

Toward improving forecast and warning systems

Ann Bostrom

“with a little help from my friends” – the Beatles

AFAC17

Sydney, Australia

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Three tasks are critical to improving hazard forecast and warning systems

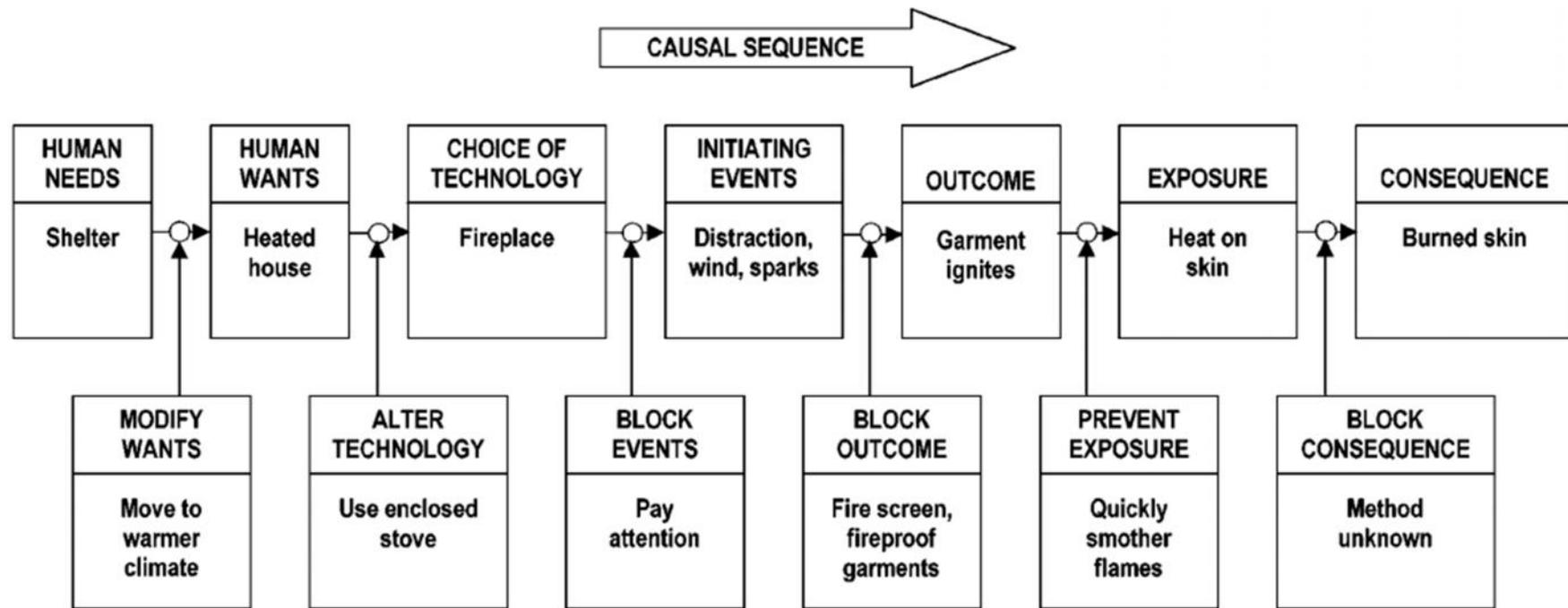
- 1) Understanding the risk decision and action context,
- 2) Identifying the commonalities and conflicts in interpretations of that context and associated risks, and
- 3) Clarifying what these insights mean for forecast and warning systems.

One way to address these tasks:

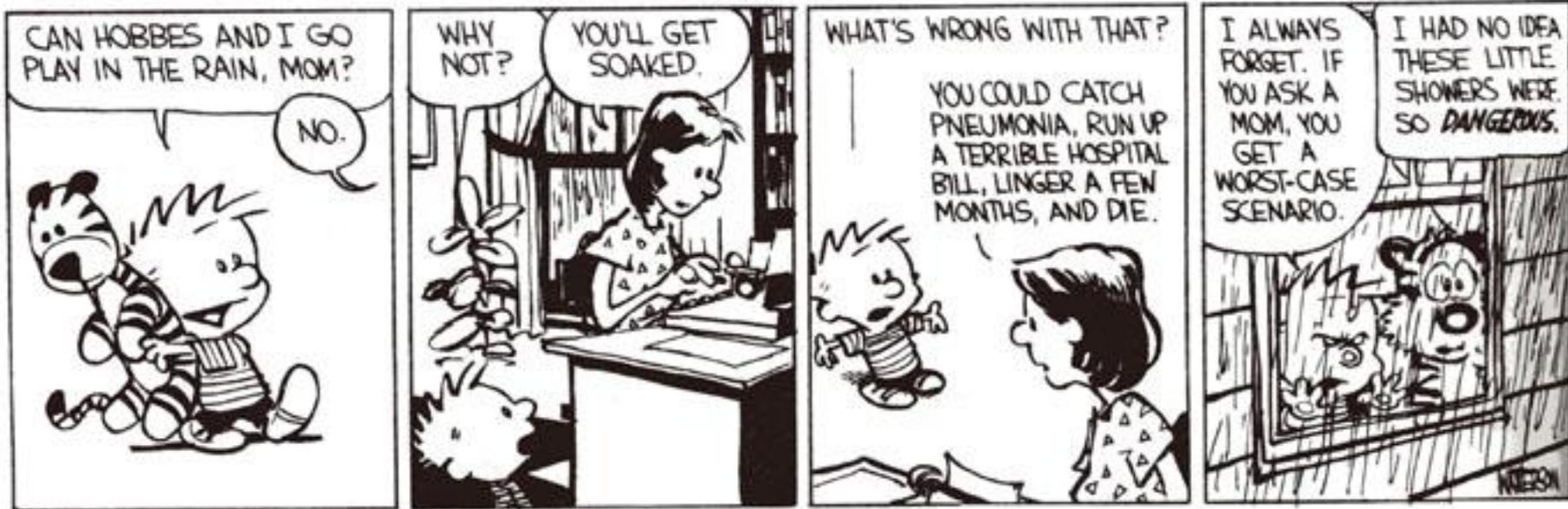
- Interdisciplinary research
 - on the risk decisions communities and professionals face,
 - the mental models they use to make those decisions, and
 - how these map to one another
- in partnership with those communities and professionals.

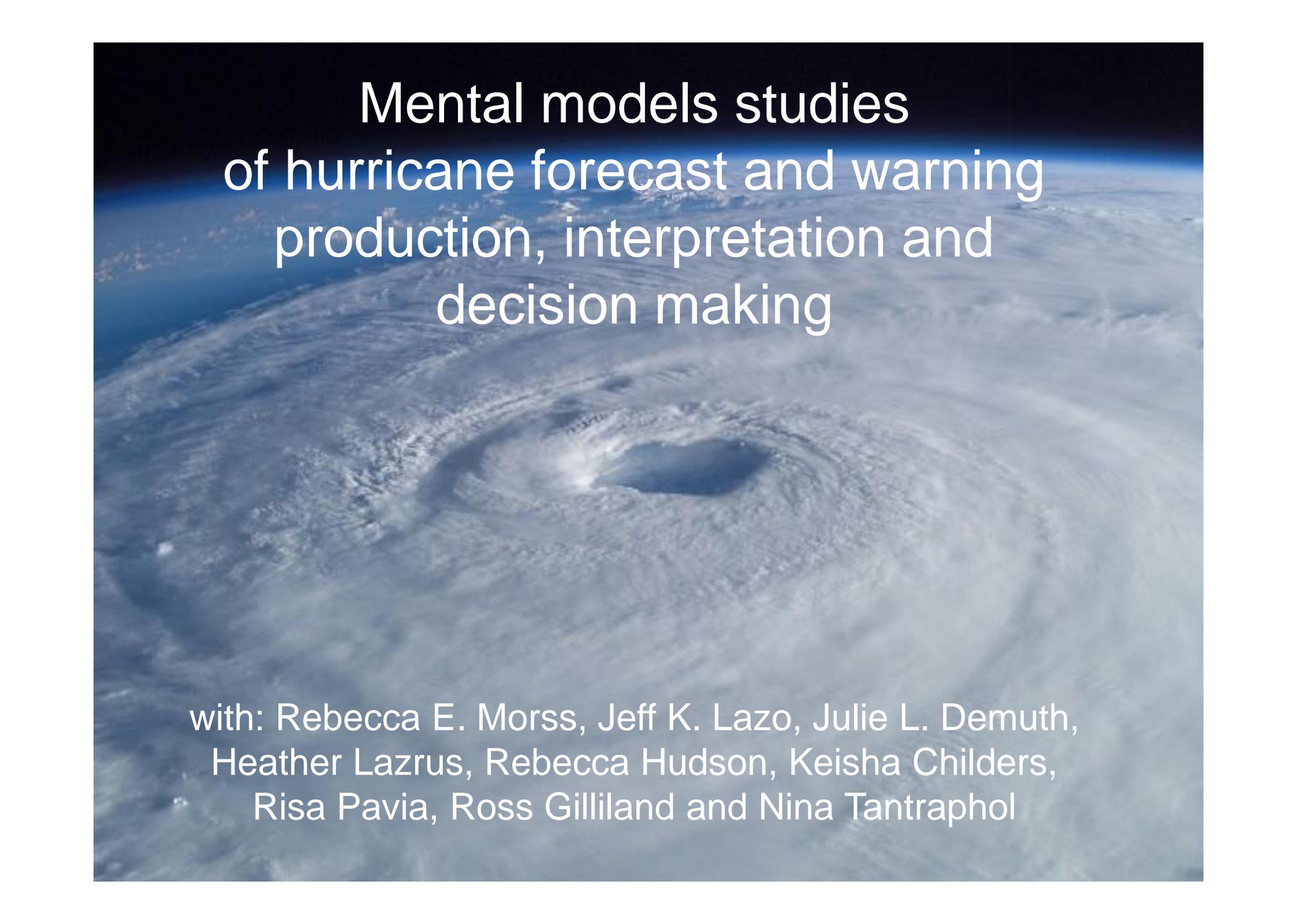
To illustrate this approach:

- Mental models research conducted on hurricane and flash flood forecast and warning systems, and
- Surveys of earthquake risk and early warning perceptions



from Kates, RW 2001. *Annual Review of Energy and Environment*, 26:1-26



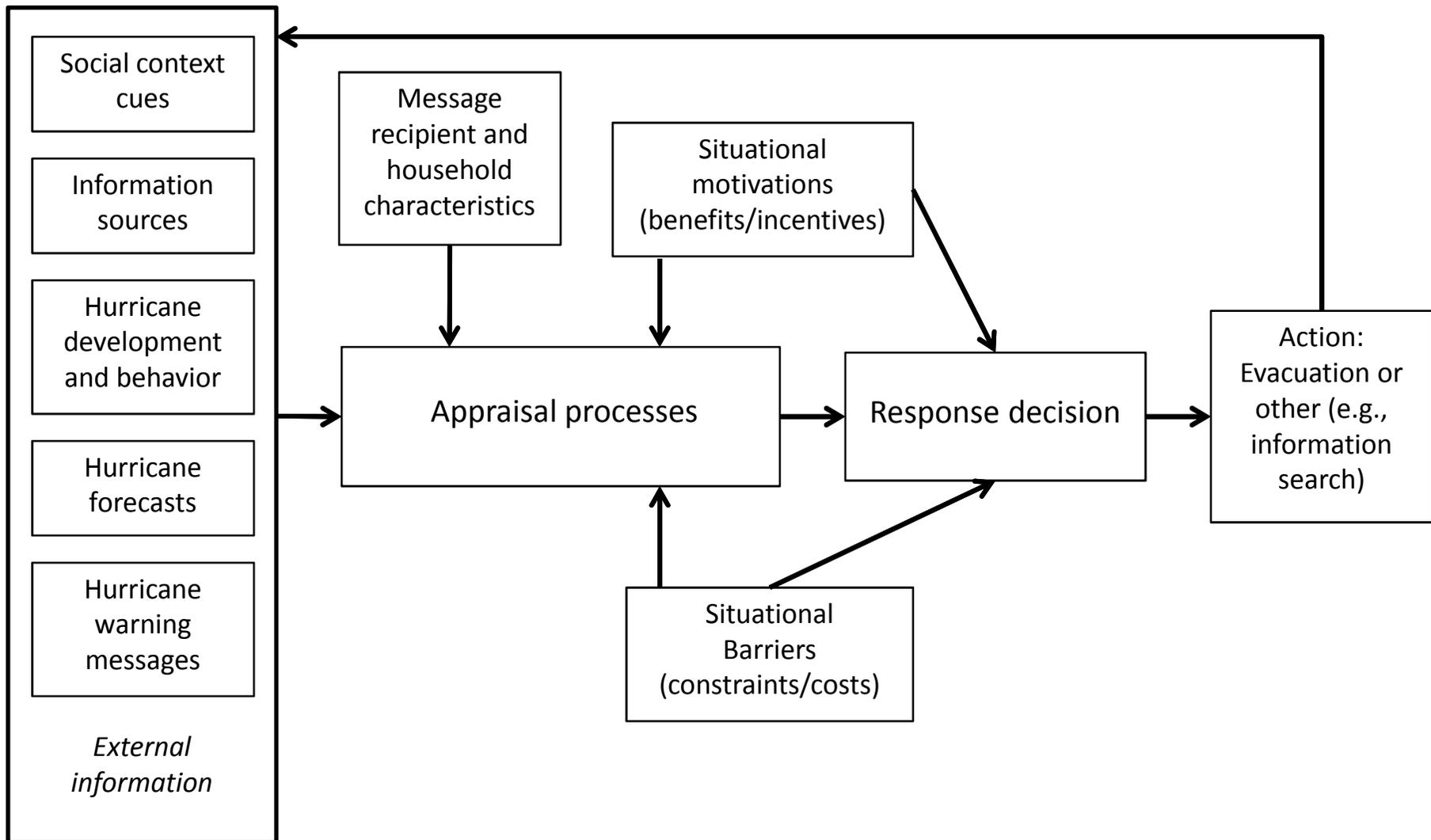
An aerial satellite-style photograph of a hurricane over the ocean. The hurricane's eye is a dark, circular center surrounded by a dense, swirling ring of white and grey clouds. The surrounding ocean is a deep blue, and the sky above is a lighter blue. The text is overlaid on the top half of the image.

Mental models studies of hurricane forecast and warning production, interpretation and decision making

with: Rebecca E. Morss, Jeff K. Lazo, Julie L. Demuth,
Heather Lazrus, Rebecca Hudson, Keisha Childers,
Risa Pavia, Ross Gilliland and Nina Tantraphol

Extreme Weather Event Risk Interpretation and Action

- 1) Understand the risk decision and action context
 - Hurricanes in Miami-Dade, Florida
 - Forecast and warning system as decision support
- 2) Understand the commonalities and conflicts in interpretations of the context and associated risks
 - Mental models interviews
 - Follow-on survey
- 3) Explore practical implications of these insights for risk management



From Lazo, J. K., Bostrom, A., Morss, R. E., Demuth, J. L., & Lazrus, H. (2015). Factors affecting hurricane evacuation intentions. *Risk analysis*, 35(10), 1837-1857.

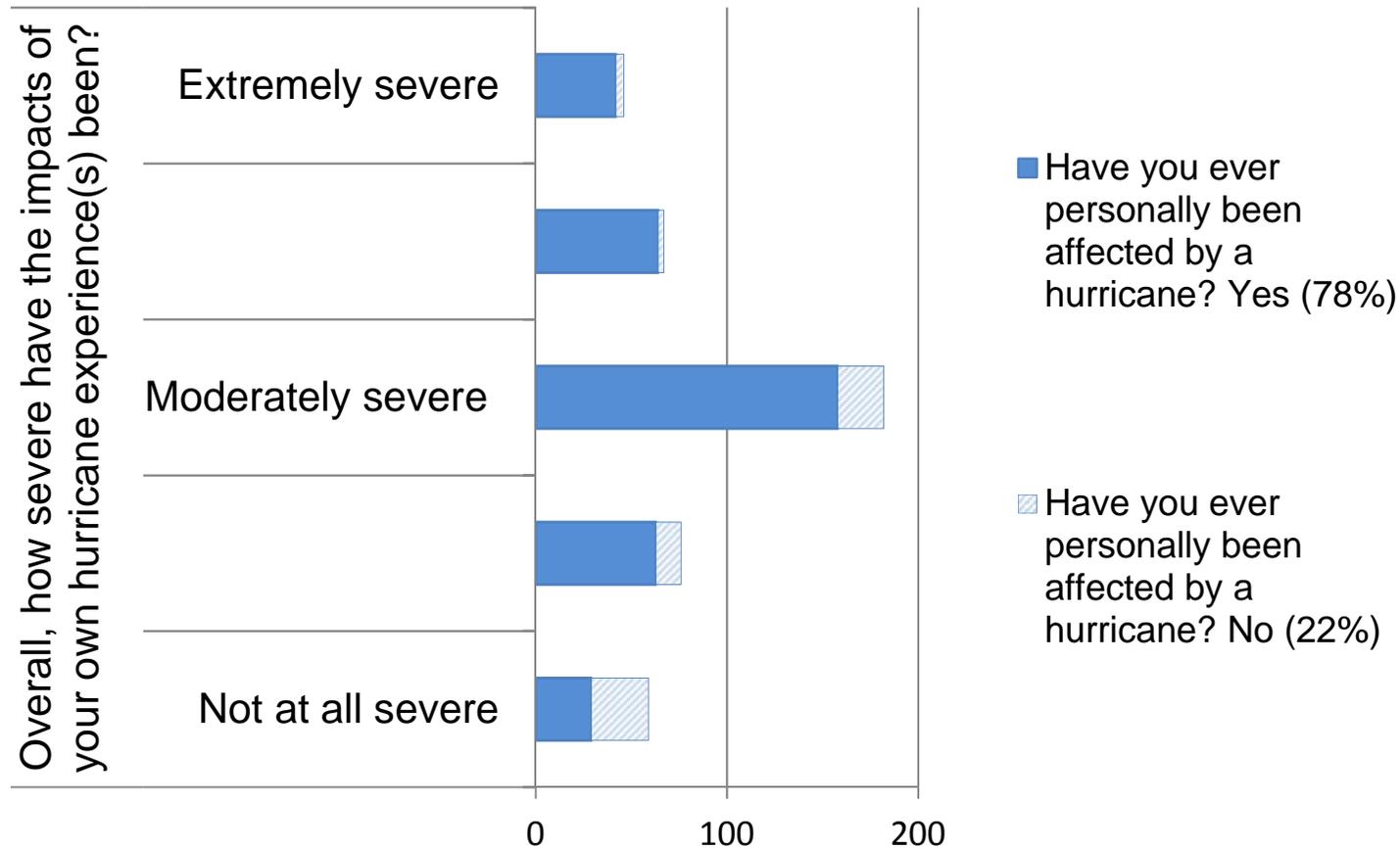
Methods: Data collection

- Forecast and warning system group decision modeling
 - National Hurricane Center (NHC) forecasters (n=4, of which 3 with PhD)
 - Miami-Dade Weather Forecasting Office (WFO) forecasters (n=4, of which 2 with BS, 2 MS)
- Individual mental models and decision making interviews
 - Public Officials (Emergency Managers) (n=6)
 - Broadcasters (n=5)
 - Miami-Dade residents (recruited via random digit dialing, face-to-face paid interviews, n=28)
- Knowledge Networks survey of representative sample
 - Florida hurricane counties, Miami-Dade (n=460)

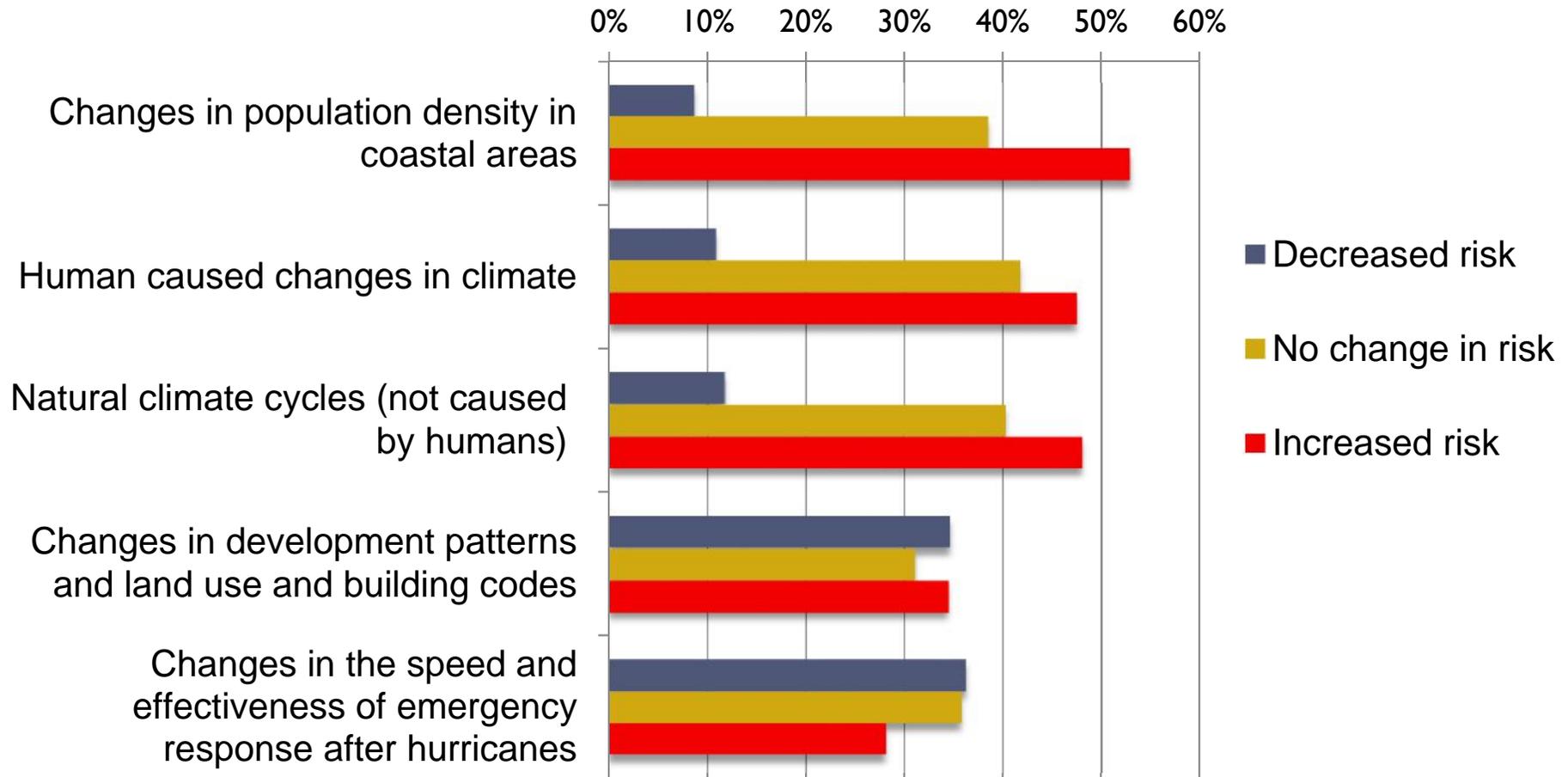
Hurricane culture

Hurricane experiences

(N=460, Florida) *Yes mean=3 Moderately severe; No mean=2.2*



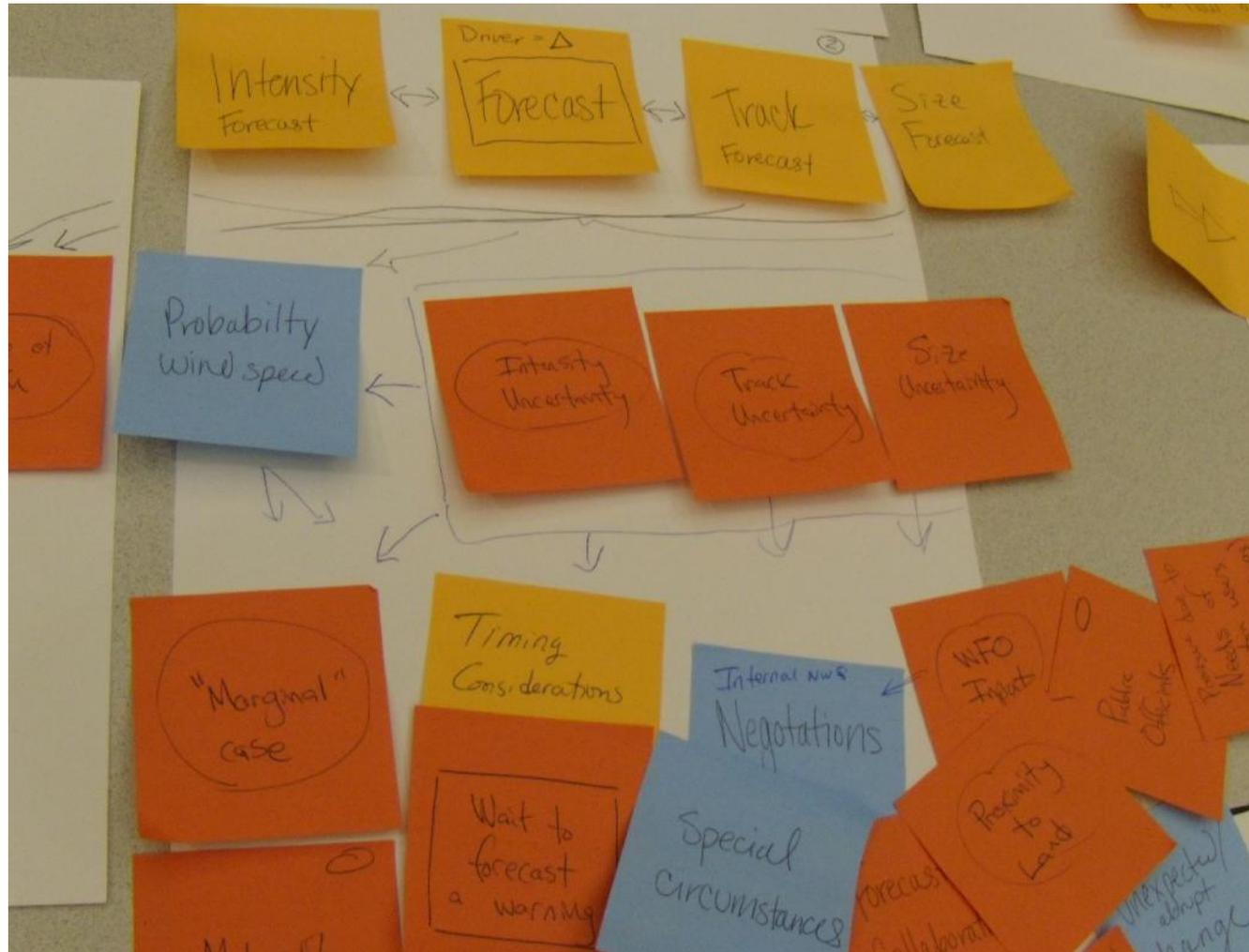
Perceived causes of changing risk (Florida, N=460)



Methods for study with forecasters: Mental models interview protocol

- **[General]** Tell me all about hurricanes ...(in Miami-Dade)
- **[Exposure]** What do you think determines whether or not a hurricane impacts Miami-Dade?
- **[Effects]** What risks are there from hurricanes?
- **[Mitigation]** What can or should be done, if anything, to reduce risks from hurricanes? ...
- **[Hurricane Warning Experience]** Describe the most recent, memorable hurricane warning or watch that you made.... How did you go about making that decision to warn? ...
- **[Influence diagram]** .. List all of the key factors that influence forecasters' hurricane warning decisions. Explain warning scenario with diagram.

Group diagramming exercise



Coding

- Interviews recorded and professionally transcribed verbatim.
- First sections of first interview (NHC1) coded iteratively by three coders.
- All interviews coded independently by two coders (blind to hypotheses).
- Reliability calculated by section and overall, using Freelon's ReCal, Cohen's Kappa (Kappa ranged from 0.48 to 0.82 for full interviews)

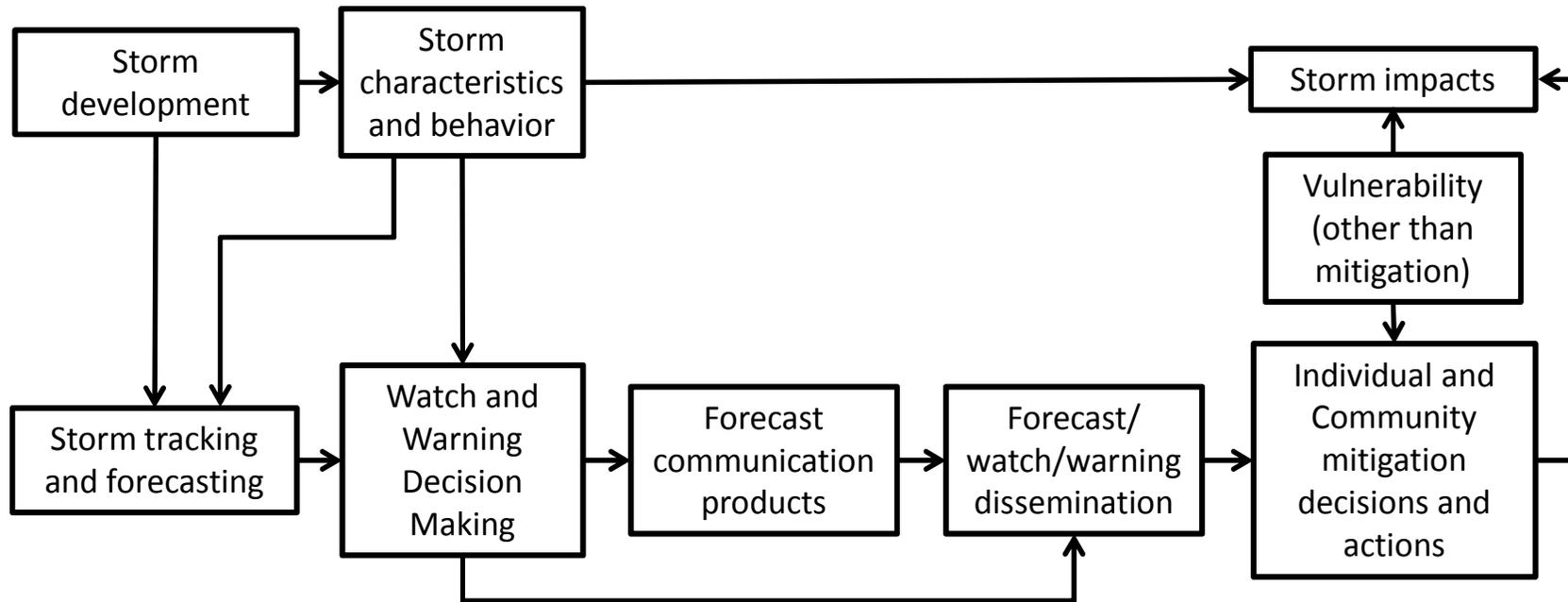
$$\frac{P_o^2 P_e}{1^2 P_e}$$

Tell me about hurricanes...

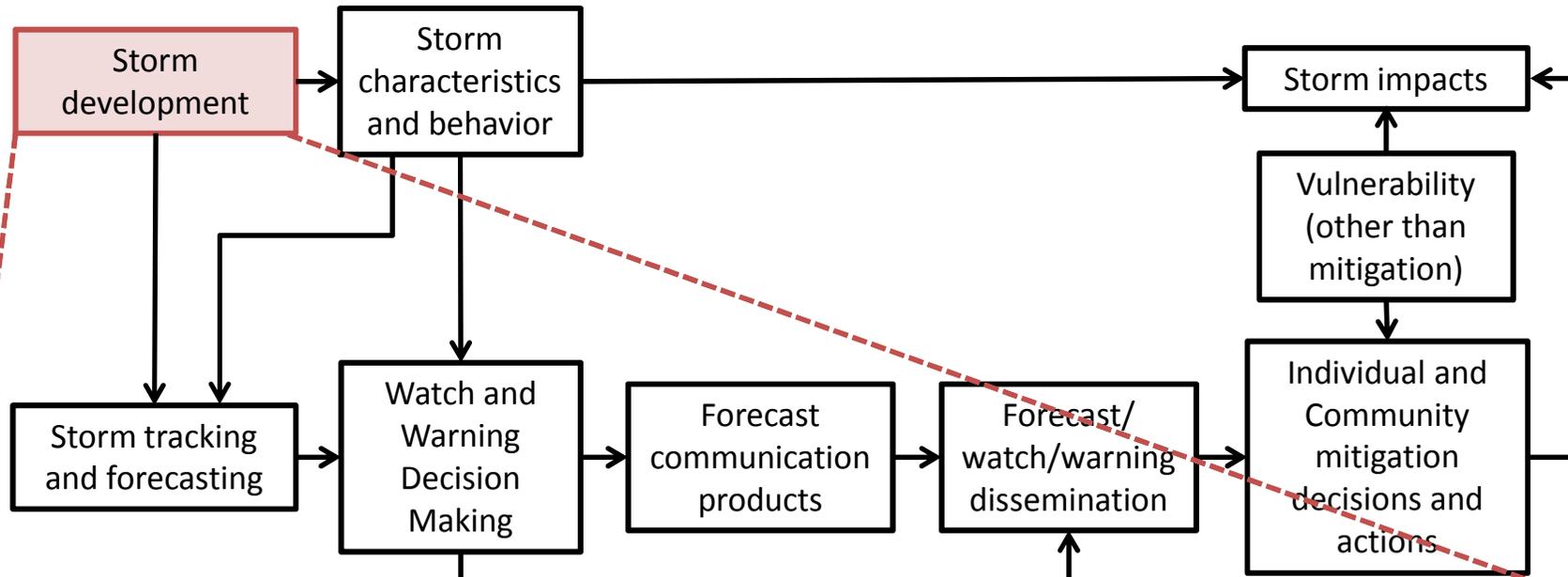
forecasters talked about:

- Storm development
 - storm's location, wind speed and category designation, season (timing), water temperature, pre-existing disturbances, and long-term trends and patterns
- Storm behavior
 - wind speed designation at which point storms either get a name or reach hurricane designation, storm surge.
- Vulnerability to hurricanes
 - person's hurricane experience and perceptions of risk
- Mitigation efforts
 - hurricane education, evacuation procedures (shelter, inland, distant, etc.)

Hurricane Forecast and warning system

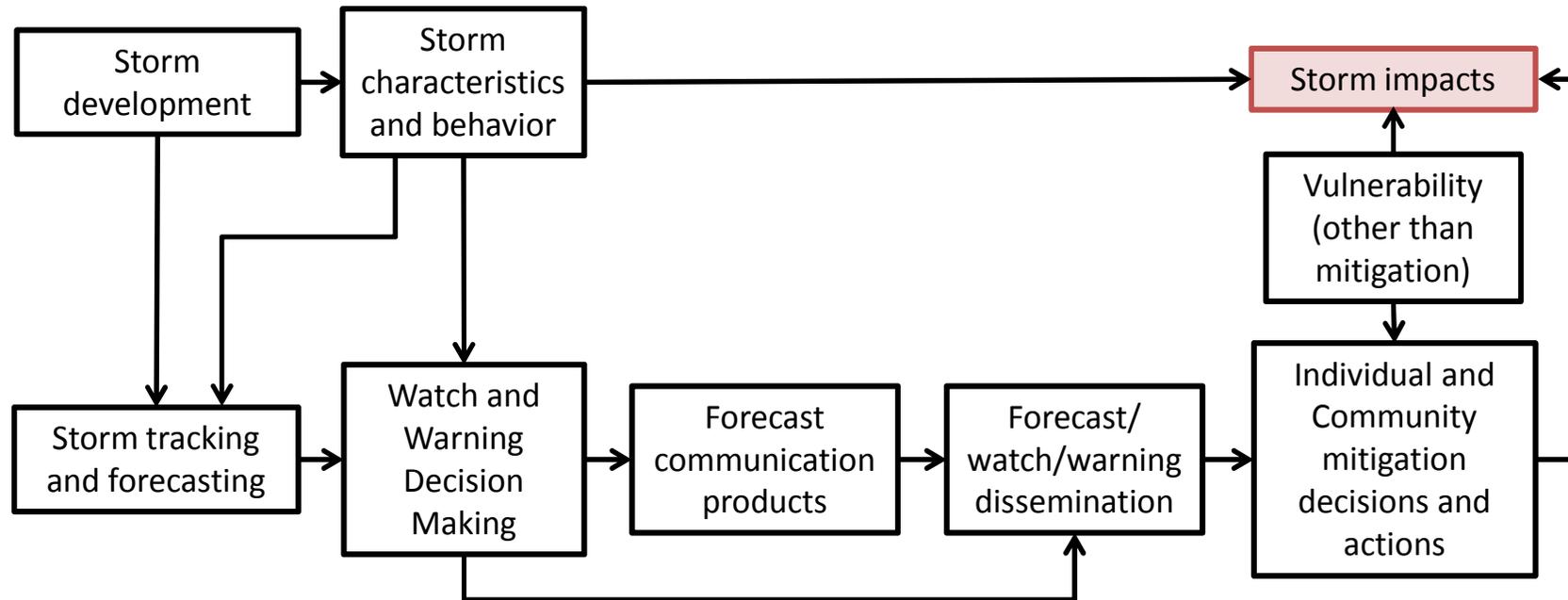


Hurricane Forecast and warning system

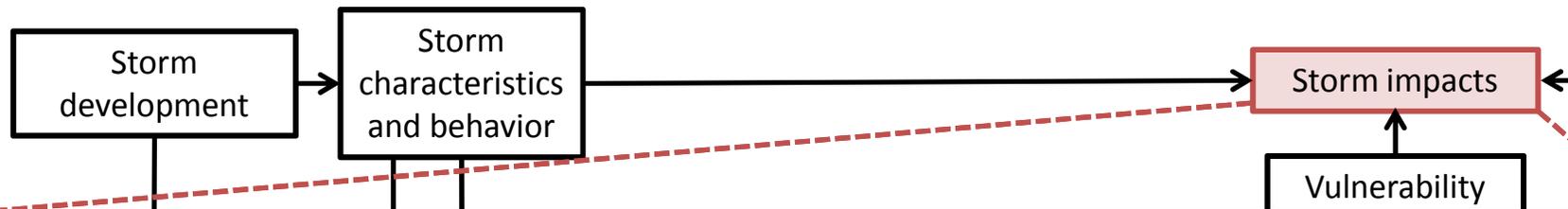


NHC (n=3)	WFO (n=4)	PO (n=6)	BR (n=5)	Public (n=28)	
33	25	-	-	7	Storm Development
100	100	50	80	71	Location (Atlantic Basin, over tropics)
100	50	33	40	54	Season (timing) - June 1- November 30, most likely August-October
67	100	67	40	57	Water (sea surface) temperature (greater than 80 deg F)
100	100	67	100	57	Pre-existing disturbances (e.g., tropical wave, tail end of cold front, upper level low, thunderstorm cluster)
100	50	17	40	14	Tropical depression formed
100	100	83	80	54	Long-term trends and patterns (cycles)
67	-	17	20	21	Climate change

Hurricane Forecast and warning system



Hurricane Forecast and warning system



NHC (n=3)	WFO (n=4)	PO (n=6)	BR (n=5)	Public (n=28)	
100	75	33	20	11	Storm Impacts
100	100	67	100	7	Flooding from storm surge
100	100	100	80	79	Inland flooding
-	50	33	20	25	Human health impacts
100	100	100	80	100	Death
67	75	83	80	82	Injury
33	75	83	40	54	Psychological trauma
100	75	83	100	75	Physical impacts
100	100	100	100	100	Property damage and destruction
100	100	100	100	89	Damage to power system and loss of power
100	75	67	80	46	Damage to drinking water system and lack of water
100	50	83	80	57	Damage to infrastructure / transportation system (roads, public transport)
-	75	67	60	61	Damage to land / land reconfiguration
67	50	100	80	79	Social/Economic impacts
67	25	67	40	61	Homelessness (temporary or permanent)
67	50	33	100	50	Cash shortages
100	100	100	100	68	Wind damage

Storm surge

- **NHC1, line 105:** “I mean that’s the main reason why we want people evacuated-from storm surge.”
- **NHC4, line 194:** “And then - so storm surge has the largest potential to kill the largest number.”
- **WFO1, line 190:** “With a strong hurricane, the storm surge would be probably the second biggest risk, because of the high winds and the effect that’s going to have on the - the magnitude of the surge right at the coast.”
- **WFO4, line 0137:** “Well, for sure the main threats out of this whole thing if it is to people first it is definitely storm surge.”

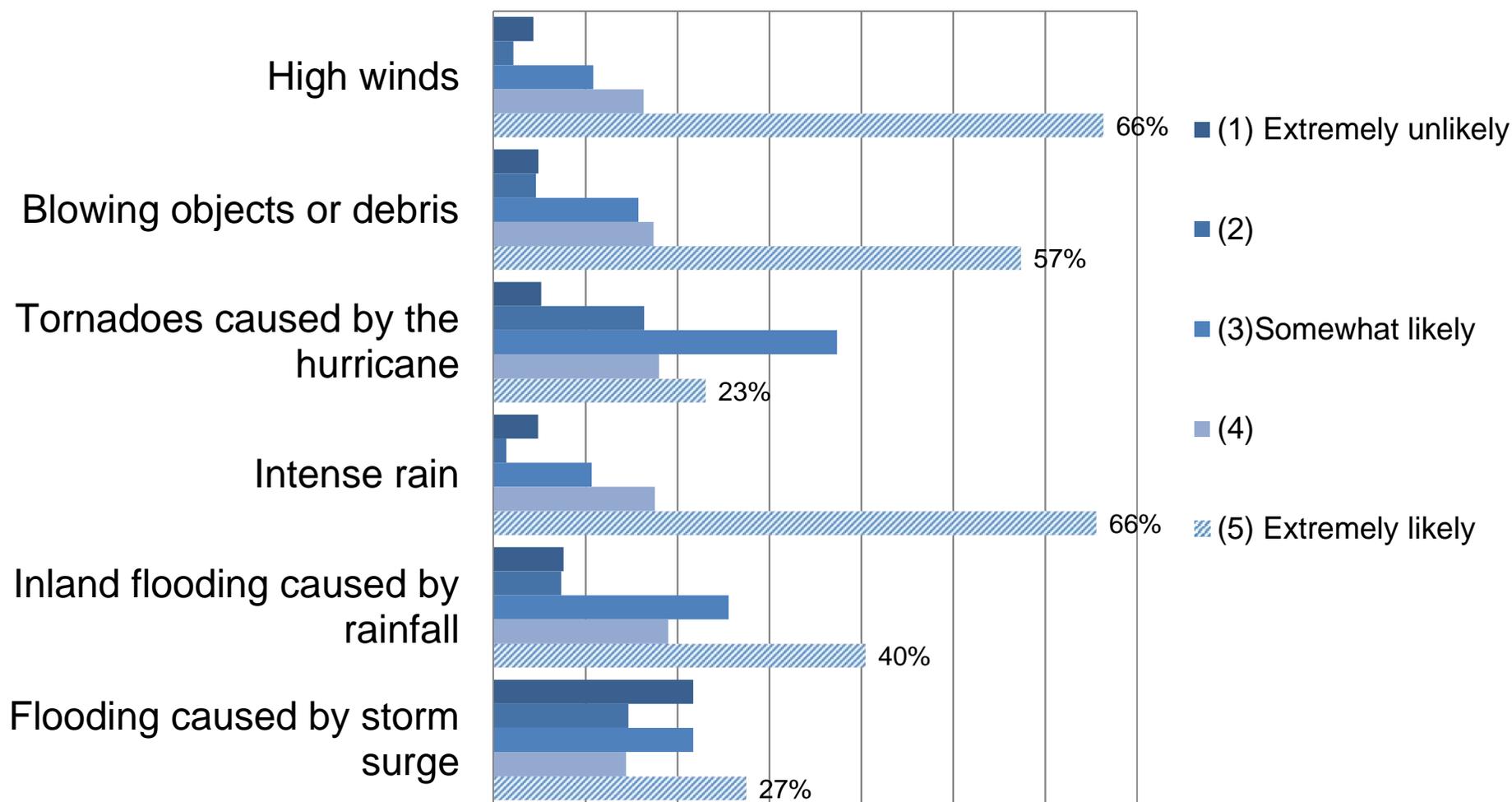
Storm surge: open-ended responses on questionnaire from public interviews

- Have never thought of storm surge since am inland and no flood zone. Would turn to media to explain and follow their recommendation.
- Wind speed is the key. If it got too strong it could blow my house down so I would go to a shelter with my family. I don't worry about storm surge too much.
- Storm surge is not as threatening because I live in an apartment in a multi-story building. However, wind speed is more threatening since all buildings and properties are exposed to wind elements.

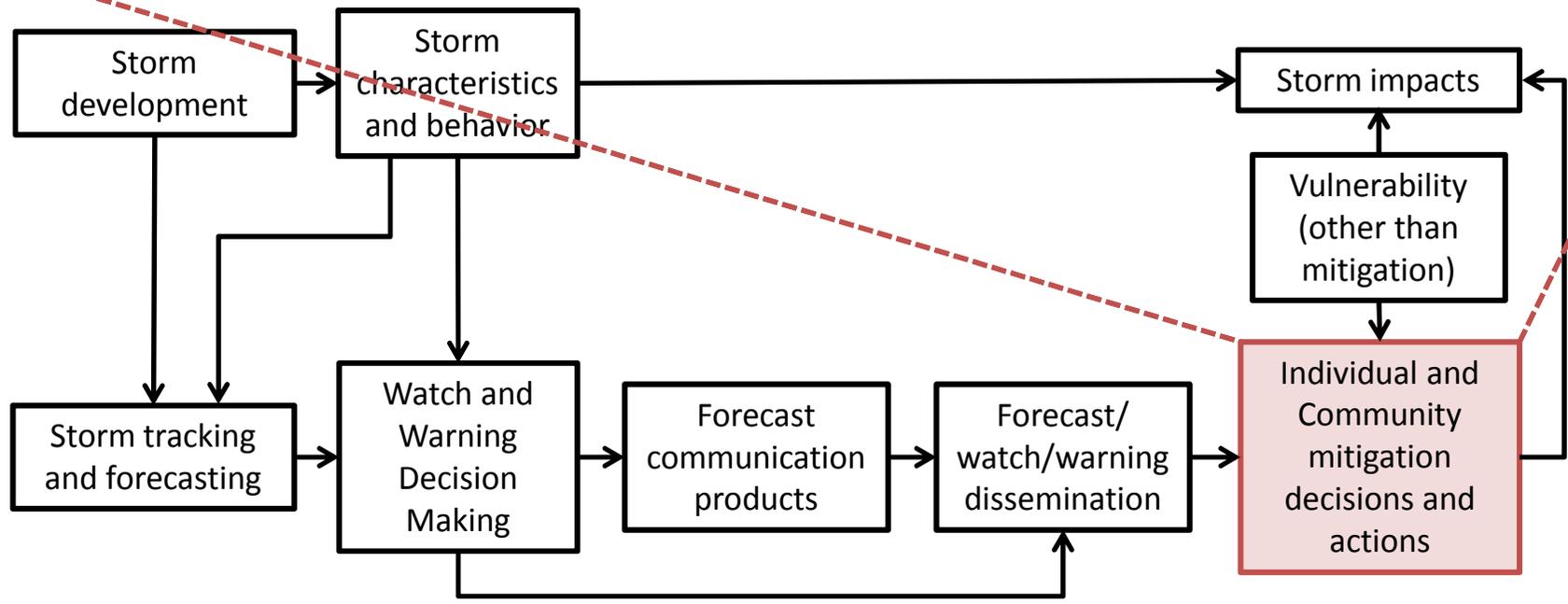
How likely would each of the following conditions be in the general area where you live if a major hurricane (Category 3 or higher) hit your area?

Florida, Miami-area (N=460)

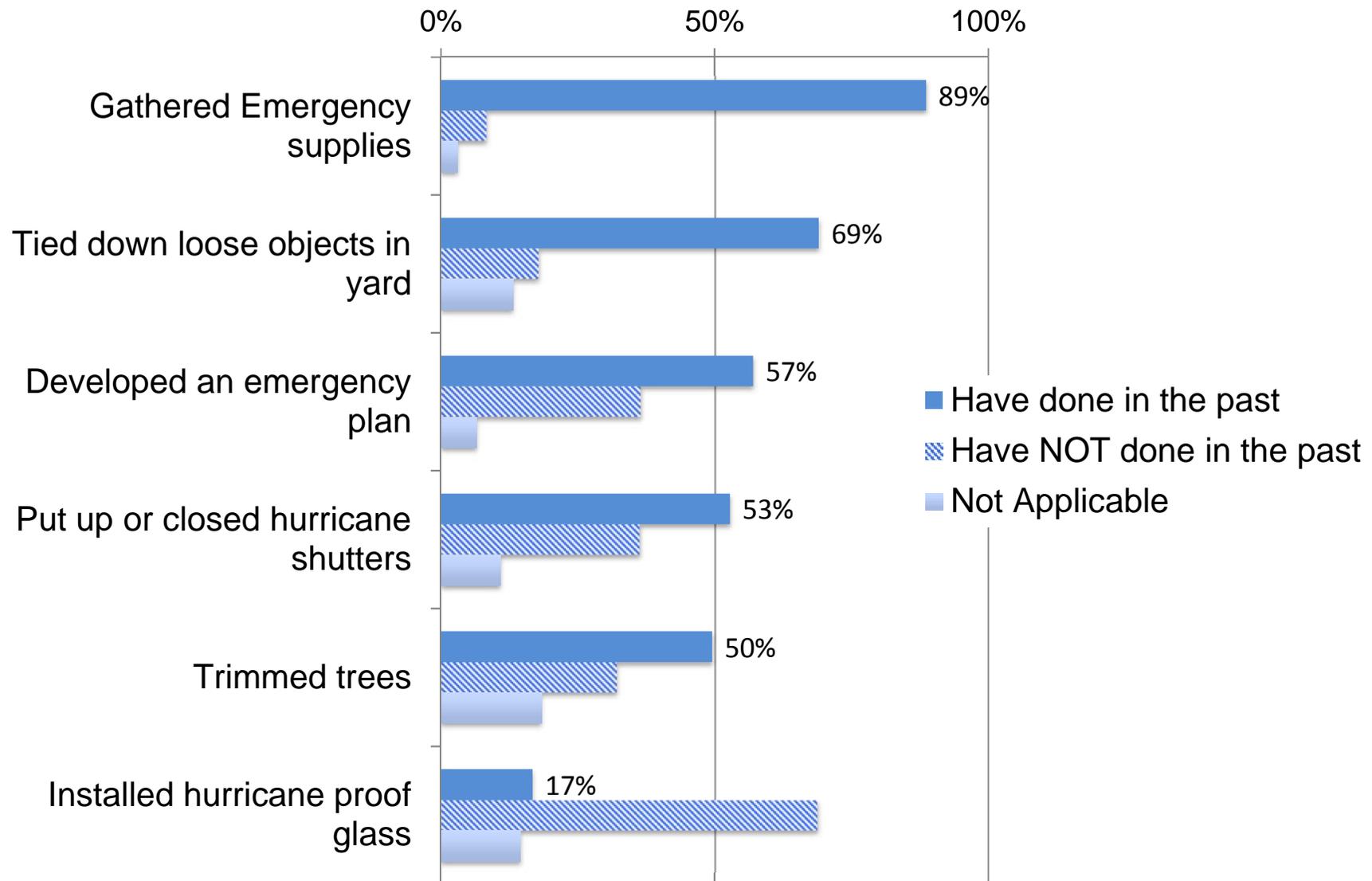
0% 10% 20% 30% 40% 50% 60% 70%



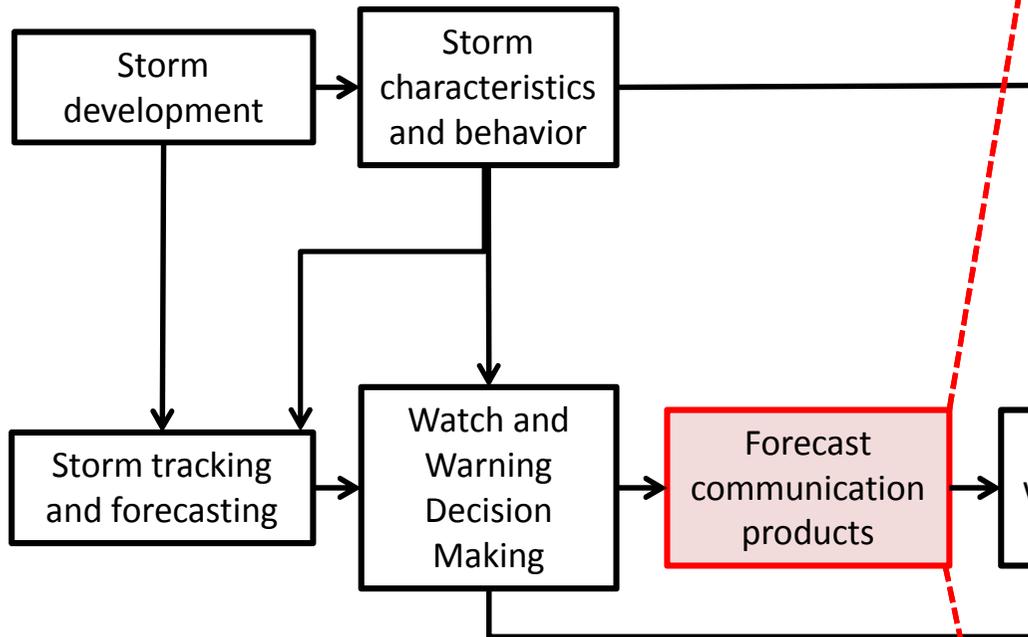
NHC (n=3)	WFO (n=4)	PO (n=6)	BR (n=5)	Public (n=28)	
100	75	83	60	50	Individual and Community Mitigation Actions and Decisions
100	100	100	100	96	Hurricane education (knowledge of evacuation zones, of preparations, of forecasts)
67	50	33	80	68	Have insurance?
100	100	100	100	57	Building codes and land use planning
100	75	100	100	96	Home protection (storm shutters - for season or for storm)
100	100	100	100	96	Emergency supplies (food, water, medicine, generator)
67	75	50	20	29	Moving/migration (from danger area)
100	100	100	80	89	Evacuation (none, shelter locally, inland, distant)
33	25	83	60	75	Secure loose property (e.g., cars, boats)
-	50	67	60	39	Trim trees



Which of the following have you done to prepare for a hurricane threat in the past? (Florida survey, N=460)



Hurricane Forecast and warning system



	NHC n=3	WFO n=4	PO n=6	BR n=5	Pub n=28	
	33	-	17	20	-	Forecast/Watch/Warning Communication Products
	100	25	17	-	7	NHC products and information output
	100	50	67	60	32	Cone graphic (3- and 5-day cones of uncertainty with an
	100	-	-	-	-	Other graphics (34-, 50-, and 64-kt wind speed probability
						historical wind swath; extent of watches and warnings)
	33	25	-	-	-	Storm surge forecasts
	-	-	-	-	-	Deterministic SLOSH runs (at issuance of hurricane wa
	67	-	-	-	-	Probabilistic storm surge (at issuance of hurricane wa
	100	25	-	-	-	Maximum wind speed probability forecasts (table) ***
	-	-	-	-	-	Gale warning (not formally issued for tropical cyclones)
	-	-	-	-	-	Eye wall wind warning (tornado warning for eye wall wir
	67	-	-	-	-	Tropical Cyclone Forecast/Advisory, Tropical Cyclone Wa
	33	-	-	-	-	(TCV; tabular data for software)
	33	-	-	-	-	Meteorological hazards (e.g., rainfall amounts, storm su
	-	-	-	-	-	Watches and warnings in effect (tropical storm, hurrica
	-	-	-	-	-	Forecaster discussion of observations and forecast reas
	-	75	-	-	-	WFO products and information output
	33	75	-	-	-	Inland hurricane watch/warning
	-	75	-	-	-	Coastal flood warning
	-	100	-	20	-	Hurricane local statement (HLS) and other products
	-	75	-	-	-	Text (HLS, public and marine forecast products)
	-	50	-	-	4	HLS graphic (tropical cyclone impact graphics: coastal f
						impact, marine threat, tornado threat, wind threat)
	-	-	-	-	-	Hazards graphics (e.g., lightning, hail, rip currents)
	-	25	-	-	-	Information about potential tropical cyclone threat (i.e.,
	-	100	17	-	11	text)
	-	100	-	-	-	Information prior to watch (i.e., public information state
	-	75	-	20	-	Information about threats during an event
	-	50	-	20	-	Information about threats during an event: tornado wa
	-	75	-	-	-	Information about threats during an event: flash flood
	-	100	-	-	-	Information about threats during an event: short-term
	-	75	-	-	4	Information about threats during an event: special wea
	-	25	-	-	-	Information about threats during an event: severe thur
	-	25	-	-	-	Information about threats after an event
	100	50	50	60	61	Storm Prediction Center products
	-	-	-	20	-	Media products
						Variants on NHC cone graphic

Cones of uncertainty



Describe the most recent, memorable—probably recent if you can—situation where you heard a hurricane warning?

Well I heard it on the news. And uh they—they show like the...the map of Florida. And they show hurricane warning for this part of Florida to this part of Florida. And it's all in red. And if the hurricane's going to for sure come then this cone of death — they call it the cone of uncertainty, we call it the cone of death.
(#26)

Cones of uncertainty

Can you tell me any more specifics about the hurricane warning or forecast? Anything specific? Yeah.

No, I mean just that you really don't know what it's going to do until it actually gets there. 'Cause they're kind of...they're –yeah they have that track, that cone that they follow, but I mean it could really do anything up until like it's pretty much on top of you already.

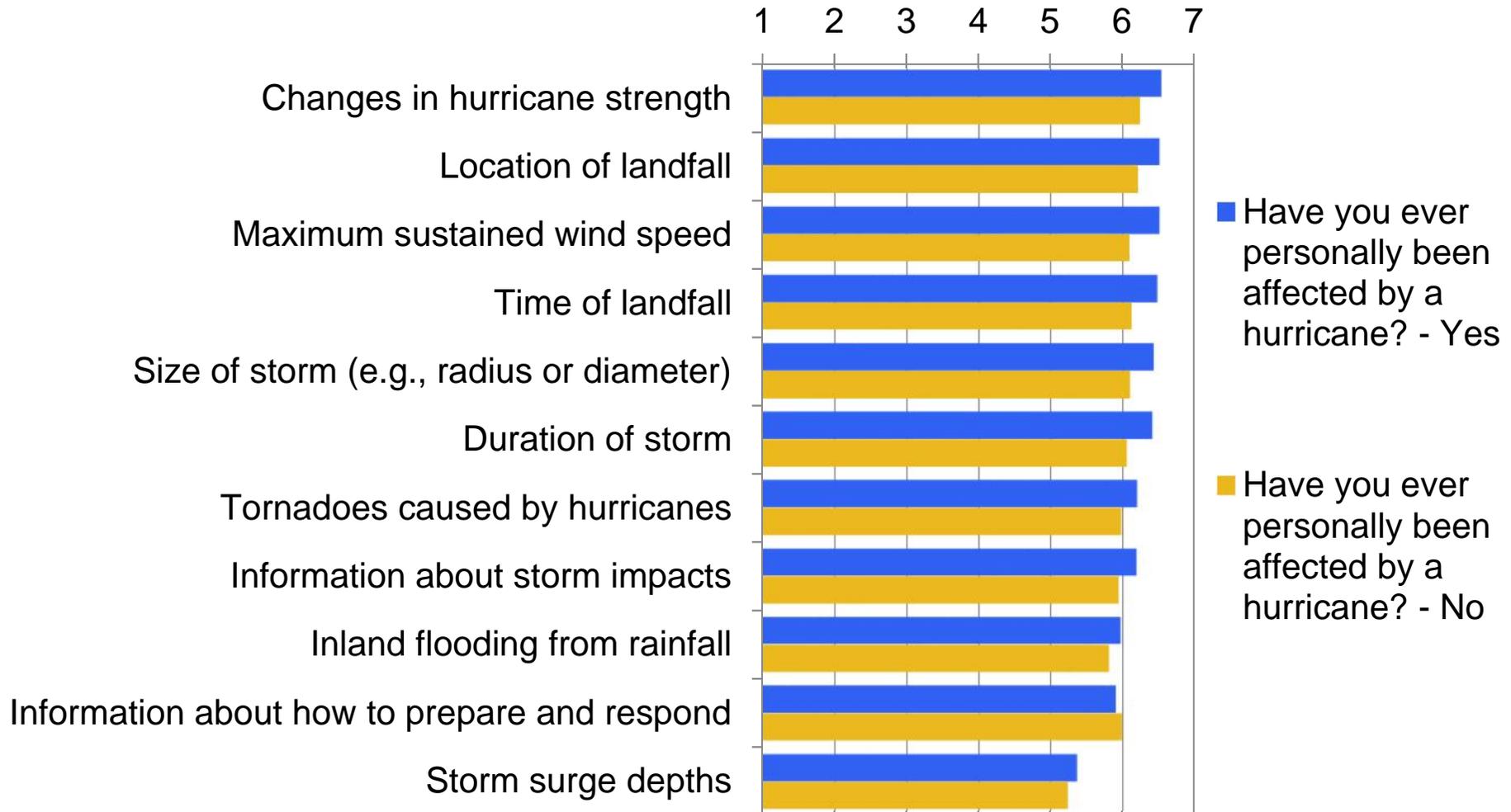
So how can a person find out if there is a risk of an approaching hurricane at a specific location? Like what the risk is at their home or where they work?

Well, I don't know that you can do that. I don't think that the prediction machine is that specific. As a matter of fact, they will tell you don't follow the little black line. Follow the cone—which openly we call it the cone of confusion because it spreads out... (public interview #23)

Forecast and warning information

How useful to you personally is the following information that may be provided with a hurricane forecast?

(1=Not at all useful, to 7=Extremely useful)



Implications for risk management

Results suggest opportunities for further improving the forecast and warning system, with regard to:

- Coordination within the system, between National Hurricane Center, Weather Forecasting Offices, Public Officials, and Broadcasters
- Surge and flood risks
- Proliferation of forecast products and presentation of uncertainty
- Cone of uncertainty

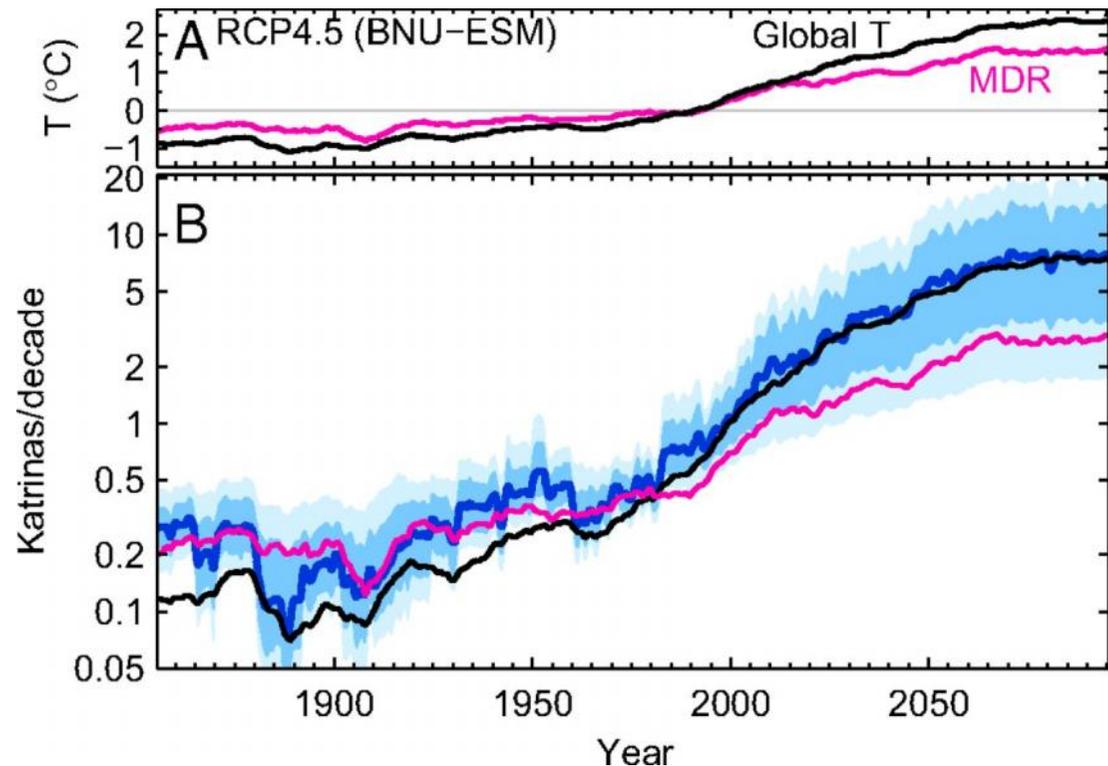
“The cone is so wide, let’s narrow down the cone.

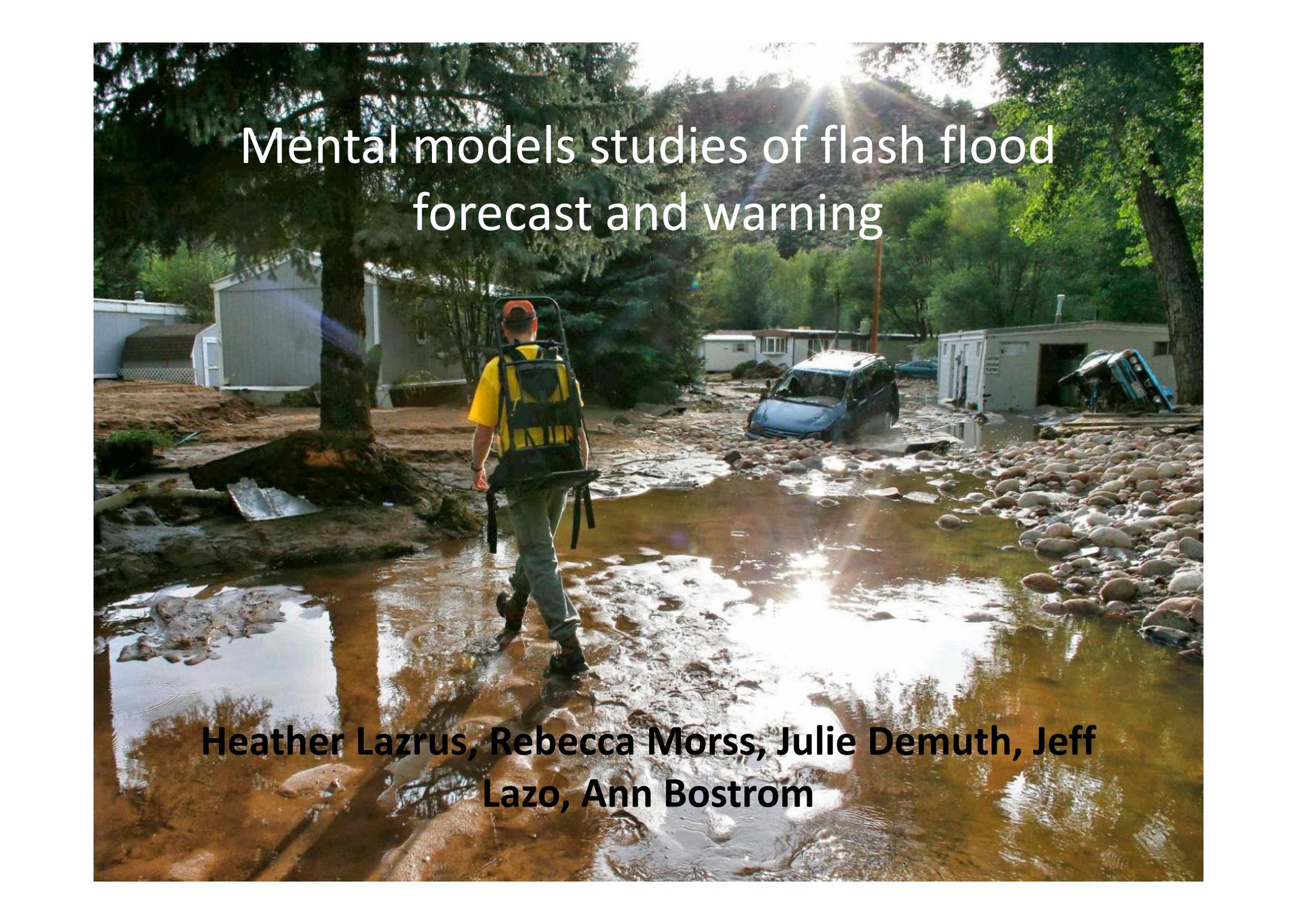
To say that the entire State of Florida is under a risk is a gross exaggeration.” (public interview #8)

Increasing storm surge hazard

- .."we estimate a doubling of Katrina magnitude events associated with the warming over the 20th century"

Grinsted A *et al.* PNAS
2013; 110:5369-5373



A photograph showing a person from behind, wearing a yellow shirt, a red cap, and a large black backpack, wading through a flooded residential area. The water is murky brown and reflects the sun. In the background, a blue car is partially submerged in the water, and a white building is visible. The scene is surrounded by trees and a hillside in the distance.

Mental models studies of flash flood forecast and warning

**Heather Lazrus, Rebecca Morss, Julie Demuth, Jeff
Lazo, Ann Bostrom**

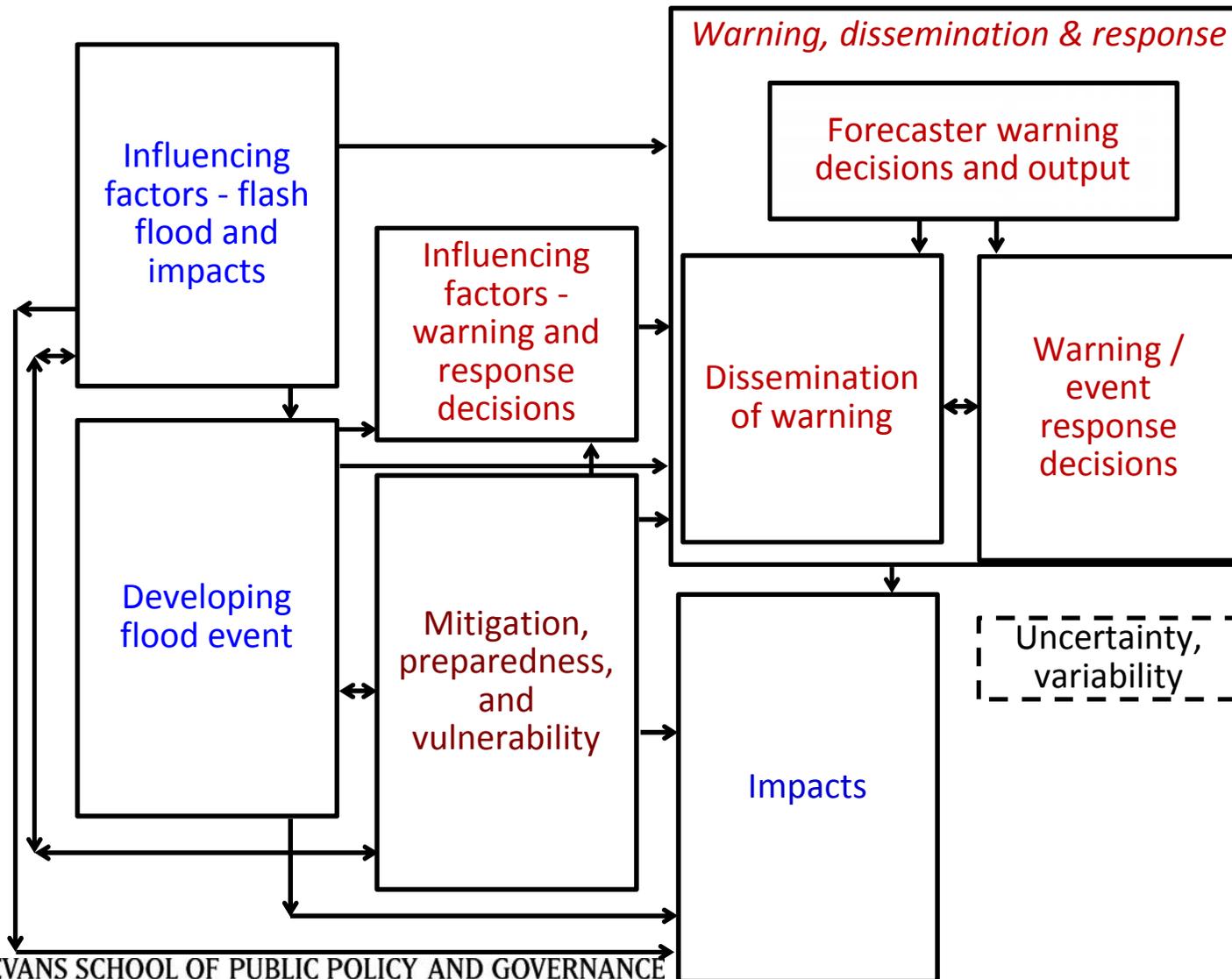
Mental models interviews

- *General*: “Tell me about flash floods....”
- *Exposure*: “What do you think determines whether there is flash flooding in Boulder?”
- *Effects*: “What risks are there from flash floods?”
- *Mitigation*: “What can or should be done, if anything, to reduce risks from flash floods?”
- *Flash flood warning experience*: “Describe the most recent flash flood warning you were involved in.”

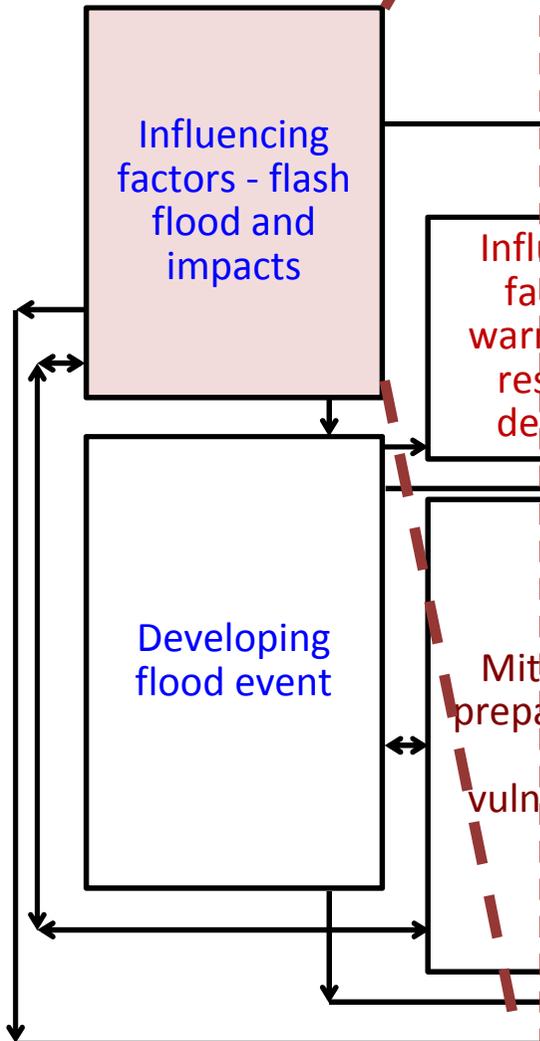
Data analysis

- Use group diagramming exercise to develop initial expert model and associated coding scheme
- Code individual expert interviews, revising expert model and coding scheme to incorporate relevant concepts

Expert Model



Expert Model Concepts → Coding Scheme



- 10000 **Drivers for flash floods and impacts**
- 11000 **Meteorological factors/environment (antecedent)**
- 11100 Moisture in air
- 11200 Atmospheric circulation / flow patterns
- 11210 Upslope atmospheric flow
- 12000 **Hydrological and geographic factors**
- 12100 Antecedent hydrological conditions
- 12200 Characteristics of built environment, land surface, and hydrology
- 12210 Land surface, land use, soil properties
- 12211 Burn area, fire
- 12212 Impervious ground (e.g., concrete, rock)
- 12213 Vegetation cover
- 12240 Floodwater engineering, storm water infrastructure
- 12250 Creeks and streams, areas along creeks and streams
- 12260 Collection and channeling of water flow
- 12300 Number of people / population density
- 12310 Rural area
- 12320 Urban area
- 12400 Terrain / Elevation / Topography
- 12410 Mountains / Foothills
- 12411 Steep slopes / gradients
- 12412 Canyons (e.g., Boulder Canyon)
- 12420 Low-lying locations/roads, basements
- 12430 Higher locations
- 12500 Floodplain, floodway, flood zone
- 13000 **Dam break (e.g., Barker Dam)**
- 16000 **Force of god/nature**
- 17000 **Climate variability and/or change**
- 14000 **Timing factors - influence on flooding**
- 14100 Time of day
- 14110 Afternoon
- 14120 Evening, night
- 14130 Other times of day (not afternoon or evening-night)
- 14200 Time of year
- 14210 Spring (April-June)
- 14220 Late summer / monsoon season (July-Aug)

Data analysis

- Use group diagramming exercise to develop initial expert model and associated coding scheme
- Code individual expert interviews, revising expert model and coding scheme to incorporate relevant concepts
- Code public interviews using coding scheme from expert model
- Quantitative content analysis & qualitative analysis of coded expert and public interviews

% of each expert group mentioning each concept

	Forecasters	Officials	Media
11000 Meteorological factors/environment (antecedent)	83	100	67
11100 Moisture in air	83	50	50
11200 Atmospheric circulation / flow patterns	83	50	67
11210 Upslope atmospheric flow	67	13	0
12000 Hydrological and geographic factors	33	75	50
12100 Antecedent hydrological conditions	83	100	100
12200 Characteristics of built environment, land surface, and hydrology	100	100	83
12210 Land surface, land use, soil properties	50	38	17
12211 Burn area, fire	33	38	83
12212 Impervious ground (e.g., concrete, rock)	67	50	50
12213 Vegetation cover	33	25	67
12240 Floodwater engineering, storm water infrastructure	67	50	50
12250 Creeks and streams, areas along creeks and streams	100	88	100
12260 Collection and channeling of water flow	100	100	100
12300 Number of people / population density	50	100	67
12310 Rural area	67	25	50
12320 Urban area	50	38	50
12400 Terrain / Elevation / Topography	100	88	100
12410 Mountains / Foothills	100	88	100
12411 Steep slopes / gradients	33	50	67
12412 Canyons (e.g., Boulder Canyon)	100	100	33
12420 Low-lying locations/roads, basements	100	88	83
12430 Higher locations	50	88	50
12500 Floodplain, floodway, flood zone	83	88	67
13000 Dam break (e.g., Barker Dam)	50	63	17
16000 Force of god/nature	0	25	17
17000 Climate variability and/or change	0	38	17
14000 Timing factors - influence on flooding	0	13	0

What is a “flash” flood?

	<i>WFO</i>	<i>PO</i>	<i>BR</i>	<i>Exp</i>	<i>Pub</i>
Happens quickly, lack of warning	100	100	100	100	69

- *Experts*
 - The “whole flash part of it is that that could **change so quickly**. You know the same situation might be unsafe a minute later or 10 seconds later.” (forecaster)
 - “The whole idea of a flash flood is the idea that it **happens so fast that you have very, very little time to react**” (public official)
- *Public*
 - “The whole point of flash floods is the flash part, **so you don’t have time ... the surprise factor.**” (25)
 - “I think ...[a flash flood] could happen within **a few days or a week** or like if it rains in the next week.” (15)

Seasonality of flash flood risk

	WFO	PO	BR		Exp	Pub
Spring (April-June)	33	88	83		70	92
Late summer (monsoon, July-August)	100	100	83		95	35

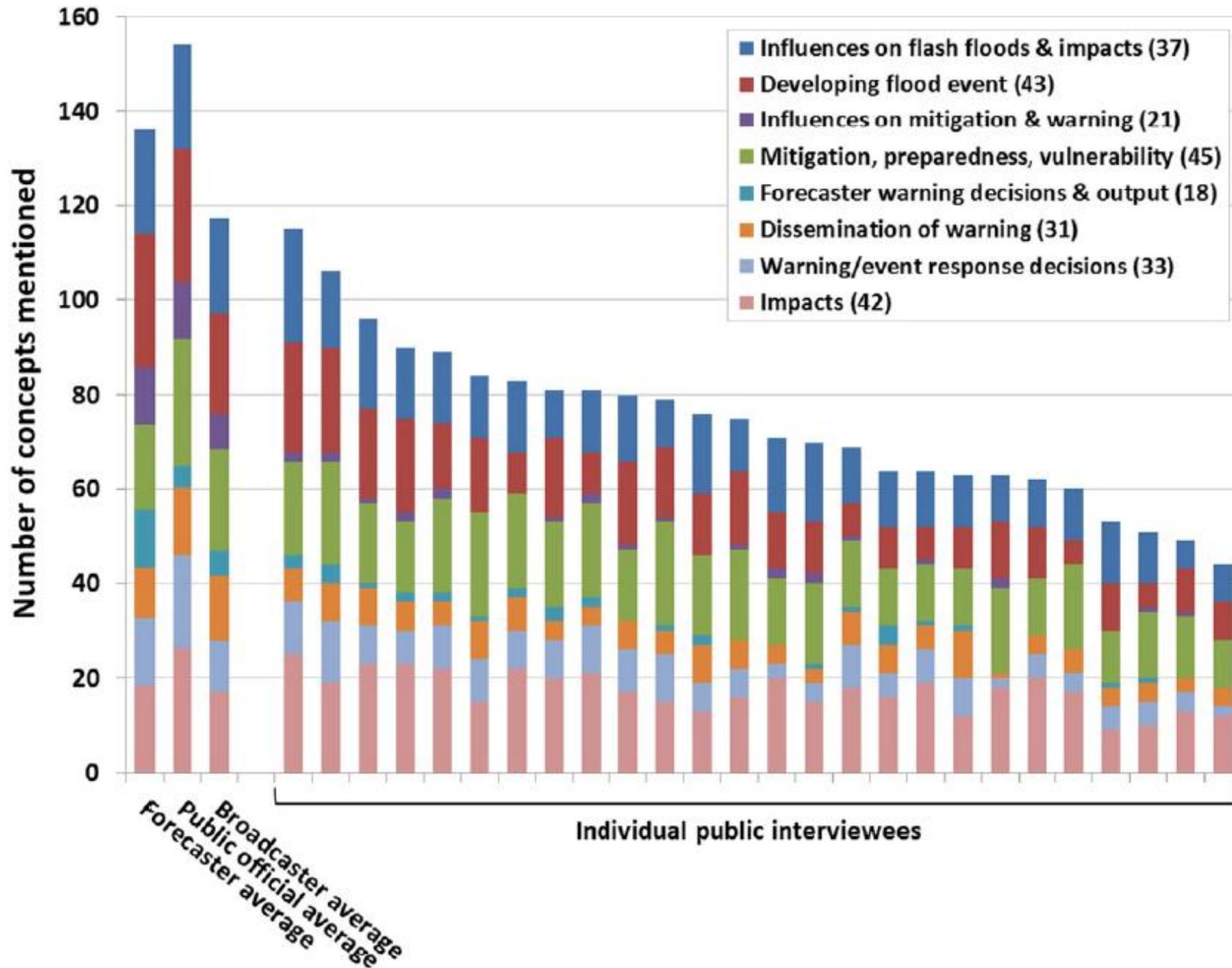
- *Experts*
 - “Well we basically talk about two types of floods, one is river floods ... that occurs typically **April to June, as you melt your snow** and you may have rainfall on top ... That is a **pretty orderly type of flooding** and sometimes you can see it coming ... and then the **flash flooding is again with thunderstorms and in the summer.**” (forecaster)
- *Public*
 - “If there is a **lot of snow in the winter and then temperatures rise super quickly ... in the springtime.**” (8)
 - “If you’re going anywhere in the **afternoon in the summer** you had better be bringing a rain jacket or something.” (7)

Experience and analogies

	<i>Exp</i>	<i>Pub</i>
Big Thompson flood (July 1976)	90	31
Fort Collins flood (July 1997)	50	8
Boulder flood (spring, late 1800s / early 1900s)	35	31
Boulder flood (May 1969)	25	0

- *Experts*
 - “The **worst case scenario here in Boulder** is probably going to [be a] **very heavy rain event, similar to, let’s say a Big Thompson Canyon flood** in 1976 ...consolidated to, let’s say Boulder Canyon.” (forecaster)
- *Public*
 - “I just know that from watching TV, obviously like there was the **Katrina incident** and so people were **sandbagging** everything to try to keep the water out as best they could.”
(7)

Variability in number of concepts mentioned in different FFW model sections



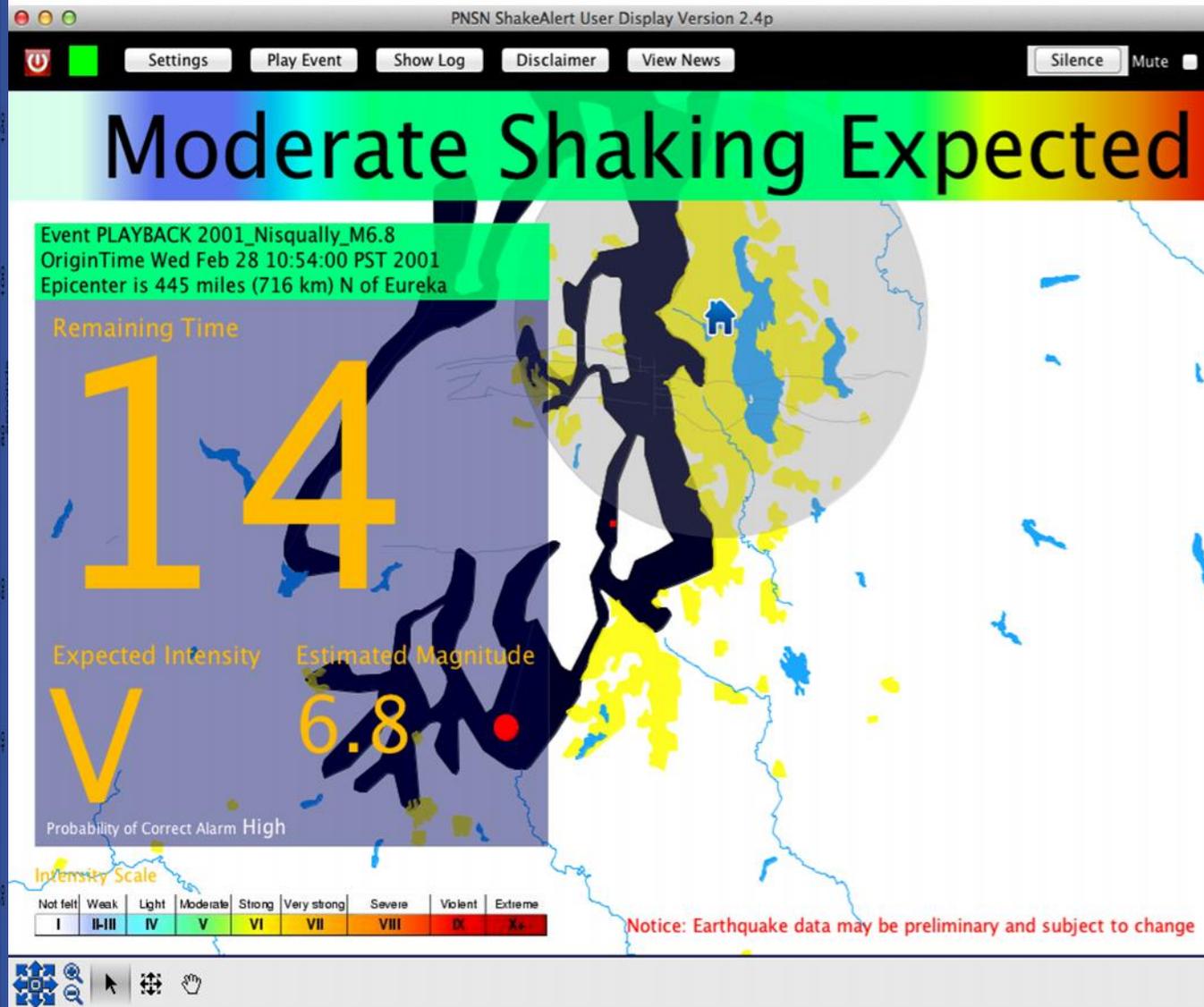
Implications for risk management

Findings → Evidence-based recommendations for long-term education and short-term communication to improve protective decision making

- Speed with which flash floods can develop and evolve (laypeople)
- Seasonality of flash flood risk (experts and laypeople)
- Importance of analogies, especially given lack of direct experience (experts and laypeople)

Lazrus, H., Morss, R. E., Demuth, J. L., Lazo, J. K., & Bostrom, A. (2016). "Know What to Do If You Encounter a Flash Flood": Mental Models Analysis for Improving Flash Flood Risk Communication and Public Decision Making. Risk analysis, 36(2), 411-427.

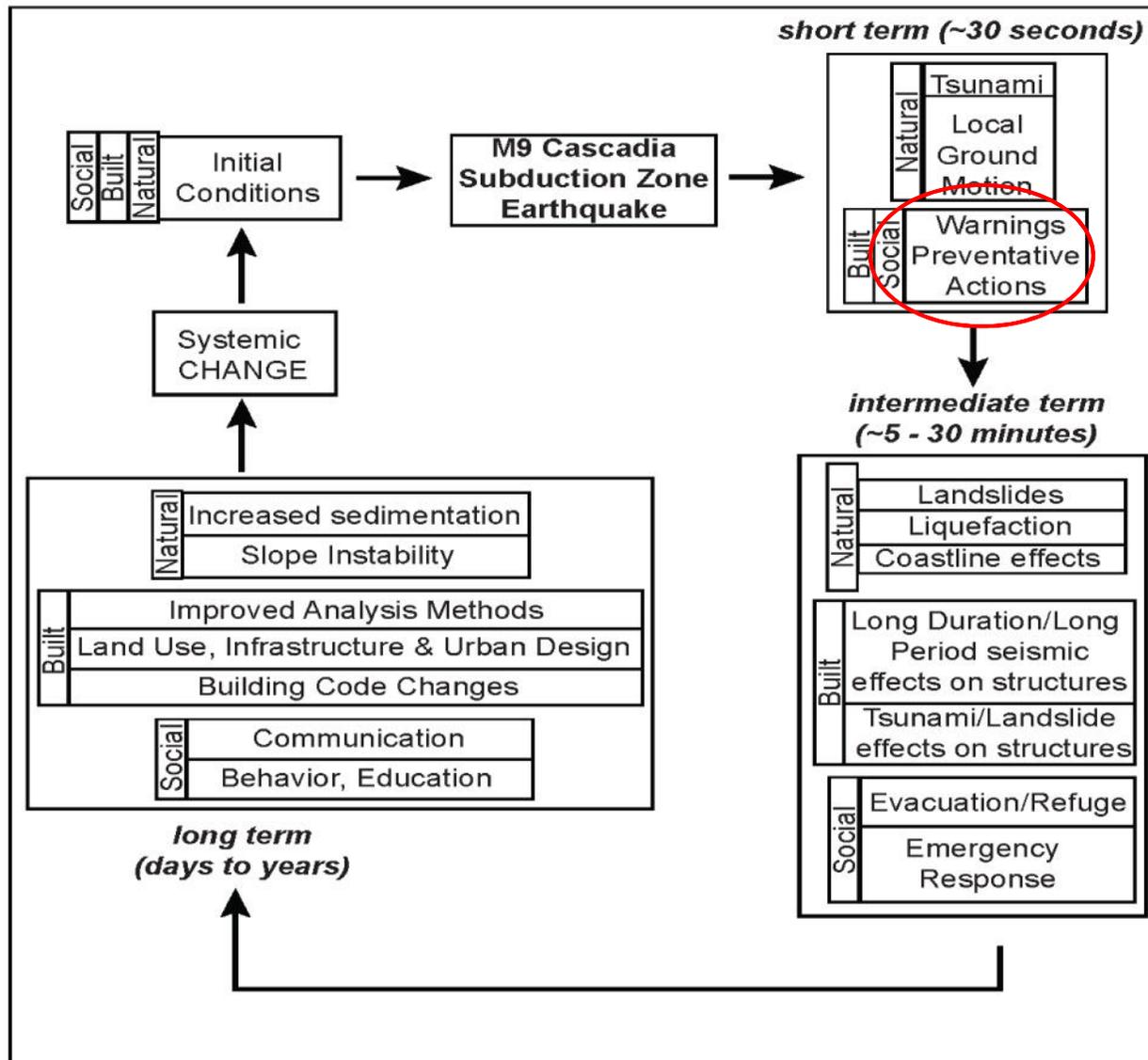
Earthquake Early Warning Perceptions and preparedness



Results from Google paywall intercept surveys in Washington state

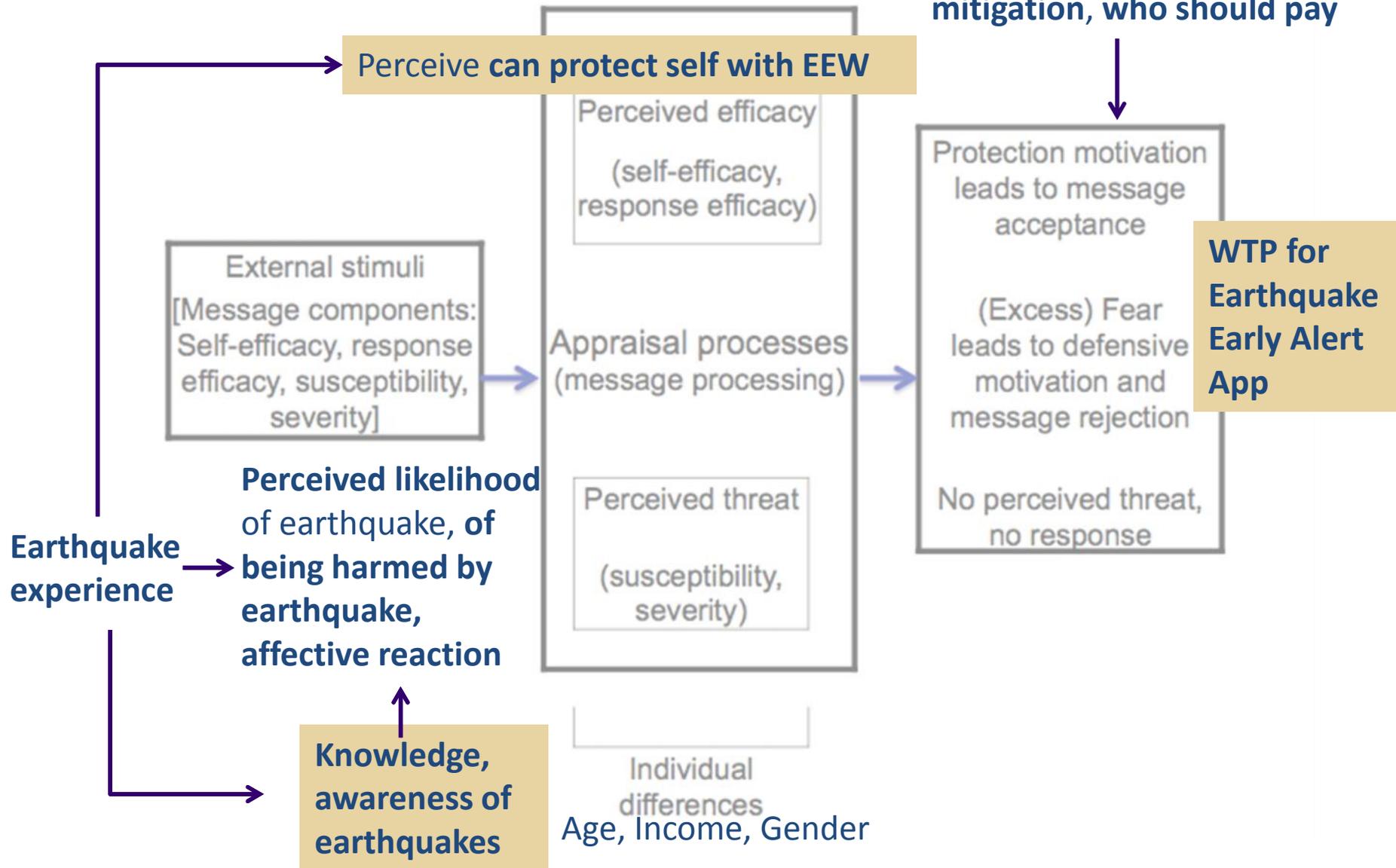
with
Alicia Ahn
Peter Dunn
John Vidale

Earthquake Early Warning Perceptions and preparedness



Actionable information is key

Survey questions



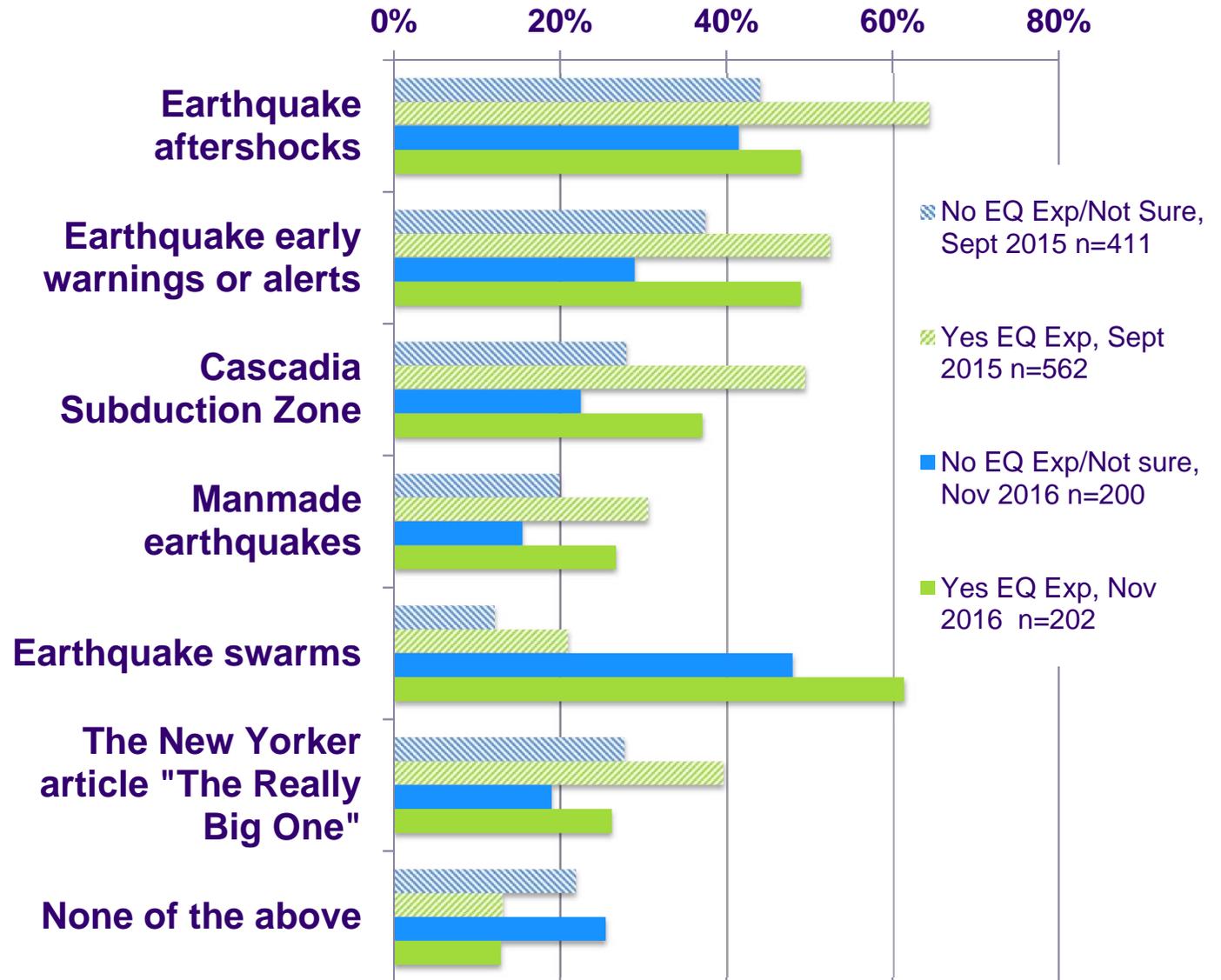


Which of the following news topics have you heard of?

Awareness

Washington

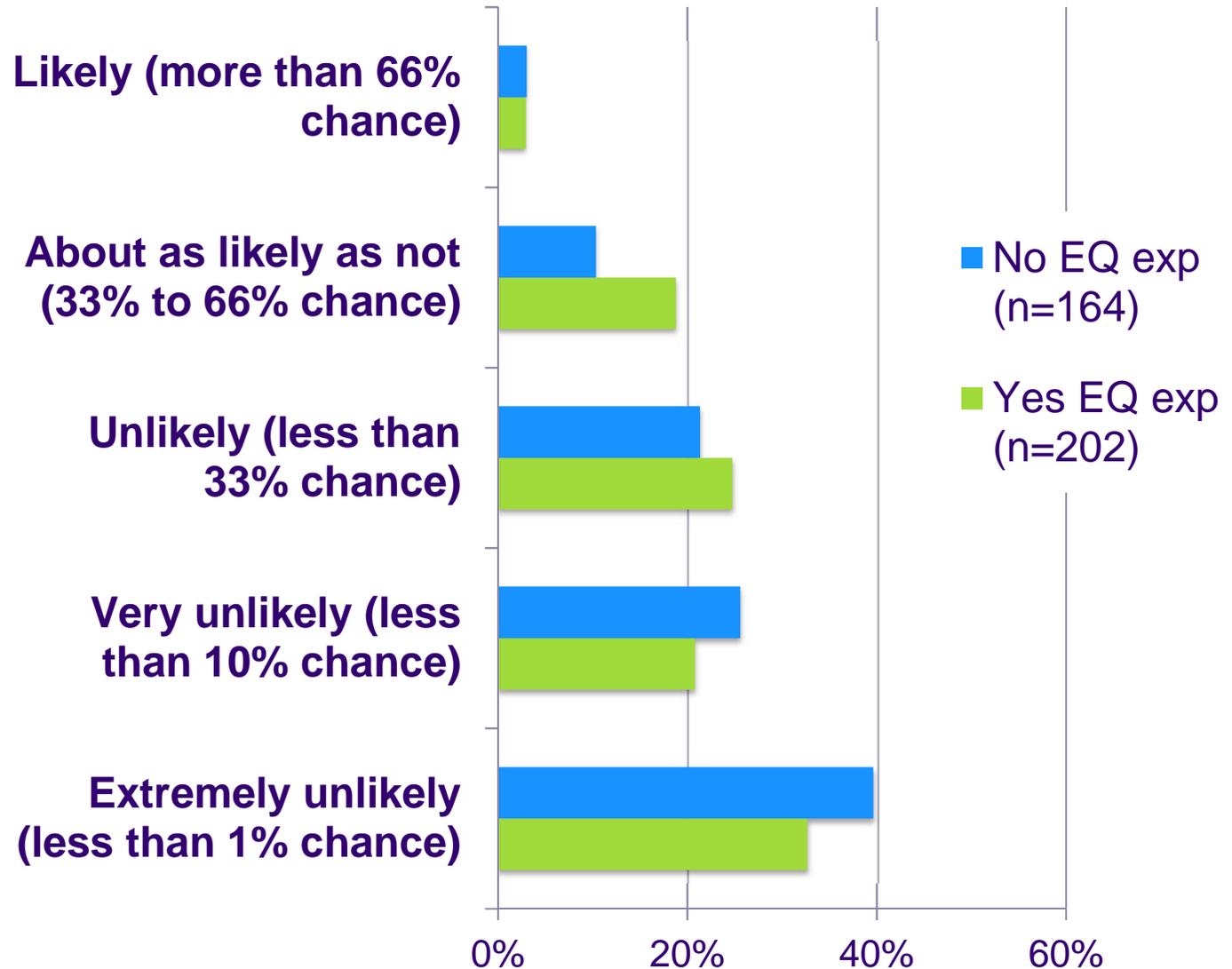
**September '15
November '16**



Threat

Washington
November
2016

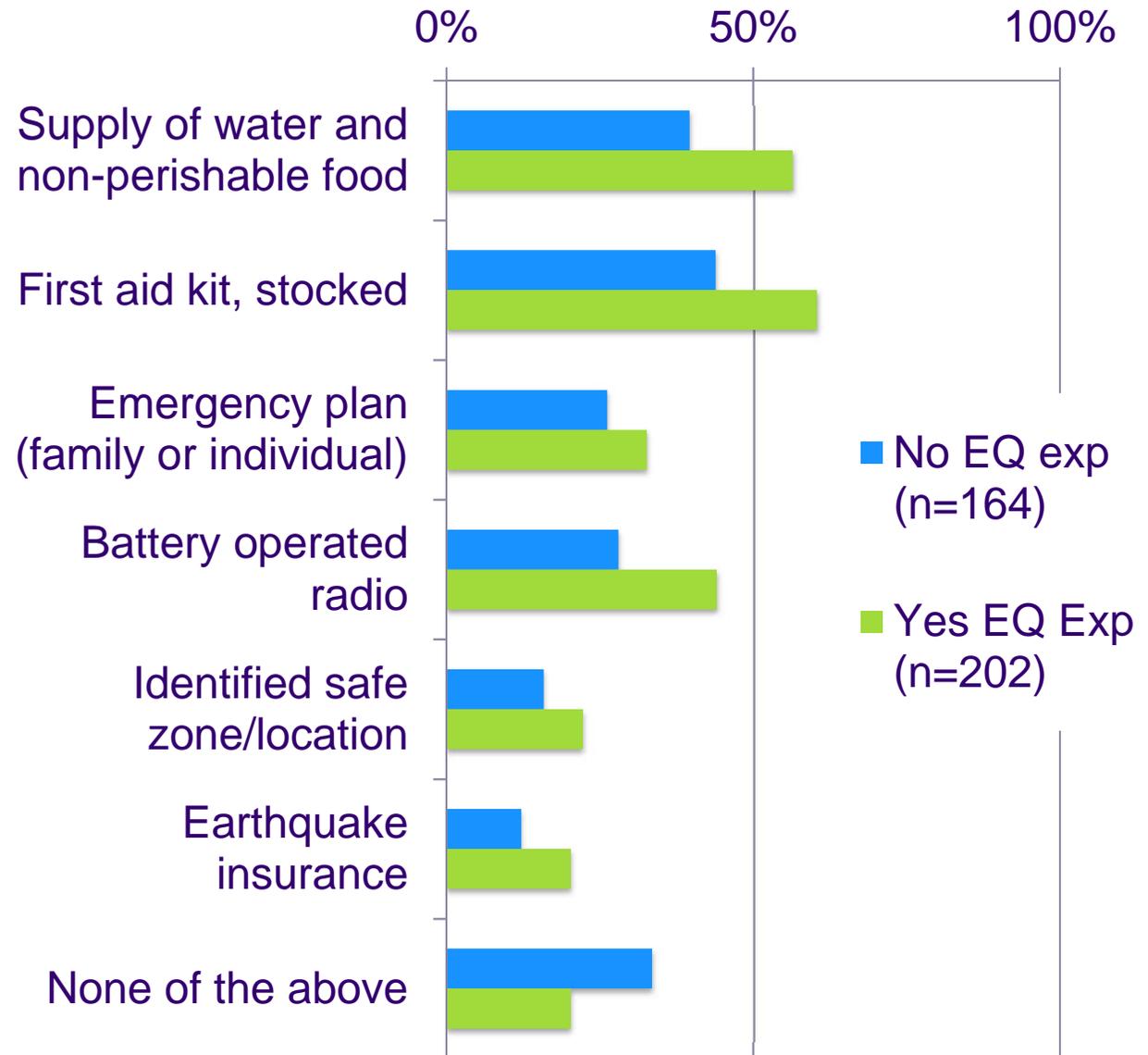
How likely do you think it is that an earthquake will harm you in the next year?



Experience, preparedness

Washington
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Which of these preparations for an emergency do you have at your home?

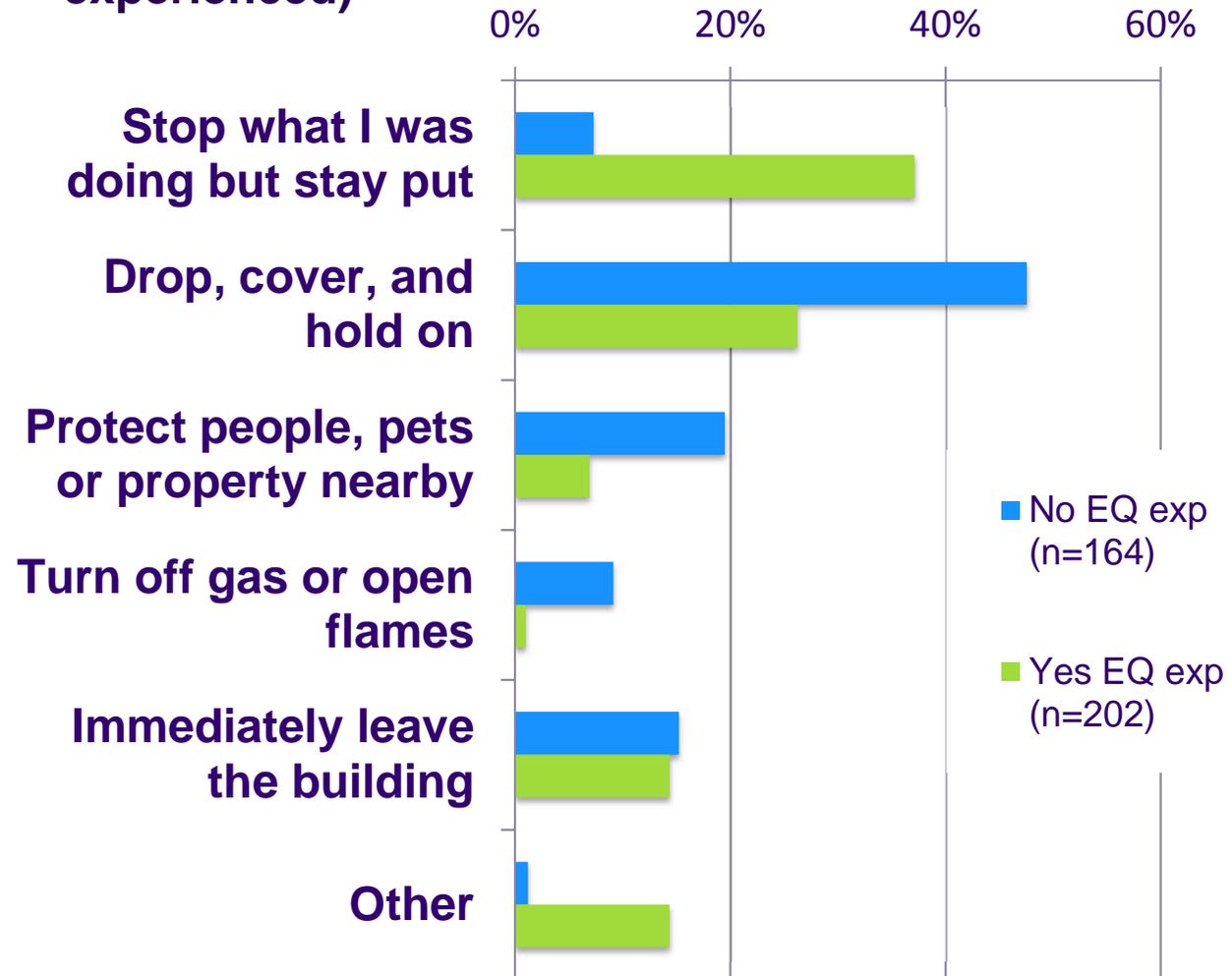


Cognition & Action

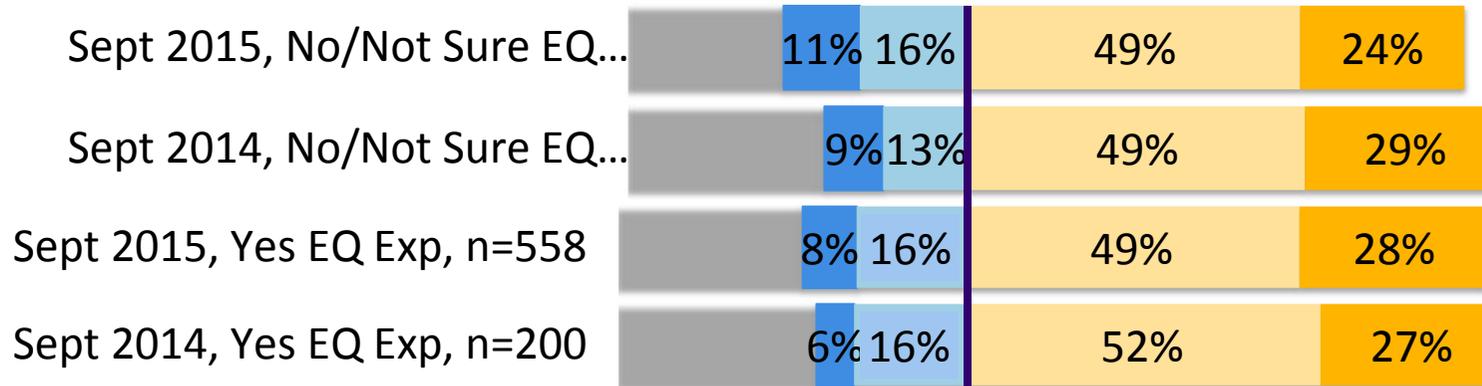
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If you were to experience an earthquake when you were indoors, what do you think your first response would be during the shaking?

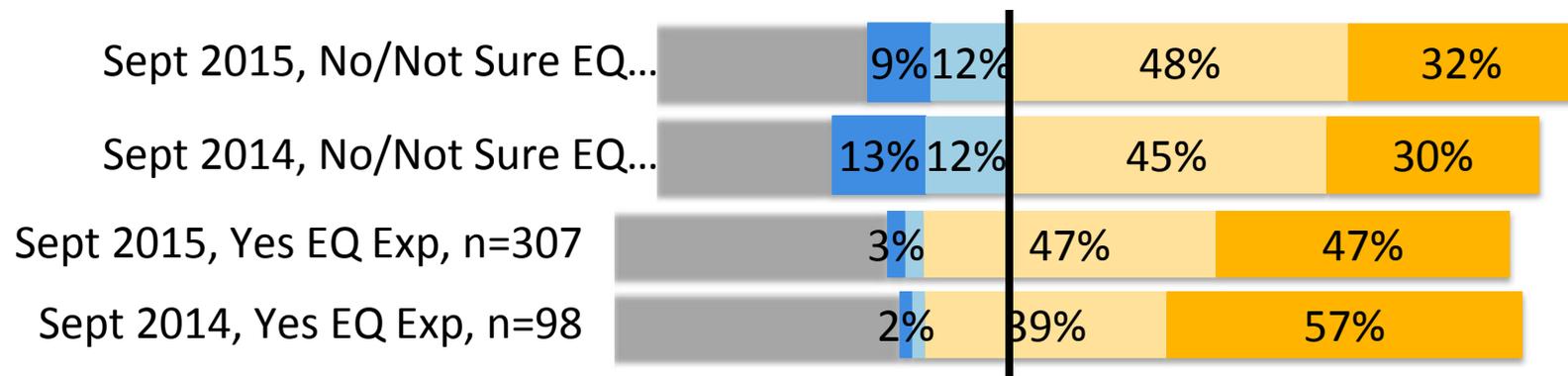
What was your first response while the earthquake was shaking? (for the most recent earthquake you have experienced)



"I would be better able to protect myself from earthquake risks, including death, with an earthquake early alert (a few seconds to minutes of warning)."



"Earthquake hazard mitigation, such as reinforcing buildings, reduces the risk of death from earthquakes."



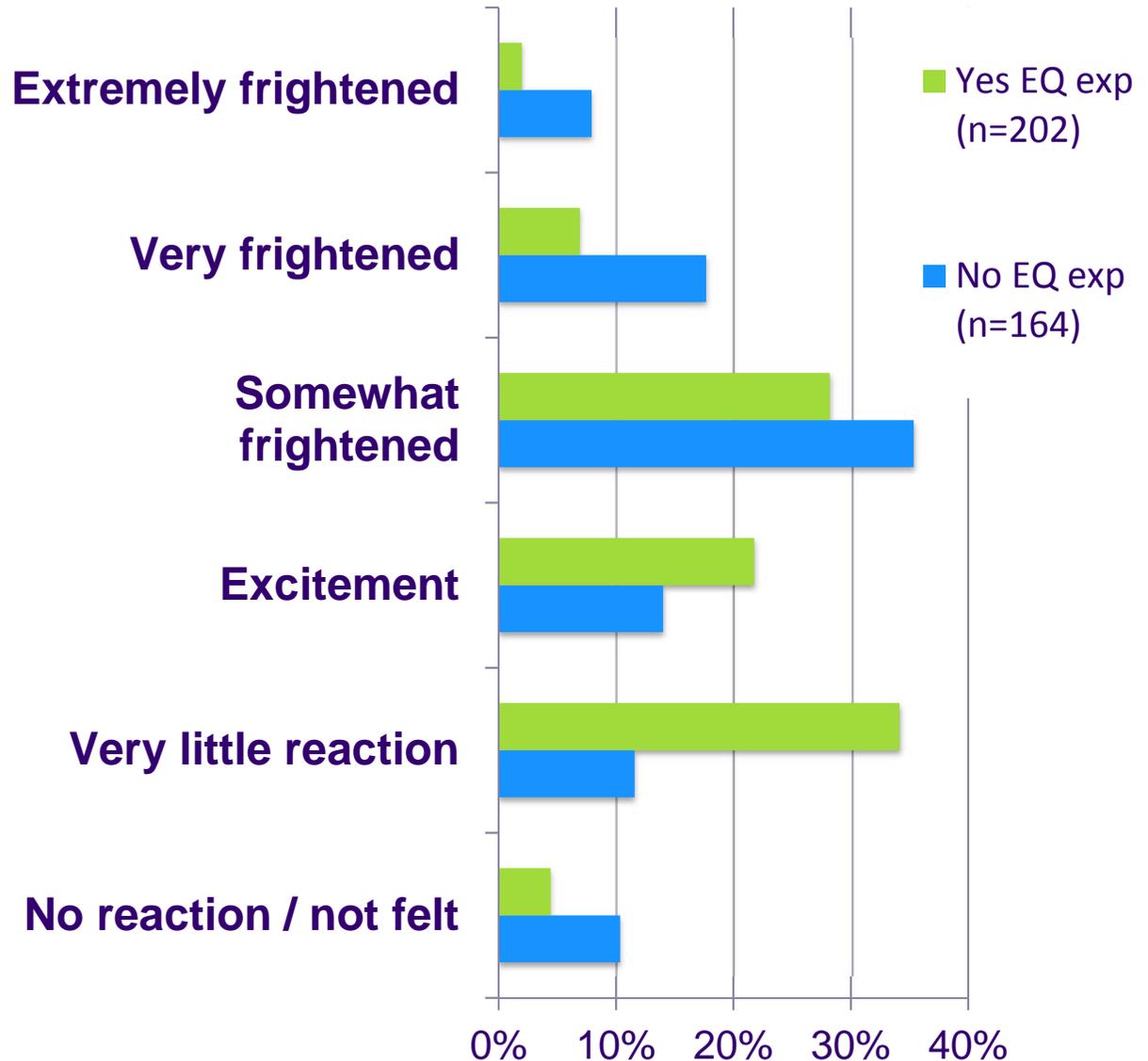
■ Strongly Disagree
 ■ Disagree
 ■ Agree
 ■ Strongly Agree

Emotion

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When you think about being in an earthquake, how do you react?

How did you react to this earthquake (your most recent earthquake experience)?

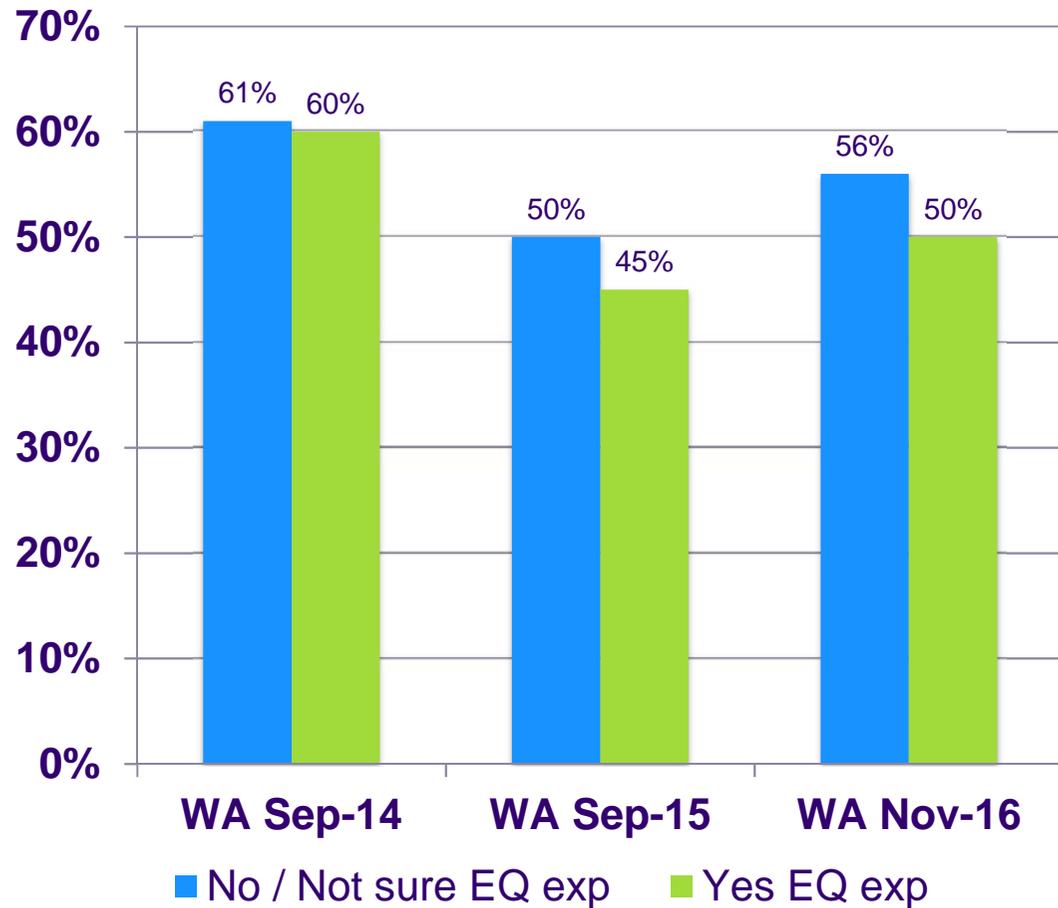


WTP

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What is the most you would be willing to pay (WTP) per month for an Earthquake Early Alert app on your smartphone or personal computer?

Percentage of those reporting willing to pay >0.



Implications for risk management

- About two thirds of WA have experienced an earthquake, and about half are willing to pay something for an EEW app.
- Robustly associated with willingness to pay for an EEW app, as expected, *ceteris paribus* (in regressions):
 - (+) Subjective likelihood of being harmed by an earthquake
 - (+) Experienced or predicted extreme fright from an earthquake
 - (+) Agreeing that one can protect oneself with EEW
 - (+) Having made emergency preparations / having insurance

Less robust, but still in expected direction:

- (+) Agreeing structural EQ risk mitigation is effective
- (+) Awareness of earthquake topics, e.g., The Really Big One

Dunn, P. T., Ahn, A. Y., Bostrom, A., & Vidale, J. E. (2016). Perceptions of earthquake early warnings on the US West Coast. Intl J Disaster Risk Reduction, 20, 112-122.

In sum

- 1) Understand the risk decision and action context
- 2) Identify the commonalities and conflicts in interpretations of that context and associated risks, and
- 3) Clarify what these insights mean for forecast and warning systems.

Interdisciplinary, decision-focused mental models studies can help. The studies reported here suggest that:

- Laypeople tend to trust forecast and warning systems and their own experience, and so
- may misunderstand the relative risks they face, especially when conditions are changing.
- Need more emphasis on communicating what exactly to do, and how.
- Some hazard forecast and warning products are confusing, many unfamiliar; more evaluation needed!
- Expertise is distributed across the forecast and warning system; better understanding at the system-level could help.

Thank you for your attention!

and many thanks to:



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- Public officials in Boulder & Miami-Dade
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- Florida and Washington participants
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