Perceptions about Social Science among NWS Warning Coordination Meteorologists

KATHLEEN SHERMAN-MORRIS, HOLLY LUSSENDEN, ALEXANDRA KENT, AND CAROLINE MACDONALD

Mississippi State University, Mississippi State, Mississippi

(Manuscript received 25 July 2017, in final form 13 March 2018)

ABSTRACT

NOAA has recently placed greater emphasis on implementing social science findings into its products, but perceptions of social science research among National Weather Service offices have not been gauged. To this end, Warning Coordination Meteorologists (WCMs) were surveyed regarding the importance of social science research themes to their local offices. WCMs were also asked to rate their knowledge about several prominent topics and to state their opinions about potential problem issues, such as false alarms, hype, and message inconsistency. Sixty-one WCMs responded to the survey, representing each U.S. climate region. The respondents were favorable toward NOAA's attention to social science, and nearly half have contacted or have been contacted by a social scientist. WCMs rated research themes that addressed how to communicate a message effectively and why individuals do not take action during a warning as being more important. They also rated their knowledge of why someone does not take action during a warning as being the lowest. WCMs expressed agreement that hype, inconsistency, and false alarms are ''key problems'' for their areas, but rated false alarms the least problematic. They also expressed agreement that inconsistency and false alarms influence credibility, as well as the precautions people take during warnings. Finally, respondents described their own most pressing research questions. The importance of behavior and communication was repeated throughout the open-ended questions. Prominent themes included how to make the message more effective and how to get people to respond in an appropriate way upon receiving warning messages.

1. Introduction

There have been examples of scholars incorporating knowledge from diverse fields into their inquiry for as long as scholarship has existed, and in recent years, scholars have increasingly brought their disciplinary knowledge together to address complex problems (National Academy of Sciences 2005). In modern times, an early example of this integration of scientific disciplines was the International Geosphere–Biosphere Program in 1983 (Mooney et al. 2013). There is widespread emphasis in the scientific community on the importance of interdisciplinary study, and this has not escaped the fields of meteorology and climatology. Interdisciplinary publications focusing on climate change research increased at a higher rate than all publications on climate change since the 1940s (Xu et al. 2016). There has also been a somewhat successful push to integrate social science and meteorology. The Weather and Society Integrated Studies program (more commonly known as WAS*IS) was founded on the notion that problems associated with hazards, such as Hurricane Katrina, were not only meteorological or only societal, and greater strides could be made through a thorough integration of the two (Demuth et al. 2007). However, tension can exist between social scientists and colleagues from natural or physical sciences. This sometimes relegates social scientists' participation in interdisciplinary research with engineers or natural scientists as ''an afterthought or 'add on' to a primarily 'scientific' or 'technical' inquiry'' (National Research Council 2006, p. 184).

A very linear conception of the connection between science and societal outcomes that stems from basic science research and eventually translates to social benefits existed throughout the latter half of the twentieth century (Pielke 1997). Partly because of this, opportunities were missed, and a closer connection between research and societal needs is necessary for the

Corresponding author: Kathleen Sherman-Morris, kms5@msstate.edu

DOI: 10.1175/WCAS-D-17-0079.1

benefit of society (Pielke 1997). Demuth et al. (2007, p. 1730) argued, "The next great leap in meteorology arguably could be the comprehensive incorporation of social sciences." Existing social science literature demonstrates the vast amount of research conducted to better understand how individuals perceive and respond to various types of weather information and hazards. The National Weather Service (NWS) has been implementing social science to help meteorologists better understand their audience, to make products more conducive for response, and to ensure effective communication. Efforts were documented as early as the 1970s, with an emphasis on calls to action in the warning process, and also in the 1990s, with a systems approach to issuing warnings (National Research Council 2006). The emphasis has become more widespread in the last 10–20 years. Social scientists have also weighed in by highlighting certain needs regarding weather information. For example, multiple papers have begun with title "Social Science Research Needs for. . ." followed by a weather-related topic, such as the hurricane forecast and warning system (Gladwin et al. 2007, 2009) or vulnerable populations, forecasting, and warnings (Phillips and Morrow 2007). However, the perspective from the weather forecasting side has not been examined. What is lacking in the literature is research performed with the meteorologists themselves about their opinions and use of social science, as well as how they think the public views the products they send out. The purpose of the current study is to better understand how meteorologists across the United States perceive social science and to determine what social science–related research would be most beneficial for them to be more efficient in communicating with their audience. The study pursued the following research questions:

1) How do Warning Coordination Meteorologists (WCMs) feel about NOAA's level of attention to social science, and what is their experience with social scientists?
2) What are the perceived social science research needs of the NWS Weather Forecast Offices (WFOs)?
3) What is the relative importance of several themes culled from existing literature as research priorities?
4) How does the relative importance of these themes relate to perceived understanding of the issues?
5) How much do offices believe they already know about these issues?
6) Do WCMs perceive issues such as inconsistency, false alarms, and hype as problems for their forecast area?
7) Do WCMs associate message characteristics such as false alarms and message inconsistency with public reactions such as lowered credibility or less protective action taken?

2. Literature

While the study did not examine how risk communication can encourage protective action or seek to determine the influence of false alarm rate and inconsistency on protective action, a review of the literature in these key areas helps to frame the questions posed by the project, as well as provide context in which to interpret the WCMs' responses. Knowledge exists regarding these topics at varying levels, and some have been studied for a significant period of time. For example, social scientists have studied those factors that lead or do not lead to protective action since at least the 1970s. Theoretical models, such as the Protective Action Decision Model (PADM) or protection motivation theory (PMT), describe the process by which external variables interact with personal perceptions and characteristics to make a behavioral response more or less likely. In PADM, environmental and social cues, along with information characteristics and receiver characteristics, lead to predecision processes such as exposure, attention, or comprehension that, in turn, lead to perceptions about the threat and protective action (Lindell and Perry 2012). Likewise, in PMT (e.g., Floyd et al. 2000; Rogers and Prentice-Dunn 1997), sources of information (including environmental and social cues, as well as formal messages), along with intrapersonal variables, lead to perceptions about both the threat and one's ability to cope with the threat. The motivation to engage in protective behavior is based on the balance of these two appraisals. Response to warning messages has also been conceptualized as a process in which individuals must hear, confirm, understand, believe, and personalize a warning message prior to acting upon it (Mileti and O'Brien 1992). This framework and PADM can be linked through the idea that action is the result of risk information that motivates people to engage in further information-seeking behavior, as noted in Mileti and Darlington (1997).

Message characteristics that tend to favor a protective response have also been studied. Because of the role of confirmation in the risk communication and response process, consistent and repeated messaging can be important (Mileti and O'Brien 1992). Consistency is often thought of in the form of consistency across sources, but with the proliferation of weather graphics available for public consumption, consistency of message characteristics

(e.g., what color is used to display warning polygons) can also be important. Recent research has demonstrated that colors may influence the way individuals perceive risk. For instance, an experimental study of tornado polygons indicated that the choice of color palette or whether to provide a deterministic- or probabilistic-style polygon led to different perceptions of risk and intended protective action (Ash et al. 2014). Color choice did not lead to differences in risk perception in a study of hurricane storm surge, although one color led to small differences in efficiency of interpretation (Sherman-Morris et al. 2015). Hurricane track forecasts may lead to different responses, depending on the choices made in communicating them. For instance, in one study, the choice to omit the center forecast track from a hurricane cone led to differences in risk perception over an image with the center line and may have led to the belief that all areas under the cone were equally unlikely to be hit, which was not the intended message (Meyer et al. 2013). Other research did not find significant differences in risk perception when participants received a graphic with just the forecast track, just the cone, or the track plus cone (Wu et al. 2014, 2015a). Research on tornado polygons has shown that larger polygons made individuals less likely to seek shelter and somewhat less likely to seek more information (Nagele and Trainor 2012).

Forecast-to-forecast consistency has also been assumed to play a role in weather-related decision-making. Forecasters have reported being concerned with a ''windshield wiper'' effect of changing forecasts on hurricane risk perception (Broad et al. 2007), but experimental research has shown that individuals may adjust risk perception (Sherman-Morris and Martinez 2017) and probability estimates (Wu et al. 2015b) accordingly as the forecast changes. This would suggest the issue is not as important as previously thought. However, these findings should also be considered, along with other research that suggests individuals may anchor their risk perceptions on the first (Morss and Hayden 2010) or most severe forecast (Losee et al. 2017) they receive. Related to the idea of a changing forecast is the notion of a false alarm—a warning that fails to verify. Often mentioned anecdotally in regards to lack of warning response, the exact influence of false alarms is not well known. In hurricanes, research indicates that people would not be less likely to evacuate in a subsequent hurricane, regardless of whether they evacuated unnecessarily in a prior hurricane (Dow and Cutter 1998; Zhang et al. 2007). Tornadoes have a higher false alarm rate than hurricanes, and there is some evidence of a false alarm effect for them. Studies using actual county warning information have provided the most evidence of a tornado false alarm effect. For example, tornadoes occurring in areas with higher false alarm rates tended to cause more fatalities (Simmons and Sutter 2009). Similarly, respondents from counties with higher false alarm ratios perceived higher false alarm ratios, which in turn led to decreased trust in the NWS and lowered likelihood of an intended protective response (Ripberger et al. 2015). Trainor et al. (2015) also found evidence that counties with higher false alarm rates and people who perceived higher false alarm rates were less likely to report taking protective action in a warning.

Finally, much research has been conducted on the individual-level variables that encourage a response upon receiving a warning message. Research on sociodemographic influences on warning response has provided mixed results, with a gender effect being one of the most stable (Sherman-Morris 2013). Education has been repeatedly linked to lack of preparedness or response to tornadoes (Liu et al. 1996; Balluz et al. 2000; Blanchard-Boehm and Cook 2004; Schmidlin et al. 2009). Some specific beliefs, such as the fatalistic belief that sheltering will do no good for a person if it is one's ''time to go,'' have also been identified in a portion of the population at risk for tornadoes (Schmidlin et al. 2009). Response also must be considered within its social context (Dash and Gladwin 2007). The consideration of environmental context with fatalistic beliefs can change the way we look at responses. A person living in a mobile home in the southeastern United States where a tornado is more likely to strike at night, and be difficult to visually confirm, may in fact have fewer effective options when a tornado warning is given. The factors influencing each phase of a protective action decision are complex (Morss and Hayden 2010). This can be illustrated by the many issues discussed above that are relevant to a study about the needs of a Warning Coordination Meteorologist. The complexity also demonstrates why, though studied for many years, questions still remain about how to encourage protective action.

3. Methods

a. Sampling frame and recruiting

To answer the research questions, a survey was developed to be sent to WCMs. Each NWS WFO has a WCM who ''serves as the principal interface between the WFO and the users of WFO products and services in leading the effort to insure their evaluation, adjustment, and improvement'' (U.S. Department of Commerce 2017). Further, WCMs are also required to ''[conduct] a WFO area-wide preparedness planning and citizen

education effort with and through various local and state agencies and organizations.'' Therefore, WCMs must not only serve to help in the detection phase of the warning process, but also work with the end users in understanding the implementation and efficiency of the products the NWS is distributing. This group was chosen to represent the NWS WFO perspective because of these roles. As such, they were thought knowledgeable to speak on behalf of their offices. While they were chosen as the best spokesperson for the perspective of the WFO, where interdisciplinary action would take place, they are part of a larger organizational structure that can empower or limit new initiatives. For example, the WCM is part of a management team guided by the Meteorologist in Charge, and local decisions are dependent on the priorities of the regional director. This is an important consideration, given the research questions, in that any changes must take place in accordance with this organizational structure. One additional caveat with choosing WCMs as the population of interest is that this may have biased the results toward nonroutine weather issues. However, we felt the benefits outweighed this potential limitation.

A list of WCM email addresses was publically available. Once approval was obtained to administer the survey (discussed below), WCMs were emailed a letter addressed to them personally with a request to complete the survey online. The first contact was made at the end of July 2016. A follow-up email was sent in September. While there are 122 NWS WFOs, the email list included 132 email addresses total due to some offices having more than one person listed in the spreadsheet. The email program sending the letter recorded 119 successful deliveries in the first attempt and 103 in the second. This does not indicate whether or not the email was read, only that it did not bounce back. The first contact achieved 38 usable responses, and the second contact contributed an additional 23 (61 total) from the 119 email addresses that did not bounce back. Using the methods suggested by the American Association of Public Opinion Research, we calculated our response rate to be 46.2%. The response rate is in line with or better than other studies of weather professionals, such as emergency managers (e.g., Morrow et al. 2015) or broadcast meteorologists (e.g., Wilson 2009; Morrow et al. 2015), and represents approximately half of the population of WCMs. Because just over half the population was not represented, however, the possibility exists that those who chose not to complete the survey would have represented viewpoints different from those expressed by the participants. Finally, while the size of the sample was small, it was large enough to appropriately identify large differences as significant and small differences as nonsignificant. To achieve a moderate effect size of 0.5 with power 0.8 and alpha 0.05, a sample of 35 would have been sufficient.

b. *The survey*

The survey was developed over the course of several months. A draft was initially sent to two social science colleagues who had worked with or for NOAA for feedback. Following feedback and revision, the survey was developed using the Qualtrics survey platform. Once developed, it was sent to three NWS meteorologists for additional feedback. One of the three had acted as a WCM at one time, but none were included in the sample of WCMs contacted to complete the survey. The survey (Table 1) consisted of both free response questions and question sets where a rating was requested. To encourage complete and thoughtful answers to free response questions, most of these were presented very early in the survey.

The first part included questions relating to WCM perceptions of social science research as it may relate to aspects of their jobs and concluded with several questions about whether the WFO had ever worked with a social scientist, or if they could identify one if desired. A second group of questions asked participants to rate their relationship with their product users on two dimensions: how well the WFO understands users of its products and how closely they partner with the media and emergency managers. Next, participants were presented with a list of potential research topics identified during the survey development and review process and asked to rate each research item regarding its importance and their current state of knowledge about the issue. Participants were then asked several questions about false alarms, forecast inconsistency, message communication inconsistency, and ''hyping'' the weather. Finally, participants were asked to provide information about themselves and were allowed an opportunity to provide any additional feedback.

c. *Analysis*

Once survey data were collected and downloaded, frequencies and descriptive statistics were viewed for each of the quantitative questions on the survey. A normality test indicated that some, but not all, of the quantitative responses were normally distributed. Therefore, where tests of significance were performed, the nonparametric Wilcoxon signed-rank test was used. This test was used to determine if participants' paired responses to questions differed.

Open-ended questions were inductively coded by the two authors following a process recommended by Thomas (2006) and used in topically similar studies

TABLE 1. Survey questions, in the order they were presented.

Purpose	Question
RQ1	First, what do you think about, or what comes to mind when you hear the words ''social science''? (open-ended)
RQ1	Do you believe the amount of attention NOAA directs toward social science is too much, about right, or not enough? (too much; about right; not enough)
RQ2	In relation to your current role at the NWS, what is the most burning question that you would like to be able to answer that might involve social science? That is, what would you most like to know that you currently do not know? (open-ended)
RQ2	What do you think is the biggest issue facing your office that could be addressed with a better understanding about your community and the people who use your products? (open-ended)
RQ2	Looking more inward, what do you think is the biggest issue facing your office that could be addressed with a better understanding about your own operations and how you create and disseminate products? (open-ended)
RQ1	Has your office ever contacted a social scientist to help you address any questions such as these? (yes; no; unsure)
RQ1	Is there a person with expertise in one of the social sciences whom you would be able to contact to help you address these sorts of questions? (yes; no; unsure)
RQ1	Has your office ever been contacted by a social scientist to provide feedback on a weather or climate research project THEY were working on? (yes; no; unsure)
RQ5	Sometimes the main users of NWS products are grouped as ''the public,'' ''media,'' and ''emergency managers.'' Thinking of these three groups, how well do you think your office understands how each group uses your products? Please use the scale from 1 to 10 where 1 means your office does not understand the users well at all and 10 means your office understands them extremely well. (1 through 10, endpoints defined)
RQ5	Using the same scale from 1 to 10, how closely do you think your office partners with media and emergency managers? (1 through 10, endpoints defined)
RQ3/4	Considering the day-to-day functions of your office, and NOAA's broader mission to protect lives and property, how important is it that research funds prioritize each of the following topics? Please rate each on a scale of 1 to 10 where 1 means the research area is not at all important and 10 means it is extremely important. (1 through 10, endpoints defined) How people use NWS weather forecast information How people get warning information How well people understand warnings What actions people take upon receiving a warning What causes someone to not take action in a warning What factors create vulnerability to weather hazards in your area How people prioritize risks How to best communicate uncertainty How forecasters make decisions Which information forecasters find most useful for warning operations Which information decision-makers find most effective in conveying threats
RQ4/5	Thinking about these topics again, how would you rate your current knowledge about these issues? Please rate each on a scale of 1 to 10 where 1 means you know nothing at all about that topic and 10 means you know it extremely well. (1 through 10, endpoints defined)
RQ6	How much of a problem do you consider each of the following issues for your warning area? Please rate the following issues using a scale from 1 to 10, where 1 is not a problem at all and 10 is an extreme problem. (1 through 10, endpoints defined) False alarms (events that are forecasted, but not observed) Forecast inconsistency (different forecasts being communicated by various sources of weather information) Message communication inconsistency (the same or similar message being communicated with symbols, colors, terminology, etc. that varies among communicators) ''Hyping'' the weather
RQ7	Please state your agreement with the following statements: (5-point Likert scale) When a warning is issued, the public typically responds in ways that lead to protective action. A single false alarm event will cause people to take fewer precautions during the next event of that type. A high false alarm rate causes people to take fewer precautions during a warning. A high false alarm rate causes the public to believe our warnings are less credible. Inconsistency among sources of weather information leads the public to believe our forecasts are less credible. Inconsistency among sources of weather information leads people to take fewer precautions during a warning.
Background	How long have you been working at any NWS forecast office (in years)?
Background	How long have you been at your current forecast office (in years)?
Background	Click on the region of the map below that contains your weather forecast office.
Background	What is your age?
Background	What is your gender?

TABLE 1. (*Continued*)

Purpose	Question
Background	Do you use, or have you ever used, any of the following sources for information about social science issues that relate to weather? Check any that apply Advisory panels College course(s) Journal articles List-servs National programs such as WAS*IS Regional workshops Sessions at professional meetings Social media

(e.g., Trainor et al. 2015; Williams et al. 2017). As in Trainor et al. (2015), the authors read all responses, took notes, and coded any relevant dimensions of the responses into themes the authors perceived as prominent in the responses. Before coding started, the decision was made to allow for multiple coding categories per response, and subsentence elements were also allowed to have multiple codes. An inductive method was preferred for two reasons. First, this research was exploratory and was not guided by theory. We preferred to allow themes to emerge from the responses. Second, participants were asked to also respond to a set of preselected research topics, so it would have been redundant to review the open-ended responses for these topics as well. Following the initial coding of responses by two of the authors, these two authors met to compare results and refine their respective coding categories. Coding categories were merged and clarified for a second round of coding. During the second round, three of the four authors coded all of the responses according to the categories set following the first round. When the coding was complete, the three met to review the responses and resolve any inconsistencies, as was performed by Trainor et al. (2015) and Williams et al. (2017). The results discussed below indicate the final codes agreed upon by the three authors involved in round two of the analysis.

4. Results

a. Sample characteristics

As mentioned earlier, the survey received 61 responses. The average age was 48.5 years old, with a standard deviation of 7.5 years. The average time spent working for the NWS was 22.1 years (SD = 7.7), and the average amount of time spent at the current office was 13.6 years (SD = 8.5). Most of the participants were male (88.3%). The region with the greatest number of responses was the Southeast with 10, followed by the South/southern Plains with nine. The Ohio Valley and the northern Rockies each had eight responses. Six responses came from the Southwest. The Northeast and Northwest both contributed five, and the remainder were from the Upper Midwest (three), West (three), and noncontiguous United States (two). Two responses were not linked to a region. Six regions had at least a 50% response rate. Regional response rates ranged from 22.2% from the region outside of the contiguous United States to 66.7% from the Southwest and the northern Rockies (see Fig. 1).

b. Background perceptions of and experience with social science

The perception of social science research needs of the WFOs was measured both through open-ended questions and by rating a list of selected priorities. Figure 2 presents a word cloud made from the text of the open-ended descriptions. The words ''study,'' ''people,'' ''human,'' and ''behavior'' are among the most prominent, indicating that they were used frequently in the responses. In fact, the study of behavior was the theme most frequently used to describe open-ended responses regarding what comes to mind when they hear the words ''social science.'' Thirty-three out of 59 responses (55.9%) mentioned something about the study of human behavior (Table 2). An example of a response coded under the behavior category was, ''The study of how people behave/react—to information, their environment, etc.'' Several other responses were very similar. The words ''behave'' or ''behavior'' specifically appeared in 16 responses. A similar number of responses (16) used the words ''act'' or ''react'' in their definitions. Social science was defined more broadly to include interaction, culture, or other disciplines in 17 responses (28.8%). A response that well reflects this category is, ''The science of humanity as a whole and its interaction with the world around it.''

Another prominent theme identified responses as related to ''effective communication, or use of NWS

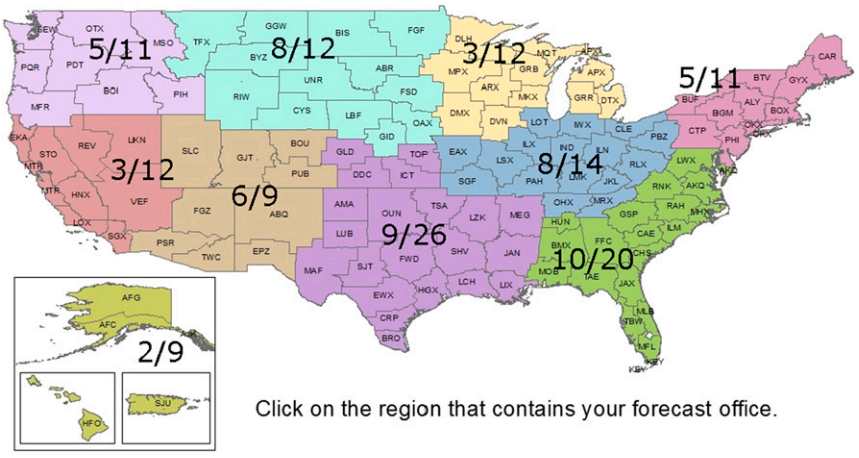

FIG. 1. Map provided to respondents to indicate which region contains their weather forecast office. Numbers indicate responses received from each region and total number contacted.

products.'' This theme was present in 12 responses (20.3%) and primarily focused on the communication of weather information and NWS products. Responses in this category had a narrower focus on communication than responses categorized as ''broad,'' including ''I think it means our ability to use multiple sources to get meaningful emergency information to a variety of constituents,'' or ''How the NWS customers utilize our products in their decision making.'' Similarly, responses also indicated an association between social science and an understanding of how people perceive or interpret information. This category represented 27.1% of responses. An understanding of ''the public'' or ''publics'' was specifically mentioned by nine participants. Seven responses (11.9%) reflected more negative attitudes toward social science. These included comments related to social science as a ''soft science'' or being skeptical of its claims. Other responses noted the lack of results from social science, such as, ''Frankly, a lot of research but not much in terms hard and fast results, or recommendations.'' Also of note, the word ''human'' or ''humanity'' appeared in 14 responses, and ''people'' appeared in 21 responses. ''Study'' was included in 18 responses, with three additional responses mentioning ''studies.'' Only five responses talked about specific research characteristics.

After reflecting on the definition of social science, participants were asked to rate the amount of attention given to it. A majority (52.5% or 32/61) said it was not enough. Twenty-four said it is about right (39.3%) and five said too much (8.2%). It is hard to say with certainty whether this accurately reflects the true perception of

FIG. 2. Common words used in describing social science.

TABLE 2. List of all themes identified for each question and the number of responses, as well as percentage in which that theme was coded present by three coders.

Question	Themes	Number (%) of responses
What do you think about, or what comes to mind when you hear the words ''social science''? (N = 59 responses)		
1	A study of behavior	33 (55.9%)
2	A definition broadened out to include social science ideas other than behavior, such as society, culture, or disciplines involved in social science	17 (28.8%)
3	An understanding of the public: perception and interpretation	16 (27.1%)
4	Effective communication or use of NWS products	12 (20.3%)
5	An expression of negative feelings about social science	7 (11.9%)
6	Other	2 (3.4%)
What is the most burning question that you would like to be able to answer that might involve social science? (N = 58 responses)		
1	How to get the public to respond in a certain way to the message	23 (39.7%)
2	How to make their message more effective	21 (36.2%)
3	How people understand NWS messages	13 (22.4%)
4	Questions about their current message delivery	13 (22.4%)
5	General questions about hazard or warning behavior	11 (19.0%)
6	Perceptions of NWS in general	5 (8.5%)
7	Questions regarding the use of social science	4 (6.9%)
8	How people understand probabilistic information specifically	2 (3.4%)
9	Other	1 (1.7%)
What do you think is the biggest issue facing your office that could be addressed with a better understanding about your community and the people who use your products? (N = 55 responses)		
1	How people use NWS products and what products and information they prefer to have	31 (56.4%)
2	How and why people respond to messages	16 (29.1%)
3	Messaging for specific user groups	15 (27.3%)
4	Issues of trust, credibility, and consistency	5 (9.1%)
5	Other	6 (10.9%)
What do you think is the biggest issue facing your office that could be addressed with a better understanding about your own operations, and how you create and disseminate products? (N = 55 responses)		
1	Understanding how people use NWS products	14 (25.5%)
2	Issues relating to NWS culture	12 (21.8%)
3	How to communicate messages effectively	11 (20%)
4	Priorities and allocation of resources	11 (20%)
5	A desire for greater flexibility	10 (18.2%)
6	Issues with the forecasting and forecast delivery process	8 (14.5%)
7	I do not know	3 (5.4%)
8	Other	5 (9.1%)

WCMs because nearly half did not respond to the survey. Even though the email was worded as neutrally as possible, it could have been rejected disproportionately by people with negative impressions of social science. We have no evidence to support this, but it is a possibility.

Participants were asked about their experiences working with a social scientist. The greatest percentage (48.3%) of WCMs had never contacted a social scientist to help them address any of their research questions. Five percent were unsure, but 46.7% had contacted a social scientist before. Those participants who indicated they had not contacted a social scientist responded to a follow-up question asking if there was a social scientist whom they would be able to contact. To this, 50% were unsure, 28.1% said ''yes,'' and 21.9% replied ''no.'' Participants were asked whether their office had ever been contacted by a social scientist. A relatively high percentage (18.6%) was unsure of this answer, with ''yes'' and ''no'' responses being evenly split at 40.7%. Finally, participants were asked if they use or have ever used a variety of sources about social science. A majority of participants have used sessions at professional meetings (74.6%), social media (67.8%), regional workshops (66.1%), programs such as WAS*IS (57.6%), or journal articles (55.9%). A smaller number have used listservs (37.3%), advisory panels (35.6%), or college courses (8.5%).

c. *Open-ended responses to perceived social science research needs of the NWS WFOs*

Three open-ended questions probed what research needs the WCMs had that might be addressed with the help of a social scientist. These focused on their most burning question, the biggest issues that could be addressed with a better understanding of their community

and users of their products, and a better understanding of their own operations (henceforth, ''burning question,'' ''community understanding,'' and ''operations'').

1) BURNING QUESTION

Eight themes emerged in the responses regarding burning questions (Table 2). These themes included how to get the public to respond in a certain way, how to make their message more effective, how people understand NWS messages, questions about their current message delivery, general questions about hazard or warning behavior, questions regarding the use of social science, perceptions about NWS in general and their role in the warning process, and how people understand probabilistic information specifically. The most commonly used words in the responses to this question included ''people,'' ''warning'' or ''warnings,'' and ''public,'' reflecting participants' questions about warning communication and response to warnings by the public.

Questions about messaging accounted for a large number of responses. Over a third of the responses expressed one or both of two themes: how to get the public to respond in a certain way to a message (23, or 39.7%) and how to make messages more effective (21, or 36.2%). How to make messages more effective included very descriptive responses, such as, ''What is the 'best' method to message weather hazard information for 1) understanding the hazard and 2) being able to make an appropriate judgement as to the level of impact (harmful, limited risk, no risk, etc.)? Not sure if its colors, words, pictures, tiers of risk, watch, warning, advisory, etc.'' It also included more succinct questions: ''If we are not saying our message correctly, how should we say it?'' and ''What is the optimal way to convey risk to the general public?'' Closely related to these responses were those regarding how to get the public to respond in a certain way to the message. In fact, 14 responses exhibited both themes together. An example of a response that exhibited both themes included, ''How can we best communicate a message of hazardous weather to result in a response to take protective action by those affected?''

Next in frequency were 13 responses (22.4%) regarding how people currently understand NWS messages and 13 responses where the burning question was about message delivery. Several responses in the message delivery category questioned the best ways to reach people, including if warnings were the best means to deliver a message or if new technology or some other method would be better. An example of a response about current understanding asked, ''Are our short-fuse warnings organized in a way that the public and our partners can understand what, when, and where is expected to occur?''

Responses expressing general questions about hazard or warning behavior accounted for 11 responses (19%). Ideas that reflected this theme included specific behaviors, such as denial of storm surge threat, driving through flood waters, or why people do not take shelter until it is too late, as well as a better understanding of behavior in general. Five responses (8.5%) were related to perceptions of NWS in general. There were two responses that raised the question of whether decision-makers understand the boundaries to NWS responsibilities. Other responses in this category questioned appropriate lead time and what NWS products should ''look like.'' Four responses (6.9%) included comments about social science. One of these could be considered negative in tone. One raised questions about whether changes suggested by social scientists have had an impact. One participant's response mentioned collaboration with a social scientist, and another response questioned why social scientists were often added after internal decisions had been made. Two responses were coded under the theme of understanding probabilistic information, and one response did not fit into any of the previously described categories.

2) COMMUNITY UNDERSTANDING

Many of the ideas raised in responses about the burning question were repeated in the community understanding question. In fact, one participant indicated, ''I'm having trouble distinguishing this from the previous question.'' The two questions did not have to produce similar responses. An office's most burning question could have been more related to products, while a community understanding issue may have had more to do with understanding the vulnerabilities of the people who use their products. There were only four themes that emerged in the responses to the community understanding question, plus a category marked ''Other.'' These themes were how people use NWS products and what products and information they prefer to have; how and why people respond to messages; messaging for specific user groups; and issues of trust, credibility, and consistency.

The category that represented the greatest number of responses was a broad theme that combined two related subtopics: how people use NWS products and what products and information they prefer to have. Thirty-one responses (56.4%) reflected this theme. Examples included, ''I think all WFOs (not just mine) could benefit from not only knowing what information our community needs and uses, but what they DON'T need or use, as well,'' and similarly, ''A better understanding of what people in the community are looking for when they seek out information from our office. What services we offer

that they find valuable, and what we're not offering that they would like to see.'' Responses also indicated wanting to know more about message delivery [i.e., ''Which tools are most effective at getting our message out (Twitter, Facebook, internet, NWR, some technology we are not currently using, etc.)''] in addition to information products.

Next in frequency were responses that emphasized how and why people respond to messages. A few of the responses in this category related to specific behaviors and a better understanding of them. For instance, why people drive through flood waters or why people build in floodplains were both mentioned. Knowing ''why they do or don't take action'' was also a repeated theme. There is a subtle difference between responses that indicate wanting to understand why people do or do not take action and wanting to know the best way to communicate so that people do take a recommended action. As examples of burning questions, these themes were coded as separate categories, but in the community understanding question, they were not as distinguishable. Sixteen responses (29.1%) reflected how or why people respond to messages.

The third most frequent category was only slightly less frequent, with 15 responses (27.3%). This category identified responses highlighting messaging for specific user groups. The focus of the specific user groups ranged from regions to special interests to vulnerable populations. One response noted, ''We don't have a good concept of who are our 'general public,' those who generally receive and heed our forecast and warning information. . .and who are our 'marginal public,' those who either are more vulnerable, less informed, or otherwise less able to receive and heed that information.'' Specific vulnerable groups mentioned multiple times were those who may not speak English (three mentions), may not understand the message (two mentions), or may be too remote or be affected by poor infrastructure (two mentions). Special interest groups mentioned included ''hikers, bikers, and other recreation enthusiasts'' and aviation forecast users. One participant also noted, ''Perhaps the solutions that are right for the citizens of Alabama and the Southeast aren't the same solutions for the citizens of the Northeast, Midwest, etc.''

Five responses (9.1%) fell under the issues of trust, credibility, and consistency theme. Specific factors mentioned in these four responses included warning fatigue, ''cry wolf'' and desensitization, inconsistent messaging, and keeping the warning program credible. The participant who mentioned ''cry wolf'' cautioned, ''Highlighting all high-impact weather as extreme may be working to desensitize people.'' One response noted the ''increasingly noisy weather environment.'' Finally, six responses (10.9%) did not fall completely into one of the established categories. This is a greater number than for other questions. Three of these responses mentioned wanting to improve messages or message delivery in a way that did not completely fit into a previous category. Other responses noted limited resources and how to better engage with the public.

3) OPERATIONS

The final question on operations produced seven themes, plus an ''Other'' category (Table 2). Once again, responses to previous questions were echoed here. The most frequently observed theme was understanding how people use NWS products, with 14 responses (25.5%). Responses in this category were similar to previous questions in which this theme emerged. For example, participants wanted to know ''How and when our products are being used, and what the information we provide leads to for the customer'' and ''How the customer views the products, graphics and text, that we issue. How they understand and interpret them, and what they think they mean.'' To address these questions, another participant added, ''I think if we better understood how people were using our services, and what they like about our services, we could gear our operations more in the direction of their interests/needs.''

When the survey was being designed, the expectation for this question was that responses would be more introspective, such as issues relating to NWS culture or issues with the forecasting and delivery process. The second most frequent theme to emerge did focus on issues related to NWS culture. Twelve responses (21.8%) fell into this category. Examples ranged from comments (both positive and negative) about the incorporation of social science to responses that questioned the influence of NWS information in the warning process. For example, one response stated, ''Even if we put out a credible warning by our standards (i.e., we receive reports of damage, injuries, deaths), if a person didn't actually see or experience that impact, they 'perceive' that it didn't happen. I don't think we can ever get around that issue.'' Four participants mentioned resistance to change being an issue.

Another theme focused on priorities and the allocation of resources. Eleven responses (20%) were coded in this theme. Responses in this theme mentioned the attention given to ''communities/populations along the periphery of the so-called deep core partners,'' the need for more feedback after an event, and the amount of attention that should be devoted to tasks such as designing graphics. Responses also discussed staffing issues or decisions. For example, one participant stated, ''We need to address our priorities. The operational shift may

need to be placed below partnering efforts to a certain extent. Not so much that one will get done over the other, but rather can we put our 'best' folks out there rather than keeping them in the office to act as Shift Leaders?'' Another participant gave a response that linked multiple themes: ''If we had a better understanding of how/when people use our information, we could more efficiently design our staffing model (and services) to better serve the needs of the 21st century public.''

As in the last two questions, a number of responses (11, or 20%) reflected the theme of how to communicate messages effectively. ''By understanding how the public responds (or does not) to different types of hazard weather watch/warning/advisories, will assist us in addressing how to better communicate differing levels of threat'' is an example of a response in this category. Responses included general ideas about improvement, such as ''crafting more effective warning messages''; questions about how to improve understanding by the public; and improvements that could ''play a role in people's inaction at times during high-impact weather.'' Two participants made suggestions ''to better cut down on the meteorology jargon'' or to ''move away from confusing terms.''

A desire for greater flexibility and issues dealing with the forecasting and delivery process were two other themes focusing on NWS operations more directly. A greater ability to ''move away from confusing terms and state what is best understood'' is an example of a response that reflected the desire for more flexibility. A desire for more flexibility was present in 10 responses (18.2%). More flexibility was suggested in making staffing assignments (three), regional differences (one), and frequency of providing information (one). One response captured several of these ideas: ''Biggest issue is we are tied to regional/national visions and rules for products and services to maintain consistency. We have little autonomy with the forecast process and dissemination.'' Eight responses (14.5%) dealt more with the forecasting and forecast delivery process. Two responses commented on the issuance of products versus communicating specific information. Verification was mentioned by two participants (with one relating more to office culture), and four participants mentioned issues resulting from gridded forecasts and technology.

d. Relative importance of research priorities and perceived current understanding

Participants rated 11 research priorities in terms of how important they are to fund and how they would rate their current knowledge on the topic (Fig. 3). First, in terms of importance, most of the topics were rated high. None fell below a score of 6 on a 10-point scale. The level of importance given to each echoes the comments provided in the open-ended questions above. The greatest priority was given to what causes someone not to take shelter during a warning, with a rating of 9.0 (SD = 1.2). Information decision-makers find most effective in conveying threats was next, with a rating of 8.8 (SD = 1.5). Rounding out the top five were how well people understand warnings, what actions they take upon receiving a warning, and how to best communicate uncertainty, each with a score of 8.5 (SD = 1.5–1.6). On the lower end were topics about the forecasters, vulnerability, how people prioritize risks, how people use NWS forecast information, and how people get warning information. These scores ranged from 6 to 8 (SD = 1.8–2.2).

The topic that received the highest priority rating (what causes someone not to take shelter during a warning) also received the lowest knowledge rating ($M = 4.7$, SD = 2.0), meaning participants thought it was most important and they had the least understanding of it. How people prioritize risks was also rated low in terms of perceived knowledge on the topic, with the same score of 4.7 (SD = 1.8). Also rated below the midpoint in the amount of perceived knowledge were what actions people take upon receiving a warning and how to best communicate uncertainty. Participants felt they had the most knowledge about their own actions as forecasters, including how forecasters make decisions ($M = 7.7$, SD = 1.65) and what information they find most useful ($M = 8.0$, SD = 1.4). In general, the trend showed that the two were inversely related. A high rating on one scale was accompanied by a lower rating on the other. Topics that fell farthest from a linear trend were how people prioritize risks, which was rated below the median values for both, and the information decision-makers find most effective, which scored above the median values for both.

In a set of related questions, participants were also asked how well they think their office understands the groups that uses their products. Perceived understanding of media ($M = 7.1$, SD = 1.8) and emergency managers ($M = 7.4$, SD = 1.8) were rated close to each other ($Z = -1.59$; $p = 0.11$) and significantly higher than perceived understanding of the public ($M = 4.0$, SD = 1.8). These differences were significant at $p < 0.001$ in a Wilcoxon signed-rank test (emergency managers vs public $Z = -6.43$; media vs public $Z = -6.29$). This mirrors understanding questions above where those dealing with the public were rated lower than forecasters and also ''decision-makers,'' which may have been interpreted more like emergency managers than the public. Participants felt they work more closely with emergency managers ($M = 8.8$, SD = 1.5) than with the media ($M = 7.4$, SD = 1.7). This was also significant ($Z = -4.72$; $p < 0.001$).

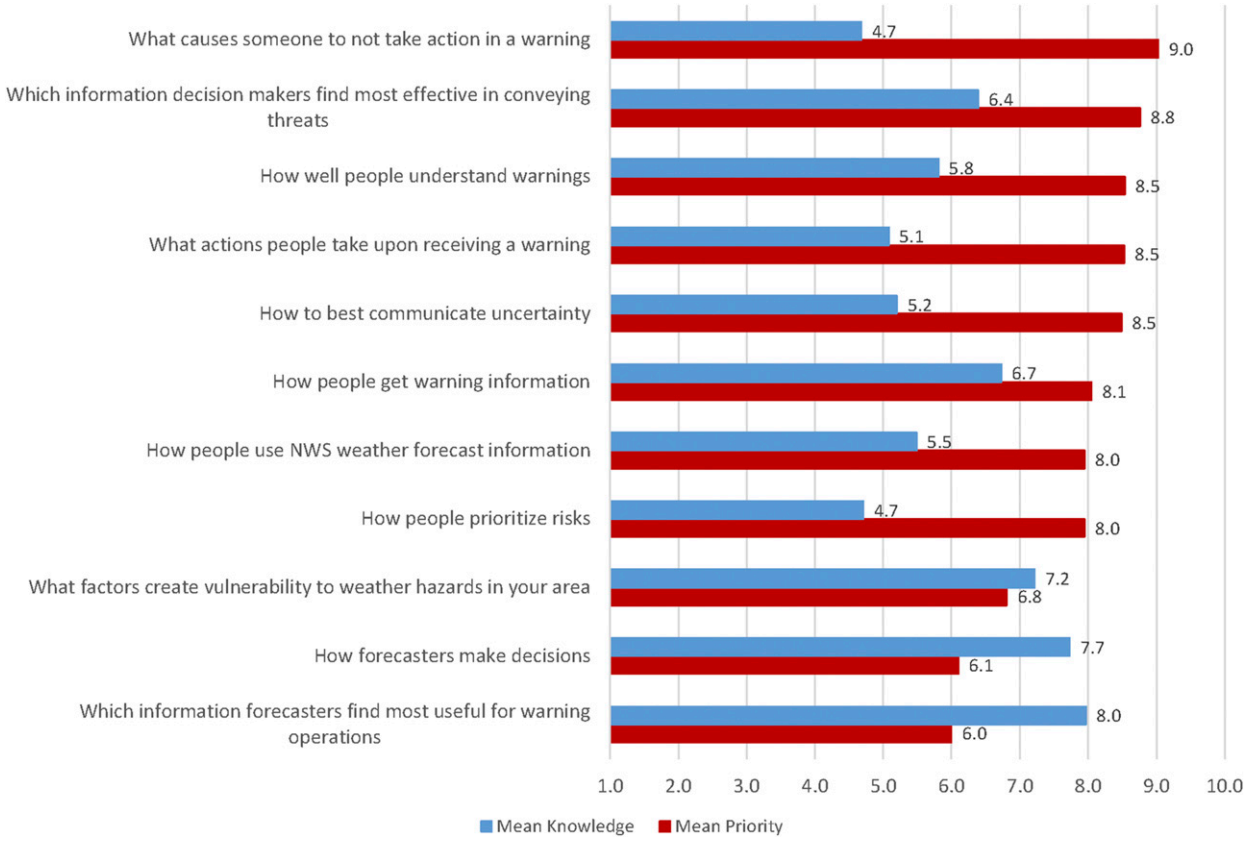

FIG. 3. Number of times prominent words were used in open-ended responses.

e. Importance of issues such as false alarms and inconsistency

The last set of questions sought to gauge participants' perspectives about how several issues rate as problems for their forecast area and to characterize their perception about the impact of false alarms and message inconsistency. Of the four issues given, participants rated "hyping" the weather as the greatest problem for their forecast area ($M = 6.6$, SD = 2.5), but not by much. The ratings of all four ranged from 5.4 to 6.6 out of 10. False alarms were rated the lowest ($M = 5.4$, SD = 2.1). False alarms were rated significantly lower than forecast inconsistency ($Z = -3.34$; $p = 0.001$), message inconsistency ($Z = -2.22$; $p = 0.027$), and hype ($Z = -3.24$; $p = 0.01$), but no differences were found among hyping or inconsistency ratings ($p > 0.05$).

To probe WCM beliefs surrounding these issues and their impact on public action or perception, participants were asked to state their agreement on a series of six statements. Statements were rated on a 5-point Likert scale. Participants were in the greatest agreement that inconsistency among the different sources of weather information leads the public to believe their forecasts are less credible ($M = 4.1$, SD = 0.7) and leads people to take fewer precautions during a warning ($M = 4.1$, SD = 0.8). No significant difference was found among these responses ($Z = -0.70$; $p = 0.486$). Also rated similarly were two statements about false alarm rates. Participants tended to believe that a high false alarm rate causes the public to believe warnings are less credible ($M = 3.6$, SD = 0.9) and to take fewer precautions during a warning ($M = 3.6$, SD = 1.0). Again, there was no difference in response to these questions ($Z = -0.14$; $p = 0.889$). Participants slightly disagreed that the public typically responds in ways that lead to protective action ($M = 2.7$, SD = 0.9) and more strongly disagreed that a single false alarm event will cause people to take fewer precautions during the next event of that type ($M = 2.4$, SD = 1.0). When the agreement scores were compared across similar questions, respondents agreed to a significantly greater extent that inconsistency would have more of an impact than a high false alarm rate on precautions ($Z = -2.43$; $p = 0.015$) and credibility ($Z = -3.52$; $p < 0.001$). Participants agreed both inconsistency and a high false alarm rate had more of an

impact on precautions than a single false alarm event ($p < 0.001$ for both).

5. Discussion and conclusions

When WCM participants in this study think about social science, most think favorably of its incorporation into NOAA activities. A slight majority replied that not enough information is given to it, and only 8% believed too much attention has been given to it. On the free response question, some participants reported being skeptical about social science. As was mentioned earlier, a large number of participants had experience working with a social scientist. This interaction may have influenced the opinion reported on the survey in one of two ways. The interaction could have helped to create a positive impression among WCMs about social science, and this was reflected in the survey. An alternative is that those with the most interest in social science already were the individuals most likely to take the survey. The response rate was high enough that it should be unlikely that a large majority of those not responding would have negative views.

When thinking about social science, participants largely thought about behavior and communication. Forecasters have been reported to view their career as public service, and as ''severe weather is the beating heart of forecasting'' (Fine 2009, p. 41), the warning is a key component of the forecaster's experience. It is logical that warning communication and response favored so prominently in the responses. The survey was also completed by Warning Coordination Meteorologists. Behavior was mentioned by over half of the participants in their definition of social science, and about 20% mentioned communication. This also makes sense in the context of NWS operations. The NWS has historically examined the warning process when negative outcomes of extreme weather resulted. Service assessments are conducted in events with significant economic impact, fatalities, or serious injuries. Thus, most historical exposure to studying the public comes after an event when the warning communication process is examined and often compared with actions taken by individuals. Also, when considering the number of factors that can contribute to fatalities or injuries during extreme weather, NWS meteorologists have the most control over their communication of the warning message. Understanding of the concepts involved shapes the way scientists approach a problem (Lach 2014), so it is natural that this experience would create the lens through which participants see social science. WCMs may or may not know what social scientists can help them with, but they understand what their key problems are, and this helps to color their impression of social science.

The importance of behavior and communication was repeated throughout the open-ended questions about what issues WCMs find most important. How to make the message more effective and how to get people to respond in some way upon receiving warning messages were the themes most present in responses to the second question about their most burning question. These two areas have a lot of overlap, which was evident in the many responses that reflected both themes. This raises the issue of what is to be considered an effective message, and it would appear from the responses that an effective message for WCMs would be one that influences people to take the recommended action. Established criteria for evaluating risk messages do suggest that if communicated effectively, responses should vary based on risk and severity of the hazards (Weinstein and Sandman 1993). Thus, effectively encouraging a behavior can be seen as important to the NWS mission of protecting life, but other responses also raised the issue of where the boundary of NWS responsibilities exists. That is, how far should they go to try to influence behavior, rather than just provide the information? Messages may be altered to encourage varying levels of risk perception among recipients [as was noted in Meyer et al. (2013); Nagele and Trainor 2012]. However, Ash et al. (2014, p. 118), who found differences in risk perception and response based on differences in warning graphics, posed the related question, ''What warning message do we want to send?'' to emphasize the possible power behind simple choices.

The desire to have a better understanding of what people want and how they use and understand their products was a prominent theme that emerged from the questions about community understanding, as well as operations. The lack of knowledge about this topic across the weather enterprise was cited as recently as 2009, but it was also noted that the private sector may have greater information about their users that is not publically available (Lazo et al. 2009). Further, the limited perceived knowledge of the public reported by the participants in the current study was contrasted with high levels of perceived knowledge about how key partners (media and emergency managers) use and understand their products. WCMs also felt that they worked more closely with emergency managers than media as partners, which could stem from historical tension between the government and private sectors of the weather enterprise (Fine 2009). Outreach activities tend to be more concentrated on partners than on the public. Hansson (2002) notes that data will only become translated into knowledge if they are in a form of

information that can be assimilated into one's belief system. This suggests the importance of the ability to incorporate information about the various users of NWS products into the working knowledge of those who hope to create more effective messaging. If the ultimate goal is effective messaging, understanding how the information is translated by all users, including partners, is key. For example, forecasts may need to be translated into a ''dramatic narrative'' by the media in order to obtain ratings (Fine 2009, p. 231). A deeper understanding of these translations is also important in considering other issues, such as hype or consistency.

The responses to research priority rankings also confirmed the important themes that emerged from the open-ended questions. Highest-rated priorities were those related to taking action in a warning (either why someone takes inappropriate action or understanding actions better), what information decision-makers find most effective, and how well people understand warning information. How best to communicate uncertainty was rated high, relative to other topics, but did not emerge as a prominent theme in the open-ended questions. The word ''uncertainty'' only appeared twice in all the responses to open-ended research need questions. Also, as was the case in open-ended responses, participants rated topics higher where they would have more control in the outcome. For example, topics related to the message were rated high, while understanding the factors that create vulnerability was not rated as high. Vulnerability or vulnerable groups were mentioned in the open-ended responses, but not nearly to the same degree as responses about effective message communication. An understanding of an area's social vulnerability is important because even though small changes in warning messages may lead to differences in risk perception or intended response, the actual decision-making process is complex (Morss and Hayden 2010). Vulnerable groups may experience more constraints to action or be best served with a different message. For example, the action statement for mobile home owners has at times been vague or encouraged residents to lie down in a ditch outside their mobile home, which is not a realistic option, and may not even be a safer option (Schmidlin et al. 2009).

Hype, forecast inconsistency, and message communication inconsistency were all rated above the midpoint on a scale from 1 to 10, indicating they were viewed more as problems than not. However, these items all fell in the 6–7 range, which demonstrated participants did not view them as very big problems for their warning areas. This is in contrast with the research priorities that were rated highest. Nine of the 11 research priorities were rated higher on the importance scale than hype, inconsistency, and false alarms were rated as problems. Participants' responses to open-ended questions also did not provide evidence that any of these issues were significant problems. Hype/hyping was not mentioned in any of the open-ended responses, and false alarms (called the ''cry wolf syndrome'' by the participant) was only mentioned once. However, consistency was mentioned four times by four different participants. Source consistency was clearly the focus of one response, but the other two did not specify message or source consistency. One comment was in regards to NWS-level consistency in products, so it would not be directly comparable. Responses to the last set of questions do support the idea that forecast source inconsistency is a concern and that it may be tied to other issues that participants were more likely to offer as research needs, such as taking action during a warning. Participants agreed that inconsistency among sources of weather information leads the public to believe their forecasts are less credible and causes people to take fewer precautions during a warning. They perceived inconsistency to have a greater influence on precautions and credibility than false alarms. Research on false alarms does suggest a relationship between actual and perceived false alarm ratios and trust in the NWS and, by extension, individuals' intended responses to a warning (Ripberger et al. 2015). This is consistent with other studies linking false alarms to actual outcomes, such as fatalities (Simmons and Sutter 2009) or protective responses in an actual event (Trainor et al. 2015). Very few studies have measured actual behaviors as a function of inconsistency or hype. However, the importance of consistent messaging was identified as important many years ago (e.g., Mileti and O'Brien 1992). In the current study, none of these issues appear to rise to the same perceived level of concern as communication effectiveness and encouraging warning-related behavior as research needs or problems. More research is needed on the influence of different types of inconsistency to determine their influence relative to false alarms.

The key conclusions from this research are that participants are favorable toward social science and would like to see more research devoted to helping them understand how to communicate effectively. Many responses indicate this would mean learning how to frame warning messages to encourage specific behaviors, although other comments indicate not all participants believe it is part of their responsibility to use the information to influence behavior. Communicating effectively could mean indirectly, through concentrating on typical partners— which the survey indicated participants feel they already work closely with—or by just forecasting the weather, as another suggested. There was a collective desire to have social science provide

answers, but at the same time, several participants cautioned about making one-size-fits-all changes or implementing recommendations based on small samples or single studies (which would be an equally important caution in physical science). The apparent contradiction may arise from the physical science background of the participants combined with the bureaucratic context in which they must operate. Finally, many of the research priorities identified by the social scientists ahead of time in creating the survey were very similar to topics offered freely in the open-ended questions.

The results can be used to plan future studies and potentially lead to further collaboration between meteorologists and social scientists. However, it should be noted that any suggestions that arise must be considered in the organizational framework of the NWS, in which regions have autonomy but are also part of a federal bureaucracy. Also, at the WFO level, publics have different characteristics and needs, and even local offices within the region have different flavors, which are the product of their shared historical experiences (Fine 2009). There are certain to be some findings with applicability to all, but research in one office may not necessarily translate to the whole organization. The funding climate may also be a hindrance to future collaboration, but programs do exist (e.g., Vortex SE) that encourage social scientists to work on projects of relevance to the social scientist, the meteorologist, and society.

There are several limitations with the research. First, even though the response rate was comparable to other studies, it is unknown if nonparticipants chose not to complete the survey due to particular opinions that would make nonparticipants different from the majority of respondents. Second, while we believe the inductive method for coding open-ended responses was the best choice for our analysis, it remains a more subjective way to examine results than asking participants to rate priorities on a scale. The survey methodology was useful to provide an overview of the perceptions of WCMs, but more in-depth, qualitative research should focus on not just WCMs, but also WFO operations, as well as interactions among other weather partners such as broadcast meteorologists. Meteorologists come from a physical science background, and disciplinary cultures lead to certain knowledge and beliefs that color decision-making (Lach 2014; Reich and Reich 2006). Many of the research questions suggested by the participants certainly drew from their experiences as WCMs. The WCMs know what their most important problems are but may need a social scientist to help articulate what social science can do for them. We agree with one of the reviewer's suggestions that to fully understand the complex issues faced by the WFOs, more in-depth and qualitative research is critical. This survey did include four open-ended questions, but future research should spend more time interviewing forecasters or observing operations firsthand.

Acknowledgments. We thank the three anonymous reviewers for their suggestions on the manuscript, as well as the individuals who provided feedback on the survey at various stages of development. Finally, we are very grateful for the WCMs who took time to provide detailed answers to the questions in the survey.

REFERENCES

Ash, K. D., R. L. Schumann, and G. C. Bowser, 2014: Tornado warning trade-offs: Evaluating choices for visually communicating risk. *Wea. Climate Soc.*, **6**, 104–118, https://doi.org/10.1175/WCAS-D-13-00021.1.

Balluz, L., L. Schieve, T. Holmes, S. Kiezak, and J. Malilay, 2000: Predictors for people's response to a tornado warning: Arkansas, 1 March 1997. *Disasters*, **24**, 71–77, https://doi.org/10.1111/1467-7717.00132.

Blanchard-Boehm, R. D., and M. J. Cook, 2004: Risk communication and public education in Edmonton, Alberta, Canada on the 10th anniversary of the 'Black Friday' tornado. *Int. Res. Geogr. Environ. Educ.*, **13**, 38–54, https://doi.org/10.1080/10382040408668791.

Broad, K., A. Leiserowitz, J. Weinkle, and M. Steketee, 2007: Misinterpretations of the ''cone of uncertainty'' in Florida during the 2004 hurricane season. *Bull. Amer. Meteor. Soc.*, **88**, 651–668, https://doi.org/10.1175/BAMS-88-5-651.

Dash, N., and H. Gladwin, 2007: Evacuation decision making and behavioral responses: Individual and household. *Nat. Hazards Rev.*, **8**, 69–77, https://doi.org/10.1061/(ASCE)1527-6988(2007)8:3(69).

Demuth, J. L., E. Gruntfest, R. E. Morss, S. Drobot, and J. K. Lazo, 2007: WAS*IS: Building a community for integrating meteorology and social science. *Bull. Amer. Meteor. Soc.*, **88**, 1729–1738, https://doi.org/10.1175/BAMS-88-11-1729.

Dow, K., and S. L. Cutter, 1998: Crying wolf: Repeat responses to hurricane evacuation orders. *Coastal Manage.*, **26**, 237–252, https://doi.org/10.1080/08920759809362356.

Fine, G. A., 2009: *Authors of the Storm: Meteorologists and the Culture of Prediction*. University of Chicago Press, 306 pp.

Floyd, D. L., S. Prentice-Dunn, and R. W. Rogers, 2000: A meta-analysis of research on protection motivation theory. *J. Appl. Soc. Psychol.*, **30**, 407–429, https://doi.org/10.1111/j.1559-1816.2000.tb02323.x.

Gladwin, H., J. K. Lazo, B. H. Morrow, W. G. Peacock, and H. E. Willoughby, 2007: Social science research needs for the hurricane forecast and warning system. *Nat. Hazards Rev.*, **8**, 87–95, https://doi.org/10.1061/(ASCE)1527-6988(2007)8:3(87).

——, ——, ——, ——, and ——, 2009: Social science research needs for the hurricane forecast and warning system. *Bull. Amer. Meteor. Soc.*, **90**, 25–30, https://doi.org/10.1175/2008BAMS2606.1.

Hansson, S. O., 2002: Uncertainties in the knowledge society. *Int. Soc. Sci. J.*, **54**, 39–46, https://doi.org/10.1111/1468-2451.00357.

Lach, D., 2014: Challenges of interdisciplinary research: Reconciling qualitative and quantitative methods for

understanding human–landscape systems. *Environ. Manage.*, **53**, 88–93, https://doi.org/10.1007/s00267-013-0115-8.

Lazo, J. K., R. E. Morss, and J. L. Demuth, 2009: 300 billion served: Sources, perceptions, uses, and values of weather forecasts. *Bull. Amer. Meteor. Soc.*, **90**, 785–798, https://doi.org/10.1175/2008BAMS2604.1.

Lindell, M. K., and R. W. Perry, 2012: The Protective Action Decision Model: Theoretical modifications and additional evidence. *Risk Anal.*, **32**, 616–632, https://doi.org/10.1111/j.1539-6924.2011.01647.x.

Liu, S., L. E. Quenemoen, J. Malilay, E. Noji, T. Sinks, and J. Mendlein, 1996: Assessment of a severe-weather warning system and disaster preparedness, Calhoun County, Alabama, 1994. *Amer. J. Public Health*, **86**, 87–89, https://doi.org/10.2105/AJPH.86.1.87.

Losee, J. E., K. Z. Naufel, L. Locker Jr., and G. D. Webster, 2017: Weather warning uncertainty: High severity influences judgment bias. *Wea. Climate Soc.*, **9**, 441–454, https://doi.org/10.1175/WCAS-D-16-0071.1.

Meyer, R. K., K. Broad, B. Orlove, and N. Petrovic, 2013: Dynamic simulation as an approach to understanding hurricane risk response: Insights from the *Stormview* Lab. *Risk Anal.*, **33**, 1532–1552, https://doi.org/10.1111/j.1539-6924.2012.01935.x.

Mileti, D. S., and P. W. O'Brien, 1992: Warnings during disaster: Normalizing communicated risk. *Soc. Probl.*, **39**, 40–57, https://doi.org/10.2307/3096912.

——, and J. D. Darlington, 1997: The role of searching in shaping reactions to earthquake risk information. *Soc. Probl.*, **44**, 89–103, https://doi.org/10.2307/3096875.

Mooney, H. A., A. Duraiappah, and A. Larigauderie, 2013: Evolution of natural and social science interactions in global change research programs. *Proc. Natl. Acad. Sci. USA*, **110**, 3665–3672, https://doi.org/10.1073/pnas.1107484110.

Morrow, B. H., J. K. Lazo, J. Rhome, and J. Feyen, 2015: Improving storm surge risk communication: Stakeholder perspectives. *Bull. Amer. Meteor. Soc.*, **96**, 35–48, https://doi.org/10.1175/BAMS-D-13-00197.1.

Morss, R. E., and M. H. Hayden, 2010: Storm surge and "certain death": Interviews with Texas coastal residents following Hurricane Ike. *Wea. Climate Soc.*, **2**, 174–189, https://doi.org/10.1175/2010WCAS1041.1.

Nagele, D. E., and J. E. Trainor, 2012: Geographic specificity, tornadoes, and protective action. *Wea. Climate Soc.*, **4**, 145–155, https://doi.org/10.1175/WCAS-D-11-00047.1.

National Academy of Sciences, 2005: *Facilitating Interdisciplinary Research.* National Academies Press, 332 pp., https://doi.org/10.17226/11153.

National Research Council, 2006: *Facing Hazards and Disasters: Understanding Human Dimensions.* National Academies Press, 408 pp.

Phillips, B. D., and B. H. Morrow, 2007: Social science research needs: Focus on vulnerable populations, forecasting, and warnings. *Nat. Hazards Rev.*, **8**, 61–68, https://doi.org/10.1061/(ASCE)1527-6988(2007)8:3(61).

Pielke, R. A., Jr., 1997: Asking the right questions: Atmospheric sciences research and societal needs. *Bull. Amer. Meteor. Soc.*, **78**, 255–264, https://doi.org/10.1175/1520-0477(1997)078<0255:ATRQAS>2.0.CO;2.

Reich, S. M., and J. A. Reich, 2006: Cultural competence in interdisciplinary collaborations: A method for respecting diversity in research partnerships. *Amer. J. Community Psychol.*, **38**, 1–7, https://doi.org/10.1007/s10464-006-9064-1.

Ripberger, J. T., C. L. Silva, H. C. Jenkins-Smith, D. E. Carlson, M. James, and K. G. Herron, 2015: False alarms and missed events: The impact and origins of perceived inaccuracy in tornado warning systems. *Risk Anal.*, **35**, 44–56, https://doi.org/10.1111/risa.12262.

Rogers, R. W., and S. Prentice-Dunn, 1997: Protection motivation theory. *Handbook of Health Behavior Research I: Personal and Social Determinants*, D. S. Gochman, Ed., Springer, 113–132.

Schmidlin, T. W., B. O. Hammer, Y. Ono, and P. S. King, 2009: Tornado shelter-seeking behavior and tornado shelter options among mobile home residents in the United States. *Nat. Hazards*, **48**, 191–201, https://doi.org/10.1007/s11069-008-9257-z.

Sherman-Morris, K., 2013: The public response to hazardous weather events: 25 years of research. *Geogr. Compass*, **7**, 669–685, https://doi.org/10.1111/gec3.12076.

——, and I. D. Martinez, 2017: Optimistic bias and the consistency of hurricane track forecasts. *Nat. Hazards*, **88**, 1523–1543, https://doi.org/10.1007/s11069-017-2931-2.

——, K. Antonelli, and C. Williams, 2015: Measuring the effectiveness of the graphical communication of hurricane storm surge threat. *Wea. Climate Soc.*, **7**, 69–82, https://doi.org/10.1175/WCAS-D-13-00073.1.

Simmons, K. M., and D. Sutter, 2009: False alarms, tornado warnings, and tornado casualties. *Wea. Climate Soc.*, **1**, 38–53, https://doi.org/10.1175/2009WCAS1005.1.

Thomas, D. R., 2006: A general inductive approach for analyzing qualitative evaluation data. *Amer. J. Eval.*, **27**, 237–246, https://doi.org/10.1177/1098214005283748.

Trainor, J. E., D. Nagele, B. Philips, and B. Scott, 2015: Tornadoes, social science, and the false alarm effect. *Wea. Climate Soc.*, **7**, 333–352, https://doi.org/10.1175/WCAS-D-14-00052.1.

U.S. Department of Commerce, 2017: HR practitioners: Meteorologist (warning coordination). U.S. Department of Commerce Rep. GS-1340-14, http://hr.commerce.gov/Practitioners/ClassificationAndPositionManagement/PDLibrary/prod01_000649.

Weinstein, N. D., and P. M. Sandman, 1993: Some criteria for evaluating risk messages. *Risk Anal.*, **13**, 103–114, https://doi.org/10.1111/j.1539-6924.1993.tb00733.x.

Williams, C. A., P. W. Miller, A. W. Black, and J. A. Knox, 2017: Throwing caution to the wind: National Weather Service wind products as perceived by a weather-salient sample. *J. Operational Meteor*, **5**, 103–120, https://doi.org/10.15191/nwajom.2017.0509.

Wilson, K., 2009: Opportunities and obstacles for television weathercasters to report on climate change. *Bull. Amer. Meteor. Soc.*, **90**, 1457–1465, https://doi.org/10.1175/2009BAMS2947.1.

Wu, H., M. K. Lindell, C. S. Prater, and C. D. Samuelson, 2014: Effects of track and threat information on judgments of hurricane strike probability. *Risk Anal.*, **34**, 1025–1039, https://doi.org/10.1111/risa.12128.

——, ——, and ——, 2015a: Process tracing analysis of hurricane information displays. *Risk Anal.*, **35**, 2202–2220, https://doi.org/10.1111/risa.12423.

——, ——, and ——, 2015b: Strike probability judgments and protective action recommendations in a dynamic hurricane tracking task. *Nat. Hazards*, **79**, 355–380, https://doi.org/10.1007/s11069-015-1846-z.

Xu, X., S. Goswami, J. Gulledge, S. D. Wullschleger, and P. E. Thornton, 2016: Interdisciplinary research in climate and energy sciences. *Wiley Interdiscip. Rev.: Energy Environ*, **5**, 49–56, https://doi.org/10.1002/wene.180.

Zhang, F., and Coauthors, 2007: An in-person survey investigating public perceptions of and responses to Hurricane Rita forecasts along the Texas coast. *Wea. Forecasting*, **22**, 1177–1190, https://doi.org/10.1175/2007WAF2006118.1.