Socio-Economic Research on Hurricane Forecasts and Warnings: A Discussion of Results and Research Plans

Jeff Lazo
Rebecca Morss
Julie Demuth

National Center for Atmospheric Research
February 23, 2009

Overview

Part 1: Hurricane Forecast Socio-Economic Working Group

Part 2: Benefits of Improved Hurricane Forecasting

Part 3: Current Research
- Hurricane Forecast Improvement Project
- Communicating Hurricane Information
- Warning Decisions: Extreme Weather Events

Part 1: Hurricane Forecast Socio-Economic Working Group

Hurricane Isabelle - September 18 2003

- **Outer Banks of North Carolina – 105 mph (Cat. 2)**

- **$3.6 B damages 2003 USD**

- **16 deaths directly related to the hurricane**

- **35 deaths indirectly related to the hurricane**

- **Washington DC**
  - **Washington Metro and Metrobus closed**
  - **$125M damages**
  - **1 indirect fatality**

Hurricane Forecast Socio-Economic Working Group

- **MISSION STATEMENT: HURRICANE FORECAST SOCIAL AND ECONOMIC WORKING GROUP (HFSEWG)**

- **Draft: October 29, 2004**

- **(*Problem*) Hurricanes have significant social and economic impacts which may be mitigated in part by the hurricane forecasting and warning system. The primary goal of hurricane monitoring and forecasting is to prevent loss of life and to reduce vulnerability to winds, storm surges, inland flooding, and other hazards. Greater incorporation of economic and social dimensions into the hurricane forecasting enterprise promises large dividends in terms of relevance and user response.**

- **(*Objective*) The objective of Hurricane Forecast Social and Economic Working Group (HFSEWG) is to identify social science research capabilities, needs, and priorities with respect to the hurricane forecasting and warning system.**

- **(*Methods*) Working with the tropical cyclone meteorology and policy community, the Hurricane Forecast Social and Economic Working Group will 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. The social science research agenda may include research on the communication, perception and understanding, behavioral responses, and costs and benefits of hurricane forecast information products.**

- **(*Output*) The Group will 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.**

Hurricane Forecast Socio-Economic Working Group

(Output) **The Group will 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.**

Hurricane Forecast Socio-Economic Working Group

- **White Papers**

- **Pomona Workshop**

- **Natural Hazards Workshop sessions**

HURRICANE FORECASTING AND WARNING SYSTEM

Workshop Report

Facilitated by:
National Water Research Institute

On behalf of:
National Center for Atmospheric Research

February 16-18, 2005

Kellogg West Conference Center & Lodge
California Polytechnic University
Pomona, California

Hurricane Forecast Socio-Economic Working Group

Jack Beven - NOAA

Susan Cutter – U. of S. Carolina

Nicole Dash – U. of North Texas

Bob Dumont - NOAA

Suzanne Frew - The Frew Group

John Gaynor - NOAA

Hugh Gladwin – FIU

Matthew Green - Natl Hurricane Center

Eve Gruntfest – U. of Colorado

Sally Kane - Consultant

Scott Kiser - NWS

Arlene Laing - NCAR

Jeff Lazo - NCAR

Stephen Leatherman - FIU

David Letson – U. of Miami

Mike Lindell - Texas A&M

Frank Marks - NOAA

William G. Massey - Dewberry

Mike McDonald - Global Health Initiatives, Inc.

Betty Hearn Morrow - Consultant

Bob O'Conner - NSF

Walter Peacock - Texas A&M

Brenda Phillips - Oklahoma State University

Carla Prater - Texas A&M

Jim Rivers - FIU

Ward Seguin - NOAA

David Sharp - NWS

Kevin Simmons - Austin College

Daniel Sutter – U. of Oklahoma

Rodney Weiher - NOAA

Dennis Wenger - NSF

Hugh Willoughby - FIU

Hurricane Forecast Socio-Economic Working Group

NATURAL HAZARDS REVIEW

VOLUME 8 / NUMBER 3   AUGUST 2007

IN BOX
INSIGHTS and INNOVATIONS

Social Science Research Needs for the Hurricane Forecast and Warning System

BY HUGH GLADWIN, JEFFREY K. LAZO, BETTY HEARN MORROW, WALTER GILLIS PEACOCK, AND HUGH E. WILLOUGHBY

THE IMPORTANCE OF SOCIAL SCIENCE RESEARCH. The 2004 and 2005 hurricane seasons awoke the United States to the potential societal impacts of landfalling Atlantic hurricanes. The toll was greater than $175 billion in damage and about 5,400 deaths throughout the Atlantic Basin. While 2006 and 2007 were quieter, climatologists believe that we are still in a period of increased hurricane activity. Given that crucial hurricane forecasts, especially those for Katrina, were accurate and timely, it is necessary to understand why many people did not or were not able to heed those warnings. In this sense, hurricane disasters are "social constructs"—as much or more manmade than "natural" disasters. Over the last decade, there has been a growing recognition that social and behavioral research is essential to understanding the causes of high societal-impact weather-related disasters. As stated in Pielke and Kimpel's *Societal Impacts of Weather* report, "It is generally accepted that weather problems are both social and physical phenomena. Research findings from the social sciences have been crucially important in understanding and improving human responses to economic, social, and environmental weather-related risks. Despite the centrality of this research area, it has in the past received too little attention and resources." Pressing meteorological, technological, and social issues that drive the need for social science research on forecasts and warnings include: changes and improvements in forecast products; changes in ways to create, manipulate, and disseminate information; increased recognition of hurricane impacts as social phenomena; increasing and increasingly diverse population and assets in harm's way; availability of new social science tools, methods, and paradigms; and institutional requirements to evaluate, justify, and develop guidance for programs and future practices.

Based on a 2005 workshop in Pomona, California; 2004 and 2005 Natural Hazards workshop sessions held in Boulder, Colorado; a series of white papers; and additional input from the broader social science research community, the August 2007 special issue of *Natural Hazards Review* (NHR) contains a series of papers on societal aspects of the hurricane forecast and warning system, written to identify gaps in understanding and needs for social science research. As Gladwin et al. stated in *NHR*, "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."

SCIENCE ISSUES. At least three cross-cutting issues necessitate innovative social science investigations. First, as was never more apparent than in the case of Hurricane Katrina, vulnerable populations require particular consideration. Many people lack economic and/or human resources to respond appropriately. Circumstances and response options of vulnerable populations must be recognized and understood to develop appropriate warning products and policies to prevent

AFFILIATIONS: GLADWIN AND WILLOUGHBY—Florida International University, Miami, Florida; LAZO—National Center for Atmospheric Research, Boulder, Colorado; MORROW—Consulting Sociologist, Miami, Florida; PEACOCK—Texas A&M University, College Station, Texas
CORRESPONDING AUTHOR: Jeff Lazo, NCAR, Box 3000, Boulder, CO 80307
E-mail: lazo@ucar.edu

Part 2: Benefits of Improved Hurricane Forecasting

- **Background**

- **Survey design and implementation**

- **Results**

- **Evacuation decision making**

- **Benefit estimation**

Benefits of Improved Hurricane Forecasting

- **Background**
  - Objective: *". . . obtain estimates of households' WTP to improve hurricane forecasts in those areas most affected by hurricanes "*
  - Approach: *". . . develop and implement a stated preference survey to elicit households' values for improved hurricane weather forecasts."*
  - Phase I – August 24, 2001 . . .
  - .
  - .
  - .
  - Small sample implementation – September 2008
  - Working paper "*Assessment of Household Evacuation Decision Making and the Benefits of Improved Hurricane Forecasting*" Lazo, Waldman, Morrow, and Thacher

Benefits of Improved Hurricane Forecasting

- **Survey design**
  - **Attribute set from hurricane researchers**
  - **Open-ended handouts**
  - **Focused handouts**
  - **Draft Survey instrument**
  - **Flesch Reading scoring**
  - **Peer review**

Benefits of Improved Hurricane Forecasting

Location	Date	Activity	Subjects
Miami	October 2002	Preliminary written questionnaire	11
Miami	April 2002	Focus groups	21
New Orleans	April 2003	Focus groups	14
Miami	Nov. 2003	Focus groups	23
Charleston	February 2004	One-on-one cognitive interviews	11
Miami	May 2004	One-on-one cognitive interviews	10
Miami	August 2008	One-on-one cognitive interviews	6
		Total	96

Benefits of Improved Hurricane Forecasting

- **Survey Outline**
  1. personal impact / vulnerability
  2. perceived risk
  3. preparation for hurricane
  4. evacuation decisionmaking
  5. likely impact on household
  6. hurricane forecasts
     - attributes
     - perceived accuracy
  7. improved hurricane forecasts
     - attributes
     - choice sets
  8. current hurricane forecasts
  9. socio-demographics

Version 1 - Subject _____ Time _____

HURRICANES AND YOU
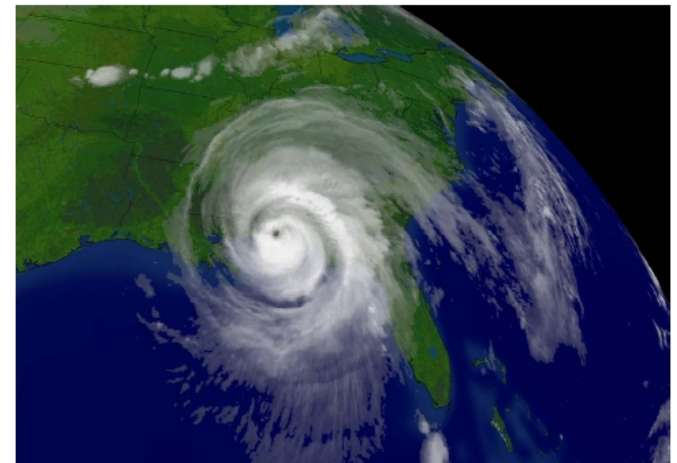
Hurricane Ivan - September 16, 2004

ANY PERSONAL INFORMATION COLLECTED IS CONFIDENTIAL AND IS ONLY USED TO GROUP YOUR ANSWERS WITH OTHERS OF SIMILAR BACKGROUND.

1

Benefits of Improved Hurricane Forecasting

- **Implementation – Betty Morrow**
  - **Miami, FL – September 4, 2008**
  - **80 subjects**
  - **recruited to focus group center**
  - **individual written**
  - **data entry and cleaning**

Benefits of Improved Hurricane Forecasting

- **Socio-demographics**
  - 16 Caucasians, 16 African Americans, 47 Spanish/Hispanic/Latino, and one "other."
  - 50% male, 50% female
  - 50% with college degree
  - Average age 43 years old - ranging from 18 to 70
  - Median income $40,000- $50,000 (Dade County - $46,931)
  - Five respondents in mobile homes
  - 39%/61% split between rent and own their residence
    - 2002 American Housing Survey of roughly 35%/65%

- **not representative sample**
  - non-random nature of recruiting
  - small sample size

Benefits of Improved Hurricane Forecasting

Some basic results

- **89% - personally affected by a hurricane in the past**
  - of these ~60% with Hurricane Andrew
  - most accurately recalled the year of Andrew – 1992

- **more than 50% had not received any information on what to do in the event of a hurricane**
  - for those who did indicate receiving information
    - Mayor and other non-specific government entities mentioned as information sources
    - no open-ended mention of NWS, NOAA, or the NHC

Benefits of Improved Hurricane Forecasting

Some basic results continued . . .

- **7 out of 10 have taken some action to prepare for a hurricane.**
  - Probit model - Prepare/Don't Prepare
    - **only significant predictor**
      - previous experience with a hurricane
      - those who had had personal experience with a prior hurricane were less likely to have taken action to prepare for a hurricane.

- **56% indicated had adequate hurricane shutters**
  - own residence more likely to have shutters
  - higher perceived tornadoes likelihood with a hurricane
  - independent of age, income, and length of time in residence

Benefits of Improved Hurricane Forecasting

Evacuation decision making

HURRICANE IMPACTS ON YOU

14 How likely is it that you would evacuate if you were to receive a hurricane **warning** for your area for each of the following categories of hurricane? *Circle the number of your answer.*

Category	Wind Speed	Storm Surge	Not at all likely	Not very likely	Somewhat likely	Very likely	Extremely likely	Don't Know
1	74 to 95 mph	4 to 5 feet	1	2	3	4	5	9
2	96 to 110 mph	6 to 8 feet	1	2	3	4	5	9
3	111 to 130 mph	9 to 12 feet	1	2	3	4	5	9
4	131 to 155 mph	13 to 18 feet	1	2	3	4	5	9
5	more than 155 mph	more than 18 feet	1	2	3	4	5	9
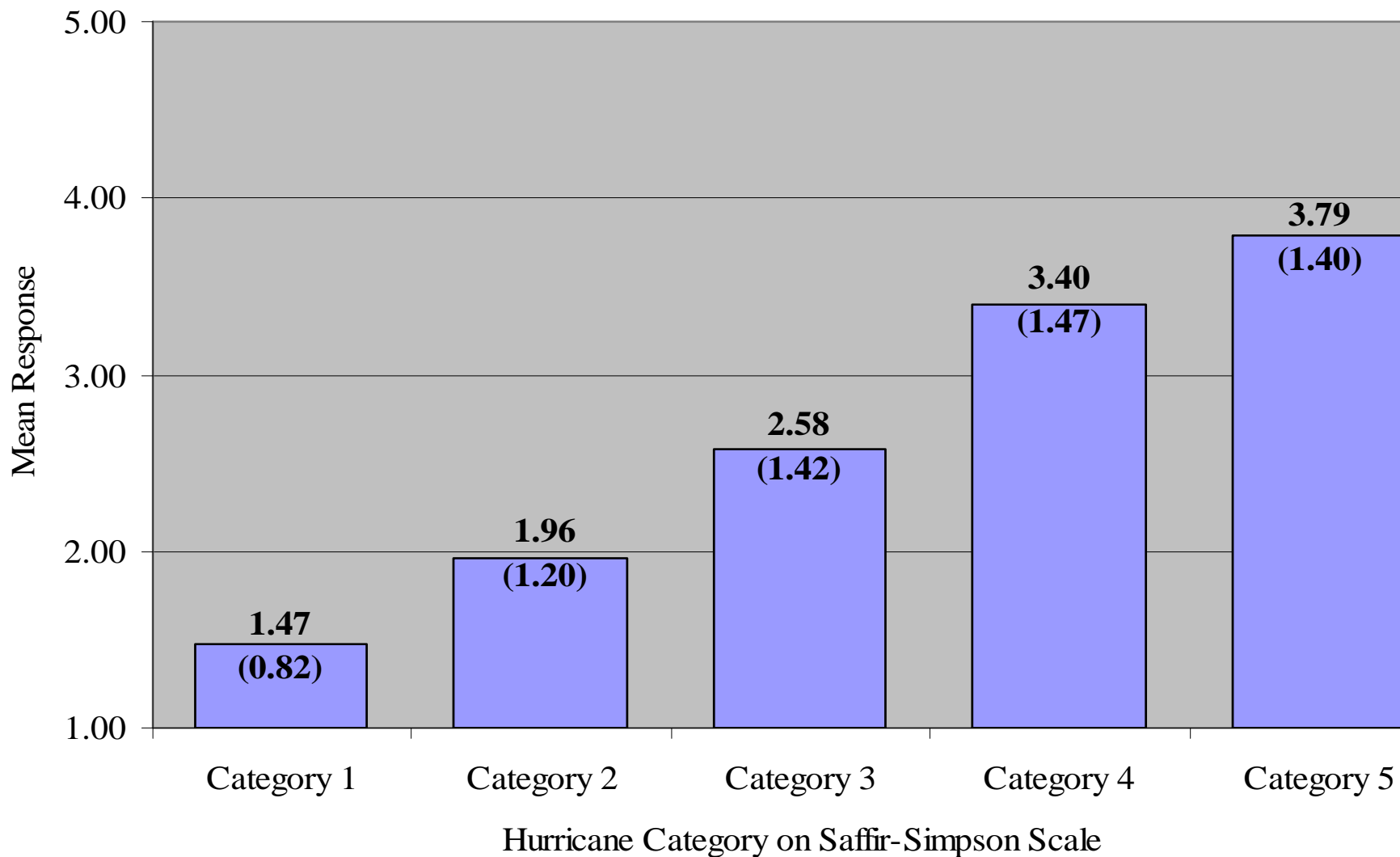
Mean Likelihood of Evacuation by Hurricane Category
Standard deviation reported in parenthesis.
1 = "Not at all likely" to 5 = "Extremely likely"   n = 80

Benefits of Improved Hurricane Forecasting

Ordinal logistic regression

- **Dependent Variable: Likelihood of evacuation**
  - **Barriers to Evacuation**
    - **Significant**
      - **"don't want to leave my home or business unprotected"**
    - **Not Significant**
      - **Having pets**
      - **Believe there would be too much traffic**
      - **Not trusting accuracy of hurricane forecasts**

  - **Risk Perception scales**
    - **Significant**
      - **Risk of flooding or storm surge damage**
    - **Not Significant**
      - **Risk of wind damage**

Benefits of Improved Hurricane Forecasting

Ordinal logistic regression

- **Dependent Variable: Likelihood of evacuation**
  - **Experience with / perceptions of hurricanes**
    - **Significant**
      - **Higher level of perceived accuracy of hurricane forecasts more likely to evacuate**
    - **Not Significant**
      - **Personally affected by a past hurricane**

  - **Socio-Demographic Characteristics**
    - **Significant**
      - **Homeowners more likely to evacuate**
      - **Longer in residence _less_ likely to evacuate**
      - **Older people more likely to evacuate**

Benefits of Improved Hurricane Forecasting

- *What is the value to households of potentially improved hurricane forecasts?*

- Stated-preference method
  - Stated Choice (conjoint analysis)

34 Please indicate which Program, if you had to choose, you would prefer.

	Accuracy of Current Forecasts	Program C ⌄	Program D ⌄
Time of expected landfall	Now accurate to within 8 hours	4 hours	No change
Maximum wind speed	Now accurate to within 20 miles per hour	No change	15 hours
Projected landfall	Now accurate to within 100 miles	80 miles	65 miles
Expected storm surge	Now accurate to within 8 feet above sea level	4 feet	No change
Increase in Annual Cost to Your Household		$12 per year	$24 per year
I would prefer (please put check mark in box indicating your preferred Program)		Program C ☐	Program D ☐

35 Would you prefer to keep forecast quality the way it is now and pay no more in taxes or stay with the Program you indicated above?

☐	Keep forecast quality the way it is now and pay no more in taxes.
☐	Undertake the Program chosen above and pay the amount indicated.

Choice Set Attributes and Levels

Level	Time of expected landfall	Maximum wind speed	Projected location of landfall	Expected storm surge	Increase in Annual Cost to Your Household
Currently accurate to within (baseline)	8 hours 48 hours in advance	20 miles per hour 48 hours in advance	100 miles 48 hours in advance	plus or minus 8 feet of height above sea level 48 hours in advance	$12
Intermediate Improvement	6 hours	15 miles per hour	80 miles 48 hours in advance	6 feet of height above sea level	$24
Maximum Improvement	4 hours	10 miles per hour	65 miles 48 hours in advance	4 feet of height above sea level	$48

Program C

	Time of expected landfall	Maximum wind speed	Projected location of landfall	Expected storm surge	Increase in Annual Cost to Your Household
		20 miles per hour 48 hours in advance			$12
			80 miles 48 hours in advance		
	4 hours			4 feet of height above sea level	

34 Please indicate which Program, if you had to choose, you would prefer.

	Accuracy of Current Forecasts	Program C ⌄	Program D ⌄
Time of expected landfall	Now accurate to within 8 hours	4 hours	No change
Maximum wind speed	Now accurate to within 20 miles per hour	No change	15 hours
Projected landfall	Now accurate to within 100 miles	80 miles	65 miles
Expected storm surge	Now accurate to within 8 feet above sea level	4 feet	No change
Increase in Annual Cost to Your Household		$12 per year	$24 per year
I would prefer (please put check mark in box indicating your preferred Program)		**Program C** ☐	**Program D** ☐

35 **Would you prefer to keep forecast quality the way it is now and pay no more in taxes or stay with the Program you indicated above?**

☐	Keep forecast quality the way it is now and pay no more in taxes.
☐	Undertake the Program chosen above and pay the amount indicated.

Benefits of Improved Hurricane Forecasting

- **Choice set design – Jennifer Thacher**
  - non-linear main-effects design
    - no interaction effects
  - quadratic effects
  - fractional-factorial orthogonal array of 36 runs with three blocks
  - 18 questions of two alternatives each
  - randomly divided
    - three survey versions
    - adjusted for "internal consistency"

Benefits of Improved Hurricane Forecasting

- **Econometric modeling and analysis – Don Waldman**
  - **random utility behavioral model**

$$U_{ij} = \beta' x_{ij} + \varepsilon_{ij}, \qquad i = \text{A, B}; j = 1,...8,$$

  - **parameter estimates represent marginal utilities**
    - **landfall time, windspeed, location, storm surge**
    - **cost** *(marginal utility of income)*
  - **estimation is by bivariate probit**
    - **first choice between A and B**
    - **second choice between A/B and "do nothing"**
  - **analyzed only choice occasions 2 – 8**
  - **80 subjects – 7 choices each = 560 "observations"**
    - **quadrature to account for intra-subject correlation**

Modeling Results
Choice Sets 2-8 Only (n = 560)

Bivariate Probit w/quadrature

	Est.	t-ratio	Marginal WTP
Landfall Time	**-0.067**	**-3.57**	**$2.18**
Maximum wind speed	**-0.008**	**-1.08**	**$0.26**
Landfall location	**-0.007**	**-3.22**	**$0.23**
Storm surge	**-0.062**	**-3.50**	**$2.04**
Annual Cost	**-0.030**	**-11.27**	

WTP Calculation: Improve Baseline to Intermediate on All Attributes

Attribute	Baseline (all 48 hours in advance)	Intermediate Improvement	Diff.	Marg. WTP	WTP
Time of expected landfall	± 8 hours	± 6 hours	2	$2.18	$4.36
Maximum wind speed	± 20 mph	± 15 mph	5	$0.26	$1.30
Projected location of landfall	± 100 miles	± 80 miles	20	$0.23	$4.60
Expected storm surge	±8' of height above sea level	± 6' of height above sea level	2	$2.04	$4.08
				Total WTP	$14.34

WTP for Intermediate Program Selected Subsamples

Income < $60,000 (n = 336)	Income ≥ $60,000 (n=224)
$14.74	$18.79
Males (n=280)	**Females (n=280)**
$14.03	$14.74
College graduate (n=280)	**Not a college graduate (n=280)***
$10.93	$17.66

* likelihood converged but would not invert, so that no t-ratios could be calculated

Part 3: Current Research

1. **Hurricane Forecast Improvement Project**
2. **Communicating Hurricane Information**
3. **Hurricane and Flood Warning Decisions**

Hurricane Forecast Improvement Project

- **Post-Katrina Assessments**

  Majority Report

  National Oceanic and Atmospheric Administration

  Science Advisory Board

  Hurricane Intensity Research Working Group

  Submitted: 5 July 2006
  Accepted by the Science Advisory Board: 25 July 2006
  Final Majority Report Prepared: 8 October 2006

- **HFIP**

  Proposed Framework for Addressing the
  National Hurricane Research and Forecast
  Improvement Initiatives

  NOAA's Hurricane Forecast Improvement Project

  July 18, 2008

  Tropical Disturbance
  09/12/07 2:04 am
  25 kts

  Hurricane Humberto
  09/13/07 2:04 am
  80 kts
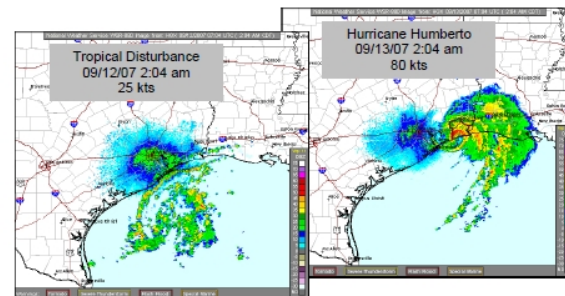
Hurricane Forecast Improvement Project

- **HFIP Metrics**
  - **Reduce average track error by 50% for Days 1 through 5.**
  - **Reduce average intensity error by 50% for Days 1 through 5.**
  - **Increase the probability of detection (POD) for rapid intensity change to 90% at Day 1 decreasing linearly to 60% at Day 5, and decrease the false alarm ratio (FAR) for rapid intensity change to 10% for Day 1 increasing linearly to 30% at Day 5.**
  - **Extend the lead time for hurricane forecasts out to Day 7**

Hurricane Forecast Improvement Project

- **Socio-Economic Impacts Assessment**
  - **Assessment of Emergency Managers - Betty Morrow**
    - **in-depth focused interviews**
    - **emergency managers**
    - **stakeholder communities (hospitals / transportation / etc)**
  - **Household valuation – Jeff Lazo**
    - **non-market stated choice assessment**
    - **adapted *Benefits of Improved Hurricane Forecasting***
    - **attribute set from HFIP**
    - **400 sample across the vulnerable region**

Communicating Hurricane Information

- **Examining the Hurricane Warning System: Content, Channels, and Comprehension**
  - NSF-NOAA joint announcement of opportunity
  - 18-24 month project
  - Collaborators
    - Julie Demuth – meteorology
    - Gina Eosco – communication
    - Somer Erickson – emergency management
    - Matthew Jensen – management information systems
    - Jeff Lazo – economics
    - Claude Miller – communication
    - Rebecca Morss – meteorology
    - Betty Morrow – sociology
    - Dan O'Hair – communication

Communicating Hurricane Information

- **Research foci**
  - **How are hurricane forecast and warning messages developed and communicated by NWS forecasters, emergency managers, broadcast meteorologists, and the public?**
  - **How do at-risk coastal residents, including more vulnerable populations, comprehend and react to specific components of warning messages?**

Communicating Hurricane Information

- **Parallel studies**
  - **Miami, Florida**
  - **Galveston, Texas**
- **Methods:**
  - interviews and observations of message development with forecasters, broadcast media, emergency managers
  - survey examining how members of the public access information and their comprehension of and reactions to different messages
  - focus groups with vulnerable populations (Miami only)
  - laboratory tests of sample messages with members of the public
  - multi-method synthesis of public component and feedback to forecast and emergency management communities through Expert Advisory Board

Hurricane and Flood Warning Decisions

- **Warning Decisions in Extreme Weather Events: An Integrated Multi-Method Approach**
  - Funding from NSF Human and Social Dynamics program
  - 3 year project
  - Collaborators
    - Ann Bostrom – risk communication
    - Julie Demuth – meteorology / communication
    - Brandi Renee Gilbert – sociology
    - Jeff Lazo – economics
    - Rebecca Morss – meteorology
    - Jeannette Sutton – sociology
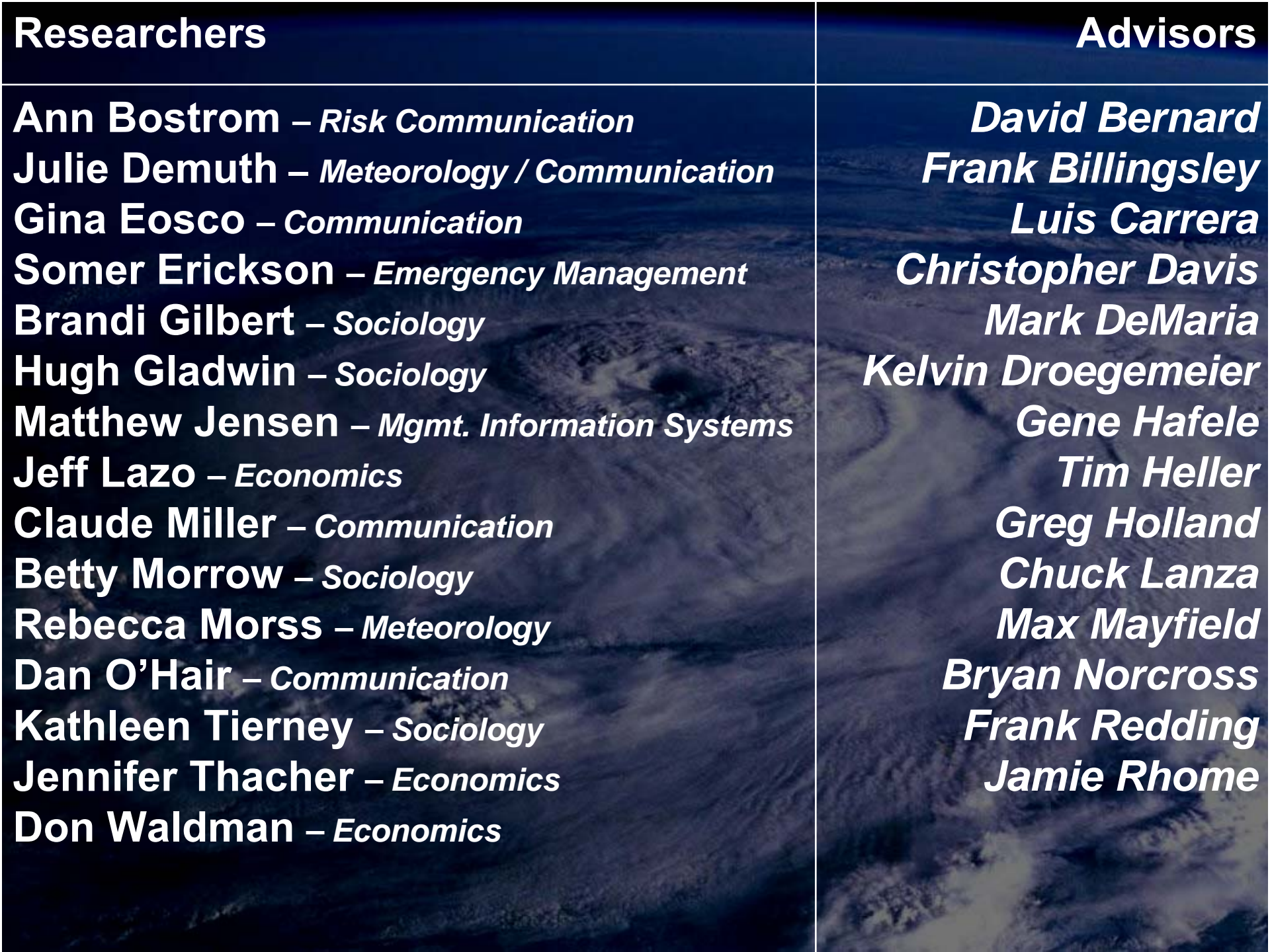   - Kathleen Tierney – sociology

Hurricane and Flood Warning Decisions

- **Research foci**
  - **How are hurricane / flash flood warnings communicated, obtained, interpreted, and used in decision making by participants in the warning process?**
  - **Challenges for decision making in the face of risk and uncertainty**
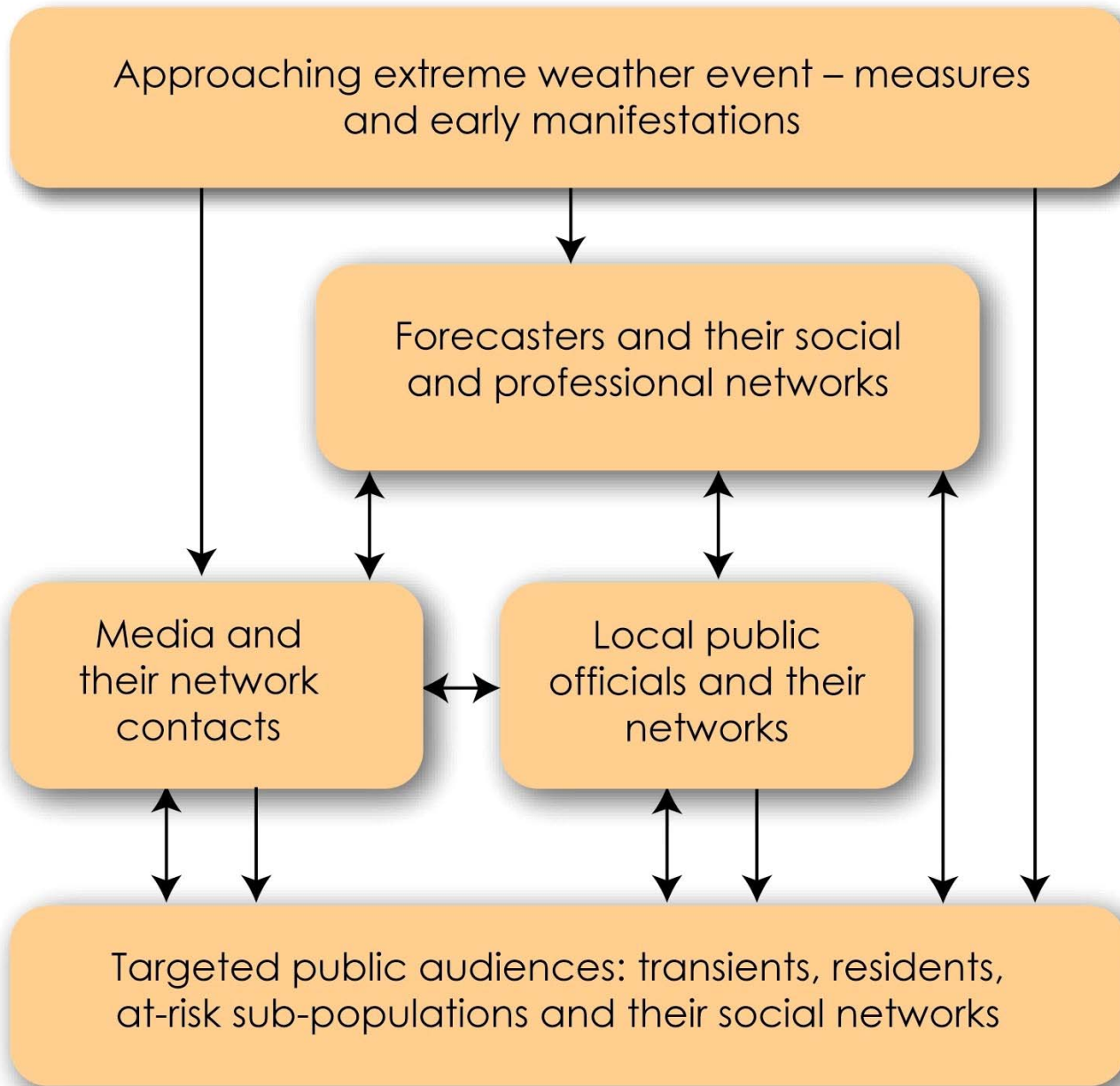
Hurricane and Flood Warning Decisions

- **Parallel studies**
  - **Flash floods in Boulder, Colorado**
  - **Hurricanes in Miami, Florida**

- **Methods**
  - **interviews, focus group discussions with forecasters, media, public officials**
  - **mental models with forecasters, media, public officials, members of public**
  - **stated-preference survey with members of public (Miami only)**
  - **multi-method synthesis**
  - **stakeholder workshop**

Researchers

Ann Bostrom – *Risk Communication*
Julie Demuth – *Meteorology / Communication*
Gina Eosco – *Communication*
Somer Erickson – *Emergency Management*
Brandi Gilbert – *Sociology*
Hugh Gladwin – *Sociology*
Matthew Jensen – *Mgmt. Information Systems*
Jeff Lazo – *Economics*
Claude Miller – *Communication*
Betty Morrow – *Sociology*
Rebecca Morss – *Meteorology*
Dan O'Hair – *Communication*
Kathleen Tierney – *Sociology*
Jennifer Thacher – *Economics*
Don Waldman – *Economics*

Advisors

David Bernard
Frank Billingsley
Luis Carrera
Christopher Davis
Mark DeMaria
Kelvin Droegemeier
Gene Hafele
Tim Heller
Greg Holland
Chuck Lanza
Max Mayfield
Bryan Norcross
Frank Redding
Jamie Rhome

Thank You!

Jeff Lazo – lazo@ucar.edu

Rebecca Morss – morss@ucar.edu

Julie Demuth – jdemuth@ucar.edu

www.sip.ucar.edu