BAMS Article

Listening to Stakeholders

Initiating Research on Subseasonal-to-Seasonal Heavy Precipitation Events in the Contiguous United States by First Understanding What Stakeholders Need

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ABSTRACT: Heavy precipitation events and their associated flooding can have major impacts on communities and stakeholders. There is a lack of knowledge, however, about how stakeholders make decisions at the subseasonal-to-seasonal (S2S) time scales (i.e., 2 weeks to 3 months). To understand how decisions are made and S2S predictions are or can be used, the project team for "Prediction of Rainfall Extremes at Subseasonal to Seasonal Periods" (PRES^{2}iP) conducted a 2-day workshop in Norman, Oklahoma, during July 2018. The workshop engaged 21 professionals from environmental management and public safety communities across the contiguous United States in activities to understand their needs for S2S predictions of potential extended heavy precipitation events. Discussions and role-playing activities aimed to identify how workshop participants manage uncertainty and define extreme precipitation, the time scales over which they make key decisions, and the types of products they use currently. This collaboration with stakeholders has been an integral part of PRES^{2}iP research and has aimed to foster actionable science. The PRES^{2}iP team is using the information produced from this workshop to inform the development of predictive models for extended heavy precipitation events and to collaboratively design new forecast products with our stakeholders, empowering them to make more-informed decisions about potential extreme precipitation events.

KEYWORDS: Communications/decision making; Precipitation; Seasonal forecasting; Social Science

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Heavy precipitation (rain or snow) poses significant risks to society (Pielke and Downton 2000; Adeel et al. 2020), including damage to and disruption of transportation systems (Suarez et al. 2005), water contamination (Curriero et al. 2001; Exum et al. 2018), economic losses from flooding (Rosenzweig et al. 2002), and loss of life (Ashley and Ashley 2008). In 2019, flooding and extreme precipitation caused an estimated $20.3 billion in damages across the United States (NCEI 2020). With advanced notice of an impending event, individuals and groups can take protective actions sooner, limiting losses and costs. However, few forecast products exist to inform stakeholders 2 weeks to 3 months—the subseasonal-to-seasonal time scale—prior to an extreme precipitation event. Actions at this time scale may include adding insurance protections, releasing water from a reservoir, updating evacuation plans, increasing public outreach, or preparing an emergency response plan and other resources. White et al. (2017) discuss sectoral applications of subseasonal-to-seasonal (S2S) predictions, including humanitarian aid, public health, energy, water management, agriculture, and emerging sectors such as retail, marine fisheries, and wildfire risk management.

The Prediction of Rainfall Extremes at Subseasonal to Seasonal Periods (PRES^{2}iP) project, funded by the National Science Foundation (NSF), is designed to address this forecast gap. The research team is examining the following questions: 1) What are the typical atmospheric patterns and common characteristics associated with subseasonal-to-seasonal extreme precipitation events in the United States; 2) does large-scale climate variability influence extreme precipitation events, and if so, how; 3) how predictable are subseasonal-to-seasonal extreme precipitation events; and 4) how can we create informative predictions of extreme precipitation events that are easily communicated to policymakers and other stakeholders? Here we describe a workshop that begins addressing the latter question.

When stakeholders are included in product development, the resulting products are more likely to be used and viewed as legitimate and trustworthy by decision-makers (Cash et al. 2003; Meadow et al. 2015). Information tends to be clearer to final users because it is communicated in familiar terms without complicated jargon (Jasanoff and Wynne 1998). Also, codeveloped products are generally easier to use and integrate into existing decision-making processes (Lemos et al. 2012).

Researchers also need to understand *how* stakeholders make their decisions (Dilling and Lemos 2011). Stakeholders have regulatory, institutional, political, and resource constraints that can hinder them from using scientific information (Morss et al. 2005). They make decisions in complex settings that change rapidly and are rife with the uncertainty that an event will occur in their jurisdiction *and* lead to substantial impacts (Lindell and Perry 2012).

In July 2018, as the PRES^{2}iP project began, the research team engaged participants whose jobs required decision-making, planning, response, or recovery work related to local or regional flooding. We held a 2-day stakeholder workshop in Norman, Oklahoma, to determine how participants defined "extreme precipitation" and used weather or climate prediction products in their professions. The "Background" section details why this workshop was needed, and the "Methods" section explains the workshop design, choice of participants, and workshop implementation. In the "Results" section, we highlight workshop activities and the information we gathered. Finally, we will summarize how we used the information in our broader research agenda and discuss future plans.

Background

Despite its impacts, there is no universally accepted definition of extreme precipitation (Pendergrass 2018). Meteorologists, for example, may have numeric definitions, such as if a month's worth of rain falls in a single day at a given location (NOAA 2018). Stakeholders' definitions, on the other hand, tend to vary based on precipitation impacts, policy constraints, decision type, or experience (Dourte et al. 2015). To develop a useful extreme precipitation product for a range of stakeholders, researchers must understand how the users define the term "extreme precipitation," which can be accomplished through scientist–stakeholder relationships.

Beneficial scientist–stakeholder relationships take time and intentional work to develop before they benefit both groups through information creation and use (McNie 2007). Previous research highlights how these relationships can be fostered. For example, communication, which is the process whereby information is exchanged and socially contextualized between stakeholder and scientist (Weaver et al. 2013), is critical. Frequent communication helps to build credibility of the researcher, making it more likely that the stakeholders will use final products and trust their information (Cash et al. 2003; Kahan et al. 2012). Through discussion, stakeholders can express their needs so that researchers can make their products most useful and further explain their process and outputs to stakeholders.

S2S prediction (i.e., 2 weeks to 3 months) has been a growing area of research in the past decade (e.g., Robertson et al. 2015; Vitart et al. 2017; National Academies of Sciences, Engineering, and Medicine, 2017). The World Meteorological Organization notes this time scale is important for developing early-warning systems of high-impact weather events, such as extreme precipitation, and that better predictions could bring substantial societal benefits (WMO 2013; White et al. 2017). Forecasts within the S2S time scale have been tested or implemented in the United States (e.g., Baker et al. 2019; DeFlorio et al. 2019), Europe (e.g., Soares and Dessai 2016), Australia (e.g., White et al. 2015), Africa (e.g., de Andrade et al. 2021), and other countries. Opportunities also exist for enhancing predictions of meso- to synoptic-scale precipitation events at the S2S time scale (Gershunov and Cayan 2003; Mallakpour and Villarini 2016) by taking advantage of expanded understanding of modes of climate variability across the Atlantic and Pacific Oceans (e.g., El Niño–Southern Oscillation, Madden–Julian oscillation). As prediction experiments attempt to address this recognized research gap (e.g., Pegion et al. 2019), the time is ripe to engage stakeholders who may use any future predictions in conversations about their decision-making needs as related to future S2S forecasts. Hence, the PRES^{2}iP team began to examine how to create informative predictions of extreme precipitation events that could be easily communicated to stakeholders by gathering insight into a sampling of decision processes.

Methods

To gather information from a range of experts, the PRES^{2}iP team hosted a 2-day, face-to-face workshop in Norman, Oklahoma, in July 2018. This activity helped the PRES^{2}iP team prioritize which subseasonal-to-seasonal extreme precipitation events to study and establish multidirectional communication pathways among PRES^{2}iP researchers, guest forecasters, and invited decision-makers. Our team planned the logistics and content of workshop sessions from November 2017 to July 2018.

We selected three primary user communities: water resource managers (six participants), tribal environmental professionals (two participants), and emergency managers (nine participants), though we also added a few representatives (four participants) from other sectors (e.g., education, energy). We recruited experts using purposive sampling (Tongco 2007) and snowball sampling (Goodman 1961), contacting those who had worked with a PRES²iP team member and gathering recommendations from them. Some invitees were recommended by other colleagues or through direct contact via email listservs or website personnel directories. Because tribal environmental professionals do intensive fieldwork during the summer, we were unable to recruit many who could leave their jurisdictions. We also invited three guest speakers or observers from the National Weather Service (NWS), including the Climate Prediction Center (CPC), to ensure our research progress was consistent with operational products and services. On 12–13 July 2018, our 19 PRES²iP team members welcomed 21 participants to the first PRES²iP workshop—the Research Priorities Workshop. Participants represented different jurisdictions (tribal, state, metropolitan, rural) and physical geographies (mountainous, coastal, plains, riverine) across the lower 48 states (Fig. 1). In their individual professions, they experienced different types of extreme precipitation events: heavy wintertime snowfall, springtime floods along rivers, landfalling hurricanes, severe convection from isolated or quasi-linear systems, or monsoons.

The workshop had four sessions, briefly described in Table 1, each designed to gather specific information. For sessions 1–3, participants were grouped based on their sector: 1) water managers, 2) emergency managers, and 3) tribal environmental professionals and other experts. For session 4, participants were sorted randomly into four smaller groups. Notetakers recorded the information exchanged within each group, and a facilitator at every table summarized the main points after each session's discussion. Facilitators and notetakers were members of the PRES²iP team, including faculty, staff, postdocs, graduate students, and undergraduates.

Session 1 focused on defining "extreme precipitation" from each participant's perspective, as different definitions could lead to different interpretations of the same event (e.g., Ćwik et al. 2021). To initiate conversations among participants, we created and played a video of researchers and forecasters from the National Weather Center in Norman, Oklahoma, answering the question, What does the term "extreme precipitation" mean to you? Next, we asked the participants a series of questions: How much precipitation in a month would be considered extreme, does the duration of an event or the intensity of an event matter more to you, and is extreme precipitation over a large or small area more impactful? These questions fostered discussions among participants and the PRES²iP team about how the participants defined "extreme precipitation" and its associated temporal and spatial scales.

Fig. 1. Geographic distribution of workshop participants.

Understanding stakeholder's decision-making process is key to developing a useful product (e.g., Klemm and McPherson 2018), so session 2 focused on what types of decisions workshop participants made before, during, or after an extreme precipitation event. Facilitators prompted the participants to think about a *specific* extreme precipitation event (of any duration or intensity) they had

Table 1. Description of workshop activities and goals.

Workshop session	Activity	Session goal
Session 1 What does extreme precipitation mean to you? Day 1: 75 min	Participants watched a short video of scientists from the National Weather Center who were asked about their own definitions of extreme precipitation. The video initiated small-group discussions among workshop participants about what they considered to be extreme precipitation events.	To clarify what spatial and temporal scales of extreme precipitation concerned the participants.
Session 2 How do the participants make decisions? Day 1: 75 min	We prompted participants to think about all decisions for which they were responsible as related to extreme precipitation. Each then selected one decision process and created a decision tree to document its evolution and the information they used to make that decision.	To learn what decisions participants made in their professions regarding extreme precipitation.
Session 3 Impacts and uncertainty Day 1: 75 min	Participants were assigned to small groups, led by a PRES^{2}iP facilitator, and asked questions about how they dealt with uncertainty and the impacts of extreme precipitation events.	To learn how the participants used forecasts to prepare for extreme precipitation events, how they considered forecast usefulness and uncertainty during the decision-making period, and how the impacts of short-term vs long-term events differed.
Session 4 Role-playing activity Day 2: 120 min	Groups assessed multiday forecast products, discussed their interpretation, and collaborated to make a recommendation to the mayor of a fictitious city. Workshop participants assumed the role of Emergency Managers, and PRES^{2}iP team members assumed roles of NWS Forecasters and Mayors.	To learn how participants interpreted different types of forecast products commonly used for S2S precipitation events.

experienced that required them to make complex decisions. Participants brainstormed a list of their decisions, such as supplying sandbags or choosing to postpone or relocate scheduled events. Next, facilitators asked them to select one decision and describe their decision-making process, beginning from when they first learned that extreme precipitation was forecast for their area. Each participant created a "decision tree" and included who they interacted with (i.e., their event-related social network), what information sources they consulted, what actions they took, and when these interactions or decisions occurred in the event timeline. We concluded by discussing similarities and differences in everyone's decision-making processes.

In session 3, conversation focused on forecast impacts and uncertainty. Our goal was to determine how participants used forecasts to prepare for extreme precipitation events, how they considered uncertainty when making decisions, and how potential impacts differed over varying time periods. First, facilitators from the PRES^{2}iP team asked questions about what forecast products participants currently used to make decisions and how their product usage varied for long-term and short-term forecasts. Participants also answered prompts about how uncertainty affected their decision-making and how skillful a forecast needed to be for them to use it.

For stakeholders, uncertainty needs to be conveyed in a way that allows end users to effectively solve problems (National Research Council 2006). One solution is to increase the usage and prevalence of probabilistic forecasts, allowing end users to make better and more informed decisions (Ramos et al. 2013). Probabilistic forecasts can improve decision quality by showing a range of potential scenarios (Joslyn and LeClerc 2012) from which a most probable, best-case, and worst-case scenario can be highlighted (Marimo et al. 2015). These three scenarios help stakeholders to identify potential impacts and prepare for them. Stakeholders also want information on uncertainty and want their forecasts compared to prior years; in other words, they want context for how a future event resembles an event they already endured (e.g., Klemm and McPherson 2017). Yet stakeholders can struggle to apply uncertainty information that is included in forecasts when they first encounter it (Berthet et al. 2016). Therefore, we wanted to know if workshop participants had similar concerns.

Last, the PRES²iP team asked the participants how their jurisdictions were susceptible to extreme precipitation events and if impacts varied for long-duration versus short-duration events. For example, we wanted to know if 10 in.(1 in. ≈ 2.54 cm) of rainfall over 2 days would be more impactful than 20 in. of rainfall over 30 days.

In session 4, participants were engaged in a role-playing game to examine how well they understand, interpret, and act on existing forecast products, such as the Weather Prediction Center's (WPC) Excessive Rainfall Outlook or the Climate Prediction Center's 1–2-week precipitation forecasts. Role-playing scenarios allow stakeholders to practice using products and become comfortable doing so (Rosendahl et al. 2019) and enable participants to observe how the products are used and interpreted. In our activity, we provided a simulated setting for workshop participants to interpret forecast products and make choices while playing the role of an emergency manager in a given scenario. The activity allowed PRES²iP researchers to see what features of forecast products are straightforward or difficult to interpret.

At each table, individuals played one of three roles: the Expert Meteorologist (role-played by a PRES²iP facilitator), the Mayor (also a PRES²iP facilitator), and Emergency Managers (all workshop participants). Mayors requested recommendations from the Emergency Managers, established constraints for them to follow, and collected input from the team. Expert Meteorologists facilitated discussions with Emergency Managers concerning their thoughts about forecast products, answered questions that arose during the scenario, and, if necessary, explained the forecast products to the participants. Five to six Emergency Managers examined possible flooding impacts on transportation, utilities, first responders, and school services. They had to interpret the forecast products, integrate that information into their decision process, and make recommendations to the Mayor about how to handle an upcoming event (e.g., sports tournament, music festival) under the threat of extreme precipitation.

Two scenarios were used: 1) the August 2016 southern Louisiana flood event (impacting central Louisiana, including Baton Rouge) and 2) the spring 2011 Mississippi River flooding (affecting Memphis, Tennessee, and New Orleans, Louisiana). These events were chosen to contrast some sources of extreme precipitation. The southern Louisiana flooding was caused by a weak tropical system while the Mississippi River flooding was due to heavy precipitation on top of melting snowpack. Dates were removed from the forecast products to reduce the chances that familiarity with the actual events would impact discussions. We did not analyze the skill of any of the events' forecasts, as the exercise was focused on learning from the participants about how they interpreted and acted on various forecast products.

In the activity, participants were presented with the CPC's seasonal outlooks at 3- and 1-month time scales; 1–2-week precipitation products from both the CPC and WPC; and, sequentially, 5-, 3-, 2-, and 1-day WPC precipitation outlooks. As simulated time approached the predicted event, we provided shorter-term forecast products and discussed those before moving forward. Finally, depending on what questions the Emergency Managers asked or additional products they requested, participants also viewed WPC excessive rainfall outlooks, 850- and 500-hPa synoptic maps, or radar or satellite imagery. The Emergency Managers discussed what they thought each product described, and if they interpreted a product incorrectly, the Expert Meteorologist explained what the product meant. In each time period, the Emergency Managers discussed how each product's information might influence their recommendation to the Mayor.

At the end of this exercise, we asked participants about each of the forecast products to learn what information they were gathering from each product and how they interpreted the associated uncertainty. We asked them what decisions they made based on each product, how comfortable they felt interpreting the product, and if there were challenges associated with using a given forecast product. Throughout the exercise, a notetaker documented major discussion points for each product, including misinterpretations that participants had made.

Because the workshop initiated a larger research project on S2S prediction of extreme precipitation events, we were limited in the types of forecast products we could show the participants and in the number and backgrounds of participants invited. We did not yet have experience developing experimental products and needed to keep the discussion groups small in order to have time for in-depth questions. We sought a variety of perspectives but limited the representation to only a few sectors so as to hear common messages. As a result, our results are not representative of all sectors, populations, or stakeholders in the contiguous United States; rather, they offer examples of issues that experts have with forecast products associated with extreme precipitation events.

Results

Over four sessions, the PRES^{2}iP team gathered a large amount of information, especially through face-to-face table activities for complex topics and side conversations during the breaks that promoted trust and deepened understanding between PRES^{2}iP researchers and workshop participants.

Session 1: What does "extreme precipitation" mean to you? As expected, "extreme precipitation" had different meanings to the participants. Most noted that the amount of precipitation was less important than whether it caused damage; thus, heavy precipitation that caused no damage, injuries, or fatalities was not considered an extreme event. Although many agreed that a precipitation rate of 1–2 in. h^{-1} likely would cause impacts,[1] no single threshold identified the amount of rain over a given time period that was considered "extreme precipitation."

However, most participants did use threshold values when they described situations in their jurisdiction. These threshold values were rates of precipitation (e.g., 6 in. of rain over 3 h) and not statistical thresholds based on climatology (e.g., 95th percentile). They knew how much rain resulted in flooding of a given low-water crossing, for landslides and building damage to occur, or for inundation of stormwater systems. These place-based thresholds depended on antecedent precipitation (i.e., with extremely dry or saturated soils leading to more severe impacts), seasonal timing (e.g., spring rains on frozen soils), soil type (e.g., clay soils), terrain (e.g., steep valleys), land cover (e.g., fire burn scars), and land use (e.g., urbanization). Several participants also mentioned wind speeds associated with the precipitation (e.g., wet downbursts, freezing rain or snow with high winds) or the precipitation type (especially freezing rain or hail) affected their definition.

All participants identified high-intensity, short-duration events as those most difficult to respond to effectively. Many had different concerns for long-duration events, as their impacts could be harder to identify in a damage survey (e.g., seepage into basements) or increased future risks (e.g., potential debris flows). Longer-duration events or more time between events spread the impacts over time, enabling more proactive solutions. Participants also noted that events with little precipitation could still affect vulnerable people. For example, vehicle owners with bald tires find wet roads particularly dangerous, and specialty crop producers with no insurance can lose their business in a minor hailstorm.

For the PRES^{2}iP team, the key message was that no single threshold for a precipitation amount over any duration was going to satisfy the participants. We needed to focus on *where* heavy precipitation events might occur and *how likely* they are, then trust local experts to do their jobs.

[1] During the workshop, participants frequently used "inches" to refer to rainfall amounts. The terminology used throughout this manuscript reflects participant descriptions.

Session 2: How do you make decisions regarding extreme precipitation? For stakeholders, decision-making is a balance among multiple, sometimes conflicting, factors. Session 2 focused on the types of decisions that participants make when extreme precipitation threatens, the processes of decision-making as captured in decision trees (Fig. 2), and comparisons of similarities and differences among decision processes. Participants' decisions ranged from enhancing local monitoring and preparing resources to communicating with the public and implementing safety plans. Table 2 lists the participants' decisions, which are mostly local and place-dependent.

Some participants apply seasonal forecasts to anticipate impacts in the coming months while others wait until specific events are predicted before implementing plans. At 2–3 months out, forecasts are primarily useful to influence resource and spending decisions. Weeks prior to a forecasted event, participants may survey their infrastructure, begin conversations with local and state governments or regulators, and check staff availability. For most participants, extensive planning that required time and energy usually did not occur until several days before the event, when uncertainty was diminished. Only then did participants begin engaging in common actions, including conversations with trusted forecasters, moving emergency vehicles outside of floodplains, readying resources, preparing to close schools, or evacuating vulnerable populations. Other considerations participants noted were desiring longer lead times during holidays, when they worked in environments with more than one level of government making decisions, or if their emergency plans required more time to execute. One participant, however, worried about staff "burning out" if concern was heightened weeks in advance. Several experts mentioned considerations of forecast accuracy or false alarms. When referencing CPC forecasts in general, another participant explained that they "do not need longer forecasts, [rather, they] need more accurate forecasts."

Fig. 2. Robert Bohannon from the Department of Public Works in Moline, Illinois, talks about his decision tree during workshop session 2.

Session 3: Impacts and uncertainty. During session 3, we asked participants how they dealt with forecast uncertainty during their decision-making process. They all highlighted the importance of their relationships with NWS forecasters. Relationship building enhanced communication and trust between the groups, generated a mutual understanding of each other's terminology and responsibilities, and increased the participants' understanding of and comfort in discussing forecast uncertainty. Without these relationships, forecast products seemed to be used less often or effectively. For example, several participants mentioned having relationships with local forecast offices but not the national centers (e.g., Weather Prediction Center), causing them to lean on products generated by local offices when making decisions.

This session's discussion showed how participants might leverage these relationships with NWS forecasters to better understand and apply forecast uncertainty and gather information that was not communicated in products posted to public-facing websites. This communication also created an opportunity to seek clarification, ask challenging questions (e.g., if you were me, would you order 10,000 sand bags?), or identify subtle cues about the event. For example, the words used by forecasters can convey uncertainty, as can the timing of forecast

Table 2. Decisions regarding extreme precipitation events identified by workshop participants during decision tree activity.

Planning decisions (months to weeks before event)				
Choose locations for weather stations	Train or retrain employees	Decide who is given weather information within the tribe	Preposition resources	Order sandbags
Monitor water sampling and frequency	Monitor upstream water quality	Calibrate flood models and monitor water levels	Monitor water sampling and frequency	Check pump equipment
Calculate percentile storm event volumes for the amount of water permittees are allowed to discharge	Stockpile/prepare additional chemical water treatments	Coordinate with river operations center	Coordinate with power generation desk about potential excess hydrogeneration	Update drinking water treatment options
Response decisions (days to weeks before event)				
Brief governor	Social media messaging before, during, and after events	Prepare road crews for salt or sand/downed trees (winter precipitation)	Warning partners (public works, regional counties, school districts, etc.)	Evacuation of hot spot areas
Emergency Operations Center activated	Decide how much information should be shared with the public ahead of time	Initiate email communications to inform upper management and hydrologists about potential flooding	Work with public works and transportation ahead of time to clear culverts	Open or close county buildings
Brief power plants in area	Move staff to dams for 24-h coverage	Establish hotel, food, and fuel supply for utility repair crews and contractors	Identify alternative routes, ensure those routes are cleared and accessible	Transport juveniles/ inmates
Coordination calls with FEMA/Office of Emergency Management/sheltering agencies if long-term impacts are expected	Bring hydrologists in for 24-h shifts	Work with contractors who may be working on dams to prepare them for heavy rain	Road closures	Take wells out of service before an event

products. One participant noted that if the NWS scheduled a webinar more than a few days in advance, they knew the Forecasters had higher confidence in the event occurring. Consistency over time also provided uncertainty information; a consistent forecast was interpreted as more certain and easier to use for making decisions. Participants noted that they needed forecasters to be frank, include probabilistic information, and discuss confidence or uncertainty regarding the forecast.

Effective communication of uncertainty mobilized participants to use forecasts in different ways. For example, they could use a worst-case scenario to prepare for an upcoming event when catastrophic impacts were possible, even if forecast confidence was low. Some participants noted that their public communication focused on the most likely scenario, which might change over time. Yet, as another participant noted, uncertainty could be used to prolong public engagement and education about a possible event because, typically, when people became certain about an event's outcome, they stopped listening. Different scenarios enabled participants to apply their local knowledge, education, and experience to best serve their jurisdiction.

Finally, the participants discussed forecast accuracy in detail, with PRES^{2}iP team members posing the question, "Would it be helpful if we were only correct *X* percent of the time when forecasting a heavy rainfall event of any duration, more than two weeks ahead of time?"

In one group, six of seven participants said 75% was their threshold for useability, while one participant said 50% was their threshold. Another group had lower thresholds for events 3–4 days in advance, ranging from 30% to 50% to start any actions. The third group did not identify threshold values but discussed situations that would result in different answers to the question. These contextualized situations depended on location (i.e., "we always get heavy rain"), event type (e.g., hurricane versus extratropical cyclone), terminology (e.g., "extreme" versus "record rainfall"), and risk tolerance (e.g., cultural or political differences). Overall, participants desired higher accuracy for not only subseasonal-to-seasonal forecasts, but also forecasts that would fall within the typical weather time scale. They felt that this increased accuracy would allow them to make decisions with higher confidence of the forecasted outcome occurring in their area.

Session 4: Understanding, interpreting, and acting on forecast products. The role-playing activity required participants to solve a complex problem together, using their varied understanding of the forecast products dispersed by the Expert Meteorologist. For the groups using the central Louisiana flooding case, participants played the role of Emergency Managers in Baton Rouge, Louisiana; for the Mississippi River flood case, they played Emergency Managers in Memphis, Tennessee (Fig. 3). To begin, they received the 3-month, then the 1-month, seasonal temperature and precipitation outlooks from the CPC (Fig. 4). After noting what public event they were planning, the Emergency Managers started discussing the outlooks.

There was general confusion about the CPC products, with several wondering what "EC" (equal chance) meant, what lead time meant, and what the confidence levels were in the different categories. Several participants discussed the difference between probability and confidence levels, with many wishing the legend used clearer language, that terminology was defined (e.g., what does "enhanced" mean?), or fonts were larger. As one stated, "I thought [they] would talk in layman's terms, not just put things out for us to interpret"; another said, "I want to know how to interpret this." In one case, a participant was concerned that the product had numbers labeled on it, as they felt it conveyed more certainty than actually existed. Most indicated that they would take no action with these seasonal outlooks.

Fig. 3. Nelly Smith from the Environmental Protection Agency Region 6 participates in the role-playing activity.

At 1-month lead time, we asked the Emergency Managers what additional information would be helpful to them. A variety of products were named: a map of the normal temperature and precipitation for that time of year, a hurricane outlook, a river stage outlook, and soil moisture conditions. One group wanted a list of potential precipitation amounts above normal (e.g., 3, 5, 8 in. above normal) and the associated probability that these amounts would occur. All groups noted that CPC seasonal outlook products should include a text explanation in layman's language.

As we moved ahead in time to 14, 7, 5, and 3 days before the event, the Emergency Managers presented quantitative precipitation forecasts (QPF). Participants were concerned about the color key changing among products, what colors were chosen to depict rainfall, what

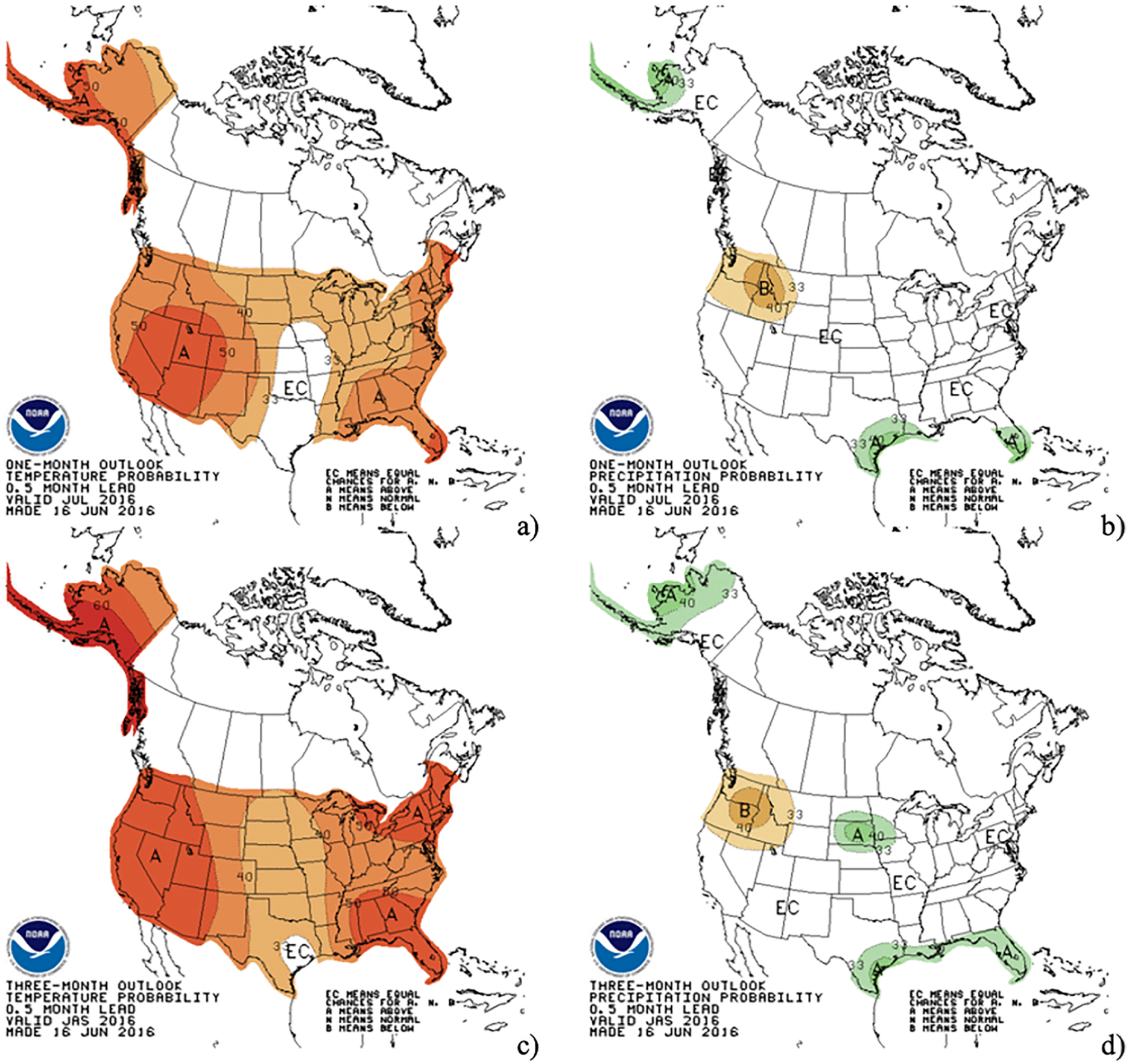

Fig. 4. Examples of Climate Prediction Center (a) 1-month seasonal temperature forecast, (b) 1-month seasonal precipitation forecast, (c) 3-month seasonal temperature forecast, and (d) 3-month seasonal precipitation forecast provided to emergency managers during workshop role-playing activity.

the time frame was, and whether any rainfall rates were implied in the products. Several wanted to know the likelihood that the precipitation amount would occur, the accuracy of the model(s) used, or how much confidence the forecasters had. Other product enhancements included: a worst-case scenario, potential rainfall rates, potential storm type, and duration of the rainfall. Many participants noted that during this time, the centroid of the event or the forecasted rainfall consistently trended in one direction, giving them a higher confidence in the forecast over time. A few participants noted that, by 2 weeks in advance, they would not trust the CPC forecast over QPF forecasts of the Weather Prediction Center. By 5–7 days before the event, the Emergency Managers started recommending actions to the Mayor, including activating the Emergency Operations Center, alerting schools, increasing staffing at critical facilities, preparing evacuation orders, and communicating with the community.

By 1–2 days before the event, the Emergency Managers had high confidence in their planning decisions and moved to full-scale implementation of their plans. Receiving more detailed products helped answer their questions about intensity, location, and likelihood of the event, increasing their confidence. These products included WPC's 1- and 2-day precipitation forecasts and excessive rainfall outlook, as well as radar and satellite imagery. At this point, some people asked what the exceedance maps meant and how to interpret them. One asked why the color scale of the QPFs were so similar to that of the CPC outlooks, as they displayed different information. Others were frustrated by the number of products and what each could add to their decision-making process.

The closer we moved toward the event, the more comfortable the participants became with the products. It was clear that they were used to applying short-term weather forecasts, satellite and radar imagery, and rainfall measurements. With a few exceptions, they were not comfortable with products beyond 5 days. Participants with water quality, longer-term water planning, or electrical utilities careers found the outlooks more useful to their actual jobs than their simulated jobs in this role-playing activity.

The participants were least familiar with the CPC's products and either had many questions about how to interpret them or made assumptions based on the wording. For example, one group initially interpreted "EC" (i.e., equal chances) as a prediction of a 50–50 chance of normal precipitation. Several participants were concerned about how to interpret percentages above normal without knowing the normal value. On the 3-month CPC predictions, probability and forecaster confidence were sometimes conflated.

Overall, participants wanted to see more explanatory text that included confidence levels associated with each product. They also wanted probabilities as best, worse, and most likely scenarios, though some indicated they wanted probability values directly on the maps. Others noted that they would ignore actual values if they saw words like "high" or "low" on a map. All but one participant wanted probability information for all forecasts, not only extreme events.

The exercise ended by bringing all groups together to discuss the main outcomes. Their main point was that they were willing to work with technical plots, but those were only useful with a narrative explaining the forecasters' thinking. Their personal experience using the product and their relationship with the forecasters who created the product were the two most important aspects to having confidence in a product.

Summary

This workshop advised the PRES^{2}iP team how participants experience and make decisions regarding extreme precipitation events. Through discussions and activities at the workshop, we confirmed that no single threshold of precipitation was used to consider an event "extreme." Instead, participants focus on the impacts of an event and make an array of decisions on differing timelines before an extreme precipitation event. Preexisting relationships with NWS forecasters play a crucial role in decision-making because they can give participants more information and insight into what a forecaster is communicating, which can alleviate some of the challenges in dealing with forecast uncertainty. Finally, participants were largely unfamiliar with long-range (5+ days) forecast products, but they were willing to try these products as long as they included layperson, narrative explanations and consistency among graphics.

Information gathered from this workshop allowed the PRES^{2}iP team to center our research goals on stakeholder needs. This includes connecting statistical definitions of extended (i.e., 14 days to 3 months) extreme precipitation with impacts on the ground through resources such as the NCEI Storm Events Database (www.ncdc.noaa.gov/stormevents/). The PRES^{2}iP team also has applied knowledge generated by the workshop participants to investigate atmospheric conditions before, during, and after extreme events with the lead times identified by the stakeholders in mind (e.g., Jennrich et al. 2020). Work is ongoing to understand uncertainty and false alarms in forecasting such events, as well as rainfall rates and types within events (Bunker 2020; Schroers 2020).

In the future, the PRES^{2}iP team plans to hold two additional workshops, the Product Definition Workshop (originally scheduled for summer 2020 but delayed due to COVID-19) and the Testbed Activity Workshop (at the end of the 5-yr project). The Product Definition Workshop aims to clarify how research results can be translated into operational forecast products. For the Testbed Activity, participants will engage with the PRES^{2}iP team in the NOAA Hazardous Weather Testbed, where they can test our predictive tools, discuss their strengths and weaknesses, and provide the feedback needed to transition products from research to operational use in the future.

Looking back, the PRES^{2}iP team recognizes the vast value we have gained by engaging colleagues from tribes, cities, towns, counties, and states across the contiguous United States at the start of our research. When we have different paths the research can take, we return to these conversations to ground us. When we discuss the design of products, we think about what our colleagues said about their decisions in the field. In particular, the graduate and undergraduate students know some of the real people who both struggle with and rely on the products that our community develops. Although we have not completed our research, the value of these conversations is clear to us. We encourage others to add some aspect of stakeholder engagement into their research and development efforts too.

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