

## 1.5A DELIVERING IMPACT-BASED SEASONAL OUTLOOKS FOR SOUTH CENTRAL TEXAS

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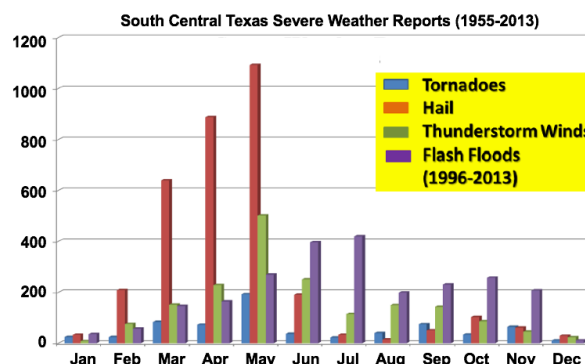
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### 1. INTRODUCTION AND MOTIVATION

Expanding and improving impact-based decision support services (IDSS) to core partners continues to be one of the highest priorities for the National Weather Service (NWS). Seamlessly linking climate and weather through IDSS to support regional and local decision making is listed as one of eleven key concepts for services within the NWS “Weather Ready Nation” (WRN) Roadmap (NWS, 2013). Enhancing climate services to help communities, businesses, and governments understand and adapt to climate-related risks is also mentioned as one of six NWS strategic plan goals in the WRN Roadmap. Furthermore, the *Weather Research and Forecasting Innovation Act of 2017* codifies funding for subseasonal and seasonal forecasting innovation to enhance national security. Considering that 219 weather and climate disasters between 1980 and 2017 have exceeded \$1 billion in damages (CPI adjusted to 2017) leading to \$1.5 trillion in losses (NWS, 2018) and thousands of fatalities, building resilience to extreme weather and climate events is becoming increasingly critical in helping mitigate losses from these events.

Improving forecasts and IDSS for extreme weather and climate events is critical for Texas, which has experienced 95 of the 219 aforementioned billion-dollar weather and climate disasters. South Central Texas in particular has recently experienced record floods during May 2015 (Furl et al. 2018) and October 2015 (Lin et al. 2018) that helped end a catastrophic drought (Nielsen-Gammon 2012) along with the most catastrophic wildfire (Murdoch et al. 2016) and costliest hailstorm in Texas history (Hampshire et al. 2017), all since 2010. Although extreme weather and climate events are not new to South Central Texas, their likelihood of causing significant loss of life and property is increasing due to rapid urbanization and population growth in the Austin-San Antonio corridor, which doubled from 2.25 to 4.50 million from 1990 to 2017 and is forecast to increase to 7.59 million by 2046 (IHS Markit, 2017). South Central Texas is vulnerable to a regular threat of flooding (Fig. 1) and fire weather (not shown) in addition to variety of seasonal weather impacts including hurricanes during summer and early fall, winter storms, and severe weather during spring (March-May; Fig. 1). Flash flooding impacts are most critical in the Texas Hill Country and the Austin-San Antonio corridor that is also



**Figure 1. Severe weather (1955-2013) and flash flooding reports (1996-2013) within the WFO EWX CWA based on NCEI Storm Events Database (courtesy Bob Fogarty, WFO EWX).**

known as “Flash Flood Alley” because it is one of the most flash flood-prone regions of the United States (Saharia et al. 2017). This is largely due to a regular occurrence of heavy rainfall events over a region with steep channel beds and thin soils in relatively small basins that contribute to rapid river rises. These factors combined with hundreds of low water crossings and rapid population growth contribute to significant fatality rates caused by regular short return-period events instead of rare, high-casualty events found in other parts of the United States (Ashley and Ashley 2008).

In order to help local core partners build resilience to high impact and climate events, the Austin/San Antonio NWS Weather Forecast Office (WFO EWX) began delivering local impact-based seasonal outlooks (LIBSOs) in fall 2015 to provide context for national subseasonal and seasonal outlooks issued by the Climate Prediction Center (CPC) and other agencies. Briefings are first presented to emergency managers (EMs), broadcast media, and other core partners during an interactive webinar that averages 17 participants. Full recordings and specific content slides are then shared on social media and through targeted outreach and media interviews. Over 70 unique core partners have participated in the live webinars, with archived webinars averaging 600 viewers on YouTube and specific social media posts approaching 100,000 views. This paper provides an adaptable structure for how LIBSOs that are consistent with CPC and other national outlooks may be created while taking into account antecedent conditions and locally relevant research. Core partner feedback and a potential objective verification process (Dickinson et al. 2018) are briefly discussed to identify strengths and areas for improvement.

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## 2. OBJECTIVES AND STRUCTURE OF LIBSOs

The main objectives of delivering LIBSOs is to brief, educate, and encourage action among EMs, broadcast meteorologists, and other core partners within WFO EWX's county warning area (CWA). Increasing core partners' situational awareness on the potential for high impact weather and climate events while educating them on the regional seasonal threats shown in Fig. 1 and how to interpret NWS and CPC products is especially important for EMs who have a broad range of educational experiences and typically only attend 1-3 training courses or workshops per year (Weaver et al. 2014). Figure 2 shows an example slide given during several LIBSOs to explain the meaning of CPC's seasonal outlooks to help prevent core partners from misinterpreting these forecasts, particularly the meaning of probabilities assigned to equally probable tercile categories (above, near or below normal) based on the most recent 30-yr climatological period. Finally, encouraging partners to make decisions or take action to improve preparedness for an increased potential of an extreme weather and climate event in a given season is the most latent and ambitious objective of LIBSOs. However, WFO EWX believes this is an attainable goal through building trust with core partners by delivering outlooks that they believe (and actually are) relatively accurate.

Briefings issued by WFO EWX are approximately 20 minutes in length and are always given on Thursdays at 2 p.m. LST to provide a consistent time block that works best for core partners based on partner surveys discussed in section 4. In addition, this time takes advantage of the Thursday morning issuance of several weekly products including some CPC outlooks and the Drought Monitor (<http://droughtmonitor.unl.edu/>). WFO EWX typically delivers webinars during early December (winter; DJF), early March (spring; MAM), and early June (summer; JJA) after the National Oceanographic and Atmospheric Administration's (NOAA) Hurricane Outlook is issued, matching the expected onset of winter, severe,

and tropical weather seasons, respectively. The fall webinar has been issued anywhere from mid-September to mid-October depending on when the reasonable threat of tropical cyclones and excessive heat ends in a given year. This seasonal transition usually coincides with the first strong front that local research suggests is most likely to occur in late September, but may be delayed during El Niño years (Fig. 3). WFOs must determine what months work best for delivering webinars for their CWA based on their seasonal impacts and operational schedules. Quarterly webinars are recommended for WFOs east of the Rocky Mountains, but different schedules may be needed for other CWAs.

All briefings begin by presenting current rainfall anomalies and the Drought Monitor before covering subseasonal and seasonal CPC temperature and precipitation outlooks and any relevant climate teleconnections behind them. Locally relevant research that helps provide context and confidence for the national outlooks is discussed next, highlighting common sources of seasonal forecast skill mentioned in Goddard and Hoerling (2006) that CPC staff account for to some extent in the long-lead forecast process (O'Lenic et al. 2008). These sources of skill include, but may not limited to: (1) global climate change, (2) interdecadal variability, (3) El Niño-Southern Oscillation (ENSO), and (4) atmosphere-land surface interactions. Finally, the briefing wraps up with an impacts outlook and questions from core partners attending the live briefing and anyone who views it later online. Archives of WFO EWX LIBSO briefings are at <https://www.youtube.com/user/NWSSanAntonio/videos>.

## 3. CREATING THE IMPACTS OUTLOOK

An example of an impacts outlook that was issued by WFO EWX during fall 2015 is presented in Figure 4. Similar to CPC outlooks, a tercile-based approach is used to forecast whether above, near, or below normal impacts are expected for a specific weather type relevant

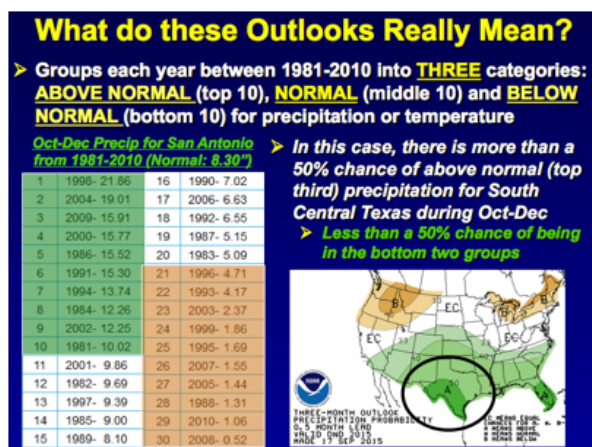


Figure 2. Example educational slide given during the fall 2015 South Central Texas LIBSO briefing that shows the seasonal (OND) precipitation outlook issued by CPC on 17 September 2015.

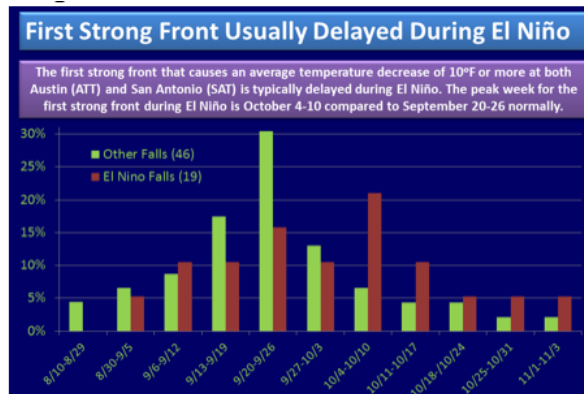


Figure 3. Example locally relevant research slide given during the fall 2015 South Central Texas LIBSO briefing that shows a histogram of the date of the first strong front of fall during ENSO-neutral and La Niña (green) and El Niño (red). Strong fronts must cause an average temperature decrease of 10°F or more at both Austin and San Antonio.

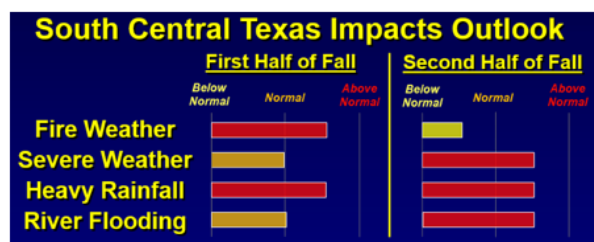


Figure 4. Example impacts outlook given during the fall 2015 South Central Texas LIBSO briefing on 8 October 2015. This figure is adapted from its original form in that “First Half of Fall” was “October” and “Second Half of Fall” was “November-December.”

to a particular season. However, WFO EWX’s relatively subjective impact outlooks are purely categorical instead of assigning probabilities to a particular tercile as in CPC monthly and seasonal outlooks. Impacts are given for the first and second half of a particular season (or first and last two months if needing to emphasize the first month’s forecast) to provide partners with the relative confidence of the forecast through the entire season, including any trends in how impacts may change. Outlooks are produced for severe weather, river and flash flooding, and fire weather for every season, with the addition of winter weather and summertime tropical weather based on the NOAA Hurricane Outlook during those seasons. WFOs in other regions may need to add or remove weather impact types by season depending on their climatology.

Creating the impacts outlook is currently a subjective collaboration between the climate, fire weather, and

tropical focal points and service hydrologist at WFO EWX to make sure all weather impact types are consistent. In addition to CPC and NOAA outlooks, antecedent conditions and locally relevant research are given significant consideration when creating the impacts outlook. Single categorical forecast of above, near, or below normal impacts are usually given for the entire CWA, but multi-county areas whose antecedent conditions or CPC outlooks differ significantly from the rest of the CWA are occasionally featured with a different forecast. The following subsections briefly describe three primary forecast drivers in the context of the first impacts outlook that WFO EWX issued for fall 2015 on 8 October 2015 (Fig. 4).

### 3.1 Antecedent Conditions

Significant wetter (drier) than normal antecedent conditions increase (decrease) the likelihood of flooding while decreasing (increasing) the threat of fire weather and drought going into a particular season, especially when CPC outlooks are forecasting an equal chance of above or below normal precipitation and temperature. Rainfall anomalies are an important antecedent condition that is covered at the beginning of the LIBSO because they are a proxy for soil moisture and potential fuel growth, but streamflow anomalies along with drought indicators and indices are also important. Prior to the fall 2015 webinar, an abnormally dry July-September period following the wettest April-June period on record in Texas (Furl et al. 2018) resulted in 90-day rainfall anomalies that were 10-50% of normal (Fig. 5a), but 180-day rainfall anomalies that were 100-200% of normal (Fig. 5b) across South Central Texas. This triggered the development of

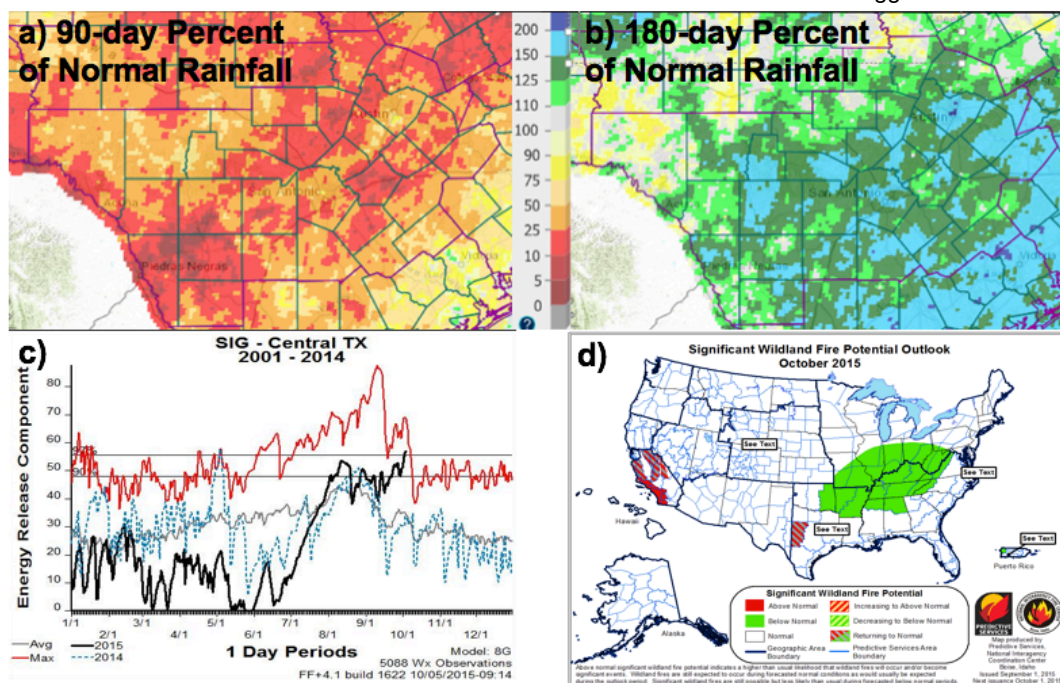


Figure 5. Antecedent conditions presented in the fall 2015 South Central Texas LIBSO on 8 October 2015. The panels depict (a) 90-day rainfall anomalies, (b) 180-day rainfall anomalies, (c) Energy Release Components (ERCs) for Central Texas, and (d) the NICC Significant Wildland Fire Potential Outlook for October 2015.



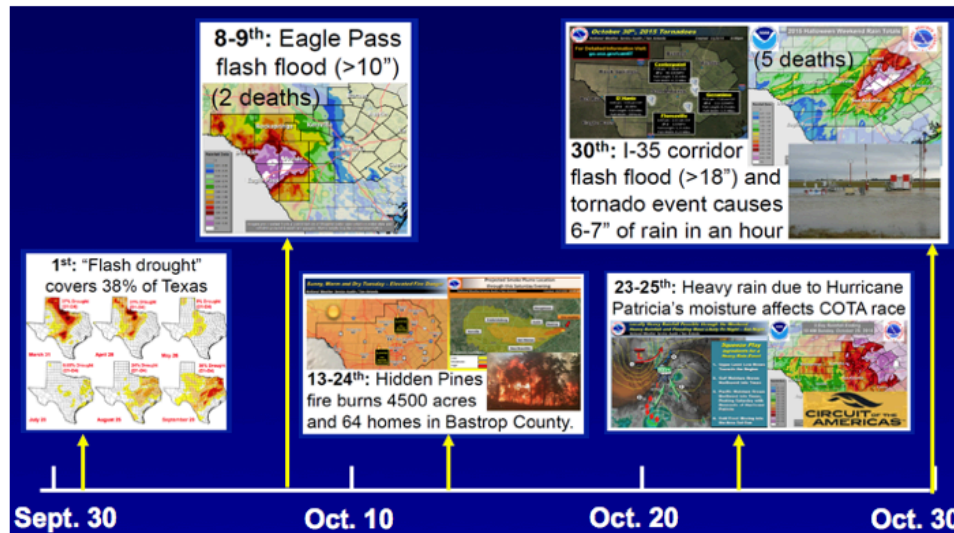


Figure 6. October 2015 timeline of fire weather, flooding, and severe weather events in South Central Texas.

a flash drought over the CWA by early fall with below normal streamflow and soil moisture anomalies (not shown) that decreased flood potential going into early fall.

However, excessive fuel growth due to the wet spring and early summer followed by very hot and dry conditions over the next three months set up favorable fire weather conditions by early fall across all of WFO EWX's CWA. Energy Release Component (ERC) trends, that are considered to be a fuel moisture index that reflects the contribution of all live and dead fuels to fire intensity (Bradshaw et al. 1978; TICC 2018), increased dramatically across Central Texas during the summer and approached near record levels by the beginning of October (Fig. 5c). Consistent with the ERC trends and rainfall anomalies, the Significant Wildland Fire Potential Outlook issued by the National Interagency Coordination Center (NICC) highlighted the potential for fire weather conditions to increase above normal during October (Fig. 5d). The NICC monthly outlook and antecedent conditions combined with 8- and 14-day CPC outlooks favoring odds tilted towards continued warmer and drier than normal conditions increased forecaster confidence that fire weather conditions would be above normal during October if rainfall did not materialize. However, fire weather impacts would be expected to decrease to below normal as flood impacts increased if CPC's prediction of above normal rainfall for the October-December period materialized (cf. Fig. 2), justifying the reversal of fire weather impacts and increase in flooding impacts highlighted in the impacts outlook (cf. Fig. 4).

### 3.2 CPC and NOAA Outlooks

In the absence of significant antecedent conditions, probabilistic monthly and seasonal CPC outlooks following O'Lenic et al. (2008) are the primary forecast drivers of the impacts outlook (excluding severe weather). Skill analyses performed by Livezey and Timofeyeva (2008; LT08) at lead times up to 1 year and

Peng et al. (2012: P12) for 0.5-month lead forecasts issued by CPC display greater skill for temperature than precipitation, most likely due to long-term warming trends associated with climate change. LT08 shows that skill generally does not vary by lead time except for cold season forecasts during non-neutral ENSO conditions, which P12 shows is the dominant contributor to precipitation skill. Both LT08 and P12 display a distinct spatial preference of regions with higher skill that WFOs may evaluate for their CWA by using NOAA's Local Climate Analysis Tool (LCAT; Timofeyeva-Livezey et al. 2015). LCAT analyses (along with figures in P12 and LT08) show that South Central Texas has some of the highest skill scores for precipitation during non-neutral ENSO conditions in all seasons except summer and above average skill for temperature all year regardless of ENSO conditions.

CPC outlooks from 17 September 2015 predicted a greater than a 40% chance of above normal (top third percentile) rainfall for South Central Texas during October and more than a 50% chance of above normal precipitation during the OND period (cf. Fig. 2). Although drier and warmer than normal weather was favored for the two weeks following the briefing, CPC predicted a transition towards wetter and cooler than normal weather evidenced by their 40% chance of below normal temperatures (bottom third percentile) for the OND period (not shown). These high confidence CPC forecasts made possible by one of the three strongest El Niño events since 1950 gave WFO EWX the ability to highlight a reversal from above to below normal fire weather impacts and an increase to above normal flooding impacts during the fall season. In addition, the updated NOAA Hurricane Season Outlook issued on 6 August 2015 forecast a 70% chance of an above normal Pacific hurricane season common during El Niño. This is significant considering that moisture from Pacific storms often causes flooding in South Central Texas during fall when they interact with slow-moving fronts. A timeline of events from October 2015 shown in Fig. 6 shows that this transition from

drought and above normal fire weather conditions to flooding did materialize due to two heavy rainfall events in late October. Although the first event associated with moisture from the strongest Pacific hurricane on record (Patricia) interacting with the first strong frontal passage of the fall did not cause much flooding, it saturated soils for a heavy rainfall event on 30 October 2015 with observed hourly and event rain totals exceeding 150 mm and 450 mm, respectively, causing widespread major flooding and five fatalities.

### 3.3 Locally Relevant Research

Simplified explanations of locally relevant research also increase WFO EWX's confidence in their impacts outlook and the CPC outlooks behind them. This research ranges from basic local office studies like the one given in Fig. 2 that shows the first strong front is delayed during El Niño, to peer-reviewed studies that highlight impacts specific to South Central Texas. Although important for all weather hazards, locally relevant research is most critical for predicting subseasonal and seasonal severe weather impacts for which antecedent conditions and CPC outlooks provide little forecast skill. Several recent studies have shown that La Niña conditions foster more frequent and intense tornado and hail activity across the U.S. relative to El Niño during winter and spring (Cook and Schaefer 2017; Lee et al. 2016; Allen et al. 2015), suggesting that long-range seasonal prediction of thunderstorm activity is possible. La Niña's linkages with tornado activity and intensity are most pronounced at higher latitudes in January-March (Cook and Schaefer 2017) and in the Southeast, Ohio River Valley, and Upper Midwest in April-May during the second spring of "resurgent" La Niña episodes (Lee et al. 2016). However, significant geographical variations displayed in these studies make performing local research of seasonal severe weather impacts critical. For example, local studies show that La Niña and ENSO-neutral conditions produce the greatest number of severe wind, hail, and tornado reports during spring within WFO EWX's CWA, but El Niño conditions are associated with twice as many severe reports during late fall and winter compared to La Niña or ENSO-neutral conditions (not shown). Finally, Research-to-Operations (R2O) innovations like the Climate Forecast System, version 2's (CFSv2; Saha et al. 2014) Severe Weather Guidance Dashboard (Carbin et al. 2016) may provide additional skill for both LIBSOs and seasonal severe thunderstorm outlooks as the CFSv2 model's skill improves in the future.

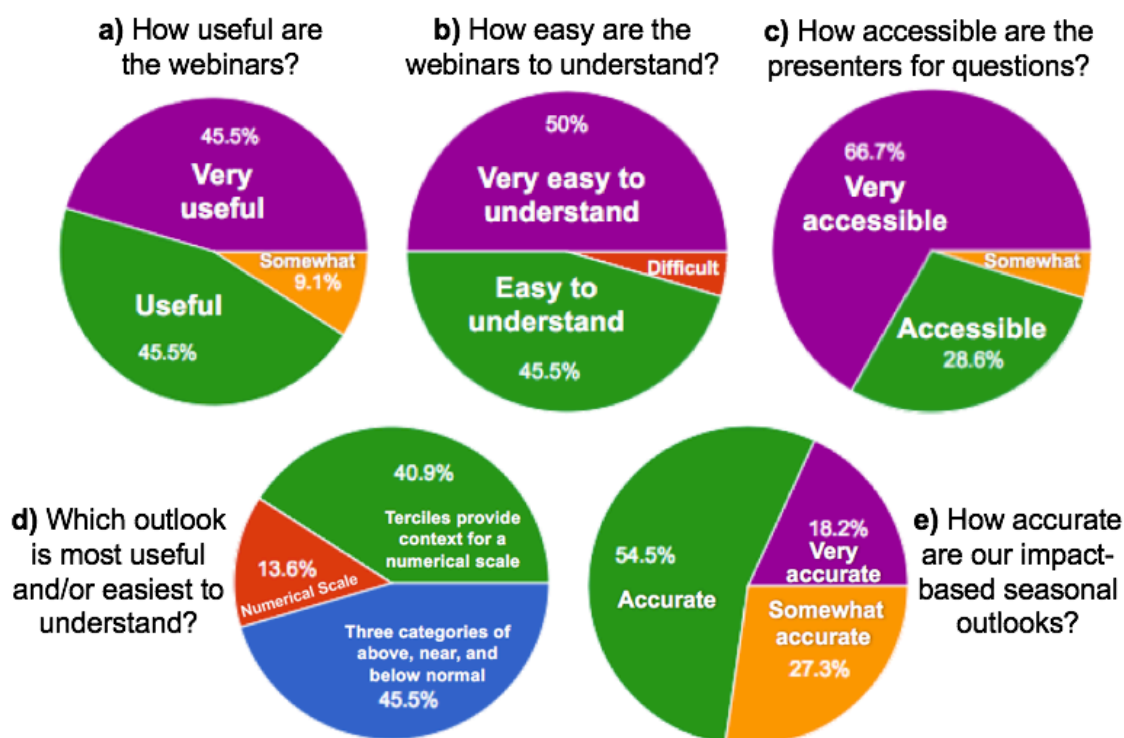
## 4. CORE PARTNER FEEDBACK

Anonymous surveys were administered in October 2017 to 72 core partners who had attended at least one live webinar to receive feedback on how well LIBSOs were serving them and evaluate whether the objectives stated in section 2 were being satisfied. This survey was completed by 22 core partners (15 EMs, 3 broadcast meteorologists, 2 government officials, and 2 other) for a response rate of 31%. The surveys show that 82% of

respondents use the information to maintain situational awareness, 59% improved their understanding of local weather, and 50% made decisions or took actions to improve preparedness based on the LIBSO. Although there is room for improvement, these surveys suggest that objectives to brief, educate, and encourage actions are being met for at least half of core partners. A few comments from EM respondents given below illustrate this as well, while also showing some of the challenges in achieving all objectives with every partner:

- "I use it as a valuable tool to receive expert insight on what patterns we can expect to see. I keep these patterns in mind for my own weather interpretation – as a form of *situational awareness*."
- "I enjoy the webinars (that are) put out. They are a great piece of information to *provide awareness on potential expectations*. I do recommend that EMs and other professionals rely on weather forecast situational awareness as well as climate. Climate can show us the overall patterns, but it is hard to use these forecasts to make decisions or stage resources. *It is important to teach EMs* to use this to have a general idea, and then supplement as the season goes on with daily or weekly weather information for a potential weather impact."
- "I am able to *better plan* for the time period covered by the (LIBSO) when some extreme or unusual pattern is predicted. We have *changed policy* based on the need to have a more rapid response to changing conditions indicated by the (LIBSO) among our elected officials and first response agencies."

Over 90% of core partners who completed the survey indicated that the briefings were useful (Fig. 7a) and understandable (Fig. 7b), and that presenters were accessible for questions during and after the webinars (Fig. 7c). More than half of survey respondents indicated that they would like monthly updates between the seasonal briefings (77%) and quarterly email briefings with a short bullet-point summary (59%), changes that WFO EWX plans to make the later in 2018. WFO EWX also began combining river and flash flooding into a single outlook in fall 2017 because river and flash floods typically occur simultaneously in the Texas Hill Country and Austin-San Antonio corridor, a change supported by 64% of core partners and preliminary verification work described in Dickinson et al. (2018). Most core partners also indicated that categorical forecasts of above, near, or below normal impacts are easier to understand than a numerical scale (Fig. 7d), but a large number of respondents are open to utilizing their preferred tercile-based forecasts to provide context for a numerical scale. Assigning probabilities to a particular tercile for each weather impact type as in CPC outlooks may achieve this in the future.



**Figure 7. Sample questions and responses from an October 2017 survey completed by 22 core partners within the WFO EWX CWA who have attended at least one live South Central Texas LIBSO webinar.**

## 5. PRELIMINARY VERIFICATION AND NEXT STEPS

Finally, and perhaps most importantly, 73% of core partners believed that the LIBSOs issued by WFO EWX have been accurate or very accurate (Fig. 7e). In order to evaluate the true accuracy of LIBSOs, WFO EWX has developed preliminary impact-based verification indices for severe weather, flooding, and fire weather. A full description of this deterministic verification approach for categorical, tercile-based LIBSO forecasts is given in Dickinson et al (2018). All forecasts are verified against 30-yr baseline climatologies for severe weather and flooding (1981-2010), but only a 15-yr climatology for fire weather (2000-2014) due to differences in past reporting. Each index uses several indicators including fatalities, number and days of reports, areal precipitation, and measures of maximum impacts (e.g, largest observed hail size, maximum two-day rainfall) that are summed to

create a score for each season in the climatology. For each season being verified, values of each indicator are assigned the rank of the closest value in the climatology, summed, and then assigned the same rank as the year with the closest sum value.

An example of this verification process for flooding during fall 2015 is shown in Table 1, whose cumulative sum of 35.5 was closest to the year ranked third in the 30-yr climatology, which verified the above normal forecast for flooding impacts. Dickinson et al. (2018) provides additional verification examples from fall 2015, showing that severe weather (above normal) and fire weather impacts (near normal due to the transition from above to below normal conditions within the season) also verified. Overall, LIBSOs issued since fall 2015 have performed 36% better than climatology (with a range of 25-50% for each impact) based on Heidke Skill Scores.

FALL Season	Reports	Report Days	Fatalities Injuries	CWA Rainfall	Adjusted Damages	1 Day Rainfall	2 Day Rainfall	River Gages
2015	54	7	7	12.37 in	\$2.30M	10 in.	13.6 in.	14
Rank	7 <sup>th</sup>	8 <sup>th</sup>	2 <sup>nd</sup>	7 <sup>th</sup>	3 <sup>rd</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	3.5
Value (Year)	48 (1981)	7 (1986)	8.196 (2001)	12.82 in (1985)	\$1.90M (1981)	9.53 in. (1998)	13.2 in (1981)	8 (2 times)

**Table 1. Sample fall 2015 verification for flooding. For example, fall 2015 had 54 flash flood reports, which was closest to 48 reports in 1981. Fall 2015 was then assigned the 1981 rank of 7. The index score is the sum of all of the ranks of the eight indicators above (i.e., 35.5 out of a maximum value of 240), for which the closest value is again found, resulting in a rank of 3. See Dickinson et al. (2018) for more examples.**

Therefore, it appears that the LIBSOs issued by WFO EWX are quantifying above, near, or below normal impacts in a way that matches both *public perception* and “*reality*,” something which may be critical for building trust among core partners so that they may take preparedness actions based on the LIBSOs. More automated verification for rolling three-month seasonal periods is being created to better satisfy core partner requests for monthly updates to seasonal forecasts while also helping improve WFO EWX’s understanding of their verification and climatological trends in weather impacts. In addition to refining the existing verification process, future work will also focus on expanding LIBSOs to other CWAs and developing a more objective process for issuing LIBSOs using ENSO, antecedent conditions, and other predictors like CPC’s seasonal outlooks and other climate teleconnections to help improve verification.

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