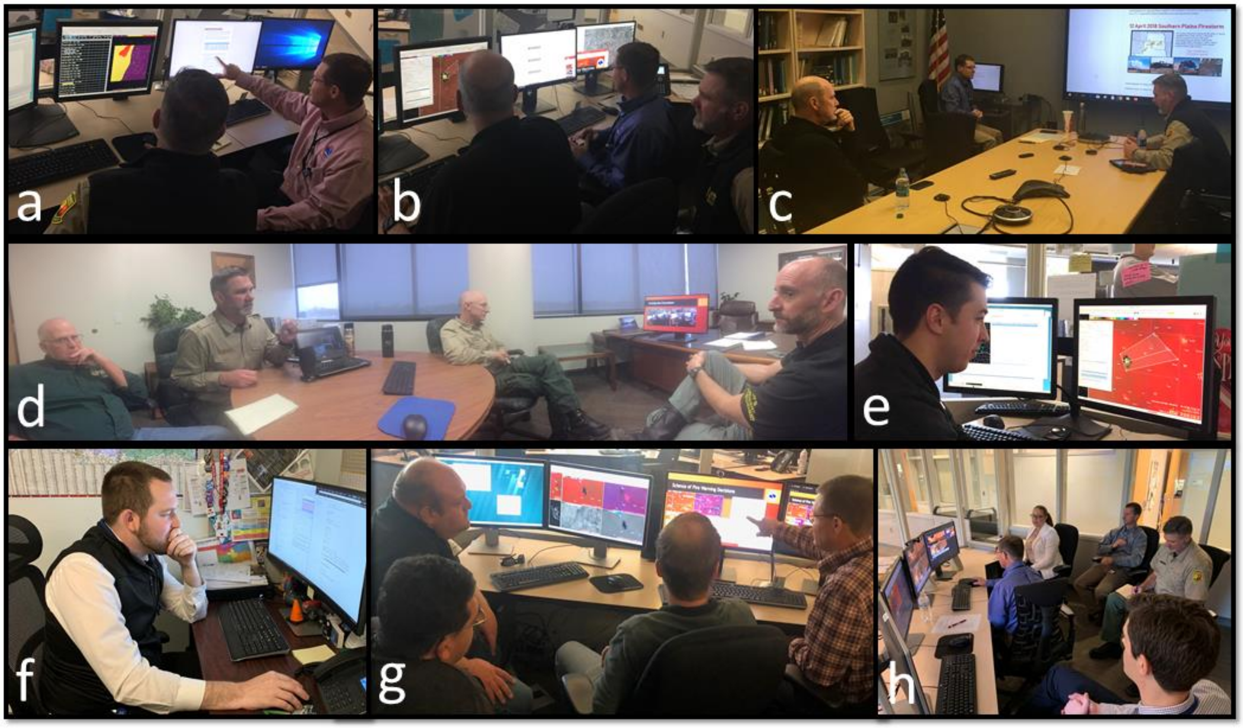


Figure 2a-h: Examples of interagency collaboration invested in proposed FRW implementation, including: criteria evaluation and simulations with a) OFS, b) TAMFS, c) OFS/TAMFS/NWS joint policy session, d) Oklahoma State Forester briefing, e) OEM messaging/concept evaluation and simulation, f) OEM technical dissemination collaboration, g) local emergency manager demonstration and h) NWS Headquarters/Fire Weather Program Lead demonstration.

Proposed warn-on-detection FRWs would be reserved for candidate fires burning under environmental conditions supportive of particularly damaging and life-threatening wildfires. In the southern Great Plains, investments have been made toward a body of research to aid predictive services and firefighting response (Pyne 2017). Some of this research (Lindley et al. 2011 and 2015) has supported adoption of nomogram guidance for fire danger statement (RFD) and fire weather watch/red flag warning (RFW) headline decisions based on energy release component percentiles (ERC, fuel model G, Bradshaw et al. 1983) and Red Flag Threat Index (RFTI, Murdoch et al. 2012). This paradigm allows meteorologists and fire analysts to assess significant fire potential via combined measures of weather and fuel moisture. Such total fire environment assessments more comprehensively quantify risks of problematic extreme fire behavior when compared to traditional RFW criteria, which are based on wind and relative humidity thresholds with minimal consideration of fuel state. In moist fuels, resistance to burning increases (as modeled by both weather and fuel moisture via ERC-G) and intense fire weather (measured by RFTI) is required to yield significant fire potential. Vice versa, as fuels dry and are more prone to fire, weaker weather results in an equivalent significant fire potential (Fig. 3).

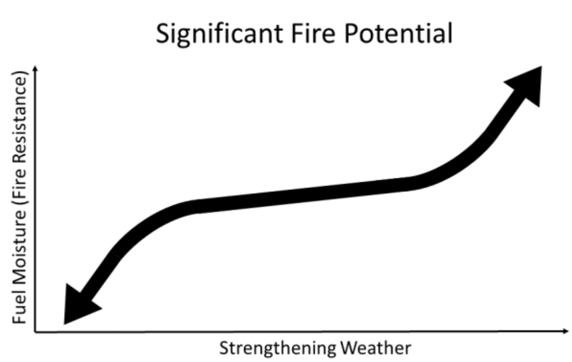


Figure 3: Simplistic graph relating fuel moisture and fire's resistance to control to strength of weather required for significant fire potential.

Weather (RFTI) + Fuels (ERC-G %ile)	NIL 0	Elevated 1-2	Near Critical 3-4	Critical 5-6	Extreme 7-8	Historic 9-10
0-25th %ile	--	--	--	--/RFD	RFD/RFW	RFW
25th-50th %ile	--	--	--/RFD	RFD/RFW	RFW	RFW
50th-70th %ile	--	--/RFD	RFD/RFW	RFW	RFW	RFW
70th-90th %ile	--	RFD/RFW	RFW	RFW	RFW	RFW
>90th %ile	--/RFD	RFD/RFW	RFW	RFW	RFW	RFW

Figure 4: Fire headline decisional nomogram used in many southern Great Plains WFOs for fire danger statement (RFD), fire weather watch/red flag warning (RFW) issuances. Environments supporting a two-tiered FRW criteria are outlined in yellow and red.

Consistent with past operational practice, FRWs would continue to be issued at the request of local or state officials for threatening fire situations that occur outside of a restrictive two-tiered fire environment parameter space for warn-on-detection FRWs. Partner requests would remain the primary FRW issuance criteria.

For wildfires in 'critical' fire weather (RFTI≥5) and modeled vegetative fuel environments with ERC-G≥50th percentile (Fig. 4 nomogram parameter space outlined in yellow), warn-on-detection FRWs would be issued for wildfires that meet the following sub-criteria:

- threatening population center and/or structures
- resultant travel disruptions along major thoroughfare (U.S. Highway or Interstate)
- signals of extreme fire behavior via remote sensing and/or ground confirmation (example: rapid increase in shortwave infrared (SWIR) brightness temperature or satellite-detected spread)
- imminent wind shift (within 2 hours).

In 'extremely critical' fire weather (RFTI≥7) coincident with ERC-G≥70th percentile (Fig. 4 nomogram parameter space outlined in red), warn-on-detection FRWs would be issued on:

- increasing trends in remote sensing SWIR brightness temperature or fire spread of established wildfire.

Forecasters would have access to visual guidance for temporal and spatial identification of the FRW environmental parameter space. Gridded ERC-G (provided by the Wildland Fire Assessment System, available online at: www.wfas.net) and RFTI are composited in 1-h, 6-h, and 24-h resolution within the Advanced Weather Interactive Processing System's (AWIPS) Graphical Forecast Editor (GFE) (Fig. 5). This would allow forecasters to quickly visualize environmental criteria relative to satellite-derived hot spots where purple grid space corresponds to the primary agency request criteria, yellow corresponds to the detection plus sub-criteria FRW requirements, and red corresponds to extreme environmental conditions that warrant warn-on-detection FRWs based on upward trends of remotely sensed behavior for established fire.

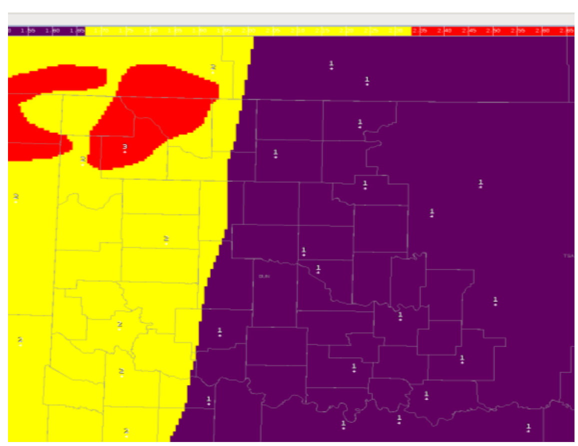


Figure 5: Example GFE guidance grids for warn-on-detection FRW criteria.

Fire analysts additionally identified knowledge of potential downwind fuel availability as a vital component to FRW issuance. While a thorough real-time fuel assessment is not required and should not be expected, simple determinations as to the immediate threat to population, potential character of vegetation, or likelihood for FRW-candidate fires to encounter natural fuel breaks should be considered in FRW decisions. To achieve this awareness within the operational AWIPS environment, street and satellite base mapping capabilities were added to the Hot Spot Notification Tool (V2.3, internally available to NWS online at: https://vlab.ncep.noaa.gov/). This allows forecasters to view GOES-16/17 3.9 µm SWIR overlays on background features (Fig. 6).

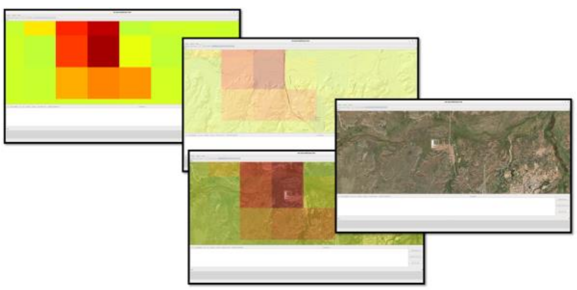


Figure 6: Screen captures of base mapping available within the AWIPS Hot Spot Notification Tool V2.3.

Warning polygons are drawn within AWIPS WarnGen commensurate with the primary hazards associated with surface fire and spread, and with long axes drawn along emanating smoke plumes to additionally account for secondary travel hazards associated stemming from visibility obstructions along major routes (Fig. 7). Fire analysts provided polygonology guidance based upon typical head fire, lateral, and back burning during on-site proof-of-concept assessments. Forecaster-selected templates for traditional agency requested FRWs (including specified "frequent caller" agency templates) and "NWS-initiated" (with predetermined agency coordination), or warn-on-detection, FRWs are available. Default warning duration time is 3-h, with hourly options from 1-h to 6-h.

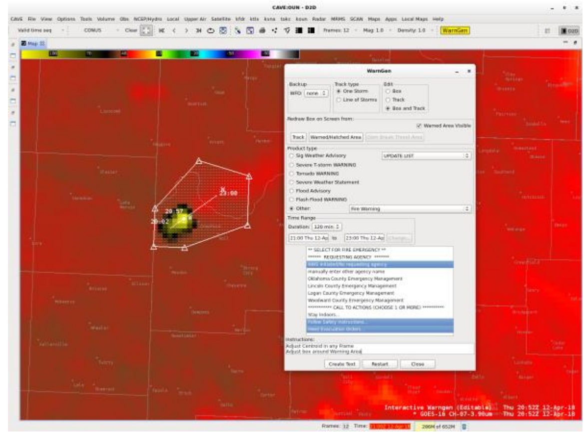
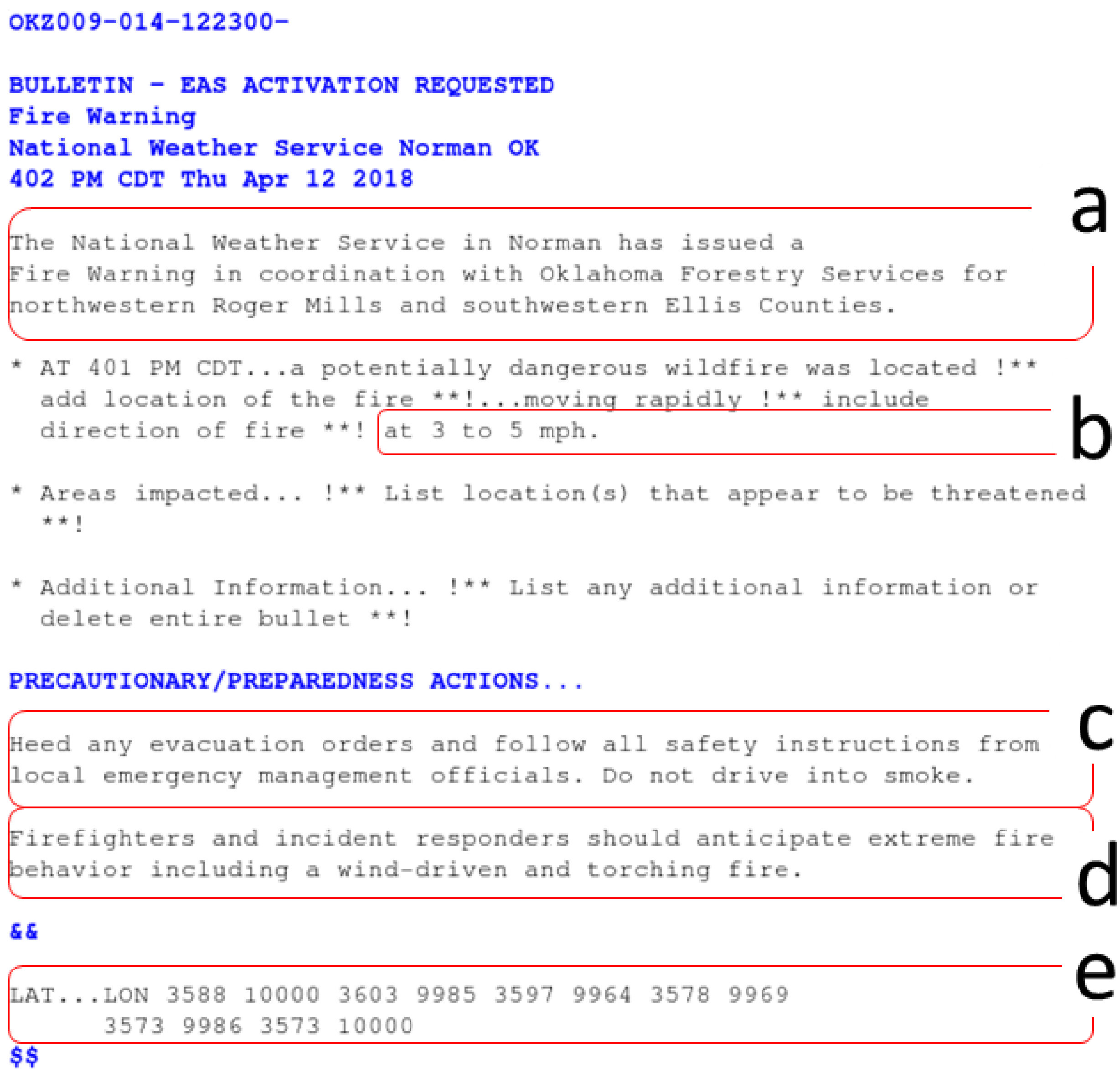


Figure 7: AWIPS WarnGen interface showing polygonology for FRWs.

Warn-on-detection FRWs are consistent with issuance criteria and agreement requirements established in NWSI 10-518 (NOAA, cited 2019). FRWs would be issued when forecasters identify multiagency-agreed remote sensing signals and trends characteristic of extreme fire behavior within predetermined environmental conditions. At that point, the detected wildfire presents an immediate threat to public (and/or first responder) safety (3.2.2.a), warning messaging is predetermined via multiagency agreement(s) with state officials (3.2.2.b), is time critical (3.2.2.c), other means of dissemination are not adequate to ensure rapid delivery of urgent information of an immediate threat to life and property (3.2.2.d), is consistent with NWS format (3.2.2.e), is non-routine (3.2.2.f), and is complementary and not counterproductive to the NWS warning program (3.2.2.g).

Figure 8 (segments a-e) demonstrates proposed warn-on-detection FRW text. In this draft, multiagency agreements pursuant to the issuance are acknowledged as the information source lead-in. A default rate of fire spread of 3 to 5 mph was requested by state forestry agencies based upon average BehavePlus (Andrews 2014) calculations representative of predetermined environmental criteria, but may be modified based on real-time agency input. Call-to-Action (CTA) messaging directed toward public preparation and adherence to potential evacuations as directed by local emergency



OKZ009-014-122300-

BULLETIN - EAS ACTIVATION REQUESTED
Fire Warning
National Weather Service Norman OK
402 PM CDT Thu Apr 12 2018

The National Weather Service in Norman has issued a
Fire Warning in coordination with Oklahoma Forestry Services for
northwestern Roger Mills and southwestern Ellis Counties.

* AT 401 PM CDT...a potentially dangerous wildfire was located !** add location of the fire **!...moving rapidly !** include direction of fire **! at 3 to 5 mph.

* Areas impacted... !** List location(s) that appear to be threatened **!

* Additional Information... !** List any additional information or delete entire bullet **!

PRECAUTIONARY/PREPAREDNESS ACTIONS...

Heed any evacuation orders and follow all safety instructions from local emergency management officials. Do not drive into smoke.

Firefighters and incident responders should anticipate extreme fire behavior including a wind-driven and torching fire.

&&

LAT...LON 3588 10000 3603 9985 3597 9964 3578 9969
      3573 9986 3573 10000
$$

Figure 8: Draft warn-on-detection FRW template. Incorporated multiagency coordination for segments a-e are described in the manuscript text below.

management officials were drafted by OEM. In the event of subsequent evacuation notifications as directed by authorized local officials, additional FRWs would be issued upon agency request using traditional templates. A similar CTA highlighting firefighter awareness of extreme fire behavior was drafted by OFS. Polygon geolocation coordinates were added below the message for users that can extract sub-county geospatial threat information. This was specifically added for use on the OEM's SitMap, but should be useful by any customers that are capable of extracting latitude and longitude information from NWS products.

4. SIMULATIONS

Proposed operational issuance of warn-on-detection FRWs were evaluated in simulations conducted on the WES-2 Bridge (Morris et al. 2017). Guidance for issuance, interpretation of criteria, and warning decisions were evaluated for participants (n=17) that included NWS meteorologists (15) and state forestry fire analysts (2). Decision points and issuance times for hot spot notifications and warn-on-detection FRWs were captured, and provide insight on the feasibility and timeliness of tactical NWS fire service products, including proposed FRWs, relative to real-world impacts (Table 1). The simulations presented participants with displaced real-time data from 12 April 2018. Events of that day featured the onset of a multiday southern Great Plains wildfire outbreak (Lindley et al. 2014) in Oklahoma that included ignition and initial spread of a long-duration megafire (the Rhea Fire, Lindley et al. 2019) and a Type I incident (the 34 Complex Fire).

All simulation participants used multispectral GOES-16 data (Fig. 9) to interrogate thermal wildland fire signatures and visual smoke plume indicators of extreme wildfire behavior. Such interrogation was employed to issue hot spot notifications on four newly emerging wildland fires and three warn-on-detection FRWs for three separate damaging and life-threatening fires. Two forecasters additionally issued hot spot notifications on a faint temporary wildland fire hot spot, or "flicker", indicative of an initial attack (IA) fire incident which was unreported and not part of the evaluated simulation results. Also, most participants issued numerous hot spot notification updates to provide tactical information about remotely sensed fire evolution and changing weather conditions.

Simulation results of interest included a median FRW issuance time for the Shaw Fire (Roger Mills County, Oklahoma) at 19:36 UTC. While the distribution of issuance times ranged from 19:31 UTC to 19:48 UTC, all participants made affirmative warning decisions based upon a dramatic increase in detected SWIR brightness temperature and fire spread in proximity to Durham, Oklahoma (applying the sub-criteria of the first-tier yellow nomogram parameter space), prior to a 19:53 burnover fatality incident. Active burning of the Rhea Fire was monitored for more than 3 hours before participants observed satellite-derived signals of extreme fire behavior that met warn-on-detection FRW issuance guidance at 20:37 UTC (median issuance time). The distribution of issuance times for the Rhea Fire, however, was broader (34 minutes) given that the fire was in a rural area and was slower to show evidence of extreme fire behavior, making initial application of the FRW criteria more subjective. Meanwhile, a narrow distribution of FRW issuance times was observed for the 34 Complex. This fire ignited in an extremely critical environment (red nomogram parameter space) and prompted forecasters to make warning decisions upon initial brightening trends and spread detected by GOES-16 SWIR between 20:46 and 21:03 UTC, with a median FRW issuance at 20:54 UTC.

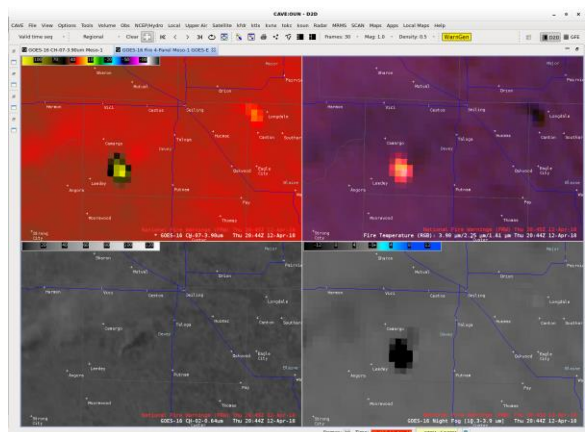


Figure 9: Example AWIPS four panel display of multispectral GOES-16 data useful for wildland fire interrogation, including: 3.9 µm (upper left), 3.9 µm/2.25 µm/1.61 µm RGB (upper right), 0.64 µm (lower left), and 10.3-3.9 µm difference (lower right).

Although the proposed warn-on-detection FRW criteria is based upon forecaster identified trends and references, and no explicit thresholds of satellite-derived data or SWIR brightness temperatures are identified, simulated warning decisions were made at similar brightness temperatures for fires in similar environments (Fig. 10a-c). The distribution of FRW issuance times for both the Shaw and Rhea Fires correspond to dramatic increases in SWIR brightness temperature, with median issuance for both fires occurring at approximately 115° C.

Table 1: 12 April 2018 fire impacts and simulation results for prototype warn-on-detection FRW issuance.

Fire Name/Incident Description and Simulation Results						
		Rhea	Shaw	Anderson Road	34 Complex	Unnamed IA
Impacts*	Area Burned (acres)	120,000	2,500	60	64,000	Unreported
	Deaths/Injuries	0/1	1/1	0/0	0/4	0/0
Message Issuance Times (UTC)	Hot Spot Notification	17:45	19:14	20:09	20:45	20:59
	FRW	20:37	19:36	N/A	20:54	N/A
**as reported on 12 April 2018*						

Given the relatively less stringent criteria applied to the extremely critical environmental parameter space of the 34 Complex, warning times relate to a shortwave infrared brightness temperature of 70° C, but the distribution of issuances also occurred during a dramatic jump in SWIR brightness temperature.

In contrast, during the course of real-world events, no FRWs were requested by local officials for either the Shaw or Rhea Fires. Emergency management officials requested FRWs for the 34 Complex beginning at 22:01 UTC, 67 minutes after the median issuance time for simulated warn-on-forecast FRWs. All three simulation-warned fires resulted in human casualties and extensive property damage. The Roger Mills County emergency managers, who managed response to the Shaw Fire, participated in a live demonstration of the simulation. The emergency managers and OFS officials stated that a warn-on-detection FRW issuance as proposed and demonstrated would have increased "big picture" situational awareness and could have informed decisions to enact more defensive management strategies, possibly saving lives.

4. CONCLUSION

The deployment of GOES-16/17 provide unprecedented new capabilities in near real-time detection and monitoring of wildland fire. In collaboration with OFS and TAMFS, WFO Norman proposes a path toward implementation of warn-on-detection FRWs that modernize NWS fire warning services toward an impacts/phenomenon-based paradigm that leverages this technology. The proposal conforms to NWS directives and does not change existing impact-based decision support services (IDSS), products, or operational models. In support of agency weather watch guidance which states *"if you see something, say something"* (Murphy, cited 2019), passive WFO warning postures prior to local emergency management requests for FRWs during ongoing evacuations would be replaced by prototype warn-on-detection FRWs. These FRWs would be based on identification of predetermined remote sensing indicators of extreme fire behavior coincident with environmental conditions supportive of dangerous wildfires as specified by multiagency agreements. The objectives and issuance guidance provided herein were evaluated in the WFO environment by forecasters and fire analysts. In displaced real-time simulations of an extreme wildfire episode in Oklahoma, FRWs were consistently issued prior to casualty events.

The scientific and technological capabilities that support implementation of this proposal already exist and are scalable across WFOs. Of course, while science and technology can advise and inform innovative proposals in operational fire services, the decision to implement belongs to policy makers (Pyne

2004). Deep core partnerships with fire, land, and emergency management agencies are required for a successful implementation, as is a thorough knowledge of local fire regimes, including objective measures of fuel and weather conditions that correlate to anomalous and high-impact wildfires within a given region's fire history. It is incumbent upon WFOs to establish such partnerships and local knowledge in order to provide IDSS and advance Weather-Ready Nation concepts.

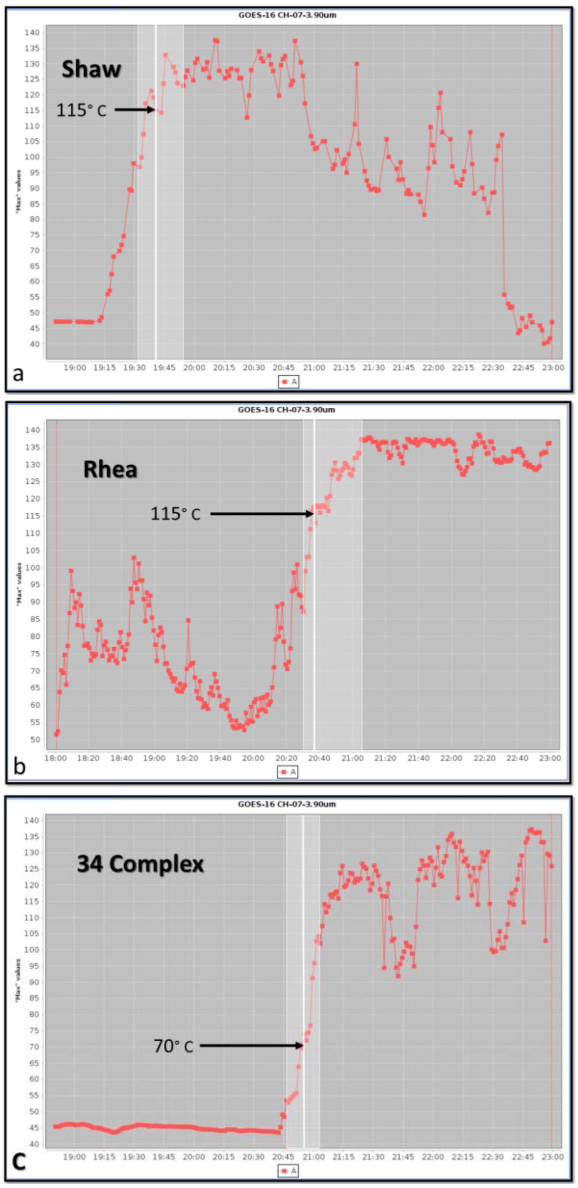


Figure 10a-c: Time series of GOES-16 SWIR brightness temperature for the a) Shaw, b) Rhea, and c) 34 Complex Fires. Distribution (white shade), median (white line), and SWIR brightness temperature at median simulated FRW issuance are denoted.

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REFERNCES

Andrews, Patricia L. 2014. Current status and future needs of the BehavePlus Fire Modeling System. International Journal of Wildland Fire 23(1):21-33.

Bradshaw, L. S., R. E. Burgan, J. D. Cohen, and J. E. Deeming, 1983: The 1978 national fire danger rating system: Technical documentation. USDA Forest Service Rep. INT-169, 44 pp. [Available online at http://www.fs.fed.us/rm/pubs_int/int_gtr169.pdf.]

Lindley, T.T., J.D. Vitale, W.S. Burgett, and M.-J. Beierle, 2011: Proximity meteorological observations for wind-driven grassland wildfire starts on the southern High Plains. *Electronic J. Severe Storms Meteor.*, **6** (1), 127.

____, G. P. Murdoch, J. L. Guyer, G. D.Skwira, K. J. Schneider, S. R. Nagle, K. M. Van Speybroeck, B. R. Smith, and M.-J. Beierle, 2014: Southern Great Plains wildfire outbreaks. *Electronic J. Severe Storms Meteor.*, **9** (2), 1–43.

____, K. Schneider, N. Fenner, G. P. Murdoch, B. R. Smith, and C. Maxwell, 2015: A statistical analysis of energy release component for large wildland fires on the southern Great Plains. *Amer. Meteor. Soc.*

11th Symp. Fire and Forest Meteor., Minneapolis, MN.

____, A. R. Anderson, V. N. Mahale, T. S. Curl, W. E. Line, S. S. Lindstrom, and A. S. Bachmeier, 2016: Wildfire detection notifications for impact-based decision support services in Oklahoma using geostationary super rapid scan satellite imagery. *J. Operational Meteor*., **4** (14), 182–191.

____, G. P. Murdoch, R. Heffernan, L. Van Bussum, A. E. Gerard, N. J. Nauslar, 2018: An impact-based decision support paradigm for National Weather Service wildfire forecast & warning services. *Amer. Meteor. Soc. 12th Symp. Fire and Forest Meteor.*, Boise, ID. [Available online at: https://ams.confex.com/ams/33AF12F4BG/meetingapp.cgi/Paper/343869]

____, D. A. Speheger, M. A. Day, G. P. Murdoch, B. R. Smith, N. J. Nauslar, D. C. Daily, 2019: Megafires on the Southern Great Plains. *J. Operational Meteor.,* Accepted, publication pending**.**

Morris, D. A., A.B. Zwink, T. Pham, P.J. Ware, and M.A. Magsig: Weather Event Simulator: Archived Data Playback for AWIPS-2. 33rd Conference on Environmental Information Processing Technologies. Seattle, WA. 24 January 2017.

Murdoch, G. P., R. R. Barnes, C. M. Gitro, T. T. Lindley, and J. D. Vitale, 2012: Assessing critical fire weather conditions using a red flag threat index. *Electronic J. Operational Meteor*., **13** (4), 46−56. [Available online at nwafiles.nwas.org/ej/pdf/2012-EJ4.pdf]

Murphy, J. D., cited 2019: personal communication, June 14, 2019.

NOAA, 2013: National Weather Service Weather-Ready Nation roadmap. [Available online at https://www.weather.gov/media/wrn/nws_wrn_roadmap_final_april17.pdf]

____, 2018: Wildfire season in southern Plains off to a strong start after a dry winter: fire 'hotspots' detected earlier than ever, thanks to NOAA's GOES-East. Press release, March 16, 2018. [Available online at http://www.noaa.gov/news/wildfire-seasonin-southern-plains-off-to-strong-start-afterdry-winter]

NOAA, cited 2019: Non-weather emergency products specifications. National Weather Service Instruction 10-518. [Available online at https://www.nws.noaa.gov/directives/sym/pd01005018curr.pdf]

Pyne, S. J., 2004: *Tending fire: coping with America's wildland fires*. Island Press, Washington, D.C.

____, S. J., 2017: *The Great Plains, a fire survey*. The University of Arizona Press, Tucson, AZ.