Risk Communication and Behavior: Best Practices and Research Findings

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NOAA Social Science Committee

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Vankita Brown, National Weather Service

Stephanie Fauver, National Ocean Service

Denna Geppi, Office of Performance, Risk and Social Science

Aisha Haynes, Office of Education

Kim Klockow, Office of Oceanic and Atmospheric Research

Danielle Nagele, National Ocean Service

NOAA Social Science Committee

Silver Spring, MD
USA

Project Team

Vankita Brown[1], Stephanie Fauver[2], Denna Geppi[3], Aisha Haynes[4], Jennifer Sprague-Hilderbrand[1], Kim Klockow[5], Danielle Nagele[2], and Tracy Rouleau[3]

[1] National Weather Service
[2] National Ocean Service
[3] NOAA's Office of Performance, Risk and Social Science
[4] NOAA's Office of Education
[5] Office of Oceanic & Atmospheric Research
[6] Office of Program Planning & Integration

Edited by:
Rachel Jacobson [6]
Kateryna Wowk [6]

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I. Executive Summary

The National Oceanic and Atmospheric Administration, NOAA, spends **billions** of dollars each year monitoring and predicting risk from environmental hazards to help people, communities, businesses, and governments find and use the right information to understand risk and make smart decisions. But that investment can only achieve its full potential value if risk is communicated effectively, empowering individuals and groups to pursue the response options that are best for them. Using research from NOAA and its external partners improves the ability to more effectively deliver weather and coastal warnings, communicate local hazards and risks, and provide guidance and decision support tools to stakeholders.

Risk communication is a process, not merely a product. To make communities more resilient, messaging strategies for hazardous events must draw on knowledge from the social, behavioral and economic sciences, and especially research on risk communication and behavior. These areas of study explain and predict the ways people receive, share, understand, and respond to information about risk. When weather forecasters or coastal managers encounter situations where their message does not lead to the desired action, they often turn to social scientists to help improve the products they issue. Products such as warnings, watches, etc. are key components of NOAA weather risk communication, and social scientists can offer useful input on product improvement. However, this report focuses on the many actions taken outside of product creation. These actions include the relationships built with community partners, emergency management, and broadcast meteorologists well ahead of a given event or any specific product being issued, and are all part of the risk communication *process*.

Communication strategies for hazardous events must draw on the social sciences to effectively communicate risk. This report provides guidance on the processes involved in risk communication for those in NOAA who communicate risk, including those responsible for creating policies, programs, or products. Highlighting risk communication best practices in Part IV; this report also provides a discussion of contemporary research topics. This report concludes with a discussion of implementation recommendations that can be used by practitioners at NOAA. This review provides motivation and insights for NOAA staff to come to a deeper understanding of the many things they can do to strengthen the effectiveness and efficiency of their risk communication processes, while also highlighting areas of active research where researchers are working on applied problems that have not yet been solved.

This report reviews risk communication and public response research literature within the context of key episodic hazards relevant to NOAA's mission. It covers three weather hazards (tornado/severe wind, flood, and tropical cyclone), findings for general weather, and four other environmental hazards (tsunami, volcano, wildfire, and fisheries-related). These specific hazards were chosen for their relevance to NOAA's mission, priorities, and vision for the future.

This report recommends best practices for risk communication relevant to NOAA practitioners. NOAA practitioners are not limited to management only. This report is also designed for forecasters, outreach coordinators, warning coordination meteorologists, communication directors, and other NOAA staff. The recommended practices include the following, discussed in more detail in body of the report:

1. Have an Informed Plan – Know what needs to be achieved and how to achieve it before beginning risk communication efforts.

2. Speak to Their Interests, Not Yours – Connect emotionally with audience and stakeholder values and concerns to help establish a relationship and improve risk communication efforts.

3. Explain the Risk (in a manner that is clear and appropriate for the audience) – Use stories and visuals to make it personal and help audiences understand the impacts and the hazard.

4. Offer Options for Reducing Risk –Facilitate a conversation to identify barriers to action. Offer options that address these barriers and are appropriate for the local situation.

5. Work with Trusted Sources and the Public – People seek confirmation from multiple trusted sources to verify risk and help them make decisions on what actions to take, if any.

6. Test Messages or Products; Evaluate Performance – Coworkers are not the audience. Test communications on target audience members before reaching out more broadly. Evaluate the results of communications efforts.

7. Use Multiple Ways to Communicate – People like to receive information in different ways; understand how the audience likes to receive information on hazards.

II. Introduction

A. Overview and Drivers

Severe weather and climatic events threaten the safety of our Nation. In recent decades, extreme events have become more destructive, creating challenges for American communities and businesses alike. NOAA's National Centers for Environmental Information (NCEI) found that during the past decade (2004-2013) more billion-dollar weather and climate disasters (80) occurred than the previous two decades combined (78) (amounts adjusted for inflation).

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Inundation and flooding are the most frequent and costly hazards in the U.S. More than 75 percent of declared Federal disasters related to floods resulted in more than 90 fatalities per year and annual flood losses averaging nearly $8 billion.[1] In addition to floods arising from heavy rainfall and snowmelt, coastal inundation from tropical cyclones and other strong storm systems is responsible for some of the most deadly and costly single events in the United States. In 2005, Hurricane Katrina caused 1,464 deaths[2] and over $150B in losses[3]. More recently, Post Tropical Cyclone Sandy caused 285 deaths and approximately $65 billion in losses in 2012.[4]

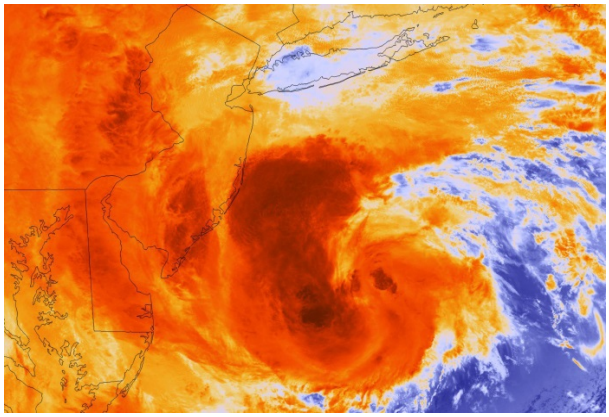

Photo Credit: NOAA

Key factors that contribute to social and individual vulnerability to severe weather and climatic events include the density of the population exposed, rate of population growth, characteristics of housing stock, and socio-cultural factors such as language, mobility, access to community resources, and poverty. About 40 percent of the U.S. population lives in a coastal shoreline county. [5] As coastal areas are further developed, the number of coastal residents is expected to increase 9 percent over the next

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[1] See USGS, Flood Inundation Mapping (FIM) Program: http://water.usgs.gov/osw/flood_inundation/

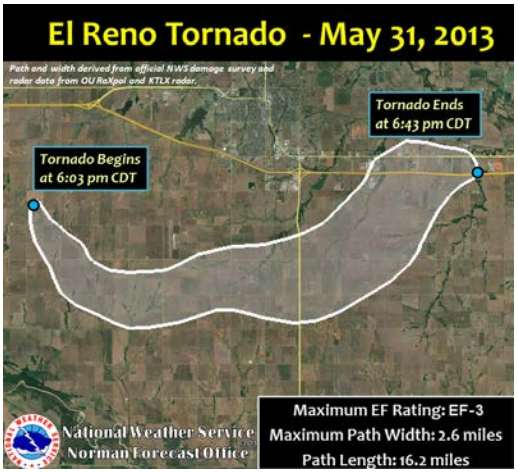
[2] See Louisiana Department of Health and Hospitals. (2006). *Reports of Missing and Dead.* Retrieved from http://www.dhh.louisiana.gov/offices/page.asp?ID=192&Detail=5248

[3] See NOAA National Center for Environmental Information (NCEI) Billion-Dollar Weather and Climate Disasters: https://www.ncdc.noaa.gov/billions/events

[4] See NOAA National Center for Environmental Information (NCEI) Billion-Dollar Weather and Climate Disasters: https://www.ncdc.noaa.gov/billions/events

[5] See NOAA Coastal Economy Pocket Guide: http://www.ppi.noaa.gov/wp-content/uploads/coastal-economy-pocket-guide-1025.pdf

six years. With this rise in coastal population, the challenges to effective management and risk communication will also increase.



Recent severe weather events in the nation's heartland highlight clear disconnects between the information NOAA provides and optimal societal response across the full range of hazards. For example, even with timely warnings from the National Weather Service, thousands of people spontaneously evacuated and jammed highways ahead of a two-mile wide tornado in central Oklahoma on May 31, 2013. One estimate shows that if the tornado had not lifted, fatalities could have exceeded 700 people, and possibly reached as high as 1,000, for an event that would normally result in less than 25 fatalities.[6] This example highlights the fact that forecasts and warnings are most effective when the public fully comprehend the risks to life and property, as well as their options for pursuing safety, demonstrating the need for improving and understanding the risk communication process.

Severe weather and climatic events also affect certain populations disproportionately, highlighting the role that vulnerability plays during hazardous weather. For example, during Hurricane Katrina, African Americans made up a disproportionate share of the hurricanes victims. About one of every three people who lived in areas hardest hit by the hurricane were African Americans. Also, sixty-five percent of poor elderly households in New Orleans did not have a vehicle, making it more difficult for them to escape the storm and its effects. [7]Vulnerability is defined as "the characteristics of a person or group and their situation that influences their capacity to anticipate, cope with, resist, and recover from the impact of a natural disaster." [8] The vulnerability perspective demonstrates how disasters are produced, namely, when hazards intersect with populations that are especially susceptible to harm from them.[9] [10] Key factors contributing to social and individual vulnerability to severe weather and climatic events include the density of the population exposed, rate of population growth, characteristics of the housing stock, and socio-cultural factors such as language, mobility, access to community resources, and poverty. For example, several of these factors intersect in portions of the Southeast U.S., where special attention should be paid to help vulnerable populations prepare for and respond to life-threatening hazards due to the large amount of residents for whom English is their second language.

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[6] See National Weather Service Weather Forecast Office Norman, OK: http://www.srh.noaa.gov/oun/?n=events-20130531-elreno
[7] See Essential Facts About The Victims of Hurricane Katrina: http://www.cbpp.org/research/essential-facts-about-the-victims-of-hurricane-katrina
[8] W. Donner, and H. Rodriguez.(2016): Disaster Risk and Vulnerability: The Role and Impact of Population and Society. http://www.prb.org/Publications/Articles/2011/disaster-risk.aspx
[9] W. Donner, and H. Rodriguez.(2016): Disaster Risk and Vulnerability: The Role and Impact of Population and Society. http://www.prb.org/Publications/Articles/2011/disaster-risk.aspx
[10] B. Wisner et al. (2004): At Risk: Natural Hazards, People's Vulnerability, and Disasters, 2d. ed. (London, Routledge).

In several studies, NOAA[11] [12] [13] and the National Academies of Science[14] [15] called for increased support for research in behavioral sciences. A 2015 Executive Order *(Using Behavioral Science to Better Serve Americans)*[16] identified the need for behavioral science to improve effectiveness and efficiency of programs across the entire Federal landscape to protect life and property. This report from NOAA's Social Science Committee offers a foundational step toward bridging the gap between research and application.

B. Report Roadmap

In the next section, risk communication is defined and discussed not in the context of a single product, but as a process. This is not only a process for the end-user as he/she understands and assesses the risk, but also for the communicator as he/she works with and learns from the audience. With this in mind, **Section III** presents best practices compiled from a variety of sources including research articles, practitioner guides, and personal experience. **Section IV** offers a look at contemporary research in risk communication and decision science for hazards. This highlight of topics can serve as a springboard for engaging research communities, commissioning more systematic reviews, and informing NOAA practitioners. Several appendices are also included for those who may desire more in-depth information on theories and models, warning behavior, and existing systematic reviews.

Feedback from the NOAA community is welcomed, especially recommendations for additional support needed to enable NOAA practitioners to better connect research to practice.

III. Risk Communication

A risk is defined as a hazard times the probability of its occurrence.

A. Risk Communication: It's a Process NOT a Product

What is risk communication?

For communicating about natural hazards, risk communication research provides valuable insights into how people create and spread ideas about natural hazard threats, and how communicators can shape those ideas. Risks are not the same as hazards. A risk is defined as a hazard times the probability of its occurrence. Each risk has its own unique characteristics (e.g., whether the situation is controllable, if the

[11] Weather Ready Nation: A Vital Conversation on Tornadoes and Severe Weather (2011): http://www.nws.noaa.gov/com/weatherreadynation/files/WRN_Vital_Conversation032912.pdf

[12] Workshop on Weather Ready Nation: Science Imperatives for Severe Thunderstorm Research (2012): http://www.nws.noaa.gov/com/weatherreadynation/files/WRN_FinalReport120917.pdf

[13] NOAA, Society and the Economy: An Assessment of NOAA's Social Science Capabilities and Needs (2013): http://www.sab.noaa.gov/Meetings/2013/july/NOAA%20Social%20Science%20Needs%20Assessment%20Report%20FINAL.pdf

[14] Completing the Forecast (2006): http://www.nap.edu/catalog/11699/completing-the-forecast-characterizing-and-communicating-uncertainty-for-better-decisions

[15] When Weather Matters (2010): http://www.nap.edu/catalog/12888/when-weather-matters-science-and-service-to-meet-critical-societal

[16] See https://www.whitehouse.gov/the-press-office/2015/09/15/executive-order-using-behavioral-science-insights-better-serve-american

audience dreads the risk, etc.)[17], and these characteristics color how the risk is perceived. Risk is personal and often subjective. What one person considers to be a risk, another may not. The National Research Council defines risk communication as, "an interactive process of exchange of information and opinion among individuals, groups, and institutions. It involves multiple messages about the nature of risk and other messages, not strictly about risk, that express concerns, opinions, or reaction to risk messages or to legal or institutional arrangements for risk management." This definition highlights several important aspects of risk communication; most importantly, that risk communication is a *process* rather than a single product or service. This process can be defined in several stages (**Figure 1**).

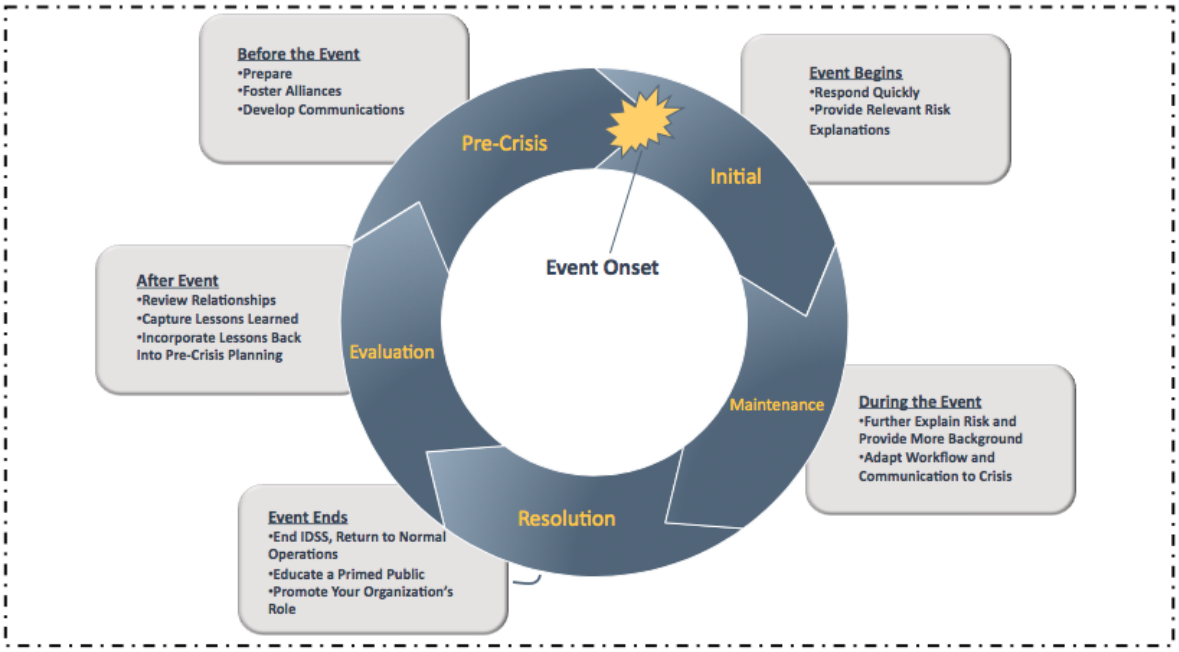

Figure 1. A depiction of the risk communication lifecycle, with activities organizations should consider pursuing at each stage. IDSS stands for Impact-Based Support Services. Adapted from NWS AWOC training course *Communicating in High-Impact Events*.

The risk communication process begins well ahead of a given event, in the "pre-crisis" phase.

- This is when NOAA practitioners can be strengthening relationships with their communities and building trust, supporting mitigation and adaptation planning, and improving information dissemination chains.

As an event nears (e.g., a hurricane getting closer to the coast), the community moves into the initial phase of the crisis.

- This is when most short-term weather forecast information including outlook, watch, and warning information is delivered and used for preparatory decision-making.

[17] Slovic, P. "Perception of Risk." Science 236(17 April): 280-285.

- Communication during this period is so critical and sufficiently unique that a whole sub-field - crisis communication - within the field of risk communication exists.
- At this time, clear and timely messages aimed at providing sufficient information for decision-making are especially important.
- Messaging is more fully explored in the Behavioral Response section, which describes the warning response process.

The maintenance phase, most applicable to long-duration hazards, occurs when a crisis is ongoing and information must be updated for use by decision-makers.

Finally, in resolution and evaluation phases, the events are examined to understand how the communication system performed, and recommendations are made to improve the system for better outcomes.

Behavioral Response When Weather Hazards Are Imminent

Decision-making on the part of the public is also a process. NOAA practitioners affect different parts of this process at different points in the risk communication lifecycle. Importantly, scientific information (such as a weather forecast) alone does not necessarily result in immediate response. Referring to **Figure 2,** people tend to go through several steps before reaching a decision. Long-term risk communication efforts can affect aspects such as hazard knowledge, resources stored in preparation, and methods by which information is disseminated when events occur. These pre-event factors influence how people will understand a crisis situation as it unfolds, and the resources they will have available to adapt and protect themselves.

During the crisis phase, or the time when warnings are issued, people become aware of the threat. This awareness can come through environmental cues, social cues, warning information, or a combination of these. After this, processing and assessment of information and situation occur before they respond. People must not only understand what the risk is, but also how (and if) it personally affects them. Even if they decide to respond, this may simply involve more information-seeking rather than evacuating or sheltering. This complex, often subconscious, process is generally not linear, but iterative. For instance, someone may see a funnel cloud, respond by seeking more information, then determine whether it will hit their home before sheltering.

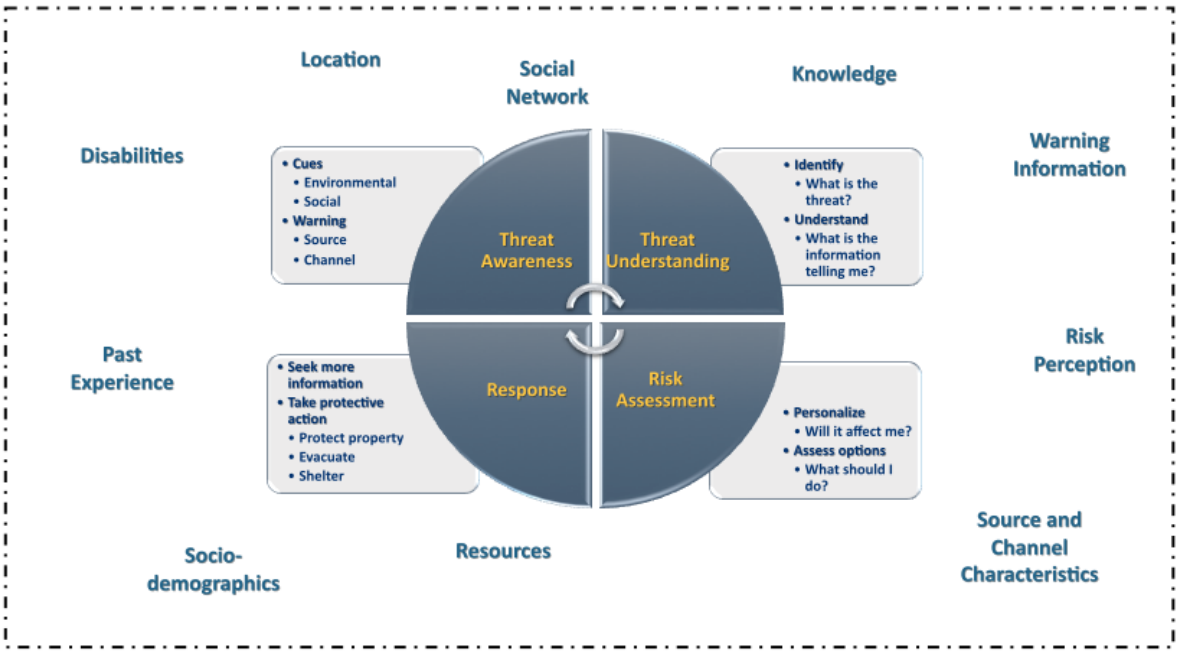

Figure 2. A depiction of the iterative warning response process. Content for this image is adapted from the Protective Action Decision Model (PADM) (Lindell and Perry 2012) and Mileti and Sorensen 1990.

People must not only understand what the risk is, but also if it personally affects them.

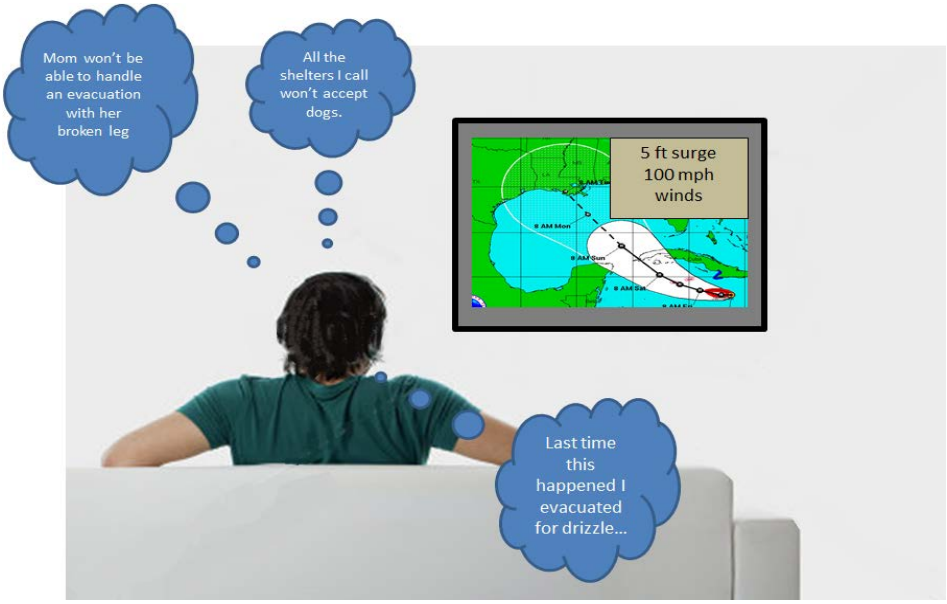

Figure 3: Fictional depiction of someone considering whether or not to evacuate from a hurricane. It shows the many factors that go into an individual's response to a warning. An SBS approach can help to identify those factors that have the greatest influence on response.

Risk Communication requires a mixture of effective best practices outlined in this report and a firm understanding of the audience and its needs.

Additionally, people view risk information through individual and unique lenses. Socio-demographics, resources, disabilities, and other factors (**Figure 2**), influence an individual's understanding and choices. (For a full list of factors and how they relate to warning response, please see ***Appendix 2.***) Some factors can be controlled and others cannot. A warning can be adjusted to include more specific information. However, disability of the receiver cannot be changed. For example, for individuals with colorblindness, colors used in the warning can be modified using hues they can more readily interpret. However, all colorblindness is not equal in ability to see color. Beyond the risk itself, priorities may be very different. For the meteorologist, the threat may be the most important message to convey. But for the public, that same threat is actually just one concern among many that they face throughout their day. Some of these concerns relate to the risk at hand and others will not. For instance, **Figure 3** depicts a person viewing hurricane information on the TV. They're not only taking into account the scientific information, but also personal worries such as an injured family member, an animal, and past experience. Beyond this, their mind may be distracted by their grocery list, unpaid bills, or any other number of issues that affect daily lives. Practitioners do not necessarily have to know what the receiver is thinking, but the practitioner has to be aware of the kinds of thoughts and processes that interfere with the messages being perceived

and acted upon as the practitioner intended. Consequently, there is no 'one size fits all' method for communicating risk. Instead, it requires a mixture of effective best practices outlined in this report and a firm understanding of the audience and its needs.

For a more in-depth background on theoretical approaches to risk communication see ***Appendix 1 Theories and Models****.*

IV. Best Practices

Photo Credit: company.clearchanneloutdoor.com

NOAA practitioners can use known best practices now to help guide risk communication efforts. These practices can improve understanding of the audience at risk, their concerns, and their values, resulting in more effective interactions that help them recognize risks and identify actions to minimize those risks. Whether forming a partnership, planning a stakeholder engagement activity, developing outreach materials, creating a new product in response to a stakeholder or partner need, or just having a conversation, these best practices can be used to improve the effectiveness of these efforts. They can be applied at all stages of the risk communication process. The result will be more effective engagement with a diverse group of stakeholders and partners. For additional information on techniques and considerations for stakeholder engagement, see the *Introduction to Stakeholder Participation* publication from the NOAA Office for Coastal Management. [18]

This report includes information from a variety of sources, including research articles, practitioner guides, personal experience and education, as well as the risk communication and behavior literature reviews of others. A table of comprehensive or systematic reviews on risk communication and behavior and a list of practitioner guides is in ***Appendix 3 Review Papers and Practitioner Guides***. These best practices are intended to provide the practitioner with ways to improve risk communication now while NOAA continues to identify and fill gaps in research and understanding of risk communication and behavior for specific hazards. These best practices are not hazard-specific, but cut across all hazards.

[18] See http://coast.noaa.gov/digitalcoast/publications/stakeholder

1. Have an Informed Plan – Know what needs to be achieved and how to achieve it before beginning risk communication efforts.

- Have a clear goal – Look to change behavior or seek action.
- Understand your audience – They are a diverse group with different values and concerns and different filters, which impact what they hear.
- Know who else is talking – People reach conclusions based on what they know and hear. Understand what they are hearing from other sources and determine if messages are consistent.
- Develop and deliver the right message – What is said, how it is said, and how it is delivered matter, as does consistency and constancy. Repetition drives the message home. (See best practice #7 for more on message delivery.)
    - What is said (the words, how to talk about the hazards, including what to do)
        - Be specific.
        - Be consistent.
        - Be clear and accurate.
        - Use plain language.
        - Meet the needs of the media and other emergency partners.
        - Describe protective actions to take and how those actions will benefit the audience.
        - Describe the hazard, including location and timing.
        - Disclose the source of the information.
        - Provide options for more information.
    - How it is said (style, tone, demeanor)
        - Speak clearly and with compassion.
        - Be honest and open.
        - Use a confident tone.
- Be consistent with the information in the message – Consistency is critical both within the office and with others that are speaking with the audience. Inconsistent information is often ignored.

2. Speak to Their Interests, Not Yours – Connecting emotionally with audience values and concerns to help establish a relationship and improve risk communication efforts.

- Find out what is important to the audience –Connect with their values and concerns.
- Be a good listener – Give the audience an opportunity to be heard. Listen to their concerns. Understand how they interpret and respond to risk information. Identify barriers to action.
- Start a dialog – Risk communication is not a one-time thing. Tailor future conversations based on what is learned during each conversation; make it important to the audience.
- Build trust – Become a trusted messenger and partner. Be honest about what is known and not know in order to build trust.
- Consider the socio-demographic and economic contexts of message recipients - Understand the needs and circumstances of those most vulnerable (e.g.., those with mobility restrictions, those

whose primary language is not English, those with weak social networks or without adequate financial or physical means to take action).

3. Explain the Risk (in a manner that is clear and appropriate for the audience) – Use stories and visuals to make it personal and help the audience understand the impacts and the hazard.

- Start with the impacts – Paint a picture of what the impacts will be in their community using graphics and visuals. Refer to past events. Use maps that are easy to understand and interpret when appropriate.
- Allow the audience to share experiences – Audience members can help explain the risk. Other community members will relate better to local stories.
- Be open about unknowns – Start with what is known. Avoid the term "uncertainty," but do not avoid the concept.
- Use doom and gloom sparingly – Scare tactics usually do not work so use them only when the situation really warrants their use. People have a "finite pool of worry" and will shut down if they don't think anything can be done to help the situation.

4. Offer Options for Reducing Risk –Facilitate a conversation to identify barriers to action. Offer options that address these barriers and are appropriate for the local situation.

- Describe some options - Provide guidance on options and describe how they benefit the audience.
- Offer options at the individual and community level – Empower residents to take responsibility for themselves while also building a resilient community.
- Engage the audience in blue sky planning – Family emergency planning and formal community level planning is best done before it is needed.
- Allow stakeholders to discuss options – There is no substitute for learning from someone who has already implemented a strategy. Set up these opportunities to learn.

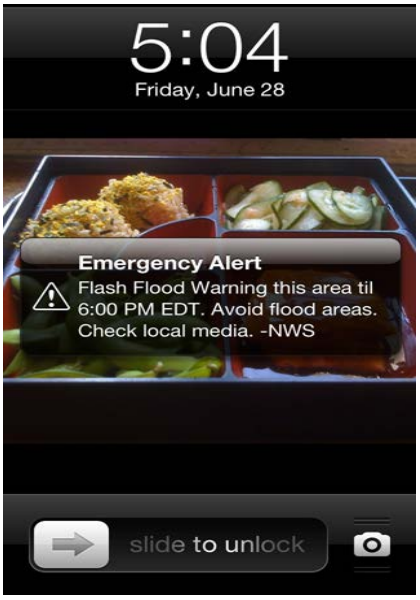

Photo Credit: NOAA

5. Work with Trusted Sources and the Public – People seek confirmation from multiple trusted sources to verify risk and help them make decisions on what actions to take, if any.

- Engage with the audience regularly – Learn their audience needs at the beginning. Modify communications to meet those needs.
- Identify trusted sources of information – Know who the audience listens to. Find the opinion leaders and early adopters in the audience's community.

- Establish partnerships with these trusted sources – Working with a variety of partners including faith-based organizations and community and social networks will improve odds that the same message will reach the audience from a trusted source.
- Work together to create and share consistent information – Multiple messengers are critical to providing a consistent message.

6. Test Messages or Products; Evaluate Performance –Coworkers are not the audience. Test communications on target audience members before reaching out broadly. Evaluate the results of communications efforts.

- Get audience feedback – Options to gather feedback can vary widely from asking a few members of the target audience what they think to conducting a formal survey or evaluation (within appropriate Federal guidelines, of course).
- Ask questions that provide useful feedback – Open-ended questions, such as questions that ask audience members for feedback in their own words works well. Watch how the audience responds to the information and ask them to share their reactions. Learn what the outcome was of the communications.
- Be willing to make changes – Test draft materials while there is still time to adjust. Make improvements to processes before the next communication. Small tweaks can dramatically improve effectiveness.

7. Use Multiple Ways to Communicate – People like to receive information in different ways. Understand how the audience likes to receive information on hazards.

- Use the medium the audience prefers – Deliver messages in preferred formats. Do not discount the use of television and social media as a source. Use newer technologies such as social media in addition to old standbys. Monitor for changes in preferences.
- Use multiple mechanisms and formats – Audiences will need to hear the message multiple times. Multiple formats will improve the chances of reaching the audience.
- Ensure messages are compatible with the medium being used – Modify the message to make it medium-appropriate and relevant but maintain consistency.

For more information on best practices for risk communication and examples showing how some of these best practices have been applied, see the NOAA Office for Coastal Management risk communication resources on the Digital Coast, or participate in the interactive webinar. http://coast.noaa.gov/digitalcoast/training/risk-communication

NOAA will use these best practices to improve risk communication efforts across the agency and increase the chances of audiences responding to risk in ways that would allow for improved resilience and outcomes at both the individual and community levels.

V. Contemporary Research in Weather Hazards

This section provides a highlight of recent research in risk communication and decision science for weather hazards. The authors identified this literature through a Web of Science query, to include articles that had both a NOAA hazard keyword (tornado/severe wind, flood, hurricane, tsunami, wildfire, volcano and 'weather' as a general term) and a keyword pertaining to communication or warning response (e.g., risk, response, communication, perception, behavior, public, social, and societal). Note that this review focuses on episodic weather hazards. Slow-onset hazards, including climate change and drought, are distinct enough that they should be separate efforts and are thus not included in this review. The search focuses on articles published between 2000 and 2014.

This highlight of contemporary topics serves as a starting point for engaging these research communities in what is hoped is an ongoing dialogue about what is or is not known about the communication of and responses to weather hazard information.

While this process is not systematic about particular issues, the resulting pool of articles presents several important topics for NOAA practitioners and researchers across many disciplines of study. These highlighted topics are an excellent starting point for engaging research communities in active, sustained dialogue about what is or is not known about the communication of and responses to weather hazard information. This list of key topics also can be a useful reference for NOAA managers and practitioners as they begin to navigate this multidisciplinary research landscape for operational or programmatic purposes.

In this report, we look at each episodic weather hazard separately. It is important to not generalize findings across weather hazards. For example, just because research provides ways to effectively communicate flood risk, these recommendations do not necessarily transfer over to ways to effectively communicate tornado risk. Future versions of this report will investigate the differences in research needs per hazard.

Summarized below are some of the major themes that emerged in the literature for each NOAA hazard. Recognizing the partiality of the methodology, recommendations for further research are also included. The authors hope to galvanize support by building and strengthening partnerships with the research community to reveal the ways these questions may be addressed across the many social and behavioral sciences that this search could have missed. For NOAA management, these themes and questions can serve as a starting point for commissioning more systematic reviews on topics of particular interest.

A. Tornado/severe wind

Introduction

Scientists and practitioners still lack a clear understanding of the public response to and most effective communication used during tornado/severe wind events. The search turned up only 17 articles addressing this specific topic. However, research on this topic has increased in popularity in the past five years, with 14 of the 17 articles published after 2009. The majority of the tornado and severe thunderstorm articles identified focused on public response following an actual event or perceived response to a hypothetical event. Other topics, such as preparedness and warning design, were more sparsely covered. Nearly all articles (16 of 17) used quantitative methodologies, primarily consisting of traditional phone, mail, or Internet surveys.

Research Highlights

Channels: A multitude of tornado warning channels were studied. To clarify, radio is a channel; the radio announcer is the source. Two stood out as the most popular[19]: television and siren systems (if installed in the area). [20]

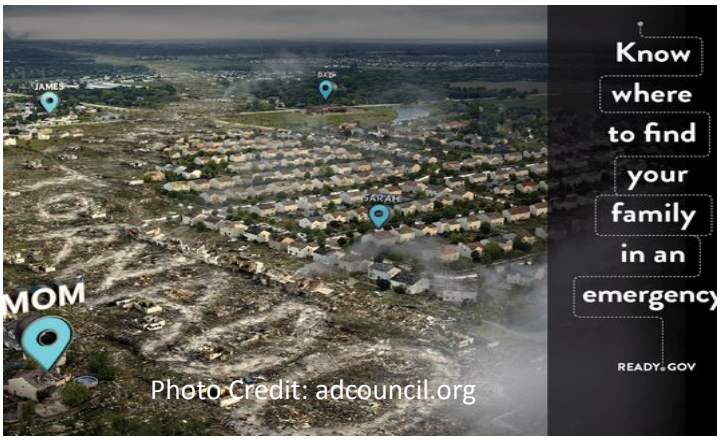

Photo Credit: adcouncil.org

Protective Action: Many factors contribute to protective action decision making during tornadoes, but three variables were consistently *positively* correlated with taking action[21]: having a family plan[22], being a woman[23], and being located relatively close to the hazard.[24]

Warning format: An article examining tornado warning polygon formats suggested that probabilistic formats tend to help people better understand the threat level relative to their actual location.[25] The

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[19] L. Balluz, L. Schieve, T. Holmes, S. Kiezak, and J. Malilay. Predictors for People's Response to a Tornado Warning: Arkansas, 1 March 1997. Disasters. (24.1, 71-77, 2000). R. Drost. Memory and Decision Making: Determining Action When Sirens Sound. Weather Climate and Society (5.1, 43-54,2013). S. Durage, L. Kattan, S.C. Wirasinghe, and J.Y. Ruwanpura. Evacuation behaviour of Households and Drivers during a Tornado. Natural Hazards (71.2, 1495-517, 2014). B. Hammer, and T.W. Schmidlin. Response to Warnings during the 3 May 1999 Oklahoma City Tornado: Reasons and Relative Injury Rates. Weather and Forecasting . (17.3, 577-87, 2002). C.E. League, W. Diaz, B. Phillips, E.J. Bass, K. Kloesel, E. Gruntfest, and A. Gessner. Emergency Manager Decision-Making and Tornado Warning Communication. Meteorological Applications (17.2, 163-72, 2010). M.F. Perreault, J. Brian Houston, L. Wilkins. Does Scary Matter?: Testing the Effectiveness of New National Weather Service Warning Messages. Communication Studies (65.5, 484-99,2014). R.S. Schumacher, D.T. Lindsey, A.B. Schumacher, J. Braun, S.D. Miller, and J.L. Demuth. Multidisciplinary Analysis of an Unusual Tornado: Metrology, Climatology, and the Communication and Interpretation of Warnings. Weather Climate and Society (25.5, 1412-29, 2010). K. Sherman Morris. Tornado Warning Dissemination and Response at a University Campus. Natural Hazards (52.3, 623-38, 2010).

[20] Durage et al. (2014); Hammer and Schmidlin (2002); League et al. (2010); Perreault et al. (2014).

[21] K.D. Ash, R.L. Schumann, G.C. Bowser. Tornado Warning Trade-Offs: Evaluating Choices for Visually Communicating Risk. Weather, Climate, and Society (6.1, 104-18,2013). D.E. Nagele, and J.E. Trainor. Geographic Specificity, Tornadoes, and Protective Action. Weather, Climate, and Society (4.2, 145-55, 2012). A. Silver, and J. Andrey. The Influence of Previous Disaster Experience and Sociodemographic on Protective Behaviors during Two Successive Tornado Events. Weather, Climate and Society(6.1,91-103, 2013).

[22] Z. Cong, D.A. Loang, and J.J. Lou. Family Emergency Preparedness Plans in Severe Tornadoes. American Journal of Preventive Medicine (46.1,89-93, 2014). Nagele & Trainor (2012).

[23] Cong et al. (2014); Perreault et al. (2014); Sherman-Morris (2010); Silver & Andrey (2013).

[24] Balluz et al. (2000); Nagele & Trainor (2012); Schmidlin et al. (2009).

researchers found that being closer to the threat in a probabilistic format provoked greater fear and likelihood of taking action. However, using NOAA's current warning format, which does not visually display probabilities, end users who perceive themselves to be at the greatest risk and likelihood of taking action were those in the center of the polygon.

Lead time: An article exploring lead time preferences found that people felt they needed 10 minutes, on average, to take shelter in the event of a tornado.[26] However, they preferred an average of 34 minutes. People expected to use this extra time to seek more information and potentially evacuate from the path of the tornado rather than shelter-in-place. This research suggests NOAA should be cautious and thoughtful about the impact of increased tornado lead time.

Preparedness: When exploring the impact of a recent traumatic tornado event, one article found that about 66 percent of respondents would change their plans by either building safe rooms within their homes or evacuating their home entirely. The remaining 33 percent were split between those who would continue to shelter-in-place in the next event and those who would not take action at all. The findings indicate how human behavior is interpreted when it comes to taking future precautionary and preparedness actions, as well as how individuals differ in hazard interpretation and precautionary/preparedness actions.

Large public gatherings: When researching a tornado event at a university, authors found that employees tended to be more knowledgeable and knew about the event well ahead of time. Students generally first heard through university alerts. [27] This highlights the complexities of a severe weather event at a university or any area with a large gathering of people. Students tend to rely on school officials to keep them informed in the same way a crowd at a stadium may rely on facility managers.

Emergency manager behavior: A qualitative study addressing emergency management response to severe weather and tornadoes found that only approximately 60 percent warn the public immediately upon hearing an NWS warning. [28] Additionally, about 66 percent would warn the public without an official warning issued by NWS. While this is only one study, the NWS warning appears to be only one factors among many, and not always the deciding factor, that emergency managers take into account to make complex decisions.

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[25] Nagele & Trainor (2012).
[26] S. Hoekstra, K. Klockow, R. Riley, J. Brotzge, H. Brooks, and S. Erickson. A Preliminary Look at the Social Perspective of Warn-on-Forecast: Preferred Tornado Warning Lead Time and the General Public's Perception of Weather Risks. Weather, Climate, and Society (3.2, 128-40, 2011).
[27] Sherman-Morris (2010).
[28] League et al. (2010).

Best Practices for Communicating Tornado/Severe Wind Risk

1) **Convey urgency in risk messages through visuals:** Those who are closest to the hazard are more likely to take protective action. This is most likely due to the increase in environmental cues, such as wind, rain, or even a visual of a tornado. By providing visualizations, detailed descriptions, and geographic specificity regarding the location of the severe weather/tornado event, those further from the threat but still in danger can be provoked to take action sooner.

2) **Ensure new warnings, technologies and messages are applicable to the most popular severe weather information source(s):** Despite an influx of new technologies in recent decades, TV still remains a popular source for severe weather/tornado information. [29]The huge impact TV media can make on public understanding and action, even in light of wide use of social media and smartphones, cannot be discounted. However, it is also important to gain a better understanding of people's use of TV for severe weather information. Is TV the most popular first source? Does it depend on age or other socio-economic characteristics?

By providing visualizations, detailed descriptions, and geographic specificity regarding the location of the severe weather/tornado event, those further from the threat but still in danger can be provoked to take action sooner.

Future Research Needs

False alarms [30]: It is crucial to know how increased or decreased false alarm rates/ratios impact protective action and sheltering. NOAA would also benefit from a better understanding of how people conceptualize a false alarm and associated terms such as 'hit' and 'miss'. Research should not only focus on traditional NWS warnings with regards to false alarms, but also on how information from the weather enterprise as a whole (TV, social media, etc.) contributes to the perception of hits, misses, close calls and false alarms.

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[29] L. Balluz, L. Schieve, T. Holmes, S. Kiezak, and J. Malilay. Predictors for People's Response to a Tornado Warning: Arkansas, 1 March 1997. Disasters. (24.1, 71-77, 2000). R. Drost. Memory and Decision Making: Determining Action When Sirens Sound. Weather Climate and Society (5.1, 43-54,2013). S. Durage, L. Kattan, S.C. Wirasinghe, and J.Y. Ruwanpura. Evacuation behaviour of Households and Drivers during a Tornado. Natural Hazards (71.2, 1495-517, 2014). B. Hammer, and T.W. Schmidlin. Response to Warnings during the 3 May 1999 Oklahoma City Tornado: Reasons and Relative Injury Rates. Weather and Forecasting . (17.3, 577-87, 2002). C.E. League, W. Diaz, B. Phillips, E.J. Bass, K. Kloesel, E. Gruntfest, and A. Gessner. Emergency Manager Decision-Making and Tornado Warning Communication. Meteorological Applications (17.2, 163-72, 2010). M.F. Perreault, J. Brian Houston, L. Wilkins. Does Scary Matter?: Testing the Effectiveness of New National Weather Service Warning Messages. Communication Studies (65.5, 484-99,2014). R.S. Schumacher, D.T. Lindsey, A.B. Schumacher, J. Braun, S.D. Miller, and J.L. Demuth. Multidisciplinary Analysis of an Unusual Tornado: Metrology, Climatology, and the Communication and Interpretation of Warnings. Weather Climate and Society (25.5, 1412-29, 2010). K. Sherman Morris. Tornado Warning Dissemination and Response at a University Campus. Natural Hazards (52.3, 623-38, 2010).

[30] League et al. (2010); D.M. Schultz, E.C. Gruntfest, M.H. Hayden, C.C. Benight, S. Drobot, and L.R. Barnes. Decision Making by Austin, Texas, Residents in Hypothetical Tornado Scenarios. Weather, Climate and Society (2.3, 249-54).

Lead time: How will longer lead times impact public perception and behavior?[31] Additionally, it will be important to know how longer lead time would change the warning process for forecasters, the media, emergency managers, and other community organizations.

Severe Thunderstorms: NOAA would benefit from an increased understanding of public perception and behavior of severe thunderstorms. Particular attention should be given to derechos and mesoscale convective systems (MCS) that present unique forecasting and societal behavior challenges.

Preparation behavior: More research is needed on preparation behavior that can be accomplished during the outlook and watch phases of a severe weather event, such as participating in drills, creating family emergency plans, and gathering supplies. It is also important to address reduced preparations in vulnerable populations, e.g., lower income families and mobile home owners.

Warning format and design: It is important to fully understand the societal impacts resulting from increasing geographic and probabilistic specificity in warning polygons. Further research is needed to understand how probabilities can be effectively communicated through a tornado warning.

Large public gatherings: Future research should address and offer best practices for institutions and organizations dealing with tornado/severe thunderstorm warning dissemination, sheltering, and preparations.

It is also important to address reduced preparations in vulnerable populations, e.g., lower income families and mobile home owners.

B. Flood

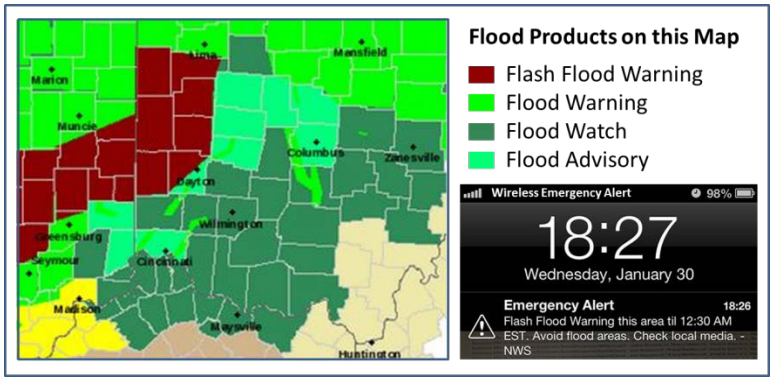

Photo Credit: NOAA

Introduction

The literature on flood hazards revealed key applications as well as limitations. The search turned up 12 articles addressing this specific topic. Regarding geographical focus, most studies were conducted outside of the United States, particularly New Zealand - and mostly in Europe. Concerning methodology, the majority of studies were of exploratory

[31] Hoekstra et al. (2011).

nature and have not applied theoretical frameworks that are available in social science research. When theoretical frameworks were used, they most commonly included Expectancy Valence Theory or variations of it, such as the Protective Action Decision Model (PADM), the Protective Motivation Theory (PMT), and the Mental Model approach.

Across the literature, the most common research questions related to mitigation and preparedness behavior, and perception of risk. Very few studies examined the effectiveness of risk communication practices or evaluating new ways to communicate flood risk. Studies in psychology tended to emphasize individual perceptions about risk, without examining a wider range of risk perceptions borne throughout society (such as those of policy-makers or of tax-payers who live outside flood affected areas). The studies also did not examine the linkages between wider perspectives and protective measures such as state-supported flood insurance schemes. In other words, while the majority of the literature examined involved individual homeowner's responses, influences and constraints, there is much more to consider with respect to flood risk mitigation.

Research Highlights

Flood risk management: The management of flood risk has traditionally fallen to communities and the government, who have instituted a system that primarily focuses on structural mitigation. Recently, however, researchers and natural resource managers have become increasingly concerned about the ways structural mitigation has increased the exposure to extreme flood risk, and strides have been made to promote non-structural solutions to flood risk. Non-structural flood risk reduction measures include elevation, basement filling, relocation/acquisition, flood proofing, berms and small-scale flood walls, flood warning systems, emergency preparedness plans, and land use regulations.[32] These measures place a greater emphasis for resilient outcomes on individuals and communities. An important flood policy, the National Flood Insurance Program's Community Rating System (NFIP CRS) rewards communities that use these measures with reduced flood insurance premiums. Unfortunately, however, participation in NFIP is still fairly low. The reasons for this are complex and not fully understood.[33]

Knowledge about floods[34]: Several studies have examined when people tend to become savvier about flood threats. Generally, people who are most knowledgeable fear natural hazards more, have had previous experience with flooding, or tend to use multiple sources of information to learn about flood threats. In other words, these individuals are inclined to be information-seeking, whether by natural inclination or through necessity. When people lacked knowledge about flood threats, they had to rely much more heavily on trusted expert communicators. A lack of a trusted source of information could therefore be very detrimental to those with less flood knowledge.

[32] Federal Emergency Management Administration. Nonstructural Flood Risk Management Measures (2015).
[33] Kunreuther and Erwann-Kerjan: *At War with the Weather* (2007)
[34] W. Kellens, T. Terpstra, and P. DeMaeyer. Perception and Communication of Flood Risks: A Systematic Review of Empirical Research. Risk Analysis (33.1,24-49,2013).

Risk perception[35,36]: While two places may both experience similar kinds of flooding, the populations can perceive the risks very differently. Research demonstrates that culture can explain some of these differences, especially as the structures and economic practices of certain cultures are better-adapted to flood exposure. From an event-based perspective, when floods are expected to last longer, the perception of risk increases among the population. Risk perception also tends to increase with age, for women, and for those with higher levels of education.

Connection between risk perception and response to warnings[37]*:* While direct linkages between individual perceptions of risk and warning response have long been assumed for many hazards, including flood hazards, the literature does not support a simple connection between these constructs for flood threat. High perceptions of risk must be coupled with measures of coping appraisal (including elements of response eff, self-efficacy and response cost) to fully understand responses to flood threats (on multiple timescales). It is not enough to relay to people that something is a risk – they need help understanding what they can do about it, and to feel empowered to take those actions. High perceptions of risk can thus be taken as a necessary, but not sufficient condition for response.

...it is not enough to relay to people that something is a risk – they need help understanding what they can do about it, and to feel empowered to take those actions.

Response and Efficacy: To improve response effectiveness, people should be provided with locally specific information that gives them simple, easy to understand options for pursuing safety (including alternate routes to avoid flood hazards.[38]) To improve self-efficacy the measures should be low-cost and easy to implement.

Other factors affecting warning response[8,10,39]*:* Responsiveness to flood warnings tends to increase with nearness to flood, prior experience with flooding, the intensity of the flood, mobility and availability of help, trust in the warning provider, and decreases in complacency brought on by flood defenses. In one study, worry did not increase preparedness, raising concerns about using worry/fear as a tactic to inspire appropriate response.

Damage/loss reduction: Research has found that flood warnings can reduce losses, but weaknesses in the communication chain can significantly limit the effectiveness of warnings. Increases in lead-time are

[35] P.W. Bubeck, J.W. Botzen, and J.C. J.H Aerts. A Review of Risk Perceptions and Other Factors that Influence Flood Mitigation Behavior. Risk Analysis (32.9,1481-95,2012).

[36] D.J Parker, and S.J. Priest. The Fability of Flood Warning Chains: Can Europe's Flood Warnings Be Effective? Water Resources Management (26.10,2927-50,2012).

[37] Completing the Forecast (2006):http://www.nap.edu/catalog/11699/completing-the-forecast-characterizing-and-communicating-uncertainty-for-better-decisions

[38] R.C. Franklin, J.C. King, P.J. Aitken, and P.A. Leggat. "Washed Away" Assessing Community Perceptions of Flooding and Prevention Strategies: A North Queensland Example. Natural Hazards (73.3, 1977-98, 2014).

[39] T. Grothmann, and F. Reuswigg. People at Risk of Flooding: Why Some Residents Take Precautionary Action While Others Do Not. Natural Hazards (38.1-2,101-20,2006).

associated with lower damage totals, and these reductions are attributable to moving property from low ground to higher ground. The effectiveness of response for damage reduction increases with preparedness and time to respond.

Flood mitigation (longer timescale)[8]*:* In the longer-term, NFIP participation is more likely for those who own their home, have higher incomes, and face more frequent flood exposure. When people perceive a higher personal responsibility for managing their flood threat, they are more likely to pursue non-structural mitigation and other preparedness activities. It is conceptually difficult to explain to people that structural mitigation measures (like dams) may actually increase their catastrophic risk potential.[40]

Representing Uncertainty: There is some evidence to suggest that certain representations of uncertainty of physical probabilities create higher levels of comprehension/concern about flood risk than others. For example, graphics generate more concern about flood risk than numbers alone. Additionally, probability format affects the interpretation and concern of flood risk. This is particularly true for the recurrence interval of flood risk used to describe flood plains.[41]

Participation: Trust in knowledge and advice of experts increases after communities are engaged in participatory processes related to mitigating flood risks. NOAA has recently begun to use stakeholder engagement methods to both understand how they can better provide integrated water risk information, and how communities use that information. This participatory process improves response for these communities, and improves relationships with other agencies, such as the United States Army Corps of Engineers (USACE). A recent focus group recommended that flash flood response can be improved with simplified flash flood messaging, improved modeling (higher-resolution flood information), and continued relationship-building between WFOs, RFCs, and local partners.[42]

Messaging: In a recent study conducted along two flood prone towns, researchers found that timing, clarity and graphic elements affected respondent's understanding of flash flood forecast and warning tools. Visual factors in products – including the use of color, patterning and font – affected respondents' understanding of products in both helpful and unhelpful ways, and must be carefully considered. Respondents in this study reported two major barriers to their use of forecast and warning tools: (1) the overly technical nature of products and (2) the use of unfamiliar terms and unclear or inadequate explanations of visual data. Products that are completely text, such as watches and warnings, were found to be excessively wordy, with key information often buried. Additionally, respondents preferred that products contain a combination of graphic and text information, citing the need for both quick and

[40] R.A. Bradford, J.J. O'Sullivan, I.M. van der Craats, J. Krywkow, P. Rotko, J. Aaltonen, M. Bonaiout, S. De Dominics, K. Waylen, and K. Schelfaut. Risk Perception- Issues for Flood Management in Europe. Natural Hazards and Earth System Sciences (12.7,2299-09.2012).

[41] H.M. Bell and G. A Tobin. Efficient and Effective? The 100-year flood in the communication and perception of flood risk. Environmental Hazards (7.4,302-11,2007).

visual identification of risk, along with more detailed explanations and specificity from the text. Respondents also reported that the use of all capital letters was burdensome to read.[43]

Since many people tend to rely on the government to take responsibility for mitigating against floods, the roles of all stakeholders need to be more clearly defined.

Best Practices for Communicating Flood Risk

1) Successful flood risk communication should include information beyond simply describing the hazard, including what individuals can do to mitigate or avoid the risk, and how successful those alternatives are – bolstering both response efficacy and self-efficacy.
2) It is important to communicate the role individuals can play in keeping themselves safe from flood threats. Since many people tend to rely on the government to take responsibility for mitigating against floods, the roles of all stakeholders need to be more clearly defined. Participatory community efforts, like that described above, could help in that process, and should be pursued in more communities throughout the country.
3) Those who are less experienced with flood threat tend to perceive less risk from flooding, and to be less likely to respond. The literature suggests that capturing knowledge from experienced flood victims could be included in a resource in flood risk communication for those with less experience. Including personal accounts from flood victims in ongoing communications can serve to highlight adverse impacts of floods, reinforcing the need to take alleviation measures.
4) Materials should be developed for individuals living in communities with structural flood mitigation so they are aware of their residual risk. Providing understandable statements on risk will lead to a greater recognition that structural protection measures will be exceeded for events greater than the design capacity.

[43] Nurture Nature Center/RMC Research Corporation. Flood Risk and Uncertainty Assessing NWS Flood Forecast and Warning Tools (2015). Prepared for NOAA's Office of Weather and Air Quality.

Future Research

Mediums of Flood Communication: For NOAA to improve its flood risk communication efforts, more needs to be known about the ways people access this information now and how effective those methods are at conveying risk, preparedness, and response information.

Past Efforts and Effects on Risk Perception: The effect of previous mitigation efforts on perceptions of risk could include such questions as: How does the presence of community-level flood mitigation (or risk reduction) or in-home mitigation change perceptions of risk? Do adaptations shift the distribution of risks a person may face, and do they understand this?

Exposure and Experience: Exposure and experience should be theorized and the connection between flood risk perception and risk communication should also be studied. This could involve more examination of how risks are communicated, and how varying the risk communication practices can affect changes in risk perception, preparedness, warning response, and/or mitigation behaviors.

Key Actors: More research is needed that moves beyond the risk perceptions of the individual to that of key actors/communities. Relationships among perspectives should be carefully examined in light of the ways they improve or hamper individual/community agency to become aware of, understand, and mitigate against flood risks (in short and long timescales).

Representing Flood Risk Uncertainty: More research is needed on the multi-dimensional representations of flood risk. A need exists to better communicate the uncertainty about the potential intensity of flood threats. More research should be conducted to explore alternatives for improved climatological risk communication.

C. Tropical Cyclone

Introduction

This hazard has been a popular area of study over the last 15 years – this review includes 55 articles focused on tropical cyclones. There are notable peaks in research in the years directly following a major event such as Hurricane Katrina. On the other hand, the number of articles published on tropical cyclones has waned somewhat in the last few years. The majority of studies dealt with response during an actual event. Other popular topics included preparedness/mitigation and hurricane risk perception. About half of the articles collected used quantitative methods, such as traditional phone, mail, or online surveys. The remaining half was split fairly even between those employing strictly qualitative methods, such as focus groups or interviews, and those using mixed methods.

Research Highlights

Preparation: A few articles examined variables significant in hurricane preparation. These varied depending on the type of preparation. For general preparedness, age, income, experience, and perceived threat were significant predictors.[44] For existence of a family plan, significant variables included confidence in the government, marital status, and risk perception.[45] Homeownership, children, length of residency, income, experience, knowledge, and building codes were significant predictors of having relevant supplies including hurricane shutters. [46] Preparation activities were also closely tied to risk perception in several articles. For instance, those who perceived the risk to be higher were more likely to have a family plan and seek more information about the threat.

Evacuation: Several articles dealt with evacuation choices and perceptions.[47] Important barriers to evacuation included confusion over where to evacuate, lack of family/friends, lack of necessary resources, health concerns, job insecurity, and perceived crime concerns. One article specifically focused on delays caused by evacuations as a potential barrier. Interestingly, those who heard about evacuation delays were less likely to evacuate in the future as compared to those who had actually experienced delays.[48] Despite barriers, many choose to evacuate. One article addressed the use of multiple sources of information to evaluate the risk posed to residents and their families, which subsequently lead to many residents making the choice to evacuate.[49] One article addressed the subsequent choices of sheltering options. Females, homeowners, and those with higher incomes were less likely to go to a

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[44] V. Basolo, L. J. Steinberg, R.J. Burby, J. Levine, A.M. Curz, and C. Huang. The Effects of Confidence in Government and Information Perceived and Actual Preparedness for Disasters. Environment and Behavior (41.3,338-64,2009). R.E. Morss, and M.H. Hayden. Storm Surge and "Certain Death": Interviews with Texas Coastal Residents following Hurricane Ike. Weather, Climate and Society (2.3,174-89,2010). D.N Sattler, C.F. Kaiser, and J.B. Hittner. Disaster Preparedness: Relationships Among Prior Experience, Personal Characteristics and Distress. Journal of Applied Social Psychology (30.7,1996-420,2000). D.N. Sattler, A.J. Preston, C.F. Kaiser, V.E. Olivera, J. Valdez, and S. Schlueter. Hurricane Georges: A Cross-National Study Examining Preparedness, Resource Loss, and Psychological Distress in the U.S. Virgin Islands, Puerto Rico, Dominican Republic, and the United States. Journal of Traumatic Stress (15.5,339-50,2002). T.W. Cole, and K.L. Fellows. Risk Communication Failure. A Case Study of New Orleans and Hurricane Katrina. Southern Communication Journal (73.3,211-38,2008). W. Peacock. Hurricane Mitigation Status and Factors Influencing Mitigation Status among Florida's Single-Family Homeowners. Natural Hazards Review (4.3,149-58,2003).

[45] Basolo et al. (2009); W.G. Peacock, S.D. Brody, and W. Highfield. Hurricane Risk Perceptions among Florida's Single Family Homeowners. Landscape and Urban Planning (7.,2-3,120-35,2005).

[46] Peacock et al. (2005).

[47] R. Burnside, D.S. Miller, J.D. Rivera. The Impact of Information and Risk Perception on the Hurricane Evacuation Decision-Making of Greater New Orleans Residents. Sociological Spectrum (27.6, 727-40,2007). N. Dash, and B.H. Morrow. Return Delays and Evacuation Order Compliance: The Case of Hurricane Georges and the Florida Keys. Global Environment Change Part B: Environmental Hazards (2.3,119-28,2000). D.M. Dosa, N. Grossman, T. Wetle, and V. Mor. To Evacuate or Not to Evacuate: Lessons Learned From Louisiana Nursing Home Administrators Following Hurricanes Katrina and Rita. Journal of American Medical Directors Association (8.3,149-49,2007).
K. Dow and S. Cutter. Emerging Hurricane Evacuation Issues: Hurricane Floyd and South Carolina. Natural Hazards Review (31.1,12-18, 2002). D.P Eiseman, K.M. Cordasco, S.Asch, J.F. Golden and D. Glik. Disaster Planning and Risk Communication with Vulnerable Communities: Lessons From Hurricane Katrina. American Journal of Public Health (97.supplement_1, S109-S15, 2007). K. Elder, S. Xirasagar, N. Miller, S.A. Bowen, S. Glover, and C. Piper. African Americans' Decisions Not to Evacuate New Orleans before Hurricane Katrina: A Qualitative Study. American Journal of Public Health (97, S124-S29,2007); J.E. Kang, M.K. Lindell, C.S. Prater. Hurricane Evacuation Expectations and Actual Behavior in Hurricane Lilli1". Journal of Applied Social Psychology (37.4.,887-903,2007). S.K. Smith, and C. McCarty. Fleeing the Storm(s): An Examination of Evacuation Behavior during Florida's 2004 Hurricane Season. Demography (46.1,127-45,2009). D. Solis, M. Thomas, and D. Letson. An Empirical Evaluation of the Determinants of Household Hurricane Evacuation Choice. Journal of Development and Agricultural Economics (2.3,188-96,2010).

[48] Dash & Morrow (2000).

[49] F. Zhang, R.E. Morss, J.A. Sippel, T.K. Beckman, N.C. Clements, N.L. Hampshire, J.N. Harvey, J.M. Hernandez, Z.C. Morgan, R.M. Moiser, S. Wang and S.D. Winkley. An In-Person Survey Investigating Public Perceptions of and Responses to Hurricane Rita Forecasts Along the Texas Cost. Weather and Forecasting (22.6,1177-87,89-90,2007).

community shelter. On the other hand, non-white races, pet owners, those with longer residency, and those with more education were more likely to stay with friends or family.[50]

Special Needs: A couple of studies focused specifically on those with special needs and/or disabilities.[51] They found that households with these vulnerabilities were less likely to evacuate and take longer when they do.[52] One of the main issues cited was perceived lack of access to needed services.[53] Older residents tended to have set opinions on information sources and relied heavily on past experiences. Newer residents understandably had fewer opinions on information sources and relied more on family and friends. Those with hearing impairments also relied on family and friends for information as well as text alerts. In general, for those with developmental disabilities, fear and anxiety were common barriers to action.[54]

Stakeholder concerns: Some articles focused on specific stakeholder concerns. Emergency managers and media both noted some trouble understanding NWS products during hurricane situations. Additionally, media stakeholders felt they needed more continually updated information and more assistance from local emergency managers when communicating with the public.[55]

Tourists: Several interesting results were found regarding tourist perceptions and behavior. Their risk perception tended to be most influenced by predicted hurricane category at landfall. Likewise, the higher their risk perception and fear, the more likely they were to evacuate.[56] Tourists tended to rely most heavily on local TV stations for information and frequently misinterpreted the information presented about the forecast cone of uncertainty.[57]

Best Practices for Communicating Tropical Cyclone Risk

1) **Address barriers the public faces for reacting to hurricane preparedness and risk information:** When communicating hurricane preparedness or risk information, it is important to address certain broader concerns in addition to physical risk. For example:
    - The cost and time of supplies, mitigation, and evacuation.
    - The extent to which shelter accommodations meet the public's needs (e.g., are they pet-friendly).

[50] Smith & McCarty (2009).
[51] J. Bateman, and B. Edwards. Gender and Evacuation: A Closer Look at Why Women Are More Likely to Evacuate for Hurricanes. Natural Hazards Review (3.3, 101-17, 2002). Eisenman et al. (2007); H. Lazrus, B.H. Morrow, R.E. Morss, and J.K. Lazo. Vulnerability Beyond Stereotypes: Context and Agency in Hurricane Risk Communication. Weather, Climate, and Society (4.2,103-09, 2012). M. Van Willigen, T. Edwards, B. Edwards, and S. Hessee. Riding Out the Storm: Experiences of the Physically Disabled during Hurricanes Bonnie, Dennis, and Floyd. Natural Hazards Review (3.3,98-106,2002).
[52] Van Willigen et al. (2002).
[53] Eisenman et al. (2007).
[54] Lazrus et al. (2012).
[55] J.L. Demuth, R.E. Morss, B.H. Morrow, and J.K. Lazo. Creation and Communication of the Hurricane Risk Information. Bulletin of the American Meteorological Society (93.8,1133-45,2012).
[56] J. Villegas, C. Matyas, S. Srinivasan, I. Cahyanto, B. Thapa, and L. Pennington-Gray. Cognitive and Affective Responses of Florida Tourists after Exposure to Hurricane Warning Messages. Natural Hazards (66.1,97-116,2013).
[57] C. Matyas, S. Srinivasan, I. Cahyanto, B. Thapa, L. Pennington-Gray, J. Villegas. Risk Perception and Evacuation Decisions of Florida Tourists Under Hurricane Threats: A Stated Preference Analysis. Natural Hazards (59.2, 871-90,2011).

2) **Convey hurricane risk information in a clear and compelling manner**
   - Include a narrative or story to accompany the facts.
   - When communicating risk to businesses, it is important to include information on potential adaptive measures, rather than just the mathematical risk.
   - Include images and examples to illustrate post-disaster conditions and past events.
   - Increase the chances that residents will be able to identify their location and correctly interpret the information on risk maps by using larger scales and labeling landmarks. Also, consider redefining risk areas so they match with well-known boundaries (e.g. rivers, roads, counties), and reduce the number of risk areas/zones when possible.

3) **Implement policy options to promote hurricane preparedness, including:**
   - Create financial incentives for homeowners to take preparedness actions (e.g., lower-cost hurricane shuttering systems).
   - Enforce emergency/action plans within families and community groups.
   - Strengthen warning systems within NOAA/NWS and organization partnerships.
   - Take time to understand businesses' and individuals' needs, constraints, and goals as they relate to hurricane preparedness.
   - Formalize information channels/systems for quick communication, but keep them flexible.

When communicating hurricane preparedness or risk information, it is important to address certain broader concerns in addition to physical risk.

Future Research Needs

Evacuation: In particular, it would be useful to explore the relationship between intention to evacuate and evacuation constraints, vulnerability and behavioral analysis, and to refine evacuation behavior models.

Preparedness: More research is needed in measuring perceptions of adaptation methods, and studying factors like efficacy, cost, and aesthetics. Understanding the influence of risk perception on preparedness, and from measuring and understanding the gap between perceived and actual preparedness, is also needed.

Stakeholder interactions and decision making: Research is needed on ways to improve stakeholder interactions, particularly with practitioners directly involved in hurricane forecasting, warning, and response. A better understanding of local and state level decision support systems during evacuations is needed.

Conceptualization of hurricane risk perception: Better conceptualization of hurricane risk perception, including the cognitive and affective elements of risk perception, is needed.

Warning communication and receipt: Future research in this area would explore the most effective wording of warnings and evacuation orders. Large scale studies on response to hurricane warnings that vary the respondent type (e.g. households, businesses) and storm characteristics (e.g. severity, predictability) are needed, along with a better understanding of the use of inter-personal networks for message diffusion.

Tourists: Research on tourist behavior, perception, and knowledge related to tropical cyclones could be achieved through longitudinal studies that explore changes in preparedness/adaptation, emotional impacts, and other important variables.

D. General weather/forecast

Introduction

The 20 articles reviewed for this section cut across a variety of hazard types. The articles investigated general weather risk communication topics on: understanding weather information, including understanding of probabilistic weather forecast information; sources of weather information; use of weather information; response to weather information; and forecast uncertainty.

Photo Credit: NOAA

Research Highlights

Sources of weather information

One study via online survey found that media sources are the top source,[58] while another found that most residents in their Canadian study group preferred a text or automated phone call.[59] Also from the Canadian study, radio was the top channel among men, with in-person communications among women coming in second. Older individuals were more likely to use TV. Younger people were more likely to use their smart phone.[60] Weather warning information among this same group was preferred from an outdoor siren but most indicated a multiple channel approach is best. [61]

Use of Weather Information

There were four articles in this review related to the use of weather information. Key findings indicate that people use weather information to: determine what to wear, mainly for the next day; work and leisure related activities; and alter travel plans, if necessary.

People mainly get weather information in the early morning or late night hours and are most interested in precipitation characteristics (i.e. location, timing, precipitation type, and chances. Forecast confidence was found to be a significant factor in the frequency of obtaining forecasts for end users.)[62] In addition, weather salience was positively related to frequency of seeking weather information, the frequency of using it to plan daily activities, and the general use of precipitation and temperature forecasts.[63]

Response to weather information

Four articles reviewed pertained to action or response to general weather information.

One article confirmed a variety of findings from previous research. Such findings include the idea that households are more likely to take steps to prepare if they observe the preparations taken by others, and information obtained from prior experiences and actionable information from multiple sources communicated over multiple channels both motivate action.[64]

The second article developed and tested a model for household response.[65] This model was an extension of the Protective Action Decision Model (PADM). Results indicated that flood and wind mitigation and flood insurance protection were all positively related to perceived personal risk and

[58] J.K. Lazo, R.E. Morss, and J.L. Demuth. 300 Billion Served. Bulletin of the American Meteorological Society (90.6,785-98,2009).
[59] A. Silver. Watch or Warning? Perceptions, preferences, and usage of forecast information by members of the Canadian Public. Meteorological Applications (2014).
[60] Silver (2014).
[61] Silver (2014).
[62] Demuth et al. (2011).
[63] A.L Stewart, J.K. Lazo, R.E. Morss, and J.L. Demuth. The Relationship of Weather Salience with the Perceptions and Uses of Weather Information in a Nationwide Sample of the United States. Weather, Climate and Society (4.3,172-89,2012).
[64] M.M. Wood, D.S. Mileti, M. Kano, M.M. Kelley, R. Regan, and L.B. Bourque. Communicating Actionable Risk for Terrorism and Other Hazards. Risk Analysis (32.4,601-15,2012).
[65] M.K. Lindell, and S.N. Hwang. Households' Perceived Personal Risk and Responses in a Multihazard Environment. Risk Analysis (28.2, 539-56, 2008).

correlated with flood and hurricane experience. Demographics had a significant impact on flood insurance purchase.

In addition, experience, gender, and income are all important in perceived personal risk. The research found that:

i. income had a negative correlation with wind mitigation;[66]
ii. being white had a correlation with flood mitigation;
iii. females had higher perceived flood and hurricane risk;
iv. whites had a lower perceived flood risk; and,
v. higher income folks had a lower perceived risk overall and actual risk.

Management Decisions

The final two articles describe the research findings of role-play experiments in which participants were asked to make management decisions based on weather forecast information. One such experience in making road treatment decisions in a winter weather event found that forecasts expressed as an increase in odds over climatological norms induce more cautious decisions for rare, extreme weather events than do deterministic or probabilistic forecasts.[67] Findings also indicate that probability forecasts were not effective in the lowest range of probabilities in which precautionary action was economically warranted, and odds ratios do a better job of encouraging precautionary action in low probability situations. [68] The other article found that context and presentation influence forecast use and that people usually infer uncertainty in deterministic forecasts, however, they were unable to use uncertainty information to make decisions. [69]

Uncertainty associated with weather information

Uncertainty is a popular topic in the literature. Seven articles on uncertainty in the general weather category were reviewed with a diverse set of key findings.

Broadcasters were found to not always directly pass along uncertainty information from the National Weather Service. However, they use this information to form their own opinions and provide uncertainty information to the public in qualitative terms.[70]

A nationwide survey on uncertainty in everyday weather forecasts found the majority of respondents were aware that there is uncertainty in forecasts and they prefer forecasts that express it.

[66] Lindell & Hwang (2008).
[67] J. LeClerc, and S.Joslyn. Odds Ratio Forecasts Increase Precautionary Action for Extreme Weather Events. Weather, Climate and Society (4.4, 263-70, 2012).
[68] LeClerc & Joslyn (2012).
[69] R.E. Morss, J.K. Lazo, and J.L. Demuth. Examining the use of Weather Forecasts in Decision Scenarios: Results for a US Survey with Implications for Uncertainty Communication. Meteorological Applications (17.2, 149-62,2010).
[70] J.L. Demuth, J.K Lazo, and B.H. Morrow. Weather Forecast Uncertainty Information. Bulletin of the American Meteorological Society (90.11, 1614-18,2009).

Recreational boaters were found to anticipate uncertainty and specific biases in NWS forecasts based on prior experience that were born out in forecast verification data. They expected a high rate of false alarms among warning and advisory forecasts, but indicated they would take precautionary action in proportion to the size of their boat. Uncertainty forecasts would be useful to these experienced forecast consumers allowing them to adapt the forecast to their specific boating situation.[71]

A nationwide survey on uncertainty in everyday weather forecasts found the majority of respondents were aware that there is uncertainty in forecasts and they prefer forecasts that express it. They expected the actual temperature to fall within two degrees either side of the forecast value when a single value was given. There was higher confidence in temperature than precipitation forecasts. Many did not understand the meteorological definition of probability of precipitation (PoP). Researchers suggest this understanding is less important than being able to infer enough information to make decisions. For precipitation, recent communications were preferred rather than relative frequencies and odds formats.[72] A similar survey (to the Morss work[73]) in the UK focusing on temperature and precipitation probabilities found that most respondents would prefer or were willing to receive uncertainty information, however, most did not understand the correct interpretation of probability of precipitation.[74]

Two articles used uncertainty information in experiments to evaluate use in the forecast process and in decision making for road treatment. A combination of an uncertainty chart with a box plot display was found to be optimal in conveying uncertainty information to the forecaster.[75] Superior decision-making was found when uncertainty information was tailored to the critical threshold for the road treatment decision.[76] Uncertainty information can be used advantageously and can be communicated to non-experts resulting in improved decision-making.[77] Only a portion of uncertainty information in online Norwegian weather reports was found to be used and participants typically interpreted the degree of certainty differently than was intended.[78] Local experiences affected the interpretations and these local experiences prevailed in the event of a conflict with forecast information.[79]

Understanding Weather Information

Much of the research on the understanding of weather-related information focused on undergraduate students and their ability to make forecast decisions given a variety of weather information. Findings from the body of work were diverse and sometimes conflicting. There was no significant difference in

[71] S. Savelli, and S. Joslyn. Boater Safety: Communicating Weather Forecast Information to High-Stakes End Users. Weather, Climate, and Society (4.1, 7-19, 2012).
[72] Morss et al. (2008).
[73] Morss et al. (2008); Morss et al. (2010).
[74] J.A. Peachey, D.M. Schultz, R. Morss, P.J. Roebber, and R. Wood. How Forecasts Expressing Uncertainty are Perceived by UK Students. Weather (68.7, 176-81, 2013).
[75] L. Nadav-Greenberg, S.L. Johnson, and M.U. Taing. The Effect of Uncertainty Visualizations on Decision Making in Weather Forecasts. Journal of Cognitive Engineering and Decision Making (2.1,24-47,2008).
[76] Nadav et al. (2009).
[77] Nadav et al. (2009).
[78] A.D. Sivle, S.D. Kolsto, P.J. Kirkeby Hansen, J. Kristiansen. How do Laypeople Evaluate the Degree of Uncertainty in a Weather Report? A Case Study of the Use of the Web Service yr.no. Weather, Climate, and Society (6.3,399-412,2014).
[79] Sivle, et al. (2014).

understanding warning information between graphic vs. non-graphic options for warning messages on a cell phone. Severe thunderstorm warning and flood watch information on NWS websites was more effectively conveyed with added graphics and additional text over the standard depiction.[80] Probability of precipitation is confusing. People have a tendency to construe it as a deterministic forecast that indicates proportion of time or area. However, the phrase describing the chance of rain is helpful additional information.[81] Having an 80 percent predictive interval and verification graphics significantly improved understanding of future weather.[82] Forecasts in a probability format were better understood than a frequency format (nine times out of 10 or 90 out of 100 percent).[83]

Future Research Needs

Communicating forecast uncertainty: As with other hazard-specific contexts noted earlier in this section, research on general weather forecasts demonstrates a need for more research on communicating weather forecast uncertainty. This includes exploring how to present expected ranges of uncertainty. There also needs thought about differentiating the ways uncertainty is communicated for particular circumstances (e.g., high impact weather) or audiences (e.g., vulnerable populations, decision makers, or other stakeholders). With respect to precipitation, other ways of reporting uncertainty besides probabilities should be considered. Generally, alternative expressions and visualizations of uncertainty to identify misinterpretations and ways to clarify uncertainty information are needed. One way to do this would be through use of interactive displays that combine advantages of visualization and consider user and task demands.

Use of and response to weather information: A better understanding of the following topics related to use of and response to weather information is needed: The complex relationships between perceptions and interpretations and use of forecast information.

- The satisfaction and confidence in weather information, how they are perceived and how they relate to attitudes and behaviors.
- Systematic comparisons of models [Protective Action Decision Model (PADM), (Protection Motivation Theory (PMT)].
- Other dimensions of forecast use, such as regular activities and surveillance.
- Specific actions that comprise household preparedness and competing variables.

Understanding of weather information: Knowledge is needed of people's' understanding of location, spatial extent, magnitude, etc. for online depictions of the watch-warning-advisory system, including when multiple hazards occur at once.

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[80] J.L. Demuth, R.E. Morss, J.K. Lazo, and D.C. Hilderbrand. Improving Effectiveness of Weather Risk Communication on the NWS Point-and-Click Web Page. Weather and Forecasting (28.3, 711-26, 2013).

[81] L. Nadav-Greenberg, and S.L. Johnson. Uncertainty Forecasts Improve Decision Making Among Nonexperts. Journal of Cognitive Engineering and Decision Making (3.3, 209-27, 2009).

[82] S. Joslyn, L. Nemec, and S. Savelli. The Benefits and Challenges of Predictive Interval Forecasts and Verification Graphics for End Users. Weather, Climate, and Society (5.2,133-47,2013).

[83] S. Joslyn, L. Nadav-Greenberg, and R.M. Nichols. Probability of Precipitation: Assessment and Enhancement of End-User Understanding. Bulletin of the American Meteorological Society (90.2, 185-93, 2009).

Other: The benefit-cost of providing information to the public about preparedness actions; explore the milling construct – i.e., the social process to affirm decisions to take action – in light of social media. Test the idea of consistent messaging; and better understand the attitudes, behaviors, and perceptions of meteorologists and forecasters.

VI. Contemporary Research in Other Environmental Hazards

NOAA's reach extends to other episodic environmental hazards including tsunamis, wildfires, volcanic eruptions, and fisheries-related hazards. The authors reviewed papers relevant to each of these hazards. A summary of findings from those papers is below.

A. Tsunami

Introduction

An assessment of 15 articles focused on tsunamis revealed common research agendas with regard to awareness, perception, preparedness and response. The articles employed both qualitative and quantitative methodologies, and with the exception of one, all were conducted outside of the US.

Research Highlights

Sources: For many coastal communities outside of the U.S., residents reported relying on social/community networks for initial sources of information and sources of confirmation before taking action.

Preparedness: While tsunami hazard awareness programs have increased general awareness about tsunamis (particularly since the 2004 Indian Ocean Tsunami), individual preparedness remains low. Furthermore, having survival items is not a good indicator of preparedness. Participants reported being in possession of certain items – tents, torches, food – and also confirmed they had experience taking care of themselves during power outages or floods. However, while reporting that they could take care of themselves in their homes, none reported having a plan for quick evacuation. [84]

Evacuation: Transient populations (including tourists and workers) evacuate faster than permanent residents. People who had children and those who had more family members were slower to evacuate.[85] Having disaster knowledge was positively correlated with prompt evacuation. Yet, students in Phuket and Phan-nga, Thailand are not taught disaster education in schools, thus people lacked the expertise to implement disaster reduction strategies.[86]

In particular, a 'people-centered' approach should replace more linear warning systems that focus on experts communicating through a series of sequential steps in a process.

People-centered warning systems: There is a need for better early warning systems in tsunami-prone/affected areas. Sirens were shown to be ineffective as a mechanism for early warnings. In particular, a 'people-centered' approach should replace more linear warning systems that focus on experts communicating through a series of sequential steps in a process. A people-centered approach considers the needs of the public by identifying target populations, especially vulnerable ones, and interacting with them to determine needs and capacities. It focuses on highly local, integrated risk monitoring and communication. These activities must be a result of the coordinated participation of many types of organizations all committed to a people-centered approach.

[84] M. Couling. Tsunami Risk Perception and Preparedness on the East Coast of New Zealand during the 2009 Samoan Tsunami Warning. Natural Hazards (71.1, 973-86,2014).

[85] T. Charnkol, and Y. Tanaboriboon (2006). Tsunami Evacuation Behavior Analysis- One Step of Transportation Disaster Response. IATTS Research (30.2, 83-86).

[86] T. Kurita, A. Nakamura, M. Kodama, and R.N. Colombage Sisira. Tsunami Public Awareness and the Disaster Management System of Sri Lanka. Disaster Prevention and Management (15.1, 92-110, 2006).

Best Practices for Communicating Tsunami Risk

1) **Use social media for public education:** Social media is a platform for people to share common discourses that will have an impact on building resilient communities. Social media has been used before, during, and after disasters and can also be used as a means of public education. Though it is known social media is a powerful tool, it would be useful to explore how to most effectively utilize social media as an instrument in educating people to recognize early warning signs.

2) **Conduct an audit of education and outreach programs:** The reviewed research consistently suggested the need for outreach and education programs. Many of these programs exist, but it is unclear how effective they are in increasing preparedness. For example, as mentioned above, even those who possess the adequate supplies are often not prepared. Thus, an assessment should be done of existing education and outreach programs to evaluate their effectiveness. As an extension to this, practitioners have seen people think of tsunamis and storm surge as the same type of phenomenon. They don't understand that the causes are different (seismic vs. storm), and that the time scales, speed, and cyclical nature of inundation can be different for each phenomenon.

3) **Integrate transportation disaster response into the transportation engineering components in evacuation planning.** This includes travel/behavior analysis and forecasting, evacuation traffic control and enforcement, and the use of mass transit and other means for the movement of low-mobility individuals.

4) **Apply economic analysis strategies to local options for risk reduction.** This would educate stakeholders on the relative costs and benefits of various options.

Future Research Needs

Evacuation models: Additional research on models that are capable of predicting tsunami evacuation more accurately (examine affected and unaffected communities).

Natural warning signs: Future research should consider what natural warning signs are, which ones people notice, and how they respond.

Models of coastal community vulnerability: Better modeling of future vulnerability of coastal communities is needed.

B. Wildfire

Introduction

Photo Credit: calfire.blogspot.com

A limited sample of wildfire articles, including one meta-analysis was reviewed. One article was a review of non-economic fire social science literature and identification of future research needs.[87] Another article examined how the threat of fire and smoke from wildland fires was communicated within agencies and to the public.[88] The final article examined the role of climate-based forecasts in forecasting fire seasons and how information is disseminated within a regional network of fire management professionals.[89] Collectively, the articles interviewed fire managers and others from the Northwest, Southwest, and Southeast to address experiences and challenges in communicating information.

Research Highlights

- Exchanges of information between fire managers and agencies are important.[90]
- Various communication strategies, such as recognizing existing social communication networks, can provide efficient means of expanding the reach of agency messages and institutionalizing the importance of communication through agency training sessions.[91]
- There is a need to communicate the health effects of smoke.[92]
- One study found that climate information is more useful during the preseason as fire managers begin planning for the upcoming season.[93]

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[87] S. McCaffrey, E. Toman, M. Stidham, and B. Shindler. Social Science Research Related to Wildfire Management: An Overview of Recent Findings and Future Research Needs. International Journal of Wildland Fire (22.1,15-24,2013).
[88] C.S. Olsen, D.K. Mazzotta, E. Toman, and A.P. Fisher. Communicating About Smoke from Wildland Fire: Challenges and Opportunities for Managers. Environmental Management (54.3, 571-82,2014).
[89] Olsen et al. (2014). G.J. Owen, D. McLeod, C.A. Kolden, D.B. Ferguson, and T.J. Brown. Wildfire Management and Forecasting Fire Potential: The Roles of Climate Information and Social Networks in the Southwest United States.
[90] McCaffrey et al.(2013); Owen et al.(2012).
[91] Owen et al. (2012).
[92] Olsen et al.(2014).
[93] Owen et al.(2012).

Future Research Needs

Future research is encouraged to address varying geographic, demographic, and land ownership contexts; to explore the entirety of the fire management cycle; and to look at the effectiveness of partnerships and organizations.

C. Volcanoes

Introduction

Four articles focused on volcanoes. Specifically they discussed the perception of risk, information dissemination, and impacts. The methodologies used were quantitative surveys or qualitative questionnaire and/or interviews.

Photo Credit: Cyrus Read, USGS

Research Highlights

- There is no difference in risk perception between residents who had just experienced a volcanic eruption and residents who had not.[94]
- One study found that residents learned about the volcanic eruption from social networks (family/friends) and television and radio warnings. After the initial warning, they received information from the official meteorological website. They trusted information given by scientists the most, followed by friends/family, and then the media.[95]
- In one study, subjects showed a skew in perceived likelihood of an eruption toward the end of the time window stated in a warning message. This study also showed that non-scientists may interpret language in a risk warning differently than scientists.[96]
- There is evidence that a contour map that clearly details hazard and risk features is the preferred type of map on which to display volcano threat information. However, an aerial photo may be better for conveying information to the public.[97]
- Residents wanted to receive more information about eruption impacts. [98]

[94] C.E. Gregg, B.F. Houghton, D.M. Johnston, D. Paton, and D.A. Swanson. The Perception of Volcanic Risk in Kona Communities from Mauna Loa and Hualalai Volcanoes, Hawaii. Journal of Volcanology and Geothermal Research (130.3-4,179-96,2004).
[95] D.K. Bird, and G. Gisladottir. Residents Attitudes and Behaviour Before and After the 2010 Eyjafjallajokull Eruptions- A Case Study from Southern Iceland. Bulletin of Volcanology (74.6,1263-79, 2012).
[96] E.E.H. Doyle, J. McClure, D.M. Johnston, and D. Paton. Communicating Likelihoods and Probabilities in Forecasts of Volcanic Eruptions. Journal of Volcanology and Geothermal Research (272,1-15,2014).
[97] R.Nave, R. Isaia, G. Vilardo, and J. Barclay. Re-assessing Volcanic Hazard Maps for Improving Volcanic Risk Communication: Application to Stromboli Island, Italy. Environmental Management (54.3,574-82,2014).
[98] Bird & Gisladottir (2012).

Recommendations

1) Implement education initiatives to promote general hazard awareness. Such initiatives should include focus on the situation and needs at local levels; evaluate the changes in threat knowledge, risk perception, and preparedness as a result of exposure to the educational materials; and, persuade society to make the adaptations needed for both long- and short-duration eruptions.
2) Optimize volcanic hazards information through graphical communication.

Implement education initiatives to promote general hazard awareness.

Future Research Needs

A few common themes and implications from these articles needed further research. It would be useful to collect longitudinal social data before and after natural hazard events. Future volcano risk messaging research should be performed to examine why people are more likely to believe that the volcano eruption will occur near the end of the warning window than any other time.

VII. Summary and Implementation Recommendations

This report was designed for NOAA practitioners, key partners, and NOAA leadership to quickly become familiar with best practices for risk communication, common risk-related theories and principles, and recent risk communication and behavior research results specific to NOAA's mission. This report also provides centralized access to a large body of work that can be used as a launching point for additional discussion with the broader research and practitioner communities. This report represents a substantial step toward applying social and behavioral science knowledge to application in NOAA, and the vision it lays out can help NOAA and external communities of research come together to build on this effort in the years to come.

NOAA will consider the following next steps to build on this effort:

Internal NOAA

- ➢ Continue to build an understanding of NOAA's needs for communicating risk effectively.
- ➢ Expand and improve dissemination of research findings and promotion of best practices.

- Identify where NOAA offices or entities have a robust risk communication program, including successful testbed efforts, and use them as teaching opportunities for other regions or entities.

- Increase the agency's role in helping individuals and communities to better understand their risk and be proactive in their planning to be more resilient to hazards.

- Improve data collection to document the ways information is disseminated, accessed, understood, and acted upon by various populations across the country. Currently, this data is only collected after rare extreme events at specific locations, which makes it difficult to understand the generalizability of findings or to track changes over time.

Engagement with the Broader Social Science Community

- Harness the power of the broader research community to expand the database of articles beyond those included in this report.

- Partner with external organizations to address research gaps.

- Improve coordination across the Federal landscape with other agencies that have authorities and missions in disaster risk communication and response (e.g., FEMA, NIST, CDC).

Additionally, reviewers provided feedback on other risk communication-related issues that they would like more guidance to address. As noted previously, feedback is welcomed from the NOAA community about information the team could provide to better meet needs. Areas that NOAA practitioners have requested more information about, and which may be addressed in future efforts, include:

- Recommendations for working with specific core partners, such as emergency managers

- Tips for working with the media and improving science communication

- Ways to better leverage social media

- For the online version of the document, adding links to electronic versions of references

Please contact PRSS.socsci@noaa.gov with any additional comments.

VII. Appendices

A. Appendix 1 - Theories and Models

The understanding of human comprehension is rooted in basic psychology. Various sub-fields within psychology as well as other disciplines have built upon this knowledge to develop theories and models to explain how people process risk information. While there are countless risk-related theories, frameworks, and models across and within the social science disciplines, the following table provides a brief overview.

Theories

Name	Overview	Prominent Scientists/Disciplines
Psychometric Paradigm	Perception of hazards taking into account qualitative information (i.e. dread) rather than just statistical probability of being affected by a hazard	Slovic, Finucane, Fischoff- Psychology
Cultural Theory of Risk	There are social and cultural influences on risk perception	Douglas, Wildavsky - Anthropology Kraik - Psychology
Mental Models Approach	Individuals have a 'mental model' (model of reality influenced by social interactions and experiences) that they use as a lens to view risky situations	Risk application: Fischhoff, Morgan - Psychology
Rational Choice Theory	People make consistent and rational choices based on simple costs and benefits	Homas - Sociology
Expected Utility Theory	People rationally weigh their options when faced with uncertain consequences	Bernoulli, Von Neumann, Morgenstern - Mathematics and Economics
Heuristics and Biases	People develop mental 'short-cuts' and use these shortcuts to help them make decisions.	Tversky, Kahneman - Psychology
Protection Motivation Theory	People protect themselves based on their perception of severity, probability, effectiveness of protective action, and self-efficacy	Rogers - Sociologist
Social Amplification of Risk Framework	Examines processes by which risks are amplified or attenuated due to individual, social, and cultural factors	Kasperson - Geography

Actionable Risk Communication	Encourages action by the general public to limit the risks they face from potential threats, and can inform education campaigns to encourage desired preparedness	Wood et al.- Health Science
Theory of Reasoned Action	A model for the prediction of behavioral intention, spanning predictions of attitudes and predictions of behavior	Ajzen, Fishbein-Psychology
Theory of Planned Behavior	Attitude toward behavior, subjective norms, and perceived behavioral control, together shape an individual's behavior intentions and behavior	Ajzen-Psychology
Image Restoration Theory	Outlines strategies that can be employed to mitigate damage to image in an event where reputation has been damaged	Benoit- Political Communication
Situational Crisis Communication Theory	Identifies how key facets of the crisis situation influence attributions about the crisis and the reputations held by stakeholders	Coombs, Crisis Communication
Habituated Action Theory	Argues that engaging in high-risk behavior many times without a negative outcome often decreases the perceived risk associated with this behavior	Kaperson et al.- Risk Analysis
Social Action Theory	People take risks because of peer pressure or a general community perception that an activity is low risk	Weber-Sociology
Social Control Theory	Connectedness to organizations promotes behavior conformity, which can reduce the probability of high-risk behavior	Hirschi- Sociology
Situational Theory of Publics	Publics can be identified and classified in the context to which they are aware of the problem and the extent to which they do something about the problem	Grunig- Public Relations
Situated Rationality Theory	Makes the argument that it is erroneous to presume that safe behaviors are inherently rational and high-risk behaviors are inherently rational	Wolterstorff- Psychology

Risk Compensation Theory	Suggests that people typically adjust their behavior in response to the perceived level of risk, becoming more careful where they sense greater risk and less careful if they feel more protected	Vrolix-Risk Analysis

Models

Name	Overview	Prominent Scientists/Disciplines
Protective Action Decision Model	Three core perceptions (threat, protective action, and stakeholder) form basis for decisions. These perceptions, along with information processing and situational factors produce a behavioral response	Lindell, Perry - Social Psychology Emergency Management/Disaster Research
Crisis and Emergency Risk Communication Model	A five-stage (pre-crisis, initial event, maintenance, resolution, evaluation) model that details best practices during various stages of a crisis event	Reynolds, Seeger - Communication
Risk Information Seeking & Processing Model	Understand how people seek and respond to processing messages about the risks associated with natural hazards. Examines how and why individuals seek and interpret information about the risks in the lives	Griffin, Dunwoody & Neuwirth- Risk Communication
Extended Parallel Process Model	Framework which attempts to predict how individuals will react when faced with fear inducing stimuli	Witte-Communication
Precaution Adoption Process Model	Attempts to explain how a person comes to decision to take action, and how he or she translates that decision into action	Weinstein, Sandman & Blalock-Environmental Studies
Systems Dynamic Model	Involves the development of computer simulation models that portray processes of accumulation and feedback that may be tested systematically to find effective policies for overcoming policy resistance	Homer & Hirsch- Public Health

CAUSE MODEL	Refers to the goals of establishing confidence, awareness, understanding, satisfaction (with proposed solutions) and enactment (or moving from agreement to action). Used as a tool for identifying a predictable set of five communication challenges present in times of disaster	Rowan et al.- Risk Communication
Heuristic Systematic Model	Delineating how people absorb and manage the information they come across in their daily lives	Eagly & Chaiken-Psychology

B. Appendix 2 - Warning Behavior

The following table lists significant predictors of warning response. It is derived from an annotated bibliography, "Public Risk Communication on Warnings for Public Protective Actions Response and Public Education" completed by Mileti et al. in 2006. Several more recent studies (Mileti et al. 2006, Mileti and Sorensen 2015, and Lindell and Perry 2012) also contributed to this compilation.

Variable	**More Likely to Respond to Warning/Alert if...**
Socio-demographic	
Gender	Female
Race	White
Education	More education
Children	Children present
Personal	
Experience	More experience
Knowledge	More Knowledge of hazards/protective actions
Self-efficacy	High perceived self-efficacy
Emotion	Fear of mandatory evacuation
Risk/Vulnerability Perception	Higher risk/vulnerability perception
Resources	More resources available
Social network	Larger/Stronger social network

Source/Channel	
Cues	Environmental and/or social cues present
Authoritativeness	Through official source
Delivery Method	In person
Familiarity	Familiar with source
Number	Multiple sources/channels
Information	
Specificity	More specific
Accuracy	More credible
Uncertainty	More certain
Frequency	Relayed more often
Consistency	More consistent
Guidance	Provides more guidance on actions
Source	Say who the message is from
Threat	Describe the flooding event and its impacts
Location	Impact areas are described
Expiration Time	Note when the alert expires/updates
Message Length	Short, between 90-140 characters
Threat	
Time	Less lead time available
Severity	Greater severity/More severity information
Proximity	Threat closer
Certainty	Threat has been confirmed

C. Appendix 3 - Review Papers and Practitioner Guides

The following papers are comprehensive or systematic reviews on risk communication and behavior topics. These papers would help establish an academic grounding in this subject.

Comprehensive or Systematic Review	Overview
Risk Behavior and Risk Communication: Synthesis and Expert Interviews (Morrow 2009)	Report created for NOAA Coastal Services Center - Synthesis of risk communication and behavior research applied to coastal risk and resilience
Communication of Emergency Public Warnings (Mileti and Sorenson 1990)	Prepared for FEMA - Overview, structure, and components of warning systems, organizational and public response aspects of a warning system, hazard characteristics, and recommendations for improvements. This report was based on a synthesis of empirical research findings in print at the time it was prepared
Annotated Bibliography for Public Risk Communication on Warnings for Public Protective Actions Response and Public Education (Mileti et al. 2006)	Compiled list with detailed annotations of over 300 studies pertaining to the communication of and response to man-made and natural hazards
Risk Perception and Communication Unplugged (Fischoff 1995)	History of risk perception and communication as an area of study broken down by developmental stages
On the State of the Art: Risk Communication to the Public (Bier 2001)	Review of empirical findings on risk communication; specifically regarding format of messages, audience nuances, mental models, credibility and trust, and stakeholder participation
Social Science Research Needs: Focus on Vulnerable Populations, Forecasting, and Warnings (Phillips and Morrow 2007)	Review of research on vulnerable populations in the context of weather forecast and warning understanding
Defining Moments in Risk Communication Research: 1996 - 2005 (McComas 2006)	Reviews risk communication research and theories over a 10 year period

Seven Cardinal Rules of Risk Communication (Covello 1988)	Seminal book listing key best practices when communicating risk information
Poverty and Disasters in the United States: A Review of Recent Sociological Findings (Fothergill and Peek 2004)	Review of literature on the impact of poverty in disasters; specifically in the context of perception, preparedness, communication, physical and psychological impacts, and emergency management
Public Hazards Communication and Education: The State of the Art (Mileti et al. 2004)	Seminal book detailing best practices for specific types of risk communication including public awareness campaigns and short fuse warnings
Hazard Warning Systems: Review of 20 Years of Progress (Sorensen 2000)	Summarizes advances in warning related predictions, forecasts, dissemination, and responses over the past 20 years
Practitioner Guide	**Overview**
University of Maryland: Understanding Risk Communication Theory: A Guide for Emergency Managers and Communicators	Overview of various risk communication models and communication theories for each disaster phase.
University of Maryland: Understanding Risk Communication Best Practices: A Guide for Emergency Managers and Communicators	Overview of factors that can influence risk perception and best practices for risk communication in each disaster phase.
Campbell Institute: Risk Perception: Theories, Strategies, And Next Steps	Overview of factors that can influence risk perception and review of important theories.
FEMA: Risk and Crisis Communication Course	A higher education course on risk communication, appropriate methods, and stakeholder interactions.
CDC: Crisis and Emergency Risk Communication	A program focused on risk/crisis communication training, resources, and examples.

IX. Glossary

Crisis: A turning point that will decisively determine an outcome, for example, the rupture of a leaking underground storage tank.
Crisis Communication: Communicating risks in the face of a crisis, such as an earthquake or a fire at a chemical plant.
Flood: An overflow of water onto normally dry land. The inundation of a normally dry area caused by rising water in an existing waterway, such as a river, stream, or drainage ditch. Ponding of water at or near the point where the rain fell. Flooding is a longer term event than flash flooding: it may last days or weeks.
Flood proofing: Any combination of structural and non-structural additions, changes, or adjustments to structures which reduce or eliminate flood damage to real estate or improved property, water and sanitary facilities, structures and their contents.
Hazard: Danger; peril; exposure to a situation that could cause loss or injury.
Inundation: Inundation is the total water level that occurs on normally dry ground as a result of the storm tide, and is expressed in terms of height of water, in feet, above ground level. Inundation provides the most clearly and commonly understood method for communicating storm surge driven coastal flooding.
Mitigation: The action of reducing the severity, seriousness, or painfulness of something.
Protective Action Decision Model (PADM): The Protective Action Decision Model (PADM) is a multistage model that is based on findings from research on people's responses to environmental hazards and disasters. The PADM integrates the processing of information derived from social and environmental cues with messages that social sources transmit through communication channels to those at risk. The PADM identifies three critical pre-decision processes (reception, attention, and comprehension of warnings or exposure, attention, and interpretation of environmental/social cues)—that precede all further processing. The revised model identifies three core perceptions—threat perceptions, protective action perceptions, and stakeholder perceptions—that form the basis for decisions about how to respond to an imminent or long-term threat. The outcome of the protective action decision-making process, together with situational facilitators and impediments, produces a behavioral response.
Protective Motivation Theory (PMT): Proposes that we protect ourselves based on four factors: the perceived severity of a threatening event, the perceived probability of the occurrence, or vulnerability, the efficacy of the recommended preventive behavior, and the perceived self-efficacy.
Public: People who may or may not be interested in the risk but who are not charged with communicating, assessing, or managing the risk.
Public Information: Information to communicate with the public as opposed to scientists or managers. Because the topic may not be risk, public information and risk communication materials are not necessarily synonymous. However, most risk communication materials will be sent to the public.

Residual Risk: The risk or danger of an action or an even, a method or a (technical) process that, although being abreast with since, still conceives the dangers, even if all theoretically possible safety measures would be applied (scientifically conceivable measures).
Response Efficacy: Refers to a person's beliefs as to whether the recommended action step will actually avoid the threat.
Risk: Probability of adverse outcome. Risk is inherent in any action, even inaction.
Risk Assessment: Determining the risks posed by a certain hazard, usually to human health or the environment; can also include legal and financial risk.
Risk Communication: The interactive process of exchange of information and opinions among individuals, groups, and institutions concerning a risk or potential risk to human health of the environment. Any risk communication effort must have an interactive component, if only in soliciting information about the audience in the beginning or evaluating success in the end.
Risk Message: Message that communicates information about the hazard, its probability, the potential outcomes, and actions that can be taken to manage the risk.
Risk Perception: Risk perception is the subjective judgment that people make about the characteristics and severity of a risk. Risk perception refers to people's judgments and evaluations of hazards they (or their environments) are or might be exposed to. Such perceptions steer decisions and after a disaster. In this process, people's risk appraisals are a complex result of hazard features and personal philosophies.
Risk Perceptions: The set of beliefs that a person holds regarding a risk, including beliefs about the definition, probability, and outcome of the risk.
Self-Efficacy: Refers to an individual's belief in his or her capacity to execute behaviors necessary to produce specific performance attainments. Reflects confidence in the ability to exert control over one's own motivation, behavior, and social environment.
Social Media: A group of interactive, online methods that integrate technology, words, pictures, videos, and audio with the concept of shared content, generated largely by users with easy-to-publish tools.
Stakeholder: A person who holds a "stake", an interest in how a risk is assessed or managed.
Structural Mitigation: Attempts to counteract natural hazards through projects such as reservoirs, levees, diversions, channel modifications, and storm sewers or basins.
Vulnerability: The characteristics of a person or group and their situation that influences their capacity to anticipate, cope with, resist, and recover from the impact of a natural disaster.

X. Acronym Guide

CDC: Center for Disease Control and Prevention
FEMA: Federal Emergency Management Agency
MCS: Mesoscale Convective Systems
NCAR: National Center for Atmospheric Research
NCEI: NOAA's National Centers for Environmental Information
NFIP: National Flood Insurance Program's Community Rating System
NIST: National Institute of Standards and Technology
NWS: National Weather Service
OAR: The Office of Oceanic and Atmospheric Research
OCM: Office for Coastal Management
SIP: Societal Impacts Program
SPC: Publications archive, NCAR SIP
USACE: United States Army Corps of Engineers
WFO: Weather Forecast Office

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