AN IMPACT-BASED DECISION SUPPORT PARADIGM FOR NATIONAL WEATHER SERVICE WILDFIRE FORECAST & WARNING SERVICES

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1. INTRODUCTION

The National Weather Service's (NWS) fire weather program, including the successful legacy of Incident Meteorologists (IMETs), is a model for the agency's evolution toward Impact-Based Decision Support Services (IDSS) and a Weather-Ready Nation (NWS 2013). IMETs have deployed to the frontlines of wildfires and incidents of national significance to provide site-specific weather support since 1928 (Gray 1929). While the modern IMET program is an unequivocal success, a clear vision for an IDSS-era evolution of NWS fire forecast and warning services has not been formulated.

In addition to the support provided by IMETs at wildfires and other incidents, the NWS is tasked with issuing red flag warnings (RFWs) for extreme wildland fire conditions that threaten life and property (NOAA 2017a). While RFW criteria differ across the country, issuance is typically based on exceedance of locally perceived critical thresholds of relative humidity and wind speed with minimal knowledge or consideration toward the fire-receptiveness of vegetative fuels. Validity of RFWs, however, is not correlated to observed wildland fire behavior. As such, a grave disconnect can sometimes exist between occurrence of large and damaging wildfires and the issuance of RFWs. Research shows that weather supportive of significant wildfires occurs along a spectrum (Fig. 1), and commonly does not adhere to established relative humidity and wind RFW criteria (Lindley et al. 2011). Variations in antecedent volatility of vegetative fuels further make fire-effective weather conditions a moving target.

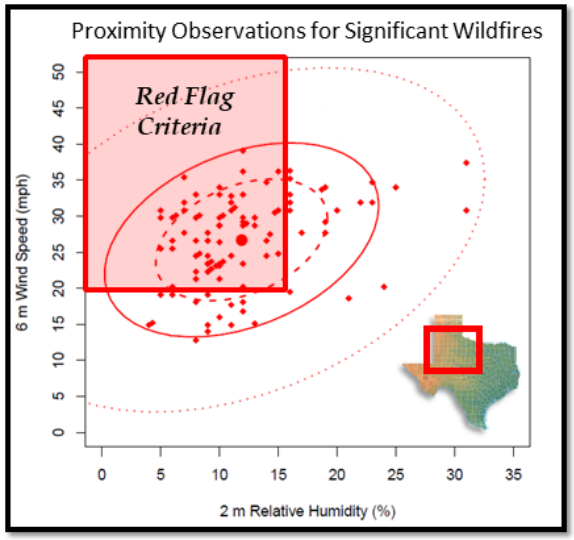

Figure 1: Proximity relative humidity and wind speed for significant wildfire starts in west Texas compared to local red flag criteria.

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Predictive methods and inter-agency logistics are beyond the scope of this manuscript. This paper, however, serves as a conceptual outline for a combined strategic and tactical paradigm of IDSS in NWS wildland fire services based upon measures of significant wildfire potential. This proposal draws upon proof-of-concept examples demonstrated via NWS and state forestry core partnerships in Texas and Oklahoma. There, probabilistic significant wildfire outlooks have influenced strategic preparations by fire/land/emergency management agencies (Fig. 2) prior to dangerous wildfires on the southern Plains since 2011 (Lindley et al. 2014). In 2016, forecasters in Oklahoma (and since elsewhere) implemented fire-specific notifications for emerging wildfires detected via high-resolution meteorological remote sensing (Lindley et al. 2016). Such 'warnings' aid tactical routing of pre-deployed firefighting resources in critical fire environments for rapid initial attack suppression and impact mitigation. These prototypes are consistent with Forecasting a Continuum of Environmental Threats (FACETs, Rothfusz et al. 2014, 2018) concepts, a next-generation approach to communicate weather forecasts via probabilistic hazard information. Such concepts may inform future evolution of NWS fire services and promote consistency with forecast/warning services for other weather-related hazards.

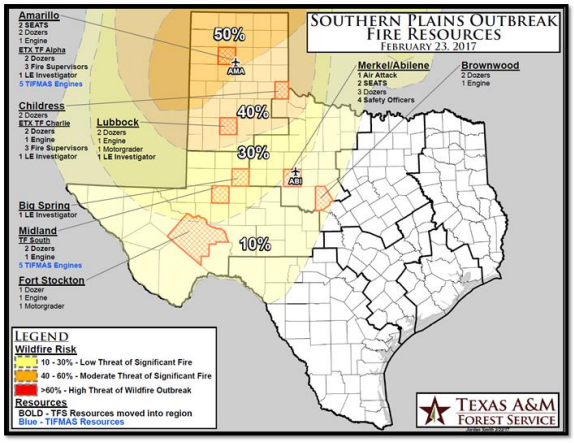

Figure 2: Experimental probabilistic significant wildfire outlook and Texas A&M Forest Service resource deployment prior to the 23 February 2017 wildfire outbreak.

2. DEFINING SIGNIFICANT WILDFIRES

"*What are we predicting?*", is a fundamental question for any phenomenon-based forecast. Additionally, establishing appropriate forecast/warning verification techniques is of equal importance (e.g., Murphy 1991, 1993; Brooks and Doswell 1996). It is not the intent of this paper to establish a definition for significant wildfires. Numerous studies have identified the need for consistent terminology in categorizing wildland fire events, as well as the complexity and geographic variability involved in doing so (Sharples et al. 2016, Werth et al. 2016, Tedim et al. 2018, and others).

On the southern Great Plains, collaborative research-to-operations efforts aimed to improve readiness for high-impact fire episodes have focused upon predictive indicators of fireline intensity, which directly influences wildland fire's resistance to control and the threat posed to life and property. Here, we categorize wildland fire into three categories: initial-attack fires, large fires, and significant wildfires (Fig. 3). Reid et al. (2010) and Weir et al. (2012) indicate that more than 90% of fires in Oklahoma occupy the initial-attack or lower bound of the large fire portion of this spectrum. Forecasters in the southern Great Plains have demonstrated ability to differentiate fire environments that support significant wildfires, or those that exceed 90th percentile physical attributes such as burn temperature, rate of spread, fireline intensity, and burn area, from those that instead promote less dangerous increases in initial-attack fires (Lindley et al. 2015). By utilizing ingredients-based forecast methods to identify fire-effective fuel and weather features, and leveraging high-resolution meteorological remote sensing for fire detection in environments that support significant wildfire occurrence, strategic probabilistic wildland fire outlooks and tactical warnings for extreme fire behavior are possible.

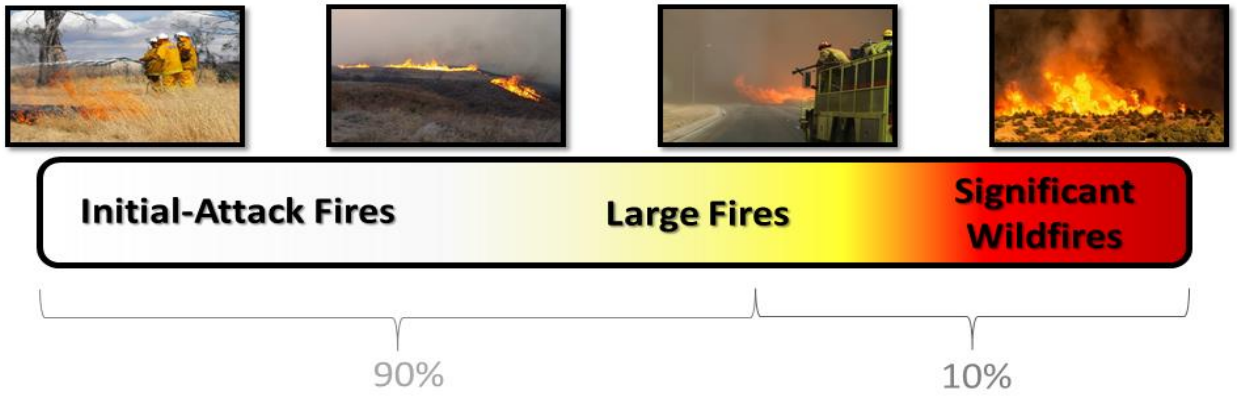

Figure 3: Spectrum and distribution of wildland fire categorizing initial-attack fires, large fires, and significant wildfires.

3. IDSS-BASED FORECAST & WARNING PROTOTYPE

Traditional NWS RFWs communicate a firefighter safety message, but lack a formal public warning component. The experimental IDSS prototype developed and operationally demonstrated by the NWS, Texas A&M Forest Service (TAMFS), and Oklahoma Forestry Services (OFS), promotes both fire/land/emergency management and public safety via a three-step forecast/warning and response process (Fig. 4). First, joint-disciplinary fire science is leveraged in multi-agency collaborated probabilistic significant wildfire outlooks. These outlooks are based upon quantified measures of the total fuel and weather fire environment known to support significant fire-effective conditions. Second, the probabilistic outlooks facilitate targeted preparatory actions from partner agencies and governing officials. Strategic responses include allocations of mutual aid firefighting resources to areas of heightened wildfire risk prior to anticipated fire episodes, as well as public and first responder awareness campaigns. Third, local jurisdictions, supported by pre-deployed state agency resources, are tactically routed to emerging wildfires as NWS forecasters issue fire-specific notifications, or 'warnings', upon detection via high-resolution meteorological remote sensing.

An IDSS approach to NWS fire forecast and warning services provides fire/land/ emergency management agencies information used to influence elected officials in actions that ultimately save life and property. While the NWS traditionally does a very good job informing about red flag conditions, identifying where the worst threat for wildfires exist enables informed decisions based on a true risk-benefit analysis (Angerer, personal communication, January 24, 2014). Partnering with the NWS to prototype IDSS-based fire forecast/warning services has transformed Oklahoma's wildland fire operations from *"reactive to proactive"* (Daily, personal communication, May 10, 2018) and allowed TAMFS to *"move metal, men, and money"* (Smith, personal communication, February 22, 2017) days prior to wildfire outbreaks. Such IDSS is impractical with current deterministic RFWs that are not correlated to significant wildfire potential and do not include tactical 'warn-on-detection' notifications (Fig. 5).

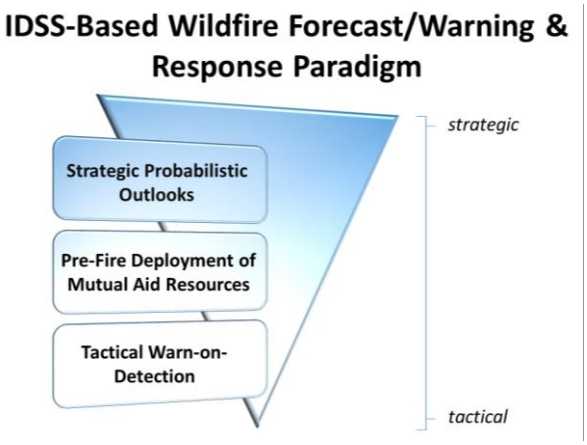

Figure 4: IDSS-based wildfire forecast/warning model from strategic to tactical timescale.

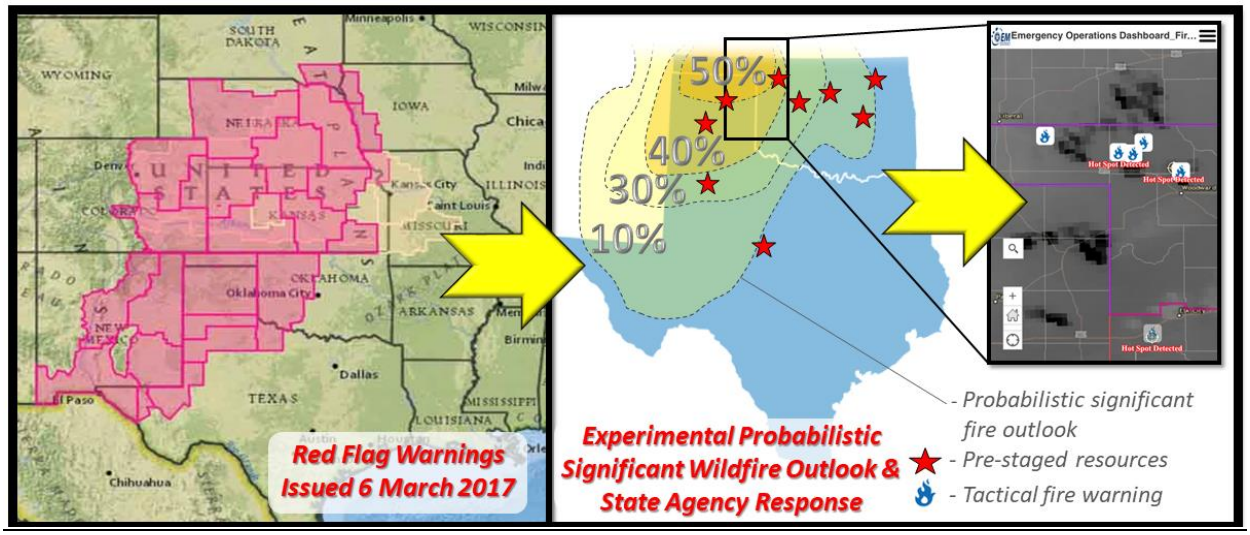

Figure 5: Comparison of legacy deterministic red flag warnings and experimental probabilistic significant wildfire outlook issued prior to a Plains firestorm on 6 March 2017. Locations of strategically pre-deployed firefighting resources by officials in Texas and Oklahoma are shown, as well as tactical fire warnings issued with initial wildfire detections via meteorological remote sensing.

4. DISCUSSION

Given the established interagency hierarchy of federal land management agencies involved in wildland fire, it is important to note the unique circumstances which fostered development and operational tests of the Plains IDSS-based wildfire forecast/warning services prototype. The Great Plains physiographic region has experienced dramatic fire regime intensification in recent decades (Lindley et al. 2013 and Donovan et al. 2017). State governments, such as Texas and Oklahoma, initially lacked resources to effectively manage impacts from escalating firestorms, and conflagrations inflicted loss of life and property on short temporal scales that precluded timely and effective federal wildland firefighting assistance. Thus, investments were made in research, predictive services, and firefighting infrastructure (Pyne 2017). Given the NWS's lead role with regard to operational fire weather forecasting (Heffernan 2017), collaborative inter-disciplinary partnerships were forged between the NWS and state forestry fire analysts. Their objective was to develop conceptual models for operational forecasts of firestorms to achieve sufficient advance notice to affect preparedness.

The experimental Plains model of strategic forecasts and tactical warnings for significant wildfires may serve as an IDSS-era prototype for a FACETs modernization of NWS fire services (Fig. 6). In a future paradigm, inter-agency/disciplinary fire forecasters may provide probabilistic significant wildfire outlooks days in advance of a potential event. Once science-based predictions provide sufficient confidence for actionable intelligence, meteorologists/fire analysts may brief management agency directors who advise elected policy makers on the potential for high-impact wildfires. In turn, strategic deployment of firefighting resources may be allocated to areas of enhanced risk. Once dangerous fire conditions occur, 'on-detection' notifications of remotely sensed wildland fire may direct rapid dispatch on emerging wildland fires. Meteorologists may additionally provide tactical IDSS as an 'eye-in-the-sky' prior to wind shifts, or for changes in the character of burning detected via high-resolution remote sensing. For prolonged incidents that represent a persistent threat to firefighter or public safety, IMETs would provide on-site support for incident management teams, just as they do today.

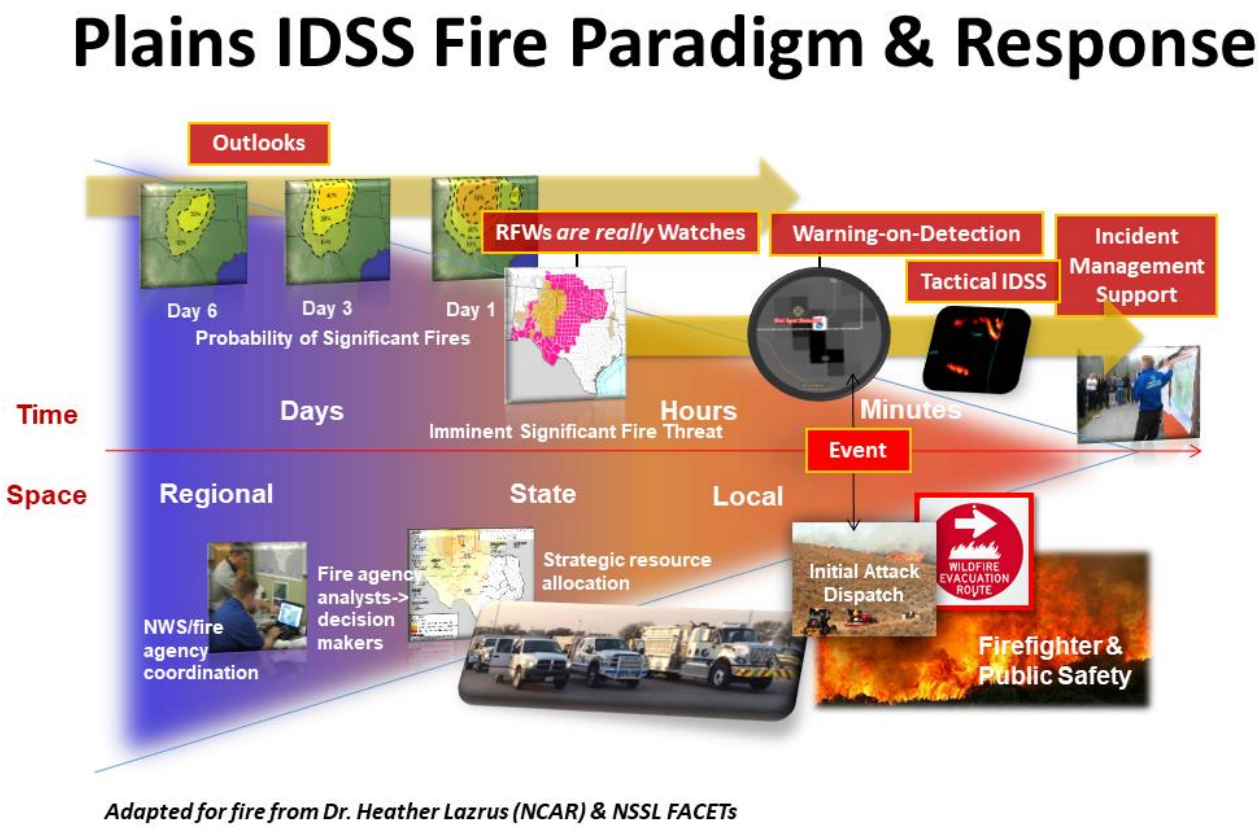

Figure 6: A graphical timeline of the Plains IDSS fire forecast/warning services paradigm and partnering agency response consistent with FACETs concepts.

The IDSS-based forecast/warning prototype detailed above has experimentally proven to enhance support for strategic and tactical response to significant wildfire events in Texas and Oklahoma. Components of this strategy are credited with saving lives and property (NOAA 2017b and 2018). Recent wildfire disasters across the nation underscore the need to evolve NWS fire services toward consistent and effective messaging that not only communicates threats to partnering management agencies, but that also influence public response. Although a complex bureaucracy of local, state, and federal agencies participate in the wildland fire community, the common and primary mission of all involved entities is the protection of life and property. While the Plains prototype has successfully influenced preparedness and improved firefighter and public safety (Fig. 7), this level of fire-related IDSS is not sustainable given current NWS wildland fire policy and infrastructure. Whether responsibility for future fire forecast/warning services falls upon state or federal predictive service units, the Storm Prediction Center, Weather Forecast Offices, or a specialized inter-agency/disciplinary unit remains to be seen. This paper simply provides proof-of-concept for an IDSS-era fire paradigm across strategic and tactical scales.

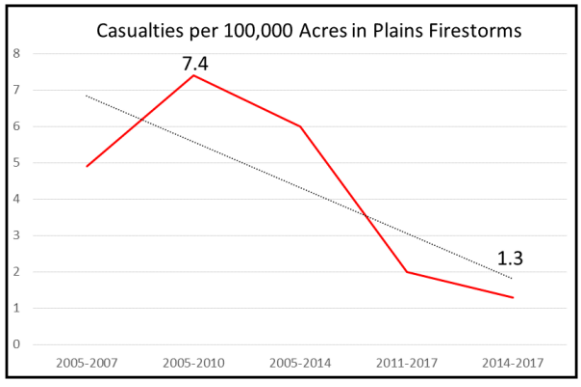

Figure 7: Casualty rates in Plains firestorms relative to benchmarks in the IDSS-based fire forecast and warning prototype.

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REFERNCES

Brooks, H. E. and C. A. Doswell, 1996: A Comparison of Measures-Oriented and Distributions-Oriented Approaches to Forecast Verification. *Wea. Forecasting,* **11**, 288–303.

Donovan, V.M.; Wonkka, C.L.; Twidwell, D. Surging wildfire activity in a grassland biome. *Geophys. Res. Lett.* **2017**, *44*, 5986–5993.

Gray, L. G., 1929: A mobile fire weather forecast unit. Mon. Wea. Rev. **57** (9), 377-378.

Heffernan, R., 2017: Who does what: The roles of scientists in wildland fire weather. *Fire Management Today*, **75** (1), 6-9.

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, B. R. Smith, K. M. Van Speybroeck, 2013: Environmental factors contributing to the emergence of southern Great Plains wildfire outbreaks. *Amer. Meteor. Soc. 10th Symp. Fire and Forest Meteor.*, Bowling Green, KY.

____, G. P. Murdoch, J. L. Guyer, G. D.Skwira, K. J. Schneider, S. R. Nagle, K. M. VanSpeybroeck, 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.

Murphy, A., 1991: Probabilities, Odds, and Forecasts of Rare Events. *Wea. Forecasting*, 6, 302– 307.

____, 1993: What Is a Good Forecast? An Essay on the Nature of Goodness in Weather Forecasting. *Wea. Forecasting*, 8, 281-293.

NOAA, 2017a: Products and services to support fire and other incidents. National Weather Service Instruction 10-401, 6 pp. [Available online at http://www.nws.noaa.gov/directives/sym/pd01004001curr.pdf]

____, 2017b: *Coordinated action prevents worst of wildfire outbreak impacts in southern Great Plains.* Press release, April 6, 2017. [Available online at https://www.weather.gov/news/170604-fire]

____, 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-season-in-southern-plains-off-to-strong-start-after-dry-winter]

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

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

Reid, A. M., S. D. Fuhlendorf, and J. R. Weir. 2010: Weather variables affecting Oklahoma wildfires. Rangeland Ecology and Management, v. 63, no. 5, p. 599-603. 10.2111/REM-D-09-00132.1.

Rothfusz, L.P., C. Karstens and D. Hilderbrand, 2014: Next-generation severe weather 875 forecasting and communication. *Eos*, **95**(36), 325–326, doi: 10.1002/2014EO360001 876.

____, L.P., R. Schneider, D. Novak, K. Klockow, A.E. Gerard, C. Karstens, G.J. Stumpf, and T.M. Smith, 2018: FACETs: A Proposed Next-Generation Paradigm for High-Impact Weather Forecasting. *Bull. Amer. Meteor. Soc.,* doi:10.1175/BAMSD-16-0100.1, in press.

Sharples, J.J., G. J. Gary, P. Fox-Hughes, S. Mooney, J. P. Evans, M.-S. Fletcher, M. Fromm, P. F. Grierson, R. McRae, P. Baker, 2016: Natural hazards in Australia: Extreme bush fire. *Clim. Chang*., 139, 85–99.

Tedim, F., V. Leone, M. Amraoui, C. Bouillon, M. R. Coughlan, G. M. Delogu, P. M. Fernandes, C. Ferreira, S. McCaffrey, T. K. McGee, J. Parente, D. Paton, M. G. Pereira, L. M. Ribeiro, D. X. Viegas, and G. Xanthopoulos, 2018: Defining extreme wildfire events: Difficulties, challenges, and impacts. *Fire*. **1** (9).

Weir, J. R., A. M. Reid, and S. D. Fuhlendorf. 2012. Wildfires in Oklahoma. v. NAREM2888-2.

Werth and Coauthors, 2016: Synthesis of knowledge of extreme fire behavior: Volume 2 for fire behavior specialists, researchers, and meteorologists. Gen. Tech. Rep. PNW-GTR-891. U. S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, 258 pp.