Social Science Research Needs for the Hurricane Forecast and Warning System

Hugh Gladwin
Florida International University

Jeffrey K. Lazo
National Center for Atmospheric Research

Betty Hearn Morrow
Consulting Sociologist

Walter Gillis Peacock
Texas A&M University

Hugh E. Willoughby
Florida International University

December 5, 2005

CORRESPONDING AUTHOR: Jeffrey K. Lazo, National Center for Atmospheric Research, P.O. Box 3000-RAL, Boulder, CO, 80307 E-mail: lazo@ucar.edu

Abstract

This paper offers an initial attempt to identify high-priority social science research issues focused on the hurricane forecast and warning system. The research agenda was distilled as faithfully as possible from the efforts of a host of scientists. These included a series of white papers; a workshop in Pomona, California, in February 2005; several sessions at the 2004 and 2005 Natural Hazards workshops held in Boulder, Colorado; and additional input from the broader social science research community unable to attend these events. Expected results from this effort are (1) a focused applied research agenda designed to generate short-term immediate benefits; (2) a broader, more basic research agenda addressing fundamental theoretical and exploratory research designed to generate long-term improvements; (3) methods to enable the social science research community to gather and further develop research priorities and future agendas; and (4) a concept for a long-term, multidisciplinary, institutional approach to undertaking identified research priorities. We present this paper as a call to action for the appropriate agencies and organizations to support social science research on the hurricane forecast and warning system to meet societal goals of protecting lives and property in the face of the ever-present threat of hurricanes.

Capsule

We identify high-priority social science research issues for the hurricane forecast and warning system as a call to action to meet societal goals of protecting lives and property in light of the ever-present hurricane threat.

Introduction[1]

Hurricane Forecasting in Context. Although the forecast and warning system is the first defense against hurricanes, policy measures such as building codes and land-use practices also limit their impacts. Nonetheless, timely evacuations, based on accurate forecasts, remain the dominant factor in reducing hurricane-related deaths by 90% compared with mid-20th century expectations. Increasingly accurate predictions of hurricane motion, combined with worst-case bounds on storm surge, form the meteorological basis for this success. Forecasts of intensity, wind and rainfall distribution, and other local impacts lag about a generation behind those of track and surge.

Hurricane forecasts, which originate from the National Weather Service's (NWS's) Tropical Prediction Center (TPC) in Miami, Florida, are broadcast and disseminated nationally and internationally. Local Weather Forecast Offices (WFOs) tailor national forecasts to conditions in their communities. Other NWS centers forecast river flows and flooding that result from hurricanes moving inland. Until Hurricane Katrina in 2005, the system was so successful at preventing deaths in the surge zone that drowning in freshwater flooding was the leading cause of hurricane-related deaths.

Because hurricanes are relatively compact and require times on the order of 1 day to evolve significantly, they are ideal subjects for research on disaster warnings in general. From 1970 through 2004, a typical hurricane season destroyed $5 billion in property and killed 21 people in the United States. During the 20th century, the risk of dying in a hurricane in the United States decayed exponentially with a halving time of 13.6 years. At the same time, the unadjusted property loss increased exponentially with a doubling time of 9.3 years. Damage numbers corrected for inflation, population growth, and greater personal wealth have, however, been essentially constant. The spectacular increase in damage is driven by the increase in property at risk. Hurricane Katrina dramatized the risk of large loss of life when a category 4 or 5 hurricane strikes a vulnerable coastal population.

The historical model of the warning system was linear. Meteorological information flowed into TPC (popularly known as the National Hurricane Center [NHC]), where forecasters posted watches and warnings for coastal segments predicted to be in harm's way. Emergency managers heeded warnings and ordered evacuations, and citizens dutifully evacuated. The TPC vision is "To be America's calm, clear and trusted voice in the eye of the storm…" (http://www.nhc.noaa.gov/mission.shtml), and to a great extent the center attains this vision.

The linear paradigm evolved into a nonlinear system as citizens, enterprises, and local governments came to rely increasingly on sources outside institutional channels, especially broadcast media, the Internet, and peer-to-peer communications. To a great extent, TPC adapted to the new model as it emerged. Starting in the 1970s the NHC (as it was then called officially) cultivated relations with broadcasters and emergency managers. Both TPC and the WFOs maintain well-designed and informative Web sites (e.g., http://www.srh.weather.gov/mia/,

[1] There is a considerable body of literature related to the hurricane forecast and warning system and social science research on warning systems. Rather than making specific citations to this literature in this paper, we refer the interested reader to the white papers referenced at the end of this paper.

http://www.erh.noaa.gov/er/lwx/). The title of the NWS strategic plan, "Working Together to Save Lives," reflects this cooperative approach. Nonetheless, information now flows to households and organizations in rapidly evolving, increasingly nonlinear, and sometimes chaotic ways that present both difficulties and opportunities for the "…calm, clear and trusted voice."

The Importance of Social Science Research. At the National Oceanic & Atmospheric Administration (NOAA) and other agencies, a cultural shift is occurring as agency representatives have come to recognize the importance of social science research and incorporate an understanding of these fields to meet their mission requirements. A spectrum ranging from basic to applied relevant research will lead to innovative tools and methods and new paradigms. Results of the investigations outlined here will also find application to threats such as tornadoes, floods, wildfires, and even human-caused hazards. Issues indicating the necessity for significant social science research on the hurricane forecast and warning system include

- Changes and improvements in forecast products (such as probabilistic forecasts)
- Increasing population and assets in harm's way
- A more diverse population in harm's way
- Changes in ways to create, manipulate, and disseminate information to individuals and organizations
- Availability of new tools, methods, and paradigms for social science research
- Increased recognition of hurricanes and their impacts as social phenomena
- Specific needs of mission agencies such as NOAA to evaluate and justify programs and to develop guidance for future practices.

Hurricane landfalls, like other disasters, are social misfortunes produced by the intersection of atmospheric forcing with humans, the built environment, and institutions. Future successes of the forecast enterprise will certainly stem in part from steadily increasing meteorological accuracy, but compelling opportunities exist by using still-imperfect forecasts in ways that meet human needs more appropriately. Reasonably, taxpayers require that success be measured in terms of outcomes—lives saved, damage prevented, or plans not disrupted—in relation to costs.

Process. In late 2003, the need for answers to pressing societal impacts questions led NOAA and the National Center for Atmospheric Research (NCAR) Societal Impacts Program to form an ad hoc working group called the Hurricane Forecast Social and Economic Working Group (HFSEWG). The group's goal is to identify social science research capabilities, needs, and priorities for the hurricane forecast and warning system. The ultimate objective is to recommend research initiatives and projects that can be supported through interagency cooperation, funding for public- and private-sector academic and commercial research enterprises, and partnerships with private-sector information consumers.

Soon after HFSEWG was formed, it began planning activities to stimulate discussions among NOAA researchers, policy makers, and the larger social science research community. The first meeting was held during the 2004 Natural Hazards Workshop in Boulder, Colorado. Shortly thereafter, 13 coauthors, guided by Walter Gillis Peacock of Texas A&M University, drafted five white papers to address the current understanding of the hurricane forecast and warning system

and its social science research needs. These white papers are cited at the end of this paper. With the white papers as background, the working group convened a workshop in Pomona, California, in February 2005. Hurricane forecasters, meteorologists, policy makers, and social scientists attended (see the end of this paper for a list of the participants and their primary affiliations) with an agenda: "To identify social science resources and efforts needed to better understand how hurricane meteorological observations, forecasts, and information products can be effectively translated into level-appropriate governmental and private sector planning, mitigation, and response decisions."

After the workshop, research topics were compiled into a draft report (available at www.sip.ucar.edu) that began to summarize them into areas of research focus. In July 2005 two sessions were held during the annual Natural Hazards Workshop in Boulder to further discuss and review research priorities. John Sorenson of Oak Ridge National Laboratory provided a perspective on the effort and suggestions for developing the research agenda. In fall 2005 a draft of this paper was developed, circulated for review and input, and finalized for circulation.

Science Issues

The following sections outline research issues identified by a majority of workshop participants as important for hurricane forecasting and warning. For purposes of this discussion, we have adopted the taxonomy of (1) Warning Process, (2) Decision Making, (3) Behavioral Response, and (4) Social Impacts and Valuation. This taxonomy is provisional because the organization of the forecast and warning system itself is a significant issue for social science research.

Certain issues cut across all these topics and received repeated emphasis before, during, and after the Pomona session. As a result, we judged that special attention should be given to the following three issues:

- Vulnerable populations: Throughout all aspects of warnings and societal responses, some segments of the population lack economic and/or human resources to respond appropriately (never more apparent than in the case of Hurricane Katrina). Circumstances and response options of vulnerable populations must be recognized and understood.
- Nonlinear warning system: Participants largely agreed that the notion of a linear warning system is outdated and must be revisited with a significant research effort.
- Interdisciplinary research: Research may pay the largest dividends at junctures between traditional disciplinary boundaries. For this reason, wherever possible, interdisciplinary teams and approaches should be formed.

Warning Process

Accurate forecasts are effective if they result in appropriate public action, a fact that is particularly obvious with hurricane warnings. Transforming hurricane forecasts into suitable advisories for public communication to guide decisions and actions no longer follows the classical communication model of **source→message→receivers**, but now appears closer to what has been called the "Communication Network Model" described by Lindell and Perry as **message→source→intermediate receivers→receivers.** The communication of hurricane risk today is especially complex, involving multiple messages and sources.

Although the NHC remains the authoritative source, private companies have moved into the forecasting business, often tailoring their messages to specific client needs. In the broadcast media, reporters no longer simply relay forecasts and warnings to their audiences. Media outlets integrate forecasts, models, radar/satellite imagery, and mapping to broadcast comprehensive weather information. Consumers can receive weather information from multiple sources in multiple ways, including the Internet; cell phones; personal data assistants; and network, satellite, and cable television. End users are also becoming more diverse, or at least their diversity is increasingly recognized.

Messages. The content and delivery of public warnings has received considerable research attention, but a number of issues remain unresolved. Warning systems in general need more research, as do the structure, format, and timing of hurricane warnings in particular. In terms of messages, relevant questions include

- Do people respond better to precise forecasts that have lower probabilities of being accurate, or are they better served by foregoing precision for reasonable accuracy?
- How can probabilistic forecasts be structured to promote public understanding?
- To what extent does the public understand terms such as "watch" and "warning"? Should alternative or additional message classes (e.g., "alert" or "emergency") be used when danger is imminent?
- Would a color-coded threat index be useful to communicate threat levels from various hazards such as wind, storm surge, and inland flooding?
- How do different cultural and age groups interpret expert representations such as the "cone of probability"?
- Are current forecast lead times (36 and 24 hours before landfall) the most useful to authorities and the public? Would a multilevel system work better?
- How can written advisories be formatted to be more useful to intermediaries and end users?
- Should surge, rain, and wind probabilities be included as part of forecast and warning products, and how might they effectively be displayed?
- What graphics and visualization techniques promote appropriate reactions?
- Is the Saffir-Simpson Hurricane Scale sufficient to communicate storm threat or would a different or additional scale be more useful?
- What are the best research strategies for testing forecast and warning message reception, interpretation, and use?

Empirical answers to these and other questions can take hurricane forecasting to the next level of protecting the public.

Sources of Messages. Rapid expansion of weather-related information sources is another issue. Private companies now issue their own forecasts and NHC advisories undergo interpretation and distribution through a gamut of public and private modalities. In general, repetition increases belief, but this effect also raises the possibility of conflicting messages. In risk communication,

believability depends on trust and confidence in the source, raising questions about ways in which citizens evaluate information sources.

Because weather is an excellent marketing tool for television stations, a growing number have professional meteorologists on staff, armed with state-of-the-art technologies. In the highly competitive media market, there is motivation to add value to NWS forecasts. Graphics are becoming fancier and messages more sensationalized to capture audience attention. This "repackaging" of NWS forecasts can mislead the public.

Many stations go to 24-hour coverage when hurricanes threaten. Media consolidation results in larger coverage areas even as new technologies increase the ability to localize weather forecasts. A small but growing number of consumers use the Internet and related technologies as their main source of weather information. These developments affect the way NHC and WFO forecasts and warnings reach the public and raise important research questions:

- What is the content and flow of information from forecasters to decision makers?
- How and where do various decision makers get their forecasts and warning information?
- What levels of authority and trust are attributed to different information sources?
- Is the top-down delivery/interpretation of forecasts an outdated model?
- How are conflicting forecasts and warning messages handled?
- Could better use be made of local WFOs when a hurricane threatens? Should their Web sites be standardized?
- What is the role of formal and informal social networks in communicating, translating, and/or legitimizing warning information among various sectors and groups?
- How does the culture of various organizations involved throughout the process encourage or impede change?
- What consequence does media consolidation and newer media sources have for communicating locally relevant forecast and warning messages?

Users. If risk communication is to be effective, the experiences, values, and beliefs of intended audiences must be understood. The U.S. population is becoming increasingly diverse, particularly along the coasts. Acknowledging that each citizen has an equal right to information essential for individual and household survival requires reaching those with special needs and limited economic and human resources. Cultural differences influence access, perception, credibility, and actions. Values and attitudes about life and death, time, circles of influence, and fate, along with comfort with technology, affect warning interpretations. Although new technologies make it possible to communicate forecasts and warning messages in new modalities, it is important to acknowledge the existence of a "digital divide" where less-affluent citizens are likely to have limited access. Information sources can be limited for those with hearing or sight disabilities, and language can pose a problem for foreign-born or less-educated citizens. Finally, children at home alone may be unable to understand a standard message and respond appropriately.

The increased diversity of consumer needs and interests poses new challenges to the NWS. Comparative analysis is needed to define the ways in which different user groups receive, interpret, and respond to warning messages. Relevant questions include

- How do different categories of citizens sift through the maze of information received when a hurricane threatens, inject their life experiences, assess their options, and arrive at informed decisions?
- How can broadcast meteorologists and other private service providers be assisted with presenting forecast and warning messages in ways that reach at-risk populations?
- How can new technologies help the NWS better serve populations with special needs?
- What are effective ways to educate various consumer groups on the meaning of forecast and warning messages?
- How do various public and business sectors interpret and use forecasts and warnings?
- Do emergency managers understand what ensemble forecast products represent?
- What resources and tools are available to assist WFOs in assessing and responding to needs of their localities?
- How can social marketing strategies be applied to promote the effective use of warning messages?
- What roles do local agencies or institutions fill in assisting people with special needs in emergencies?

Decision Making

A clear consensus emerging from this process is that hurricane-related decision making is nonlinear, multilayered, and complex. Furthermore, when considering decision making in response to forecasts and warnings, we are dealing with a complex network of interacting systems, all of which involve interpretation of forecast information. Historically, research into decision making has typically focused on individuals as if they were operating in isolation. The dynamic social network, though, consists not only of individuals but also of households, families, and more complex organizations ranging from small local businesses to large national or even international corporations. In addition, all levels of government are involved, some of which are officially tasked with making evacuation decisions. In summary, workshop participants clearly saw the need to focus on various dimensions of decision making across a variety of social and political units.

Emergency Management Decision Making. The activation- and evacuation-related decisions of emergency management organizations generally involve evaluating meteorological information (e.g., track, intensity, rainfall, forecast uncertainty, and forward speed); community-related information (e.g., population size, distribution, and evacuation routes); and situational factors (e.g., time of day or week, seasonal events, and current situations). This complex process has had minimal objective assessment. Relevant questions include

- How do life-safety issues and economic or credibility losses figure into the process?
- What political constraints are placed on decisions?

- How do coordination issues (e.g., shelter openings, state and federal coordination, mutual aid, and community activation) influence the process?
- What legal, structural, and organizational complexity issues affect decision making?

Decision Support Systems (DSS). Many governmental organizations, as well as businesses (e.g., the airlines, insurers, and agricultural concerns), utilize DSS. A better understanding of how widely these support systems (e.g., HURREVAC and HURRTRAK) are used in the decision process is required. Relevant questions are

- How is NWS-generated forecast and warning information used?
- What types of additional information or displays might improve decision support?
- Are NOAA's areas of research focus and product development plans consistent with needs of emergency management organizations, households, and businesses?
- Can improved DSS be developed and, if so, how might they be designed?

Integrating Temporal Aspects into Decision-Making Research. The temporal nature of decision-making processes needs better research and understanding at all levels of scale. Researchers frequently fail to capture the dynamic nature of decision making. Protective-action decision-making processes are often iterative and interactive through time. Different sequences in this process move at different rates. Relevant questions are

- How do forecast and warning message information influence timing in decision making?
- How does consistency and dissonance of the information affect the temporal nature of the process?
- Does message form and quality have an impact on the timing of critical hurdles that decision makers must address in formulating decisions?

Decision Making in Businesses. A major constraint on individual and household response can be how businesses (including public sector and government institutions such as schools and nonemergency agencies) respond to forecasts and warnings. If businesses fail to release their employees or suspend operations, employees often will not jeopardize their jobs to begin their own preparations and make household decisions. Business community responses can either undermine or add legitimacy to official warnings. Relevant questions include

- What sources and forms of forecast and warning information do different types of businesses utilize?
- What role does this information play in the process?
- How do decision processes differ for local versus national or international businesses? For large and small firms?
- What effects do individual values and attitudes toward work and business have on decision making?

Risk Perceptions. The literature generally recognizes that risk perception is critical in protective-action decision-making processes. Yet little is known about how forecasts and warnings

influence the more transitory elements of risk perception critical for promoting appropriate evacuation decisions (sheltering in place versus evacuating). Relevant questions include

- What factors related to forecast and warning influence appropriate risk perception and ultimately protective-action decisions?
- How do probabilistic forecast- and format-related issues (e.g., cones, lines, and graphs) shape risk perceptions?
- How do factors such as location (risk zones) and perceptions of housing or business survivability shape risk perceptions?
- How transitory and changing are risk perceptions?
- How do social vulnerability issues (gender, race, and class) play out in risk perceptions?
- How are hazard risks (i.e., wind, surge, inland flooding) evaluated? Are some risks over or under evaluated and how do these variations influence actions?

Formal and Informal Warning Networks. In many situations, informal "contagion" components of the warning network come into play along with formal or official broadcast elements. Informal networks emerge based on proximity (neighbors and coworkers), familial relationships, and other social ties (friends and acquaintances). These networks have the potential to alter the initiation of decision-making processes and the influence forecasts and warnings have in the process. Indeed, the nature of forecast and warning information itself might well shape how rapidly informal warning networks activate and spread. Research questions might include

- Do formal and informal networks operate differently among socially vulnerable populations?
- How do these networks influence the timing of evacuation decisions?
- Do certain types of forecast and warning information promote the activation of informal networks?

Warning Perception Rate Estimates. When warning messages are given, they are not perceived and acted on simultaneously. Messages go through different communication links (media and otherwise), and people perceive and respond differently. Multiple channels of information operate and can deliver conflicting messages. Information/warning criteria in evacuation models should deal with the impact of varied and sometimes conflicting information. Relevant questions are

- How do warning perception rates vary in heterogeneous populations?
- Do certain types of forecast and warning information enhance warning perception?
- What is the lag between warning perception and initiation of protective actions by individuals and households?

Decision Constraints. The issue of constraints in decision-making processes can be critical. Constraints can vary considerably across social actors. Political and economic constraints on emergency management decision making can lengthen the time required to make final decisions. At a broader level, constraint-related issues need firmer integration into research on decision-making processes at the individual, household, and organizational level. In particular, issues of

political economy (i.e., power, socioeconomic status, and class) and social vulnerability (i.e., race, gender, and ethnicity) need more complete examination. Questions to examine in this area include

- How do social and economic resources facilitate or thwart decisions?
- Can better forecast and warning information alter constraint parameters for emergency management decisions?
- Can better education about forecast and warning processes shape decision-making processes of elected officials?

Behavioral Response

Although hurricane forecasts call for many behavioral responses important for social science research, evacuation has the broadest consequences. Home protection and other mitigation and preparation measures are important, but they do not require the same large-scale planning, coordination, and timing. Many people tend to wait until the last minute, putting themselves and others at risk. Others may evacuate when they would be safer in their homes (e.g., the "shadow" evacuation from Houston for Hurricane Rita). Above all, large numbers (often more than 50%) of those who should evacuate from storm surge areas do not do so. Behavioral research needs to determine how to reduce this number.

Facing this complexity, forecasters and emergency managers need to know how and when people will respond to hurricane warnings. This calls for research leading to modeling of evacuation behavioral response in more precise and comprehensive ways. Evacuation behavior modeling must better integrate the specificity of qualitative research with the quantitative modeling required to predict aggregate evacuation rates and timing. Research also needs to be more multidisciplinary, given the multiple dimensions of the evacuation decision processes. One multidisciplinary requirement is utilization of spatial (GIS) and temporal data frameworks for analysis so evacuation models can integrate with other issues such as traffic clearance times and shelter requirements. The following discusses specific areas where better evacuation modeling can make the hurricane forecast and warning process more effective.

Traffic Modeling and Estimated Time of Evacuation (ETE). Getting large numbers of people out of densely populated, threatened areas requires knowing how long evacuation will take. Longer evacuation clearance times require earlier warnings. The lower precision of longer-lead-time (e.g., 5-day) forecasts means more evacuations and more false alarms. Transportation researchers can model clearance times if they have better input data on the number of people who will evacuate from each location as well as where and when they will go. Traffic issues also feed back into the decision process as people learn from past experience and media coverage. Research questions include

- How can "microscopic" individualized decision models be integrated with "macroscopic" measurement and modeling of evacuation rates and traffic flows?
- How can traffic and preparation behaviors (e.g., commuting to and from work, picking up children from school) be modeled?
- How can feedback effects of news of traffic jams on evacuation route selection be better modeled?

Spatial Evacuation Modeling. Ideally, an evacuation model should include variables that predict the effects of all conditions specific to each location. Because this goal is not always attainable, geolocation allows model relationships to be spatially tested. When model coefficients change in different locations, further qualitative inquiry and quantitative variable development may capture local conditions. Using a GIS framework also enables hierarchical modeling of individual survey responses in relation to demographic and other data in geographical units (e.g., census tracts, zip code areas, and administrative jurisdictions).

Spatial analysis is needed to answer questions such as

- How are terms like "flood," "surge," and "wind" understood at different spatial locations given that the same words are used in survey instruments applied across a wide region?
- Can models be spatially differentiated to deal with both refusal to evacuate and shadow evacuation?
- How should findings from individual/household-level models be aggregated to create models predicting census block, block group, or tract level evacuation rates?

Common Protocols and Data Depository. Each hurricane evacuation study addresses responses to warnings and other conditions of one hurricane. To make inferences about evacuation as a process and thus obtain general estimates, predicted evacuation rate curves, and other parameters, comparable studies of a number of hurricanes are necessary. This consideration means that questionnaire protocols and data sets across hurricanes must be made available for analysis. Many research issues and questions could be addressed with more consistent research protocols and data set availability. Two such questions are

- How can researchers collaborate to do studies that measure the effects forecast and warning messages across hurricanes?
- How can researchers ensure the protection of human subjects when data sets are available for wide use?

Responses Other Than Evacuation Related to Forecasts. Other activities like preparation, mitigation, and education also depend on forecasts in crucial ways. And they have implications for evacuation itself—people consistently give the safety of their homes as a principal factor in their evacuation decisions. The working group's charge was to focus on immediate consequences of hurricane forecasts so participants paid the most attention to evacuation, but social science research must continue to study and integrate understanding of the full range of hurricane effects.

Societal Impacts and Valuation

Limiting value estimates to obvious costs related to insurance payouts, response expenses, business losses, and economic values for forecasts fails to account for a range of human and social costs. Identifying and representing these "hidden costs" is inherently complicated and involves studying largely invisible and powerless groups. Much human suffering and social disruption could be reduced by better understanding the context of people's lives. Doing so would lead to more appropriate and timely communication and responses to their circumstances and needs.

Hidden costs of hurricanes include aspects such as differential distributional impacts on vulnerable populations. Most economic analysis does not deal well with issues of the distribution and individual impacts of policies and programs—economics generally treats a $50 direct economic loss to a millionaire the same as a $50 direct economic loss to a homeless person. From a societal perspective, appropriate treatment of equity and fairness issues may appear missing in economic analysis. Here the relevant questions include

- Are there relevant societal values that are incommensurate with economic value?
- Can we educate policy makers about long-term hidden costs?
- How can we document long-term social costs through field studies, ethnographies, and case studies?
- How can we support the importance of more widespread use of qualitative methodologies where they can offer significant insight into societal costs?

Economic Aspects. Reliable data on the value of current and improved hurricane forecasts and warnings can give policy makers information on the net benefits to society of investments in forecast efforts and guide decisions on where and how to allocate resources to maximize the associated societal benefits.

In studying human behavior and decision making, economics has not been adequately integrated with other social sciences. As a result, little information exists on the economic value of improvements in the communication and understanding of forecasts or on values for responses to forecasts and warnings (including the costs and benefits of evacuations).

Reliable studies of the value of hurricane forecasts will help inform policy makers and will also make quantitative economic information available in support of current forecast programs and ongoing forecast improvement research. Economic valuation studies are needed to encompass different aspects or attributes of forecasts (e.g., is it relatively more useful to improve wind field forecasts or increase landfall lead times?); different methods (e.g., stated and revealed preference, Bayesian decision models, cost–loss models, and cost minimization studies); different spatial scales (e.g., city, regional, and national studies); different temporal scales (e.g., hourly, weekly, and decadal decision modeling); and the range of stakeholders (e.g., the public; emergency managers; and the aviation, tourism, and oil and gas industries).

Economic studies also need integration with the physical and other social sciences. As an example, experimental economics methods could be used in conjunction with risk communication research to evaluate preferences for probabilistic forecast information. Integrating economic theory and methods with sociology, psychology, hazards research, communication, and other approaches in an end-to-end-to-end approach offers new avenues of understanding to meet societal objectives. Unanswered questions in this area include

- What are the costs and benefits associated with either shrinking the area included in warnings or increasing the lead time?
- Can we develop meaningful metrics for the economic performance for hurricane forecasts and warnings comprising the (1) quality dimensions of the forecast, (2) value of communication/understanding of forecast variables, (3) value of responsiveness to the forecast, or all three?

- Is it even relevant to put a value on forecasts or improved forecasts separate from the entire process of **forecast→communicate→perceive→respond**?
- Are new or unique valuation methodologies required?
- Can we develop economic measures of hidden values or vulnerable populations?
- What are the priority sectors (e.g., households, individuals, and governments)?
- How do we integrate economic studies with other disciplines?

Advancing the Social Science Research Agenda

Although these ideas on social science needs were developed in consultation with a diverse group of researchers, an ongoing discussion within this community is needed to identify research needs, broaden participation, and facilitate interdisciplinary discussions. Several activities, in addition to funded research, are recommended.

Workshops on Developing the Social Science Research Agenda. The research community would benefit significantly from workshops focused on specific areas within the forecast and warning process. The Pomona effort made it clear that the diverse social science community is primed for developing multidisciplinary advances relevant for forecast and warning. In addition to a multidisciplinary workshop exploring broad research needs, small-scale workshops could appraise the state of the art; review current and new research methods; discuss research needs and opportunities; and foster discussion across the disciplines on the warning process, decision making, hurricane impacts, forecast valuation, and evacuation.

Common Protocols. To permit comparability across events and integration of knowledge gained from diverse social science research efforts, common protocols for gathering, analyzing, maintaining, and reporting data are needed. By unnecessarily beginning data collection and modeling efforts from scratch, researchers slow down the overall process. Researchers across the disciplines need to share questionnaires and other data collection protocols,.

Data Depository. An important component of collaboration is the need for a data depository where all researchers would be encouraged—or, in the case of federally funded research, required—to make their data accessible for replication and further analysis by other researchers, including graduate students.

National Hurricane Social Science Research Program

This paper presents a diverse set of research issues proffered by an even more diverse group of scientists. Individually, each issue represents an interesting and important potential research focus. Collectively, they highlight the need for a more coordinated, consistent, goal-oriented, long-term research agenda.

Retrospective research will not yield all the information necessary for understanding how individuals prepare for hurricanes and respond to forecasts and warnings. Researchers and research tools need to be in place, ready to respond to hurricanes from first landfall forecast through post-storm recovery.

To maximize its value, ongoing work must integrate diverse research across disciplines and . Developing interdisciplinary research requires a long-term commitment and a fundamental culture change on the part of researchers.

The development and long-term funding of a National Hurricane Social Science Research Program is crucial to this effort. This program should extend beyond the forecast and warning system to integrate research on mitigation, preparation, recovery, and other aspects of the societal impacts of hurricanes. The program should extend beyond NOAA to integrate with other agencies such as the National Science Foundation, NASA, the U.S. Department of Transportation, and FEMA and its parent organization, the Department of Homeland Security, along with state and local agencies, the private sector, and international research entities.

Conclusion

Meteorology has evolved considerably, both as a science and in terms of the tools and modalities used to communicate messages to an increasingly diverse array of users. Nowhere is this more obvious than in the case of hurricane forecasts and warnings where interested parties—jurisdictions, enterprises, households, and individuals—receive more information than ever before. As suggested by this paper and the white papers, these changes raise many issues and questions that can best be addressed by social science research.

Each social science discipline brings unique vocabularies, theories, and methodologies to bear on the forecast and warning process. The topics and questions presented here require a coordinated interdisciplinary approach that incorporates qualitative and quantitative methods. Most research so far has been in the form of case studies untested through replication or comparative analysis. Greatest gains will come from a coherent, coordinated, and ongoing social science research program that promotes comparative and longitudinal work.

An important focus of this research agenda must be on ways in which different end users receive, interpret, and act on messages. A considerable body of knowledge is accumulating about those who respond appropriately to warnings. If the cost-effectiveness of hurricane forecasts and warnings is to increase in any substantial way, we must now find ways to reach the remainder of the at-risk population. This more-difficult task will require a deeper understanding of the beliefs, social and economic circumstances, and options available to people and organizations in harm's way. Of particular importance is learning more about those whose physical, economic, or social conditions make them especially vulnerable. In most cases, qualitative research such as ethnographies, focus groups, or in-depth surveys will be necessary before more quantitative work can begin.

This paper identified key issues and knowledge gaps. The dialogue initiated through the white papers and the workshops provides a solid foundation, but is only a beginning. Further discussions are essential to ensure that research remains not only relevant, but has the potential for breaking new ground and exploring new paradigms. In addition to addressing the range of pressing research questions, it is equally important to bring together social science researchers in workshops to focus on particular topics such as the development of appropriate research protocols. To accomplish this, however, sufficient, stable funding is necessary and a mechanism for sharing and building on prior research must exist.

The establishment of a National Hurricane Social Science Research Program to coordinate funding, bring researchers together, design research protocols, share results, and address transitioning research to operations is of paramount importance.

Acknowledgements

The authors would like to thank all of the individuals who have participated in and supported this ongoing effort to develop a social science research agenda on the hurricane forecast and warning system. This includes the co-authors of the White Papers, the participants in the February 2005 workshop in Pomona, participants in meetings at the 2004 and 2005 CU Natural Hazards Workshops, the organizers of the CU Natural Hazards Workshop for supporting in the organization of these sessions (especially Greg Guibert and Kathleen Tierney), and other members of the *ad hoc* Hurricane Forecast Socio-Economic Working Group (including John Gaynor, Jim Rivers, Inger Gallo, Ward Sequin, Dave Letson, Rodney Weiher, Ed Rappaport, Frank Marks, and Pai-Yei Whung). We would like to especially thank John Sorenson for his review of the Pomona workshop materials and his honest and insightful assessment of options for moving this effort forward. As always, any remaining errors are the authors.

White Papers

Papers prepared for the Hurricane Forecast Socioeconomic Working Group, 16–18 February 2005, Pomona, California (available at www.sip.ucar.edu):

Dash, N., and H. Gladwin, 2005: Evacuation decision making and behavioral responses: Individual and household.

Letson, D., D. Sutter, and J.K. Lazo, 2005: The economic value of hurricane forecasts: An overview and research needs.

Lindell, M.K., C.S. Prater, and W.G. Peacock, 2005: Organizational communication and decision making in hurricane emergencies.

Phillips, B.D., and B.H. Morrow, 2005: Social science research needs: A focus on vulnerable populations, forecasting and warnings.

Willoughby, H. E., E. N. Rappaport, and F. D. Marks, 2005: Hurricane forecasting: The state of the art.

Pomona Workshop Participants

John (Jack) Beven—NOAA
Susan Cutter—University of South Carolina
Nicole Dash—University of North Texas
Robert Dumont—NOAA
Suzanne Frew—The Frew Group
John Gaynor—NOAA
Hugh Gladwin—Florida International University
Matthew Green—FEMA
Eve Gruntfest—University of Colorado
Sally Kane—Consulting Economist
Scott Kiser—NOAA
Arlene Laing—NCAR
Jeffrey Lazo—NCAR

Stephen Leatherman—Florida International University
David Letson—University of Miami
Michael Lindell—Texas A&M University
Frank Marks, Jr.—NOAA
William Massey—Hurricane and Emergency Management Programs, Dewberry
Michael McDonald—Global Health Initiatives, Inc.
Betty Morrow—Consulting Sociologist
Walter Peacock—Texas A&M University
Brenda Phillips—Oklahoma State University
Carla Prater—Texas A&M University
James Rivers—Florida International University
Ward Seguin—NOAA
David Sharp—NOAA
Kevin Simmons—Austin College
Daniel Sutter—University of Oklahoma
Rodney Weiher—NOAA
Hugh Willoughby—Florida International University