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Perspective

# From principles to action: Applying the National Research Council's principles for effective decision support to the Federal Emergency Management Agency's watch office

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ABSTRACT

The National Research Council (NRC) proposed six principles for effective decision support in its 2009 report *Informing Decisions in a Changing Climate*. We structured a collaborative project between the Federal Emergency Management Agency Region R9 (FEMA R9), the Western Region Headquarters of the National Weather Service (WR-NWS), and the Climate Assessment of the Southwest (CLIMAS) at the University of Arizona around the application of the NRC principles. The goal of the project was to provide FEMA R9's Watch Office with climate information scaled to their temporal and spatial interests to aid them in assessing the potential risk of flood disasters. We found that we needed specific strategies and activities in order to apply the principles effectively. By using a set of established collaborative research approaches we were better able to assess FEMA R9's information needs and WR-NWS's capacity to meet those needs. Despite our diligent planning of engagement strategies, we still encountered some barriers to transitioning our decision support tool from research to operations. This paper describes our methods for planning and executing a three-party collaborative effort to provide climate services, the decision support tool developed through this process, and the lessons we will take from this deliberate collaborative process to our future work and implications of the NRC principles for the broader field of climate services.

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## Introduction

Emergency managers are charged with making decisions before, during, and after disasters that have direct impacts on the health and well being of people and communities. Most often, these events are caused by climate or weather phenomenon like severe storms or flooding events (which may have a weather event as a proximate cause, but can be influenced by climate conditions such as whether recent precipitation has left the soils saturated). About 80% of the 181 federal disasters declared between 1964 and 2012 in the Federal Emergency Management Agency Region R9 (FEMA R9) – which spans California, Arizona, Nevada, Hawaii and U.S. territories in the Pacific Ocean – were directly related to climate and weather; 33% of the disasters were classified as floods (Federal Emergency Management Agency, 2014). To help FEMA stay abreast of potentially harmful weather events, the Watch Office, within the Response Division, monitors weather, climate and other hazard-related information. The Watch Office keeps FEMA personnel updated on conditions that could escalate into disasters, helps keep incident managers informed about potential disaster conditions, and manages FEMA's initial disaster response, making the Watch Office important users of climate and weather information. Historically, FEMA has utilized weather forecasts, primarily provided by the National Weather Service (NWS), which are skillful for up to about 10 days (Li and Robertson, 2015; Slingo and Palmer, 2011), to monitor weather conditions that could lead to disasters. They have not, however, used climate information as systematically.

In late 2011, leadership within the FEMA R9 Response Division approached the Western Region Headquarters of the NWS (WR-NWS) for information to help them identify potential weather-related threats beyond the 10–14 day forecast; in other words at a climate time scale. FEMA R9 was looking for a way to extend the time horizon of its current disaster early warning system through

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the use of climate information. Initial discussions between the two organizations revealed that providing climate information to the FEMA R9 Watch Office would require more than simply directing them to existing information; they were requesting information and interpretation that did not exist at the time (personal communication, A. Bair). The WR-NWS subsequently engaged the NOAA-funded Climate Assessment of the Southwest (CLIMAS) at the University of Arizona to help develop and deliver that information to the FEMA R9 Watch Office. CLIMAS has demonstrated experience in delivering climate and weather information to resource managers and other decision makers through synthesized and value-added products (Guido et al., 2013).

Communicating and using climate information is not without challenges. For example, critical information can be (or can be perceived to be) inaccessible and difficult to understand (Steinemann, 2006), at the wrong temporal and spatial scales for decision-making (Braman et al., 2013; McNie, 2007; Srinivasan et al., 2011), out of alignment with users' climate literacy or information processing and management abilities (Lemos and Morehouse, 2005; Srinivasan et al., 2011), and more uncertain than many managers are comfortable with (Braman et al., 2013). In this paper, we present a case study of a partnership between researchers in CLIMAS, WR-NWS and FEMA R9 that sought to overcome these challenges and improve access to and use of climate information by emergency managers in FEMA R9. We applied the principles for effective decision-support activities outlined by the National Research Council (NRC) in their report *Informing Decisions in a Changing Climate* (National Research Council, 2009) as well as core tenets for the co-production of science knowledge and the delivery of climate services (long-term relationships between producers and users, two-way communication, and focusing on usable products). As we have argued elsewhere (Meadow et al., 2015), successful co-production of usable climate science requires deliberate planning and execution of collaborative research methods and participatory processes to ensure effective collaboration. This paper describes the methods and activities that helped us apply the NRC principles to the development of a disaster early warning decision support system (DSS) and the lessons we learned about providing effective climate services to emergency managers.

## Literature review: principles for effective decision support

Climate services have been defined as the provision of timely, tailored information and knowledge to decision makers, generally in the form of tools, products, websites, or bulletins (Vaughan and Dessai, 2014). Weather services can provide decision makers with important information about conditions at a particular time and place, as well as short-term forecasts, but longer-term information about average conditions, departures from those averages, and the occurrence of low-probability events – climate information – are all crucial to the understanding of the potential impact of weather events (Vaughan and Dessai, 2014). The World Meteorological Organization has identified climate services as a key tool to enable climate adaptation and climate risk management and stresses that climate services must include engagement between users and providers of the services (Hewitt et al., 2012). Climate services involve providing climate information in a way that supports decision makers' needs, making their provision an example of a DSS.

Despite the acknowledged need to provide both greater context and longer term outlooks, climate service providers often lack guidance about the most effective strategies for providing that information (Vaughan and Dessai, 2014). General principles, however, have been proposed. For example, research has shown that more engagement and collaboration between the climate information producer and user tends to make that information more usable (Dilling and Lemos, 2011; Jasanoff and Wynne, 1998; Lemos and Morehouse, 2005). Creating more usable science requires two-way communication and long-term engagement between producers and users (Lemos et al., 2012). These activities can also help increase users' perception that the information is credible and legitimate and can help providers tailor information to be more salient to users (Cash et al., 2003, 2006; Clark et al., 2011).

The 2009 NRC report *Informing Decisions in a Changing Climate* condenses these insights, as well as evidence from many other disciplines, into six principles for the provision of effective decision support: (1) begin with user needs; (2) prioritize process over product; (3) link information producers and users; (4) build connections across disciplines and organizations; (5) seek institutional stability; and (6) design the process for learning. The NRC (2009) notes that decision support activities should be driven by the *needs of users*, which should be identified collaboratively among the producers and users (National Research Council, 2009). The focus on user needs distinguishes climate services from more general climate research, in which the goal is a deeper understanding of the physical climate system (Vaughan and Dessai, 2014) but not necessarily application of that information to management or policy decisions. In the second principle, *prioritize process over product*, the NRC points to the importance of spending time and effort to understand how the climate information and DSS will be used by the stakeholder. This process helps to ensure that the information and tools are usable and considered salient, credible, and legitimate by the user (Cash et al., 2006; Feldman and Ingram, 2009; Lemos et al., 2012). Principle three, *link information producers and users*, reflects the NRC's understanding that DSSs require networks and institutions to link information producers and users. The links should allow the distinct cultures and incentives of science and practice to be respected and maintained, while also enabling the strengths and abilities of each to be maximized. The simultaneous linking and boundary maintenance may require the use of a boundary organization, which is one role that CLIMAS plays, to manage the process (National Research Council, 2009). In principle four, *build connections across disciplines and organizations*, the NRC recommends that DSSs account for the multidisciplinary character of the needed information and the numerous organizations that share decision areas and the decision context. The fifth principle, *seek institutional stability*, is crucial to the success of a DSS. Long-term stability depends on establishing and maintaining networks that include information producers and users who can continually interact to refine and revise the necessary information and DSS tool (National Research Council, 2009). Tangible tools, such as our online dashboard, also require stable technical support throughout their lifespan. The sixth principle is to *design decision support activities for learning* in order to allow decision makers to respond to the continually evolving environment (National Research Council, 2009). The DSS should have the ability to incorporate scientific and other factors that influence decisions, products should be created within the decision context they will be applied, and the DSS should be able to respond to policy windows when they open. We broaden this definition to also include evaluation of the development process, the usefulness of the tool, and impacts of the DSS, which we argue allows for the possibility of double-loop learning (Argyris and Schon, 1978). Double-loop learning involves reflecting on the norms in place in an institution and questioning whether and how those norms should be changed to achieve a desired outcome.

## Hydro-climate dashboard

We applied the NRC principles and tenets of co-production and climate services to co-design and produce an online hydro-climate dashboard tool for FEMA R9. The hydro-climate dashboard is designed to present a curated set of climate information about flood risk in FEMA R9 that can be integrated into their existing DSSs. Although FEMA R9 responds to a range of disasters, at the request of our partners, we focused this phase of tool development on hydro-climate information because flooding is the most common climate and weather-related disaster in the region. The prototype dashboard consists of four sections: 1) historical climate information in the form of a precipitation climatology for the FEMA R9 region, climatologies of flash floods and river floods, and the climatology of FEMA flood and severe storm-related disaster declarations; 2) current conditions, including a 30-day percent-of-average precipitation map, percent-of-average snowpack, current streamflow, and reservoir conditions; 3) outlooks for the next season – three-month forecasts of precipitation, floods, and the El Niño Southern Oscillation (ENSO) and a map of the historical odds for extreme precipitation associated with the current ENSO event for the upcoming three-month season; and 4) a summary written by WR-NWS provides a concise description of the images and helps to articulate what the climate conditions mean for upcoming flood risk. Fig. 1 is a partial replica of the dashboard landing page.[1] Other features of the dashboard are designed to help users interpret and use the information presented. Each map or figure includes an interpretation link that provides the user with guidance about the strengths and limits of the data and provides ‘best practices’ for interpreting the images. Interpretation information includes non-jargon descriptions of the data source, the content of the image, additional web links that provide more information about the content of the image, and recommendations on how to interpret the image. For example, for Climate Prediction Center seasonal precipitation forecasts, the guidance reads “This map does not provide information on the intensity of precipitation. It is possible to have numerous floods within a dry season”, and for Reservoir Conditions, “Reservoir storage increases and decreases seasonally. Storage in reservoirs in Arizona, for example, tends to increase in the spring as snowmelt increases.” For those images that show monthly summaries, a panel of all 12 months is also available (Fig. 2). Table 1 summarizes the components, data sources, and update cycles on the dashboard as well as identifying the creators of each component.

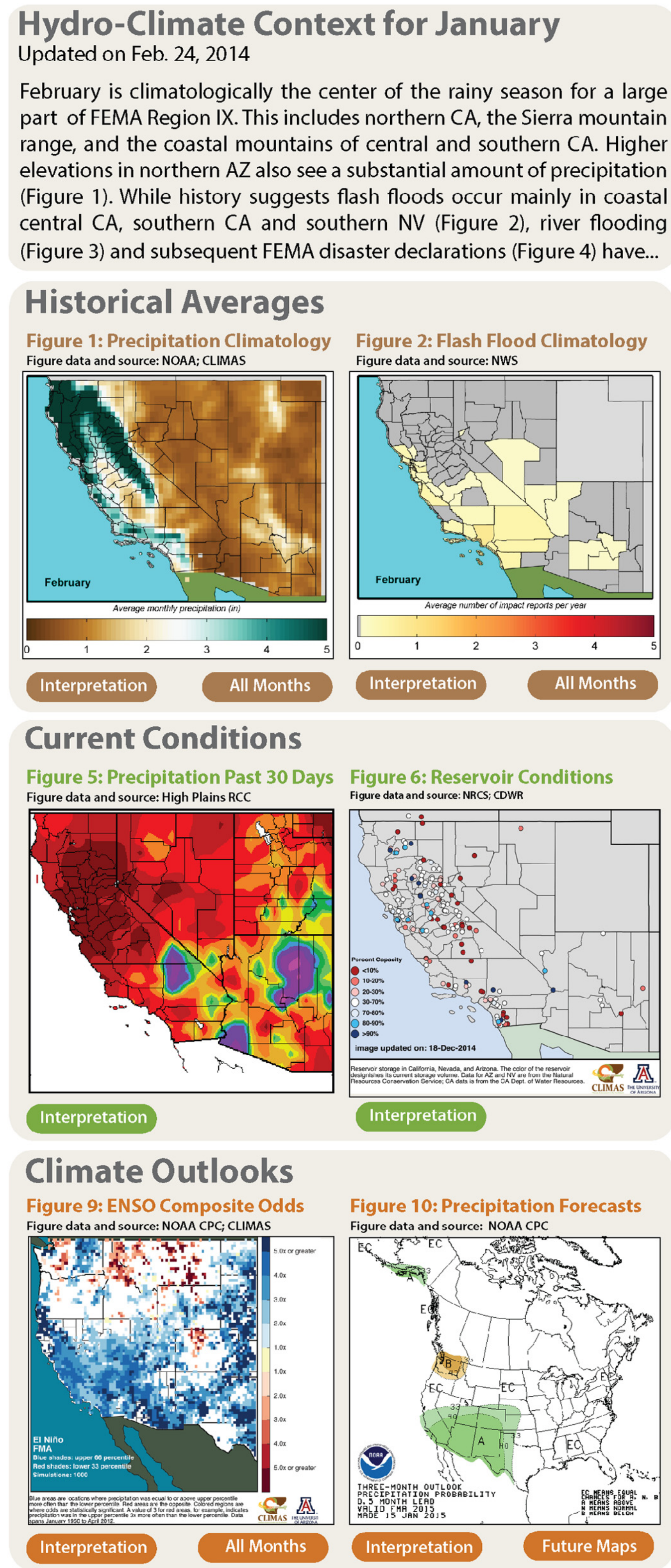


**Fig. 1.** Sample images from the FEMA hydro-climate dashboard.

## Methods

We designed this project in three phases that each incorporated at least one of the NRC principles. The assessment phase combined principles 1–2; the development phase involves principles 3–5; and the evaluation phase focuses on principle 6.

Choo (2009, p. 1072) defines early warning as “the process of gathering, sharing, and analyzing information to identify a threat or hazard sufficiently in advance for preventative action to be initiated”. Choo further notes that an early warning system, such as that already in place within FEMA R9, consists of a network of actors, practices, resources, and technologies that contribute to detecting and warning about the threat. Moss et al. (2014) discuss the role of people and networks in all DSSs. Working from the assumption that decision support for disaster early warning requires an understanding of the people, practices, resources, and technologies involved, we began our inquiries using an ethnographic research approach, Rapid Assessment Process (RAP) (Beebe, 2001) to help us delve into the organizational culture and function of the FEMA R9 Response Division. RAP is a qualitative research approach designed to be effective even with relatively short periods of ethnographic data collection. It relies on two interrelated tenets: triangulation of data, which results from multi-person teams collecting data together from multiple sources (key informants and a broad cross-section of organization members) and iterative analysis, which requires the research team to spend time discussing and analyzing what they heard and saw during fieldwork.

[1] The link to the hydro-climate dashboard is currently available only to FEMA IX and WR-NWS; it will become public once WR-NWS has taken over management of the site.

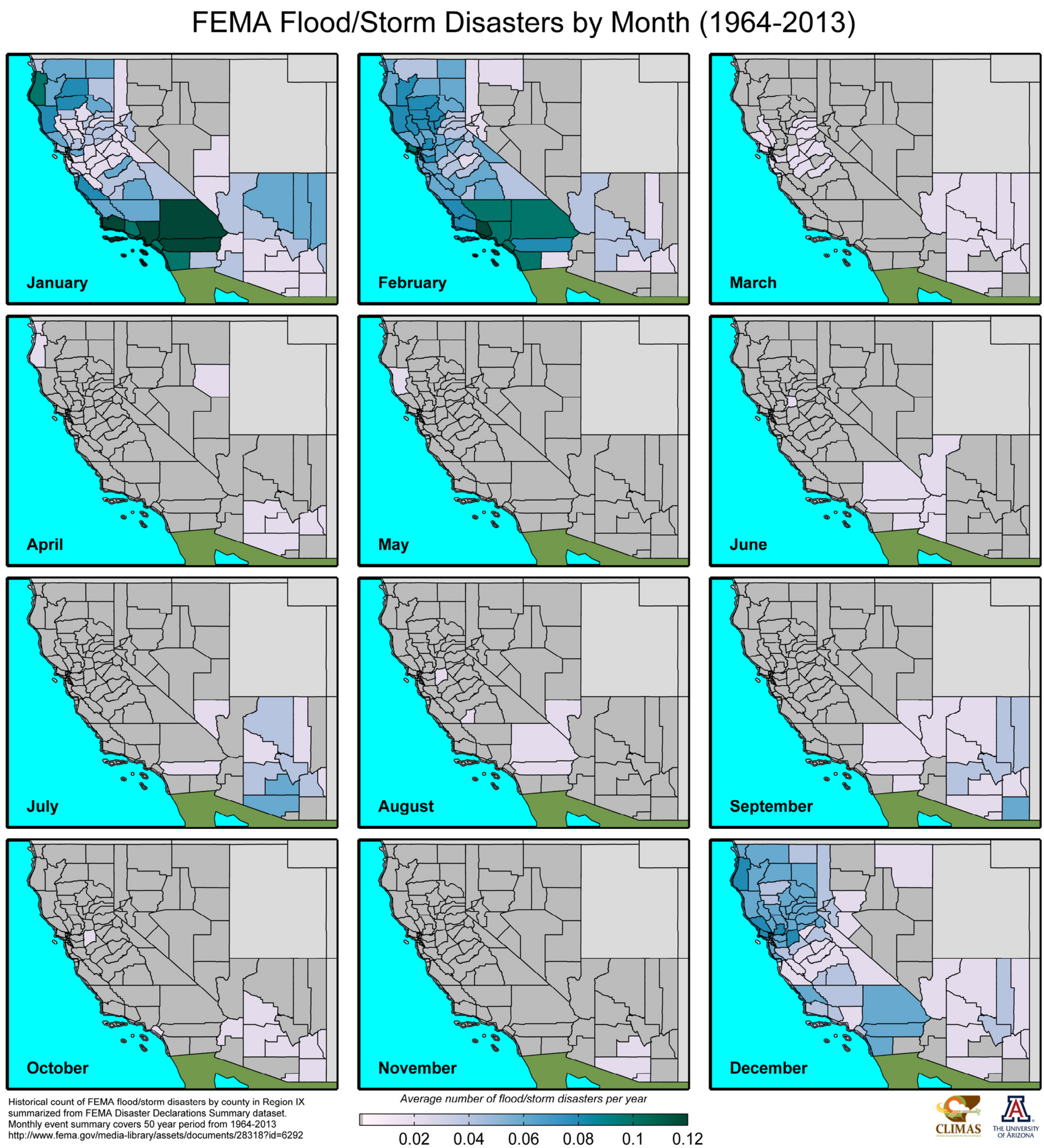


**Fig. 2.** Sample product developed for FEMA hydro-climate dashboard: flood disaster climatology for FEMA Region R9.

We began with a review of literature tracing the history, structure, and function of FEMA (Mener, 2007; Miskel, 2006) and NWS (Hughes, 1970) and FEMA R9's and WR-NWS's organizational documents. We then undertook interviews with eight FEMA R9 informants, three WR-NWS employees, and two state emergency managers; some informants were interviewed multiple times. Interviews typically lasted 45–60 minutes and focused on participants' job responsibilities, their current use of climate and weather information, and their goals for this project. We also conducted one focus group with FEMA R9 staff focused on their decision-making frameworks and the technical demands for the decision-support tool.

To further focus our assessment phase, we used the information use environment concept (Choo, 2009; Taylor, 1991) to develop an inquiry framework and data collection tools (interview guides

**Table 1**
FEMA hydro-climate dashboard components, data sources, and update cycles.

| Component | Data Source | Created by | Update Cycle | Existing or New Product |
|---|---|---|---|---|
| Regional precipitation climatology | NOAA-Climate Prediction Center Unified Precipitation Dataset (http://www.esrl.noaa.gov/psd/data/gridded/data.unified.html) | CLIMAS | Yearly | Created for Hydro-climate Dashboard |
| Flash flood impact climatology | NOAA-National Climatic Data Center Storm Events Database (https://www.ncdc.noaa.gov/stormevents/) | CLIMAS | Yearly | Created for Hydro-climate Dashboard |
| Flooding impact climatology | NOAA-National Climatic Data Center Storm Events Database (https://www.ncdc.noaa.gov/stormevents/) | CLIMAS | Yearly | Created for Hydro-climate Dashboard |
| Flood disaster climatology | Federal Emergency Management Administration (https://www.fema.gov/media-library/assets/documents/28318) | CLIMAS | Yearly | Created for Hydro-climate Dashboard |
| Antecedent (30 day) precipitation percent of average | NOAA-National Weather Service Cooperative Observation Network (http://www.hprcc.unl.edu/maps/current/index.php) | CLIMAS | Yearly | Existing |
| Watershed snowpack conditions | USDA-Natural Resources Conservation Service (http://www.wcc.nrcs.usda.gov/gis/snow.html) | High Plains Regional Climate Center | Daily | Existing |
| Streamflow conditions | U.S. Geological Survey (http://waterwatch.usgs.gov/?id=ww_current) | U.S. Geological Survey | Daily | Created for Hydro-climate Dashboard |
| Reservoir levels | USDA-Natural Resources Conservation Service; CA Department of Water Resources (http://www.wcc.nrcs.usda.gov/wsf/reservoir/resv_rpt.html; http://cdec.water.ca.gov/reservoir.html) | CLIMAS | Monthly | Created for Hydro-climate Dashboard |
| ENSO Composite Precipitation Extremes | NOAA-Climate Prediction Center Unified Precipitation Dataset (http://www.esrl.noaa.gov/psd/data/gridded/data.unified.html) | CLIMAS | Monthly | Created for Hydro-climate Dashboard |
| ENSO 3.4 Index Outlook | International Research Center for Climate and Society (http://iri.columbia.edu/our-expertise/climate/forecasts/enso/current/) | International Research Center for Climate and Society | Monthly | Existing |
| ENSO Seasonal Precipitation Forecasts | NOAA-Climate Prediction Center (http://www.cpc.ncep.noaa.gov/products/predictions/long_range/seasonal.php?lead=1) | NOAA-Climate Prediction Center | Monthly | Existing |
| Seasonal Streamflow Flood Forecasting Outlook | NOAA-National Weather Service (http://water.weather.gov/ahps/long_range.php) | NOAA-National Weather Service | Daily | Existing |

**Table 2**
Elements of the information use environment framework. Based on Taylor (1991).

| Elements of an Information Use Environment | Description of Elements |
|---|---|
| Sets of people | Demographic (such as educational background) and nondemographic (such as media use and social networks) characteristics of the people in the organization of interest. Are there differences in terms of information use within each set? |
| Typical problem the set of people is concerned about | The nature of the problem – for example, the dimension of the problem such as complex/simple, familiar/new patterns – is more important that the subject matter. |
| Setting | What is the nature and variety of settings these groups of people work in? How does organizational structure influence behavior in the organization? What is the domain of interest of the unit of concern? How do people within the setting perceive their access to information? What is the organization's past experience with using new information? |
| Resolution of problems | What constitutes, for a given set of people, resolution of a typical problem? What kinds of information (amount, degree of relevance, quality, format, etc) do people in a particular set anticipate in order to resolve their problems? |

and questions) based on the use, potential use, and provision of climate and weather information in FEMA R9 and WR-NWS. Information use environments are defined by the sets of people within an organization, the type of problems the organization typically faces, how information moves within the organization, the attitude toward information, access to information, and the organization's history and experience with information (see Table 2). These variables affect the flow and evaluation of information within an organization and helped us understand the current application of climate and weather information to early warning in FEMA R9 and identify how best to insert our new, climate-focused information into the existing system.

At each stage of the development of the dashboard tool, we revisited our key informants, either in person or via teleconference so that we could incorporate their feedback into revised versions. We conducted approximately 5 feedback sessions over the course of one year. Once the dashboard was operational for approximately 10 months, we conducted an in-person evaluation meeting where we gathered feedback from FEMA R9 staff.

## Findings: applying the principles in practice

### *Assessment*

The assessment phase allowed us to identify both FEMA R9's information needs and promising approaches to collaboration with FEMA R9 and WR-NWS. A key finding early in our assessment phase focused on the "process" needs of our two partner agencies. FEMA is, in the words of one of our partners, a "no notice agency" in which scheduling meetings in advance is not always possible because the staff is often out of the office on assignments or responding to emergencies (personal communication, S. Bryson). We tried to work within their organizational structure and hold meetings at times when FEMA staff were more likely to be assembled and available – such as in conjunction with their bi-monthly regional coordination meetings. Our NWS partners also had constraints on their ability to meet due to travel restrictions placed on all federal agencies during the time frame of our project. We made efforts to travel to meet with them and to hold frequent teleconferences.

The intended users of the hydro-climate dashboard are the Watch Standers within the FEMA R9 Response Division. They are the front-line staff dealing with weather and climate information. Watch Standers monitor events that may become emergencies, keep FEMA and other agencies updated on events, and coordinate FEMA's immediate response in the event of a disaster. Watch Standers are not, in most cases, trained meteorologists. In FEMA R9 we found that most have military backgrounds, which they reported provides valuable experience for Watch duties such as consuming a great deal of diverse information, remaining aware of complex situations, and coordinating response activities in highly uncertain and rapidly changing situations.

Three Watch-Stander-responsibilities, related to monitoring and communicating about potential disasters, became the focus of our DSS and correspond to the "problems" found in the information use environment. Watch Standers regularly issue several reports: spot reports, which are intended to make FEMA staff aware of potential disaster events; incident reports, which are tied to the allocation or anticipated allocation of federal funds for a disaster; and daily situational awareness reports (DSAR) that include information from the spot reports and summarize activation and readiness levels for any on-going disasters. Watch Standers also brief regional FEMA leaders and other staff on a weekly basis, keeping them up-to-date on potential and on-going disasters, and they brief in-coming Incident Management Assistance Teams (IMATs) monthly. IMAT teams deploy during disasters to provide support and coordination for on-the-ground emergency responders. The purpose of the briefings is to inform the IMAT about what events they may be expected to respond to in a given month as well as provide weather forecasts for the next 10–14 days (personal communication; A. Campbell). The common threads in these three responsibilities are that Watch Standers need (1) a comprehensive understanding of the regional climate in order to communicate "what to expect", and what might be unusual to see in a given month; (2) to understand how longer-term climate conditions influence the ways in which a particular weather event might become a disaster; (3) a store-house of information on regional climate to help mitigate the effects of Watch staff turnover and bring new staff members up-to-speed quickly (such as how ENSO impacts different parts of the region differently); and (4) a tool that facilitates communication about this information within and outside of the agency.

The credibility of information used by FEMA is crucial. In order to be used in FEMA decision-making, information must be provided by a federal agency. One participant explained: "Credibility is huge for use. For the weather, we get [NWS] – that's it. How clean is clean? EPA. You will always hear FEMA say 'The NWS said . . . The USGS [U.S. Geological Survey] said . . . the NSA [National Security Agency] said. . .. ' " The information about credibility helped us recognize that our role as providers of information was to supply background and context information while ensuring that NWS and other federal agency information is prominent and easy to access.

Another example of how FEMA R9 ensures it is using credible information comes from the staff's reliance on knowledge brokers (Meyer, 2010), to provide additional explanation of climate and weather phenomena and to validate (or invalidate) Watch Standers' interpretation of unfolding events. FEMA R9 staff has a close connection with a WR-NWS meteorologist and with a new FEMA Hurricane Liaison. Both of these trained meteorologists and their colleagues act as on-call climate and weather consultants who provide critical meteorological information and interpretation to Watch Standers.

Climate and weather information is only one strand of information the Watch Standers consult as part of their duties. Early in our assessment phase, the Senior Watch Officer gave us a spreadsheet with 54 links to websites including weather, climate, earthquake, volcano, and space weather information that the Watch Standers consult throughout the day and while developing their reports and briefing materials. The Watch Office has organized these links into a dashboard of their own design; we recognized the need to integrate any new information into this existing structure rather than attempt to disrupt such a complex and integrated information delivery system.

The climate and weather information presented within the hydro-climate dashboard was selected based on the needs and questions posed by FEMA R9 staff during our assessment process. First, the staff expressed an interest in gaining a longer time horizon for climate information, which they initially noted might help them pre-position response resources more effectively. They found that neither the 10–14 day forecasts nor the seasonal forecasts were a good match for their decision scale. The weather forecasts do not provide enough information to learn about the climate regimes and seasonal risks in the region. But, seasonal outlooks do not provide enough detail about the potential for individual extreme events to occur in a given season (Mason, 2008). Second, they asked for a way to place current events in an historical context in order to better understand and communicate the potential scale of disaster impacts. Finally, they wanted more synthesis and explanation of the climate and weather information, which could help improve their understanding of an unfolding event and help them communicate about the event to their many contacts.

*Development*

A key goal of this DSS was to link the main information provider – WR-NWS – more directly to FEMA R9, particularly as NWS shifts its focus to impacts-based forecasts and greater collaboration with end-users of climate and weather information (NOAA – National Weather Service, 2011). The links between FEMA R9 and WR-NWS pre-date this project, dating to 2007 when NWS embedded a meteorologist in a FEMA field office in Pasadena, CA to coordinate fire forecasts for deployed IMATs during the fire season. The links expanded in 2014 when FEMA added, in the position of Hurricane Liaison, a meteorologist who had previously been with the NWS. By including these two key links in this DSS (discussed above as knowledge brokers), FEMA R9 staff is able to vet information immediately with trusted sources. The direct links also ensured that NWS heard detailed discussions about FEMA R9's need directly from them, which helped WR-NWS understand the design and function of the tool. While we facilitated the inclusion of these links into the new DSS, in our role as a boundary organization, we recognized the importance of creating more direct connections between WR-NWS and FEMA R9 to ensure that multiple people in each agency became part of the DSS.

While working to link our two partner organizations, we also linked research disciplines. Our research team consists of an applied climatologist, an applied hydroclimatologist, and two social scientists – all with expertise in working closely with climate information users. The interdisciplinary make-up of the team matched the RAP data gathering process. During the assessment phase we drew on our social science knowledge to conduct thorough background research to inform project design, develop interview protocols and conduct interviews. Having physical scientists present during data collection ensured that technical information was interpreted correctly.

The dashboard requires ongoing support to maintain the graphics and the monthly narrative updates. It was explicit from the outset that the operational home of the tool would be the WR-NWS, making WR-NWS's early and continual involvement all the more important. While our direct partners at WR-NWS have been enthusiastic about stewarding the dashboard, two critical issues first had to be resolved: the capacity of WR-NWS to curate the content of the dashboard and how to develop the dashboard on WR-NWS web servers. We struck a balance that allowed CLIMAS to design the framework and contribute the bulk of the content while WR-NWS Regional Operations Center (ROC) has taken over monthly updates of the dashboard.

Unfortunately, transferring the dashboard from its beta-version, housed at CLIMAS, to the NWS became a hurdle. Limited resources within WR-NWS meant that technical staff has not been able to allocate time and expertise to completely rebuild the dashboard in the NWS system. The technical staff also felt that they were not consulted during the development process about design features that would need to be built into their system. At the time of writing, the dashboard is still hosted by CLIMAS and provided to FEMA R9 in a hidden URL.

Table 3 summarizes the needs and interests of FEMA R9 staff and how they influenced the design of the hydro-climate dashboard. The assessment process helped identify the specific information content and delivery needs of FEMA R9 Watch Standers, although the specifics of these elements have changed over the course of the project as we gained a deeper understanding of the Watch Standers' work. For example, initially we heard that a longer time horizon for weather and climate information might help FEMA pre-position disaster response resources earlier, thus saving time, money, and potentially lives in a disaster. However, as we learned more about the agency and emergency management in general, we came to understand that it is not common for resources to be pre-positioned more than a few days before a disaster, for a variety of logistical and political reasons (similar to Demeritt's (2012) findings in the United Kingdom). The ability of FEMA to pre-position resources is somewhat limited by the regulations governing them. FEMA cannot act to intervene in a disaster until a state governor requests federal aid; meaning that their ability to pre-position resources is constrained by an external process. Braman et al. (2013) present a successful example of pre-positioning of resources in the context of international disaster relief. Despite the lack of direct impact on response decisions, FEMA R9 staff were clear that they value the longer-term climate information because it places current conditions and events in historical context and helps them better understand the region for which they are responsible. The hydro-climate dashboard is likely to provide information with more conceptual uses, like increased regional climate literacy, than instrumental uses like resource allocation decisions.

## Evaluation – the NRC principles in use

Our goals for this project were to both design a usable DSS and analyze the way in which we designed it in order to glean lessons for future work. Like the entire RISA program, of which we are a part, we consider this project to be an experiment in the delivery of climate services (Pulwarty et al., 2009). Using the NRC principles for effective decision support provided us with a framework to guide our decisions about engagement and collaboration with both of our partner agencies. We found that in order to act upon the principles we had to draw upon our past experience with climate service delivery and background in collaborative social science research in order to construct an effective collaborative research process. The principles themselves do not constitute a framework for engaging in climate service or decisions support work – they are too broad and aspirational. They do not adequately capture the realities of today's research and development funding constraints, research reward systems, or the constraints faced by management agencies as they try to both integrate new information and maintain

**Table 3**
Each element of the hydro-climate dashboard was designed to link directly to a need or interest posed by FEMA R9 staff.

| Hydro-climate dashboard element | Description | Purpose | Example of expressed need or question |
|---|---|---|---|
| Summary | Interpreted and synthesized synopsis of current and forecasted conditions produced by NWS. | Provide succinct and interpreted discussions that highlight monthly scale flood risks. Summary can guide an analyst in the interpretation of information on the dashboard and share information through existing networks. | "Keep the message clear . . . FEMA staff need to know how to explain what the product says to Congressional staff." *Based on FEMA R9 feedback, we will redesign the summary so that each map frame has an individual sentence beneath it, rather than an overall statement at the top of the dashboard.* |
| Historical Averages | Monthly precipitation and flooding event impact climatologies produced at the regional scale using existing historical datasets | Spatially identify inherent seasonal flood risk across region. | "It gives me a baseline. Seasonally, I know what is expected . . . It is very important for the Watch Standers to understand the climates they deal with." |
| Current Conditions | Hydroclimate monitoring products produced by multiple agencies characterize current and antecedent conditions that could condition flood risk for the next 30 days. | Preliminary analysis of historical FEMA flooding disasters revealed some events that evolved slowly over a season and can be anticipated through the use of hydroclimate monitoring information. Antecedent precipitation as a proxy for soil saturation, snowpack, streamflow and reservoir levels can all provide insight into the level of enhanced flooding risk for the upcoming month regardless of having highly confident forecast information. | *Based on evaluation of the tool with FEMA R9 staff, we will remove current conditions from the tool.* "We already get the current conditions from the sources (NOAA, NWS, California Department of Water Resources) that we find most useful." |
| Outlooks | A selection of regionally relevant, hydroclimate-focused climate outlook and guidance information to highlight potential flood risks over the upcoming 30 days. | Outlook and guidance information leverages known teleconnections between hydroclimate and climate phenomenon like the El Nino-Southern Oscillation. Helps close the gap on the limited skill in monthly scale climate outlook information. | "A climate briefing could obviously be useful and could be used during IMAT change over, which happens every month . . . a briefing about expected, normal conditions and the outlook." |
| Map format | All information is presented as a map, many include information at the county level. | Provide a visual summary of information and present information at the geographical scale (county) at which most disasters are managed and for which most storm information was available. | "One of my goals is to develop a common operating picture. Literally a picture – a map." |
| Interpretation links | Each map includes a tab that provides additional information about how to interpret the information and some guidance about the strengths and weaknesses of the information. | Provide additional guidance about the climate information, the source of the information, and best practices for its use in order to increase general climate literacy. | "ENSO, La Nina, MJO – lots of people don't know what these are, so explanations of what they are and how they might impact climate and weather would be really helpful." |

services, often while also facing budget tightening (Kemp et al., 2015). However, they provide a good starting point for planning and executing an engagement strategy. Here we discuss the research approaches, outcomes of the collaborative process, and the challenges of applying the NRC principles to climate service delivery.

*Begin with users' needs*

Engagement and needs assessment processes are inherently social science activities. They require research about the target organization, their frames of reference, needs, and decision-making processes. If needs assessment work is not done well, the DSS will not meet the needs of the users. Poor research design in any project leads to poor research outcomes – this is just as true for the social science of collaborative research and needs assessment. But seldom are adequate resources available to conduct an intensive needs assessment prior to beginning development of a DSS.

The task of identifying specific and high-priority user needs required us to identify and work directly with the specific end-users of the DSS, as well as with higher-level decision-makers. Both Patton (1978) and Jacobs (2002) note the importance of working with the most direct users of the information in order to identify the most salient needs and have the best chance of new information being used. A higher-level decision-maker may provide guidance and support for a project, acting as a champion within the organization, which is often crucial to project success, but they may not be attuned to the specific decisions being made by others within the organization. In our case, we had the support and input of the Response Division Chief, but our key informants were the Chief Watch Stander and another member of the Watch Office. Despite our relatively high-level support, we still could not avoid the challenge of staff turnover during our project.

Over the course of the project, both of our key informants took new positions within FEMA; we lost our direct connection to the information end-users for approximately 6 months during tool development. When we did connect with a new liaison assigned to the project, we found that the climate information needs, as expressed by the newer group of users, were somewhat different than those of the original informants. This leads us to conclude that we should have cast a wider net during our early needs-assessment activities and revisited the question multiple times with key informants because new ideas and insights can, and did, emerge over the course of the project. The RAP guidelines point to the need to interview both key informants and a wider group of community members (Beebe, 2001). By reaching out to a wider group of informants earlier in the project, including all members of the Watch Office and the IMATs, it might have been easier to re-establish a key informant when needed, we would have gained a better sense of the range of climate information needs and interests among key users, and we would have had greater continuity in terms of familiarity with the project goals and researchers throughout the lifespan of the project.

Principle 1 seems to imply that users' needs are static and uniform throughout an organization; our experience was that when our key informant changed, the expressed information needs also changed. In addition to casting a wide net during information needs assessments, climate service providers should be cognizant of the heterogeneity in information needs and the potential for needs to change over the course of a project. Continually re-framing projects to meet new goals is not realistic, but establishing clear expectations between and among producers and users early in the DSS development process may help to keep the focus on attainable goals.

A broader implication of Principle 1 is the implied assumption that researchers will start each new project with a blank slate, then identify the needs of their stakeholders. However, this is challenging when the vast majority of researchers are reliant on grant funding to accomplish their work. Funders require that a project be planned out at the time of the funding application. There is a mismatch in expectations – researchers either have to have done an intensive needs-assessment ahead of time or propose one idea and risk doing something quite different once the user needs have been identified. As Arnold and Fernandez-Gimenez (2007, 483) note, when research goals are set ahead of time, researchers "may not have the flexibility to engage in the participatory process". As our understanding of the need to tailor climate services grows, funders may become more accustomed to reading proposals that treat both stakeholder engagement and needs assessment activities as integral parts of broader projects. A hybrid funding model that provides some seed funds to support needs assessment activities and collaborative project development prior to submitting a full proposal is one way to address this challenge.

*Prioritize process over product*

Moss et al. (2014) note that decision support includes processes, tools, and services – and those processes include the people involved in the decision making. Our efforts to prioritize process over product included our emphasis on the needs assessment work, consciously incorporating existing links between FEMA R9 and WR-NWS into the DSS, and taking time to reflect upon how the process was working. However, prioritizing process does not fit well into the current reward structures for researchers, which largely focus on products and publications as the measures of success (Bell et al., 2011; Roux et al., 2010). This reality for many researchers can incentivize skipping over a detailed needs assessment (which may not be fully funded anyway) in favor of having a product at the end of the project. It cannot be ignored that end users enter into these arrangements in hopes of getting a usable tool at the end. While they may be aware that a better process is likely to lead to a better product, they also may feel pressure to produce a tangible output in a timely manner (Oh, 1996; Patton, 1978). If a product is not provided or the end-users do not feel that their questions have been answered, frustration, rather than collaboration, can be the main outcome. Finding a balance between undertaking a process of needs assessment and delivering a usable tool, even if in a beta format, should be discussed and negotiated by the researchers and end-users at the start of the project, so that expectations are clear at the outset (Ferguson et al., 2014).

*Link producers and users*

The NRC notes the importance of creating links between producers and users while allowing each to maintain credibility and autonomy; they suggest using boundary organizations as an approach to meet this goal. We acted as both a boundary organization and information provider in this project, but considered our task of linking WR-NWS more firmly with FEMA R9 as a key outcome of the project. We were fortunate to be able to build on existing relationships between FEMA R9 and WR-NWS. Had we not incorporated the existing connections into the DSS, it is likely that the system would have failed because the FEMA R9 team may not have trusted a climate information tool that did not have the support and backing of their key WR-NWS connection. However, we broadened the network to include additional people at NWS who are aware of and involved in the design of the tool and can provide support so that the DSS is not overly reliant on a few key people.

The restrictions placed on federal employee travel meant that we did not have as many opportunities to meet in-person with the whole project team as we would have liked. However, we often were able to take on the role of physical link between NWS and FEMA – communicating information and findings from one part of the DSS to the other. While in the early stages of the project we could act as intermediaries – accomplishing tasks neither organization could do alone (such as easily meet in person), we endeavored to transition our facilitated links into direct connections without intermediaries. We recognized that part of building stability into the DSS required that the two organizations be in direct contact, build their own relationship, and build trust and credibility amongst themselves. The people involved in the DSS network must trust each other and view each other as credible and legitimate sources of information. A weak link risks the credibility and legitimacy of the whole DSS; trust should be built through direct links between producers and users whenever possible.

*Build connections*

The nature of climate-focused decision support work is multidisciplinary and the teams assembled to address information needs should reflect the complexity of the problem. Building connections across disciplines and organizations requires effort on the part of the research team as the NRC authors note. Building connections presents many of the same challenges as beginning with user needs and prioritizing process because these activities do not match well with current research funding and reward systems (Bell et al., 2011; Roux et al., 2010). In our case, we were fortunate to have preexisting collaborative relationships among the researchers, which allowed us to immediately focus our efforts on building the connections to FEMA R9 and WR-NWS.

These less-tangible outcomes, like the strength of connections, can be measured and tracked, which provides researchers with ways to demonstrate the broader impacts of their work. For example, the Pacific RISA developed an evaluation model in which the strength and longevity of network connections are tracked, which provides a model for climate service providers to highlight the outcomes from the process of collaboration (Ferguson et al., 2015). Other RISA programs and Department of the Interior Climate Science Centers are also consciously working to develop performance metrics that more closely match the requirements for developing actionable climate science.

*Seek institutional stability*

The NRC notes that for a DSS to continue over time, the network involved must continually revise and refresh it. We should not equate stability with stationarity. The ability to monitor, reflect upon, and refine the DSS as needs evolve should be built into the system to ensure it can be a stable source of decision support. The other consideration for stability is the need to secure an appropriate level of technical capacity to support the DSS. As discussed above, securing an operational home for the dashboard tool was not without its challenges, even with the support of an operational partner in WR-NWS. The transition from research to operations has been noted as a common issue for RISA researchers (personal communication C. Simpson) and NOAA more broadly, a process the NRC referred to as "crossing the valley of death" (National Research Council, 2000). This process may be eased by more explicitly planning for the ultimate technical home of the DSS. Even if the tool is in a pilot phase, developers can be asking questions about what will be required to support the tool, where it will be housed, and how much capacity is required to support the DSS tool. Similar to the lesson about including the end-users of the tool in development, we suggest including the technical staff in the development process at the very early stages of the process.

A broader issue for stability arises when we consider the roles of university-based and agency-based partners. While the National Research Council (2009) discusses some university-based groups, such as RISAs, as examples of stable institutions for decision support, some caution is warranted. University-based programs are often adept at initiating projects – but they are not necessarily ideal entities for providing long-term operational support because much of their funding is based on individual, short-term projects (Moran et al., 2009). Project-based funds, or "soft money", can hinder an organization's ability to plan long-term or commit to activities not supported by new funding sources (National Research Council, 2000). In contrast, federal programs may be less nimble in the development phase of a new tool, but may have more institutional support and steady funding to maintain a tool (Moran et al., 2009).

In addition to the technical capacity to house a DS tool, teams should consider the effects of stability and instability on the user side of the partnership. Turnover within the user agency had a detrimental effect on our project during the development phase, causing us to lose important key informants and institutional knowledge about the goals and objectives of this project. Agencies who are requesting decision support tools should be cognizant of their role within the DSS and the need to create stability within the system by committing staff and resources to maintaining the system function. If we think of the provision of climate services as an ongoing, iterative partnership built around continual refinement and tailoring of information needs, end-user organizations will need to consider policies that help to support DSSs in the long-term.

*Design for learning*

The NRC describes design for learning as having three components: incorporating scientific and non-scientific knowledge, designing within the decision context, and making the system flexible enough to respond when policy windows open. As we've discussed above, all three are crucial to the success of DSS development and climate service delivery. But, missing from the NRC principle is the role of evaluation in providing investigators and end users with opportunities to reflect upon the process and critically assess the usability of the product. Evaluation serves a number of purposes including improving operations and practices in a specific program, generating information that can contribute to improved decision making at the level of organizational policy decisions, and developing and testing general knowledge about social problems and their solutions (Mark et al., 2006). We see a role for all three purposes in this project and designed an evaluation framework that allowed us to examine the impact and effectiveness of the hydro-climate dashboard itself, reflect on our practices as climate service providers, and use our experiences to consider broader lessons for the funding and provision of climate and decision support services.

Through the course of the evaluation phase of this project, we learned that even our evaluation approach needed to be assessed and refined to better fit the decision context and needs of our agency partners. After several unsuccessful attempts to use a short online survey to collect data about use of the hydro-climate dashboard,[2] we revised the plan to focus on an in-person evaluation meeting. Based on feedback from FEMA R9 staff at that two-day meeting, we are refining the dashboard to remove the current conditions panel, which Watch Standers felt was duplicative of information they regularly receive from other sources; provide more information on ENSO projections to help Watch Standers answer questions they anticipate from IMAT and other staff; and we are planning future work that will focus on linking past climate and weather information to the disaster event database maintained by FEMA in order to provide FEMA staff with more context in which to assess current events.

Lessons for our own practice and broader lessons for climate service provision are discussed throughout this paper. Some of the key insights for our practice have included the need to pay even more attention to the depth and breadth of needs assessment activities to ensure that we have connected with all potential key informants and revisited needs multiple times throughout the course of the project. We also recognized the importance of beginning the process of research-to-operations transition at the start of the project by bringing in technical staff to help design the decision support tool. Finally, this project reaffirmed our past experience that applied work can lead to novel science inquiries (Stokes, 1997). For example, the process of developing the dashboard highlighted a need to understand how different spatial and temporal precipitation patterns can lead to disaster declarations, which may help untangle the climate signal from the other socio-economic determinants of disaster declarations.

Broader lessons about providing climate services include the value in using social science research approaches to conduct detailed needs assessments; and the challenge of committing to an in-depth process when adequate resources are not always available to research teams. Designing useful and used DSSs, or any usable climate science, may require more resources than our current funding system often allocates to the process. Making the case that the longer, more in-depth process is worth the investment requires us to develop ways to evaluate and measure our success and learn from our stumbles. Several climate service organizations are currently undertaking such work, including a project led by the lead author of this paper to design an evaluative framework for collaboratively produced climate science research. Production of usable science is a different model than most research agencies currently use, and large-scale system change will take time and effort. As we document more models of success (and constructively critique our failures), we can build a body of knowledge about how to do this work more effectively and efficiently – and contribute to the kind of institutional changes that will further support this work.

At this point, the CLIMAS team must largely pull back from this project, having reached the end of the funding cycle, which will limit our ability to continually refine the tool to meet FEMA R9's needs over time – the stability of the people within the DSS has been reduced. We have attempted to build processes and connections into the DSS that will allow it to evolve in our absence, such as strengthening the connections between FEMA R9 and staff at WR-NWS. With WR-NWS taking over the monthly summary and updates of the tool, it is our hope that the two agencies will continue to communicate and collaborate about this specific tool and other climate science needs in the future.

## Conclusions

Although we applied the NRC principles for effective decision support as well as lessons from the literature on co-production of knowledge and delivery of climate services, we also recognized the need to be flexible and adaptable in our approach. Our partners at FEMA R9 were somewhat constrained in their ability to interact with us regularly due to the nature of their agency. Our partners at WR-NWS also faced budget-related restrictions on travel, which limited the number of in-person meetings. However, the RAP approach

[2] Among other challenges, we discovered that the Department of Homeland Security, in which FEMA is housed, would not allow access to our survey link on their computers.

helped provide a framework in which to quickly obtain input and feedback from our partners including guidance on who to talk to, how to structure data collection, and how to focus post-field-work discussions. Using the information use environment framework helped us determine how to fit new climate information into existing, well-functioning information use structures.

Perhaps the most important insight we gained through this project related to the amount of time required to develop the new partnerships that form the basis of DSSs. Prior to beginning this project, we had no connection to FEMA R9 and a significant portion of the time and resources of this project have been dedicated to establishing that relationship, learning about the agency, and letting our agency partners learn about us and our capabilities. At the end of three years, we have an operational tool that FEMA R9 plans to integrate into its existing early warning DSS. However, we consider this only one step in the process of collaboration. Based on the evaluation meetings we held with FEMA R9 staff, we envision the hydro-climate dashboard as a boundary object – a common object that allows us to engage in further discussions and collaborative efforts with FEMA R9 and WR-NWS (Star and Griesemer, 1989) – not as an end product in-and-of-itself. We will refine the tool in response to FEMA R9 staff's evaluation of its utility and we are seeking opportunities to build upon this project to create additional components of the tool that would cover fire weather and the tropical storms that affect the Pacific Islands that also fall into FEMA R9's responsibility.

The NRC principles are just that – guiding principles that require specific strategies to enact. We found that by using a collaborative research framework, we were able to identify users' needs, focus on process over product, and effectively link information producers and users in a long-term collaborative relationship. Using a framework to guide interactions between scientists and stakeholders helped both to smooth the project-related work and gave us a structured way to reflect on the successes and challenges of the project. As we found, application of a framework need not be rigid – there is room for flexibility in the NRC principles and in collaborative research approaches. Having an engagement and collaboration plan helped our team gather necessary information about our partner agencies, provided guidance on developing a strong relationship with stakeholders, allowed us to reflect on strategies and activities that have been successful, course-correct when necessary, and consciously apply these lessons to future work.

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