AN INTEGRATED WARNING TEAM APPROACH TO FIRE WARNINGS

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1. INTRODUCTION

The mission of firefighting and emergency management agencies, as well as the National Weather Service (NWS), intersect at the *"protection of life and property."* In pursuit of this mission, the NWS in cooperation with partnering agencies, has adopted an Integrated Warning Team (IWT) approach to achieve effective messaging and mitigative actions toward weather-related hazards (Uccellini and Ten Hoeve 2019). At many NWS Weather Forecast Offices (WFOs), the IWT operates through meetings designed to facilitate critical partner engagement and build trusted relationships that form the basis for successful impact-based decision support (IDSS). To truly evolve the NWS and build a Weather and/or Fire-Ready Nation, however, IWT concepts must extend beyond the controlled environment of scripted scenarios played out in workshops. These concepts must mature from philosophical sand table exercises and permeate real-time operational warning decision making. Warning messages for dangerous wildfires present a unique opportunity for such evolution. Renowned fire historian, Stephen Pyne, states that we must *"address how fire really exists, and not how select sciences can handle it"* (2007) and *"if an agency stays only within its jurisdictional boundaries, it will fail"* to successfully address the complexities of wildland fire response (2020).

The need to establish warning protocols for particularly dangerous wildfires has been the subject of media commentaries and public discourse following numerous wildfire disasters across the nation (Warren, Knabb, and Niziol cited 2018, Cappucci, cited 2018, and others). Further, multiagency governmental reports have found *"There is a need for increased levels of communication and planning from…the federal government to the public about wildfire safety measures, especially warnings"* (Karels 2022). Also, *"there exists available technologies (both government and commercial), which- if implemented- could immediately help emergency responders reduce the number of lives lost during WUI* (wildland urban interface) *fire incidents. In particular, these technologies could immediately support ignition detection, fire tracking, public information and warning, evacuation, and responder safety"* (Berlin and Hieb 2019).

This paper documents the operationalization of collaborated IWT processes for interagency fire warnings (FRWs) that include: 1) pre-fire coordination of fire environments known to support extreme fire behavior, 2) remote sensing-informed identification of potentially dangerous wildfires communicated to forestry/emergency management agencies, 3)

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ground-truth corroboration of local wildfire threats via on-site agencies, and 4) state forestry requests for FRW issuance, including Emergency Alert System (EAS) and Wireless Emergency Alert (WEA) activation. The development of science-based warning decisional guidance, as well as multiagency agreements for partner requests and defined procedures for coordinated warning processes pursuant to agency directives, are detailed here and demonstrate a path toward implementing effective fire-scale warnings. This proactive, collaborative, science and remote sensing-based process, where multiple local, state, tribal, and federal agencies efficiently work to message authoritative hazard information with one voice, represents the epitome of applied IWT ideals and may serve as a prototype for future fire-scale warning systems.

2. PRECEDENCE, POLICY & IWT GUIDANCE

Fire warnings (FRWs) were implemented by the NWS as a non-weather emergency message in 2006, and are governed by Directive NWSI 10-518 as *"a warning of a spreading structural fire or wildfire that threatens a populated area"*. The directive 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 operational practice, however, the NWS has almost exclusively issued FRWs only at the request of local officials as a means to disseminate ongoing evacuation information via EAS. Through 2021, 86% of all FRW issuances have been by the 16 WFOs that service Oklahoma and Texas (Iowa State University, cited 2022).

Lindley et al. (2019) documented a science-based paradigm for proactive FRWs developed through simulations of past extreme wildland fire episodes conducted collaboratively by fire analysts and meteorologists. Leveraging knowledge of the fire environment (weather and fuels) coupled with satellite-based remote sensing signals, forecasters were able to consistently issue simulated FRWs in displaced real-time prior to times of real-world adverse fire impacts, such as fatal burn overs and evacuations. These interdisciplinary simulations were used to develop FRW decisional guidance based on quantifiable measures of the combined fire environment, represented by percentiles of energy release component (ERC, Bradshaw et al. 1983 and Jolly et al. 2019), Red Flag Threat Index (RFTI, Murdoch et al. 2012) and *Geostationary Operational Environmental Satellite-R* series (specifically *GOES-16)* shortwave infrared (SWIR) brightness temperatures (BT). This guidance is shown in Table 1. In routine burning conditions (purple/criteria-1 parameter space in the table), legacy FRW issuance at the request of a local EM remains the trigger for warnings. In critical fire weather (RFTI≥5) and ERC≥50^{th} percentile values (yellow/criteria-2), candidate FRW wildfires are recognized by satellite-depicted SWIR BT≥95° C, with a median BT=115°C. In extremely critical or historic fire weather (RFTI≥7) and ERC≥70^{th} percentile (red/criteria-3) a SWIR signal with minimum BT≥55° C and a median BT=70° C was found to relate to extreme fire behavior.

Policy and operational infrastructure to implement an IWT FRW approach was not yet in place when the Highway 50 Fire impacted Ellis County, Oklahoma, on 26 November 2019. Applying results of the aforementioned simulations, however, WFO Norman (OUN) meteorologists identified the Highway 50 Fire as *"potentially life threatening"* at 21:08 UTC in communications with Oklahoma Forestry Services (OFS). In adherence with established operating plans and procedures, coordination between OUN, OFS, and local emergency managers (EMs) ensued to secure an authorized FRW request. The process was complicated by 'the fog of war' and overwhelming demands on local EMs during the evolving emergency situation. Meanwhile, evacuations in Fargo, Oklahoma, began at 22:07 UTC. Ultimately, an FRW was issued per local EM request at 22:29 UTC, 82 minutes after identification of the fire as an imminent threat to life and property through the proposed science-based environmental and remote sensing methods (Lindley et al. 2021).

Combined Fire Environment & SWIR FRW Coordination Decisional Guidance						
Weather (RFTI)	NIL 0	Elevated 1-2	Near Critical 3-4	Critical 5-6	Extreme 7-8	Historic 9-10
Fuels (ERC Percentile) >90th				(2)	(3) BT_{min}=55° C	
70th-90th				BT_{min}=95° C	BT_{med}=70° C	
50th-70th				BT_{med}=115° C		
25th-50th	(1) Local EM Request Only					
<25th						

Table 1: FRW coordination decisional guidance derived from combined environmental information (ERC percentiles and RFTI) and satellite-based SWIR BT. Adapted from Lindley et al. 2019.

Following the Highway 50 Fire, the Directors/State Foresters of OFS and Texas A&M Forest Service (TFS) submitted memos to OUN and NWS Southern Region Headquarters asserting their *"authority as the state wildfire suppression agency to…request a fire warning…to protect lives and property when potentially dangerous wildfires occur"*. The Directors noted *"many notification delays due to the EM's workload during a rapidly emerging wildfire incident"* and that *"collaboration between NWS and TFS/OFS fire behavior analysts can assess and identify the potential threat of wildfires to the public"* through *"collaborative analysis of the environment factors* [and] *current satellite technology"*.

A 2021 update to the NWS Fire Weather Services Directive NWSI 10-401 addressed *"the provision of warnings for fires on the ground"* as *"not…within the purview of NWS operations"*, but states that WFOs *"must work closely with local land management and emergency management partners to define instances where the NWS may assist in disseminating messages alerting emergency managers or the public for active fires"*. The directive emphasized it is *"important that WFOs provide detection and warning products for active fires…under the explicit auspices of external (non-NWS) fire control or emergency management authorities"* (NOAA, cited 2021).

The Oklahoma Fire Weather Annual Operating Plan (AOP) was updated to include: *"FRWs are issued by NWS offices, and are tone alarmed on NOAA Weather Radio, at the request of state, local, or tribal land or emergency management coordinators and agencies. These warning products are reserved for wildfire events which present an immediate threat to life and property or those incidents that require the immediate dissemination of evacuation instructions to the public"*. Additionally, an OUN/TFS/OFS Multiagency Agreement prescribed: *"FRW requests from local emergency managers to disseminate evacuation information will remain the primary and foremost criteria for issuance. However, this practice will be supplemented by real-time inter-agency collaboration between NWS and [TFS/OFS] fire behavior analysts…to provide a timely assessment of the potential threat of the wildfire to public safety… FRWs will have pass-through status for [OUN] upon request of authorized state fire officials and…will allow efficient FRW issuance within the critical time space for effective public notification".* In Oklahoma, this agreement was codified by signature of the Secretary of Agriculture on 14 December 2021.

3. INITIAL IWT FRW IMPLEMENTATION – DECEMBER 2021-2022

With the above policy and operating plans implemented, Texas and Oklahoma state forestry fire analysts requests for proactive FRWs began in December 2021 (Fig. 1). Specifically, at OUN, a true IWT workflow for state agency-requested FRWs was enacted to assist fire/land/emergency agencies in timely, informed, and collaborated warning decision making based in science and real-time intelligence (Fig. 2). This IWT process involves coordination of the pre-fire environment represented by hourly 2.5 km resolution gridded forecasts of ERC percentiles and RFTI through the Advanced Weather Interactive Processing System's (AWIPS) Graphical Forecast Editor (GFE) EnhancedFire Tools (Lindley et al. 2021) relative to the fire environment previously shown in Table 1. This output is shared with OFS/TFS/Oklahoma Department of Emergency Management (OEM) partners early in the day when a favorable fire environment is present. When and/or if a candidate wildfire exhibits the prescribed SWIR BT indicated within a specified fire environment per the decisional guidance, a hot spot notification (Lindley et al. 2016, 2021) is issued containing the action triggering headline *"Potentially Dangerous Fire Detected"* (PD notification), which also contains meteorological reasoning for concern and FRW request instructions in remarks. Upon receipt of a PD notification, state agencies corroborate the on-the-ground threat via on-site resources and local authorities. If the threat is verified, the respective state agency then responds to OUN with either a "warn" or "no-warn" decision. Therefore, the initial implementation of state-requested FRWs across Texas and Oklahoma from December 2021 through 2022 occurred with two distinct processes:

1) state agency fire analyst requests without NWS-provided real-time environment/ remote sensing intelligence, and-

2) NWS forecasters initiating IWT FRW coordination through monitoring real-time environmental/remote sensing fire data.

The former methodology, an artifact of operational readiness at respective WFOs, represents a de facto control group for comparison to IWT FRWs. Also, initial non-IWT FRWs were county-based, with fire-scale polygon-based warnings adopted in later FRWs.

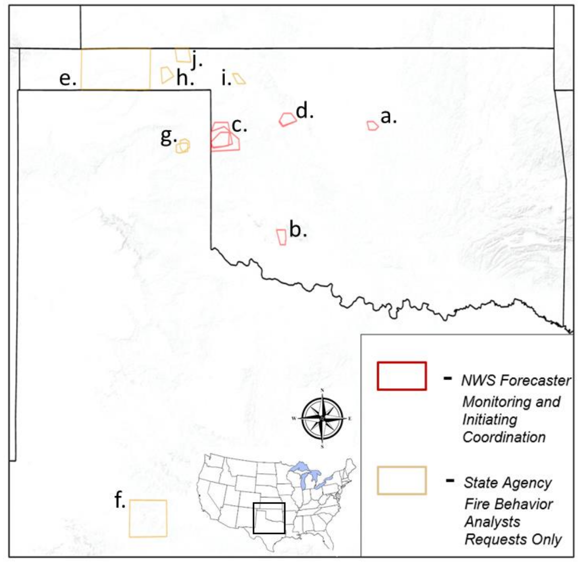

Figure 1: State forestry agency requested FRWs in Oklahoma and Texas December 2021-2022. FRWs are detailed by letter designation in Table 2.

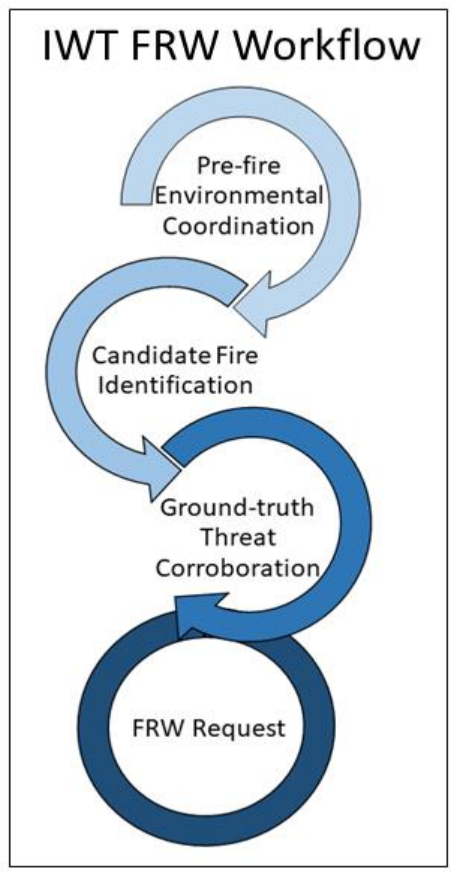

Figure 2: IWT FRW workflow implemented at OUN with Texas and Oklahoma state forestry agencies.

a. 66 Fire – 5 March 2022

The first OUN-issued IWT FRW was for the 66 Fire near Mulhall, Oklahoma, on 5 March 2022. For multiagency awareness and coordination, a gridded pre-fire environment forecast was shared with the state agencies at 14:35 UTC, which showed that predicted ERC percentiles and RFTI would favor extreme fire behavior and potential FRW candidate wildfires. The daily MaxFireWarning grid depicted conditions exceeding yellow/criteria-2 values over most of western and central Oklahoma during the peak diurnal burn period, with red/criteria-3 environmental parameter space over far northwestern and northern Oklahoma (Fig. 3).

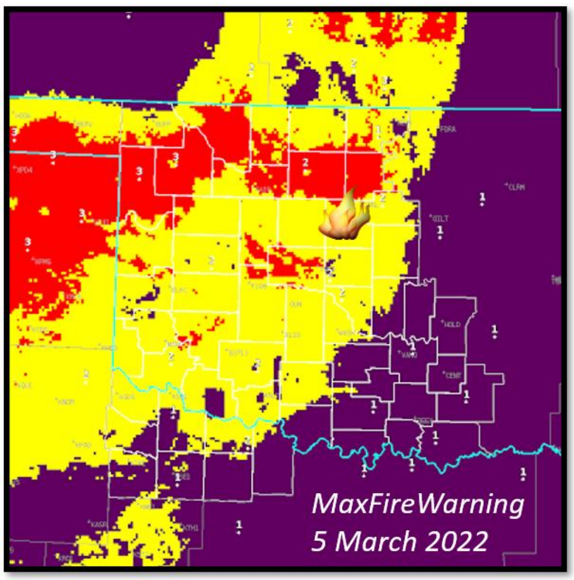

Figure 3: OUN MaxFireWarning grid showing ERC percentile and RFTI parameter space on 5 March 2022. Depicted criteria correlate to Table 1, and location of the 66 Fire shown.

The 66 Fire ignited in the yellow/criteria-2 environmental parameter space at approximately 21:43 UTC. The fire showed evidence of problematic spread and a gradual increase in *GOES-16* detected SWIR BT, and began to intermittently exceed the minimum guidance for IWT FRW coordination by 23:11 UTC (Fig. 4). An OUN transmitted PD notification to the state agencies at 23:25 UTC stated *"hot spot has intensified with a temperature near 100 deg C and has shown eastward movement toward Mulhall. A wind shift will be approaching the location as well in the next 1:30 to 2 hours"*. On-site confirmation of extreme fire behavior (Fig. 5) and an imminent threat to life and property with an affirmative warning request was subsequently received from OFS. An IWT FRW was issued at 23:29 UTC. The IWT FRW process spanned 28 min. Ultimately, six structures were destroyed.

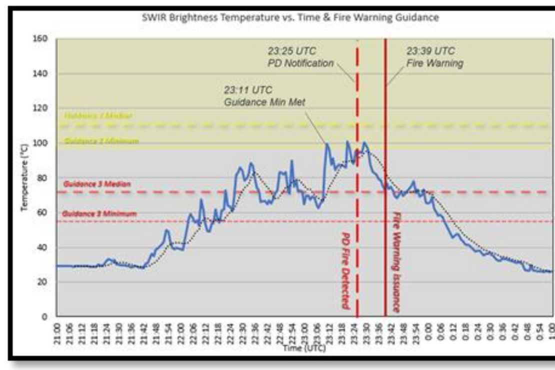

Figure 4: GOES-16 SWIR BT timeseries for the 66 Fire. Applicable IWT FRW guidance is highlighted and critical times/actions denoted. Same format used in Fig. 8, 10, 12, and 13..

Figure 5: Photographic evidence of extreme fire behavior on the Fire 66.

b. Berlin Road Fire – 12 April 2022

Forecast environmental criteria MaxFireWarning grids were coordinated with state forestry agencies and OEM for pre-fire awareness at 18:02 UTC 12 April 2022. Extremely critical fire weather with ≥70th-90th percentile ERCs was forecast over western Oklahoma, commensurate with red/criteria-3 IWT FRW parameter space (Fig. 6). The Berlin

Road Fire initiated in Roger Mills County, Oklahoma, at approximately 21:15 UTC, and quickly escalated to meet minimum IWT FRW guidance for coordination by 19:17 UTC. Visual evidence of extreme fire behavior, including fire whirls, were streamed live by local broadcast media (Fig. 7). Forecasters, however, were conservative in initiating IWT FRW coordination, and sent a PD notification as the *GOES-16* SWIR BT signal approached higher end red/criteria-3 guidance thresholds near 100° C at 22:17 UTC (Fig. 8). The PD notification stated, *"hot spot has accelerated to the north-northeast with BT between 80 to 95 deg C"*. At 22:38 UTC, a coordinated OFS/local EM response indicated *"no warning needed…only have 2 residences threatened and evacuated"*. Thus, in this case, no FRW was issued.

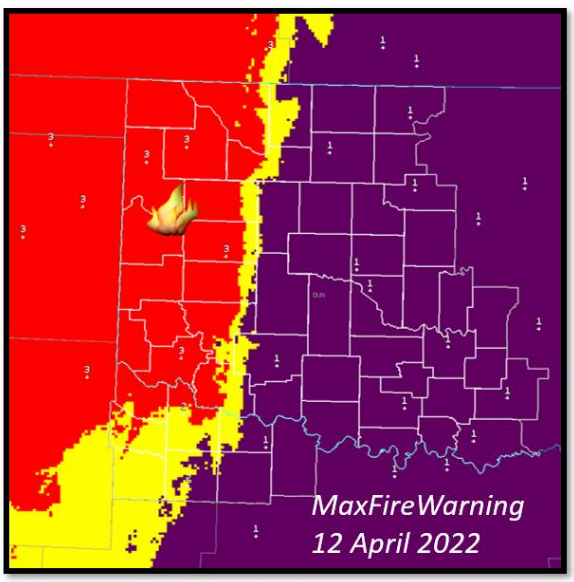

Figure 6: OUN MaxFireWarning grid showing ERC percentile and RFTI parameter space on 12 April 2022. Location of Berlin Road Fire shown.

Figure 7: KOCO-TV live stream of Berlin Road Fire.

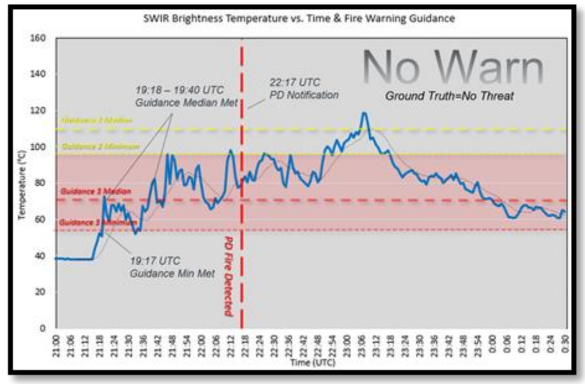

Figure 8: GOES-16 SWIR BT timeseries for the Berlin Road Fire. Applicable IWT FRW guidance is highlighted and critical times/actions denoted.

c. Canadian River Bottom (TX) and Washita River Complex (OK) Fires – 29 March 2022

On 29 March 2022, two similarly damaging wildfires ignited, destroyed a total of 13 structures, and burned 16,013 ha and 15,239 ha respectively in close spatiotemporal proximity and in the same fire environment. These incidents provided a unique opportunity to directly compare IWT FRW processes to FRWs decisions based solely on partner requests. The Canadian River Bottom (CRB) Fire in Hemphill County, Texas, occurred in WFO Amarillo's (AMA) county warning area (CWA), whereas the Washita River Complex (WRC) Fire occurred 30 km to the east in OUN's CWA. While AMA issued FRWs at the request of TFS fire analysts, agreements for meteorologists to provide fire analysts with real-time environmental and remote sensing fire intelligence, and NWS-initiated IWT FRW coordination, were not adopted into AMA AOPs.

OUN coordinated a high-end wildfire environment with the state agencies at 14:13 UTC 29 March 2022. Pre-fire environmental MaxFireWarning grids showed a narrow corridor of red/criteria-3 parameter space along the eastern Texas Panhandle and Oklahoma state line during peak burning (Fig. 9).

The WRC Fire initiated near the Texas/Oklahoma state line shortly after 20:00 UTC and immediately spread with escalating

GOES-16 detected SWIR BTs into Roger Mills County, Oklahoma. Again, OUN forecasters were conservative in initiating IWT FRW coordination. A PD notification was sent 41 min after the fire exceeded minimum guidance thresholds, with SWIR BTs exceeding 100° C and the fire *"…advancing 2 miles west of Durham"* at 21:05 UTC (Fig. 10). OFS responded with an affirmative warning request confirming extreme fire behavior and an imminent threat to Durham (Fig. 11), and an IWT FRW was issued just 3 min later at 21:08 UTC. Evacuations were ordered in Durham at 21:16 UTC.

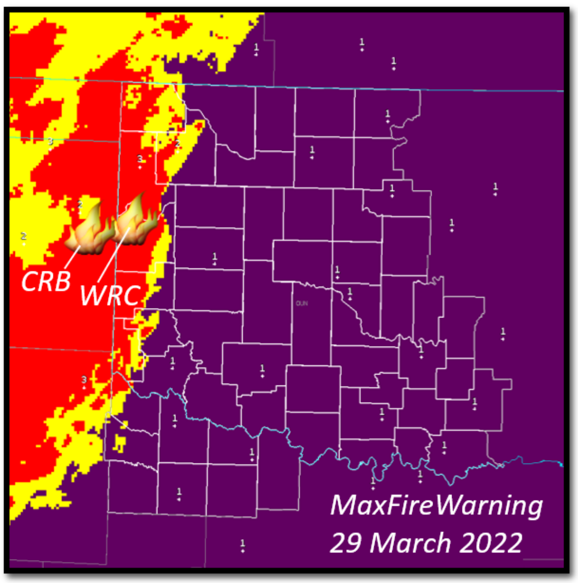

Figure 9: OUN MaxFireWarning grid showing ERC percentile and RFTI parameter space on 29 March 2022. Location of CRB and WRC Fires shown.

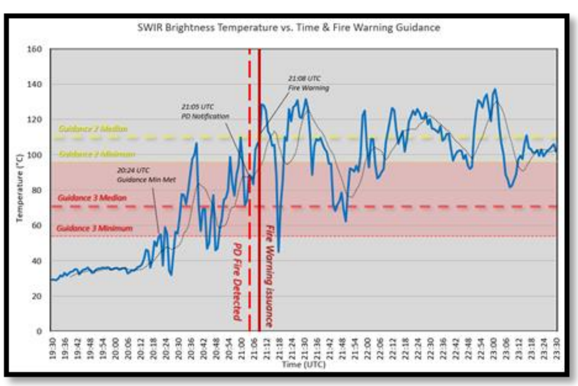

Figure 10: GOES-16 SWIR BT timeseries for the WRC Fire. Applicable IWT FRW guidance is highlighted and critical times/actions denoted.

Figure 11: Photographic evidence of extreme fire behavior on the WRC Fire and subsequent home burning in Durham, Oklahoma.

Meanwhile, a request by TFS fire analysts prompted AMA's issuance of an FRW for the CRB Fire at 22:15 UTC, 2 h 28 min after the fire initially met minimum IWT FRW coordination guidance in the same fire environment as the WRC Fire (Fig. 12). It is important to emphasize that AMA appropriately issued the FRW upon authorized request pursuant to AOP agreements. IWT FRW operational practices were not implemented at AMA, and forecasters there had neither received training on nor used IWT FRW guidance in the operational environment.

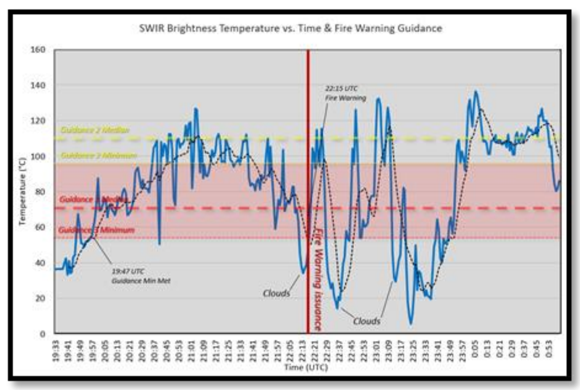

Figure 12: GOES-16 SWIR BT timeseries for the CRB Fire. Applicable IWT FRW guidance is highlighted and critical times/actions denoted.

d. Discussion

Throughout December 2021-2022, Texas and Oklahoma state forestry agency fire analysts requested FRWs for 10 separate wildfires. Initial warnings for four of these fires were issued following the IWT FRW workflow presented here. Table 2 details all 10 incidents, as well as times that each fire reached minimum IWT FRW guidance criteria in its respective fire environment, and lapsed time of IWT FRW actions. Data shows that throughout the initial implementation period, OUN forecasters initiated IWT FRW coordination with PD notifications an average of 42 min after candidate wildfires met minimum guidance thresholds. Forecaster-initiated coordination was intentionally conservative in many cases, particularly when considering extremely critical environmental parameters (red/criteria-3) where lower SWIR BTs were indicated. Given that the IWT FRW process was novel, forecasters acknowledged that there was a desire to reserve IWT FRWs for truly dangerous wildfires that presented a clear and immediate threat to life and property. Once coordination was initiated, however, the multiagency IWT process to corroborate threats, return agency requests, and issue FRWs ranged from 3 to 15 min, with IWT FRWs issued on average 10 min later, or an average of 52 min after initial minimum guidance was met. While not shown, the average IWT FRW issuance time was 49 min after median guidance SWIR BTs were observed. Recall the aforementioned pre-IWT FRW implementation case of the 26 November 2019 Highway 50 Fire, which demonstrated an 82 min lapse between identification of a *"life threatening"* fire to FRW issuance. To-date, two instances of IWT FRW coordination have resulted in no-warn decisions.

FRWs issued by request only from state forestry agency fire analysts, without the benefit of NWS forecasters providing real-time monitoring of both fire environment and satellite-based remote sensing leading to the initiation of IWT FRW workflows, resulted in FRWs on average 1 h 41 min after wildfires exceeded the same guidance thresholds. Again, NWS forecasters outside of OUN were not utilizing the IWT FRW guidance in operations. It should be noted that all FRW wildfires shown in this study achieved IWT guidance satellite-detected SWIR BTs relevant to their respective fire environment prior to FRW issuance.

4. NEXT-GENERATION IWT FRWs IN 2023

In 2023, OUN and OFS partnered to issue next-generation IWT FRWs. During the 31 March 2023 Simpson Road and Hefner Road Fires, and the 4 April 2023 Route 66 Fire in Oklahoma, IWT FRW decisions were informed by coupled fire spread modeling.

December 2021-2022 State Agency-requested FRWs in OK & TX									
Fire Name (Fig. 1 designation)	Date	IWT	Env. Guidance	T_{min}	T_{PD}	T_{FRW}	T_{PD}-T_{min}	T_{FRW}-T_{min}	T_{FRW}-T_{PD}
66 (a)	5 Mar 2022	Y	1 (Yellow)	23:11	23:25	23:39	0:14	0:28	0:14
62 (b)	13 Mar 2022	Y	2 (Red)	21:30	23:05	23:16	1:35	1:46	0:09
Washita River (c)	29 Mar 2022	Y	2 (Red)	20:24	21:05	21:08	0:41	0:44	0:03
Delong Hill (d)	29 Apr 2022	Y	1 (Yellow)	19:17	19:35	19:50	0:18	0:32	0:15
Cobb (e)	15 Dec 2021	N	1 (Yellow)	17:55	--	19:53	--	1:57	--
Chico Lane (f)	17 Mar 2022	N	2 (Red)	18:46	--	20:56	--	2:10	--
Canadian River Bottom (g)	29 Mar 2022	N	2 (Red)	19:47	--	22:15	--	2:28	--
Beaver River (h)	6 Apr 2022	N	2 (Red)	19:03	--	19:42	--	0:39	--
23 (i)	7 Apr 2022	N	1 (Yellow)	20:13	--	21:30	--	2:17	--
North Canadian (j)	7 Apr 2022	N	1 (Yellow)	16:25	--	17:01	--	0:36	--
IWT FRW Mean	--	--	--	--	--	--	0:42	0:52	0:10
State-request FRW Mean	--	--	--	--	--	--	--	1:41	--

Table 2: December 2021-2022 state forestry agency requested FRWs, both IWT FRWs and FRWs issed at the request of state fire analysts only; all shown with and color coded relative to IWT FRW guidance (Env. Guidance) within which they occurred. Time the fire initially met relevant SWIR BT (T_{min}), time PD notification(s) issued for IWT FRWs (T_{PD}), time of FRW issuance (T_{FRW}) all shown in UTC. Lapsed time from acheiving minimum guidance SWIR BT and PD notification ($T_{PD-Tmin}$) and FRW (T_{FRW}-T_{min}) are shown, as well as the time from PD notification to FRW (T_{FRW}-T_{PD}). Time differences are shown in a h:min format.

For the Simpson Road Fire, a hot spot notification was initially issued by OUN for satellite-detected fire ignition at 18:47 UTC, and provided immediate weather support. The fire started within yellow/criteria-2 ERC/RFTI parameter space for IWT FRW coordination, and was burning within the WUI of north Oklahoma City (Fig.13). The fire's *GOES-16* detected SWIR BT quickly intensified, and a PD notification was sent at 19:06 UTC noting *"fire 3 se of Seward is now at 123 deg C and sustaining at greater than 100 deg C. To request Fire Warning contact WFO Norman"*.

Upon PD notification receipt, OFS initialized a Wildfire Analyst™ (Technosylva, cited 2023) coupled fire spread model. Spread model output indicated that the fire would cross Interstate 35 with flame lengths of 1.2 to 2.4 m and present fire behavior rated as 4 out of 5 with "very high" values at risk. OFS fire analysts responded with an affirmative IWT FRW request at 19:10 UTC. The IWT FRW was issued at 19:11 UTC (Fig. 14). Given the urgent threat posed by the Simpson Road Fire, the timeline of IWT processes was compressed. The IWT FRW was issued just 24 min after fire initiation, 12 min after minimum IWT FRW coordination guidance was met, and 5 minutes after the coordinating PD notification. By 19:38 UTC, local broadcast media began airing helicopter footage of homes burning. Ultimately, 55 homes and 156 outbuildings were destroyed. No lives were lost and only minor injuries were reported.

A subsequent IWT FRW for the Route 66 Fire in Custer County, Oklahoma, on 4 April 2023 was further enhanced when OFS shared preliminary spread model output with OUN in real-time (Fig. 15). This information informed placement of the IWT FRW polygon. For instance, meteorologists were able to precisely draw the major axis of the warning polygon along the direction of fire spread, and were able to confidently omit the city of Weatherford from the warned area. Although this incident demonstrated future IWT capabilities in the provision of fire-scale warnings, it also brought to light possible complexities inherent to newly evolving public warning systems. For instance, the proximity of the warning polygon to Weatherford prompted WEA activations for most of the city's population. This undesirable outcome was likely an artifact of localized fire-scale risks coupled with cellular tower coverage in proximity to a population center.

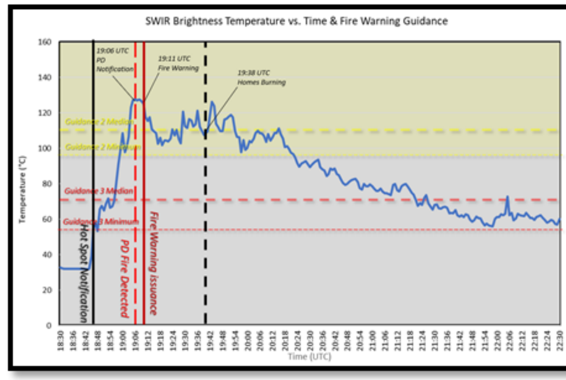

Figure 13: GOES-16 SWIR BT timeseries for the Simpson Road Fire. Applicable IWT FRW guidance is highlighted and critical times/actions denoted.

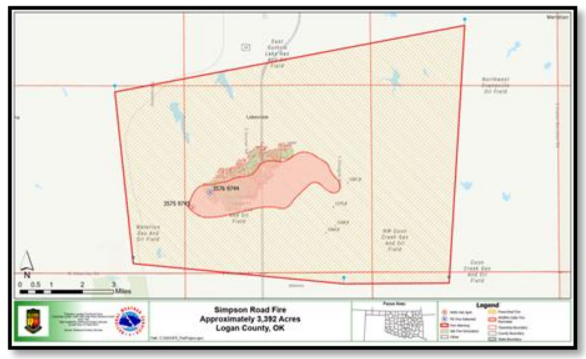

Figure 14: Map of IWT FRW (red polygon) for the Simpson Road Fire, including: initial hot spot notification (red dot), PD notification (blue dot), spread model (green shade), post-fire surveyed burn area (red shade).

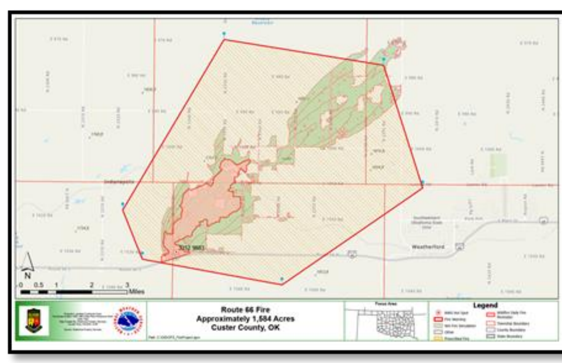

Figure 15: Map of IWT FRW (red polygon) for the Route 66 Fire, including: initial hot spot notification (red dot), spread model (green shade), post-fire surveyed burn area (red shade).

5. SUMMARY OF LESSONS LEARNED

Through simulations and preliminary implementation of IWT FRW operational practices, a proof-of-concept of fire-scale warnings for imminently dangerous wildfires has been demonstrated. By leveraging knowledge of the fire environment and satellite-based remote sensing, a multidisciplinary science-based approach has been applied to achieve timely wildland fire hazard messaging that influences public and first responder safety consistent with IWT principles. Lessons learned during the initial December 2021-April 2023 implementation of IWT FRWs in Oklahoma include:

1) IWT FRW methodologies, where meteorologists conduct real-time monitoring and coordination of the fire environment and fire-specific satellite-based interrogation, result in FRW issuance significantly earlier than FRWs issued by request of fire analysts.

2) OUN forecasters were conservative with respect to initiating IWT FRW coordination through the 2022 fire season. Anecdotal evidence and experience with the 2023 fires in Oklahoma suggest that earlier warning issuances are possible.

3) The NWS should implement capabilities to update, cancel, and modify FRWs, as well as independent WEA activation.

4) The addition of fire-scale coupled spread modeling has proven to be an essential component of the IWT FRW process, particularly useful in informing the placement of warning polygons.

5) There is a need to educate the public and fire/land/EM partners on emerging warning services for dangerous wildfires. Such efforts should be analogous to those utilized historically for the fledgling NWS severe weather warning program. The addition of modern social sciences can further inform methods to communicate mitigative actions in future fire-specific warning systems.

The authors advocate for an increased role of NWS meteorologists in the provision of multidisciplinary warning services for dangerous wildfires. The adoption of IWT FRWs at OUN has not resulted in an appreciable increase in the volume of FRWs issued compared to legacy FRW issuances (Fig. 16). Further adoption of IWT FRW practices in Oklahoma and Texas should be implemented. Additional expansion of these efforts in other regions would require forecaster training and the development of partnerships with numerous fire/land/EM agencies, consistent with the evolution of a Weather/Fire-Ready Nation. Lastly, either the NWS or other partnering fire agencies should proliferate the use of coupled fire spread modeling systems to inform IWT FRW processes. Such systems should eventually initialize with satellite-derived fire detections and be processed using meteorological expertise to determine the most representative atmospheric modeling inputs.

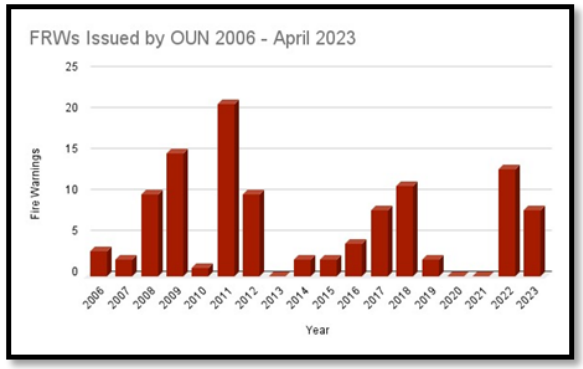

Figure 16: Number of FRWs (including legacy FRWs, IWT FRWs in 2022-2023, and continuation FRWs) issued by OUN between 2006 and April 2023.

Fire is a complex natural hazard that truly demands cross-jurisdictional multiagency responses for effective mitigative actions. Perhaps no other NWS service area offers such explicit opportunities to pursue the agency's IDSS, deep core partner, and FACETS initiatives, identified by NWS leadership (Uccellini and Ten Hoeve 2019 and Graham 2023), as the fire weather program. Hopefully the IWT FRW pathway documented here will help to inform future life-saving warning systems for dangerous wildfires. Probably the greatest lesson learned is that it is incumbent upon operational practitioners to work across scientific disciplines in order to achieve the provision of such warnings and meet our common missions in the *"protection of life and property."*

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