Visualizing Uncertainty About Environmental Hazards

Michael K. Lindell[1], Hao-Che Wu[2], Carla S. Prater[1], Shi-Kai Huang[1]

Donald House[3] & Charles D. Samuelson[4]

[1]University of Washington [2]Oklahoma State University

[3]Clemson University [4]Texas A&M University

U.S.-New Zealand Joint Committee Meeting
on Science and Technology Cooperation
Science and Risk Communications Joint Workshop

Acknowledgement: This research was supported by the National Science Foundation under Grants 0838654, IIS1212790, and IIS-1540469. None of the conclusions expressed here necessarily reflects views other than those of the authors.

Background

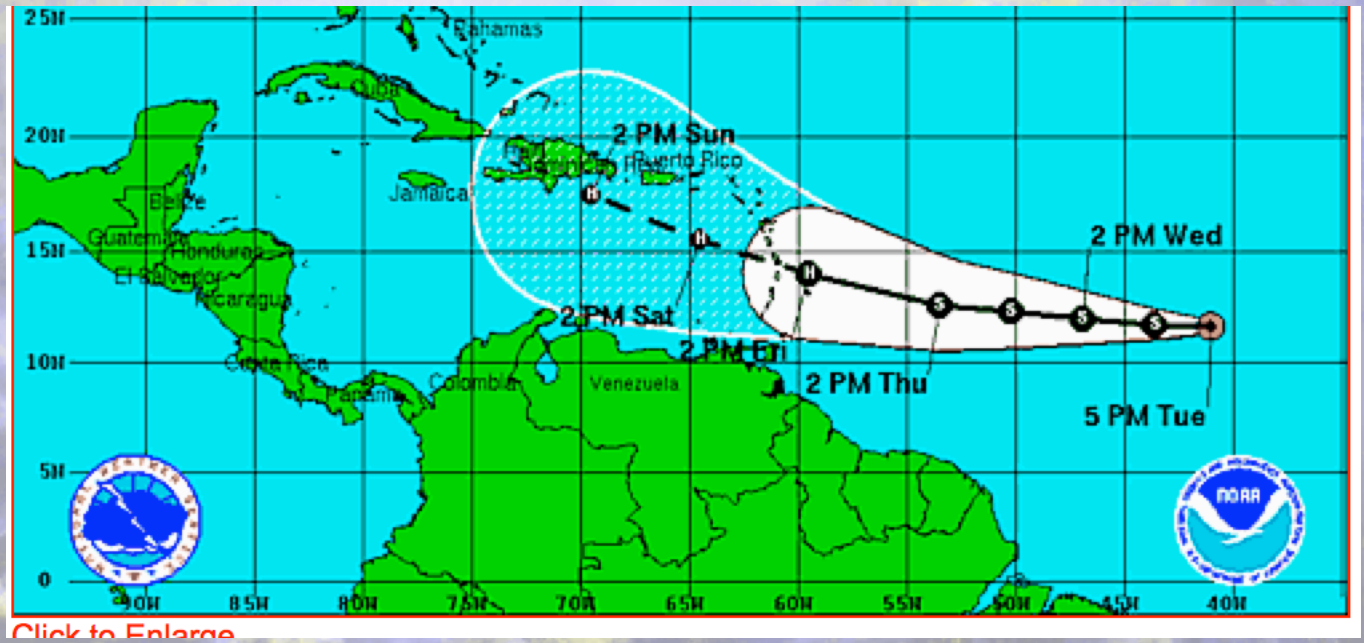
- For most environmental hazards, risk is a function of proximity to a hazard source, so emergency managers have tried to communicate people's risk using hazard maps.
- The level of risk at any given point on the map is subject to uncertainties that should also be displayed.
- How do different representations of uncertainty affect people's inferences about their risk and motivation to take protective actions.

Background

- Some studies have examined uncertainty displays for hurricanes and tornadoes.
  - > Hurricane uncertainty cone—uncertainty about the storm's forecast track.
  - > Tornado warning polygon—uncertainty about locations at which a tornado might strike.

Hurricane Uncertainty Cones

- An *uncertainty* cone depicts the area having a 67% chance of containing the hurricane track.



Click to Enlarge

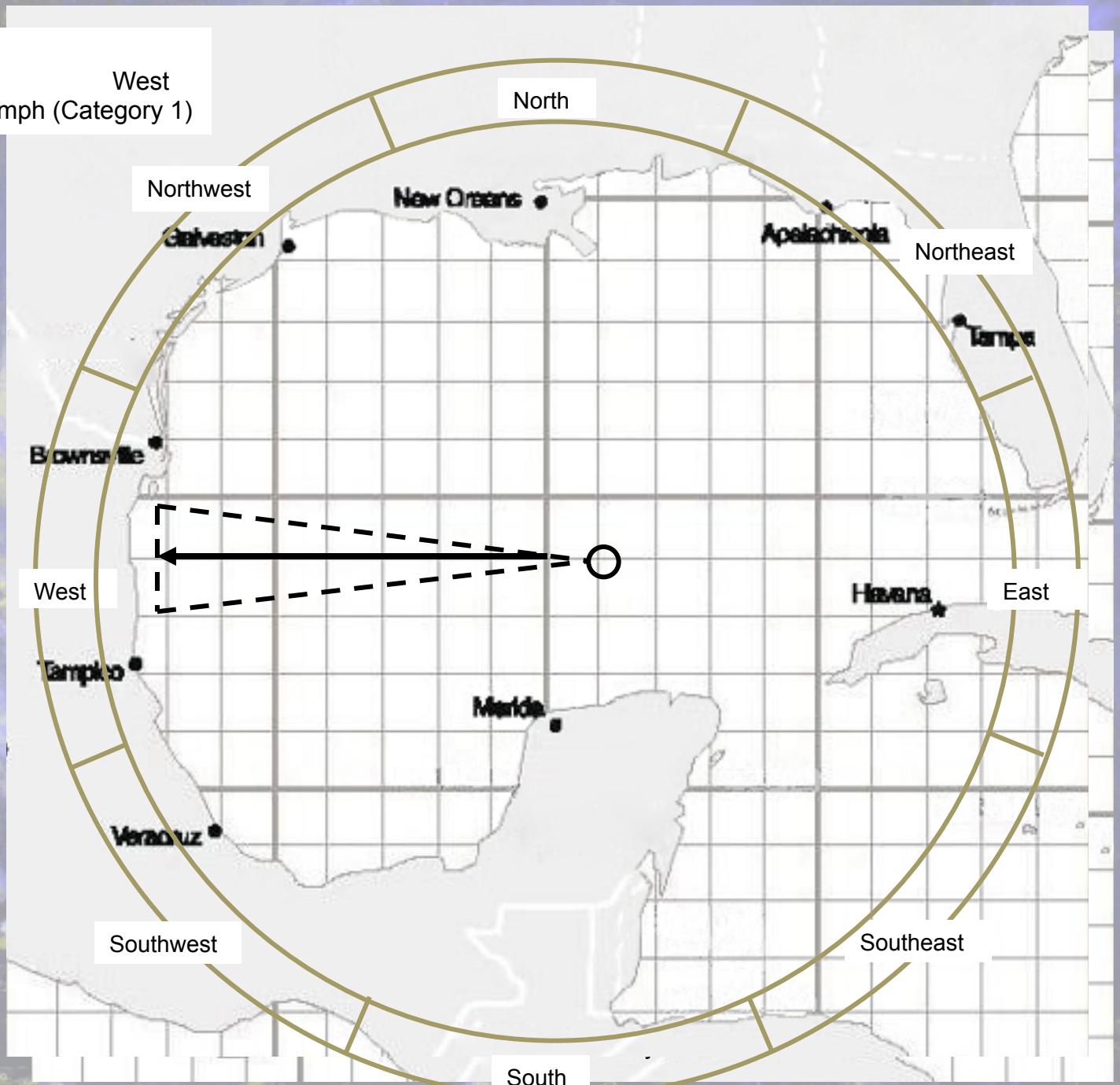
Background

- Broad et al.(2007) concluded from archival evidence that some people might be misinterpreting uncertainty cone displays.
- Meyer et al. (2013) found that
  - > People who saw forecast track displays were more concerned and prepared more than those who saw uncertainty cone displays
  - > This pattern was found even among those who were located farther from the forecast point of landfall.

Wu et al. (2014)

- Participants viewed eight hurricane tracking maps that varied in
  - > Direction: West, Northwest, North, or Northeast
  - > Intensity: Category 1 or Category 4.
- Hurricane direction was indicated by
  - > Forecast track only,
  - > Uncertainty cone only, or
  - > Forecast track plus uncertainty cone.
- Participants judged the strike probability (p_s) in each of eight sectors corresponding to the eight cardinal and ordinal compass directions.

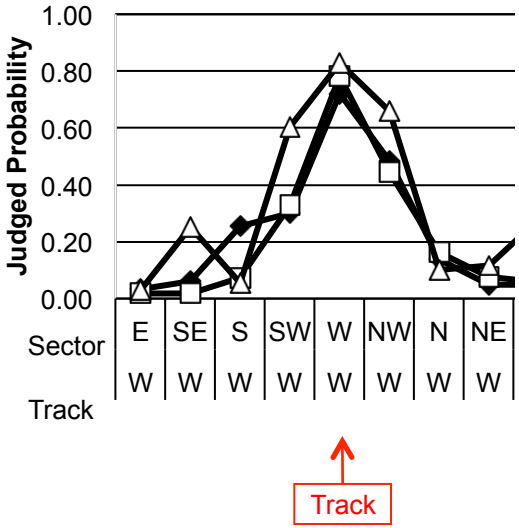
Hurricane 1
Track Direction: West
Wind Speed: 85 mph (Category 1)



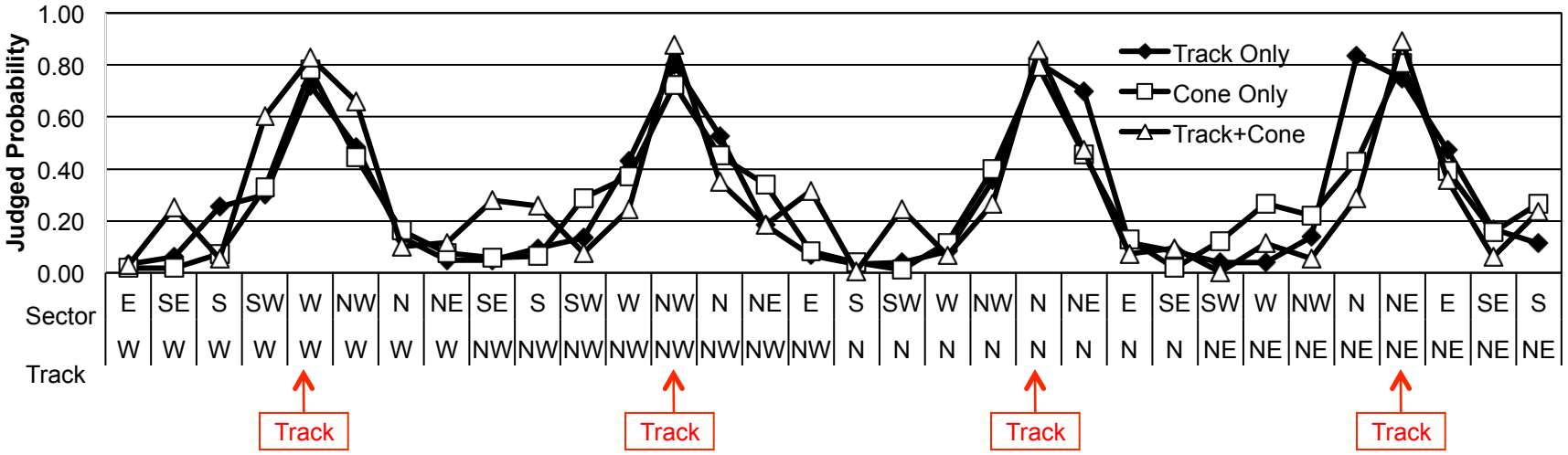
Wu et al. (2014) Results

- There were no differences among track information conditions (track, cone, track + cone).
- Participants' p_s judgments were *qualitatively* reasonable (i.e., decreased over distance from likely landfall).
- These results suggest that people are generally not misinterpreting uncertainty cones.

Wu et al. (2014) Results

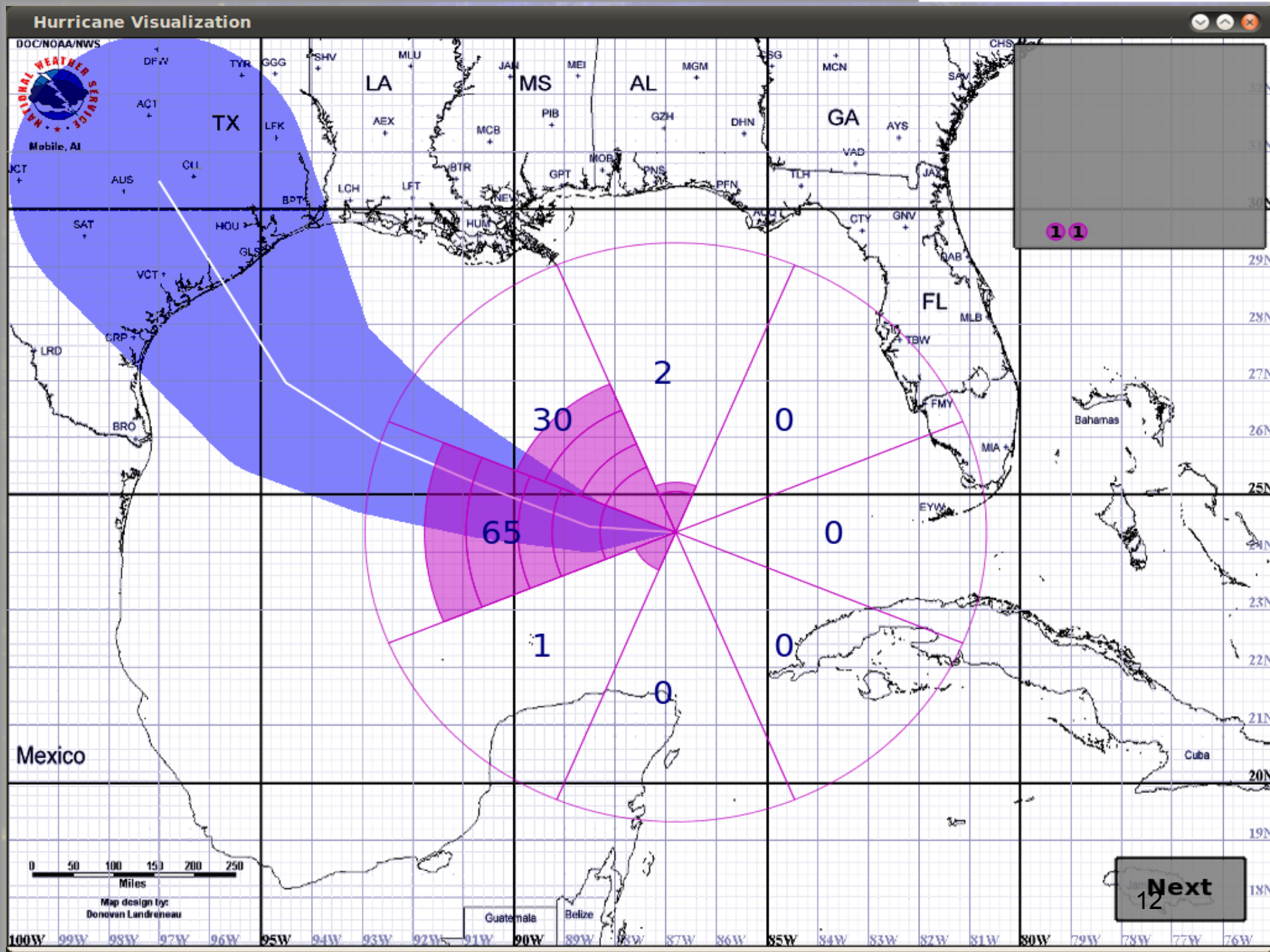


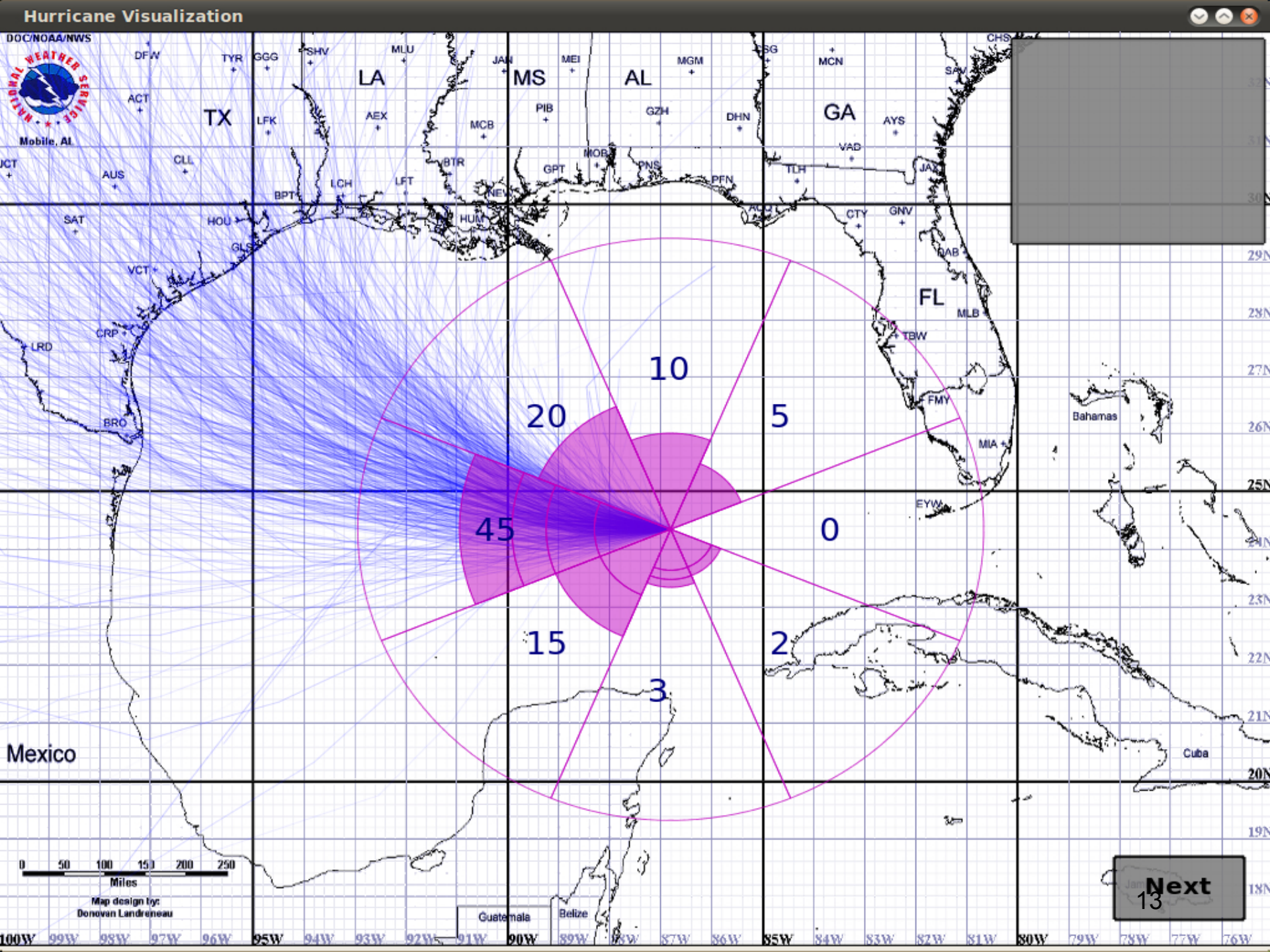
Wu et al. (2014) Results



Cox et al. (2013)

- This experiment tested track ensembles as an alternative representation of track uncertainty.
  - > A *track ensemble* is a representative set of hurricane tracks that could potentially occur, given the past history of Gulf hurricanes.
  - > Each track is displayed and gradually disappears while additional tracks are randomly generated from the historical distribution of track directions.
- Participants provided p_s judgments in eight cardinal and ordinal sectors for six hurricanes.
  - > Each participant made judgments using both the uncertainty cone and track ensemble displays.

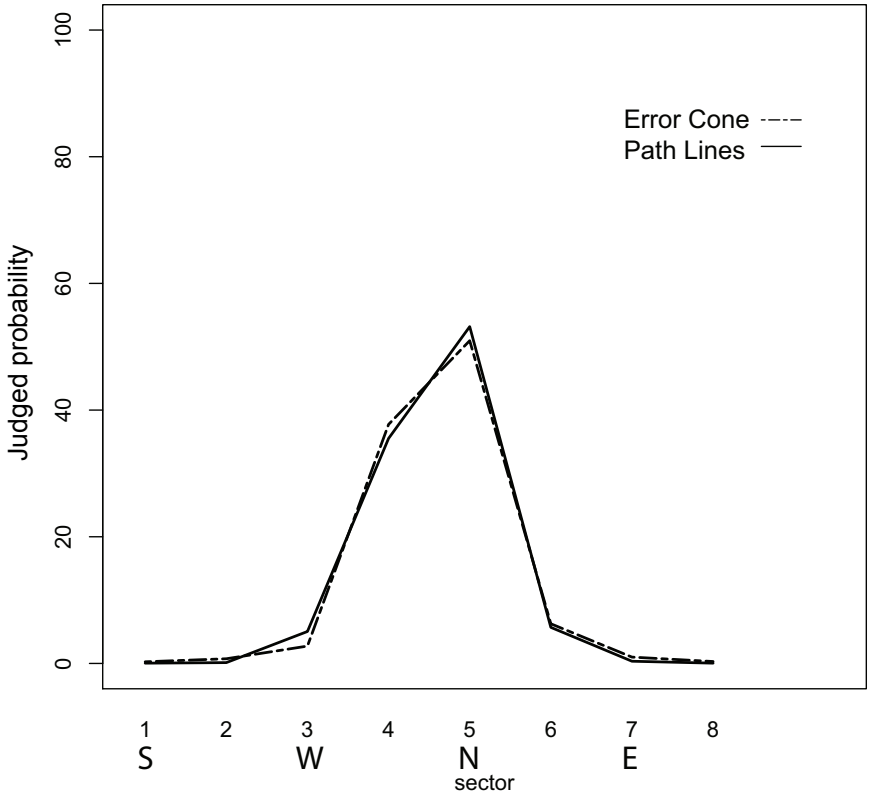

Hurricane Visualization
DOC/NOAA/NWS
NATIONAL WEATHER SERVICE
Mobile, Al
TX
LA
MS
AL
GA
FL
Mexico
Bahamas
Cuba
2
30
0
65
0
1
0
0
Next
Miles
Map design by:
Donovan Landreneau


Hurricane Visualization
DOC/NOAA/NWS
NATIONAL WEATHER SERVICE
Mobile, AL
DFW
TYR
GGG
SHV
MLU
JAN
MEI
MGM
SG
MCN
CHS
SAV
LA
MS
AL
GA
TX
ACT
LFK
AEX
PIB
MCB
GZH
DHN
AYS
VAD
MOB
PNS
GPT
BTR
TLH
JAX
CLL
AUS
BPT
LCH
LFT
PFN
CTY
GNV
SAT
HOU
HUM
GLS
VCT
DAB
FL
MLB
CRP
LRD
TBW
FMY
BRO
MIA
Bahamas
EYW
10
20
5
45
0
15
2
3
Mexico
Cuba
0 50 100 150 200 250
Miles
Map design by:
Donovan Landreneau
Guatemala
Belize
Next
100W 99W 98W 97W 96W 95W 94W 93W 92W 91W 90W 89W 88W 87W 86W 85W 84W 83W 82W 81W 80W 79W 78W 77W 76W
29N 28N 27N 26N 25N 24N 23N 22N 21N 20N 19N 18N

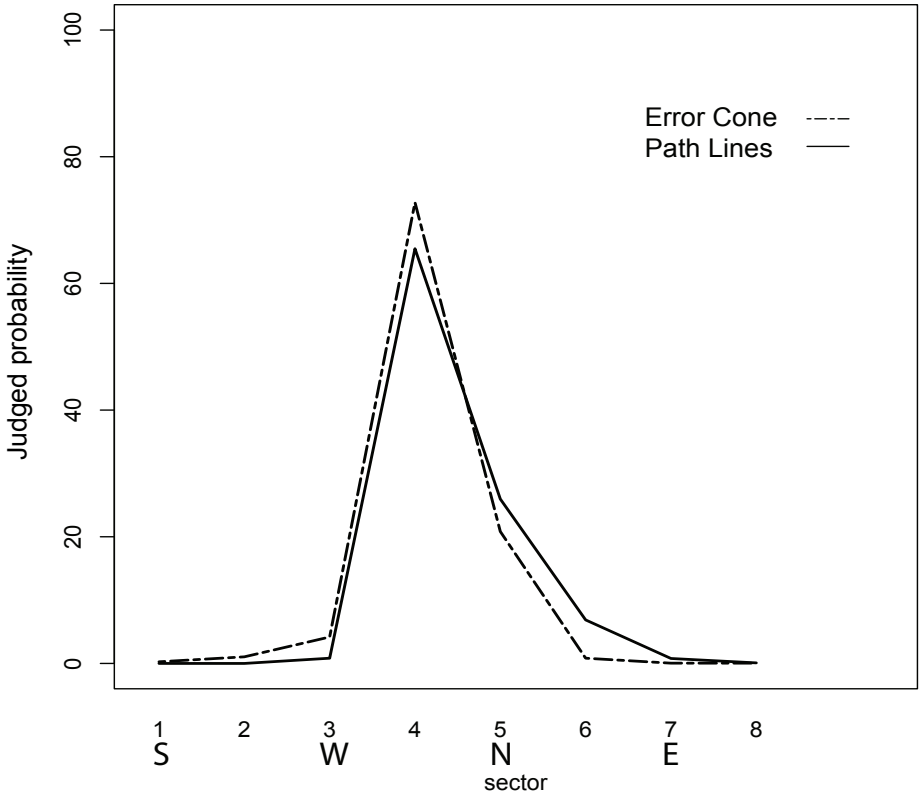
Cox et al. (2013)

- p_s judgments were
  - > highest for the sector in which the concentration of tracks was densest or the cone was pointing.
  - > moderately high for sectors perpendicular to the one in which the concentration of tracks was densest or the cone was pointing, and
  - > low for sectors opposite the one in which the concentration of tracks was densest or the cone was pointing.

Cox et al. (2013) Results



Most similar scenario



Least similar scenario

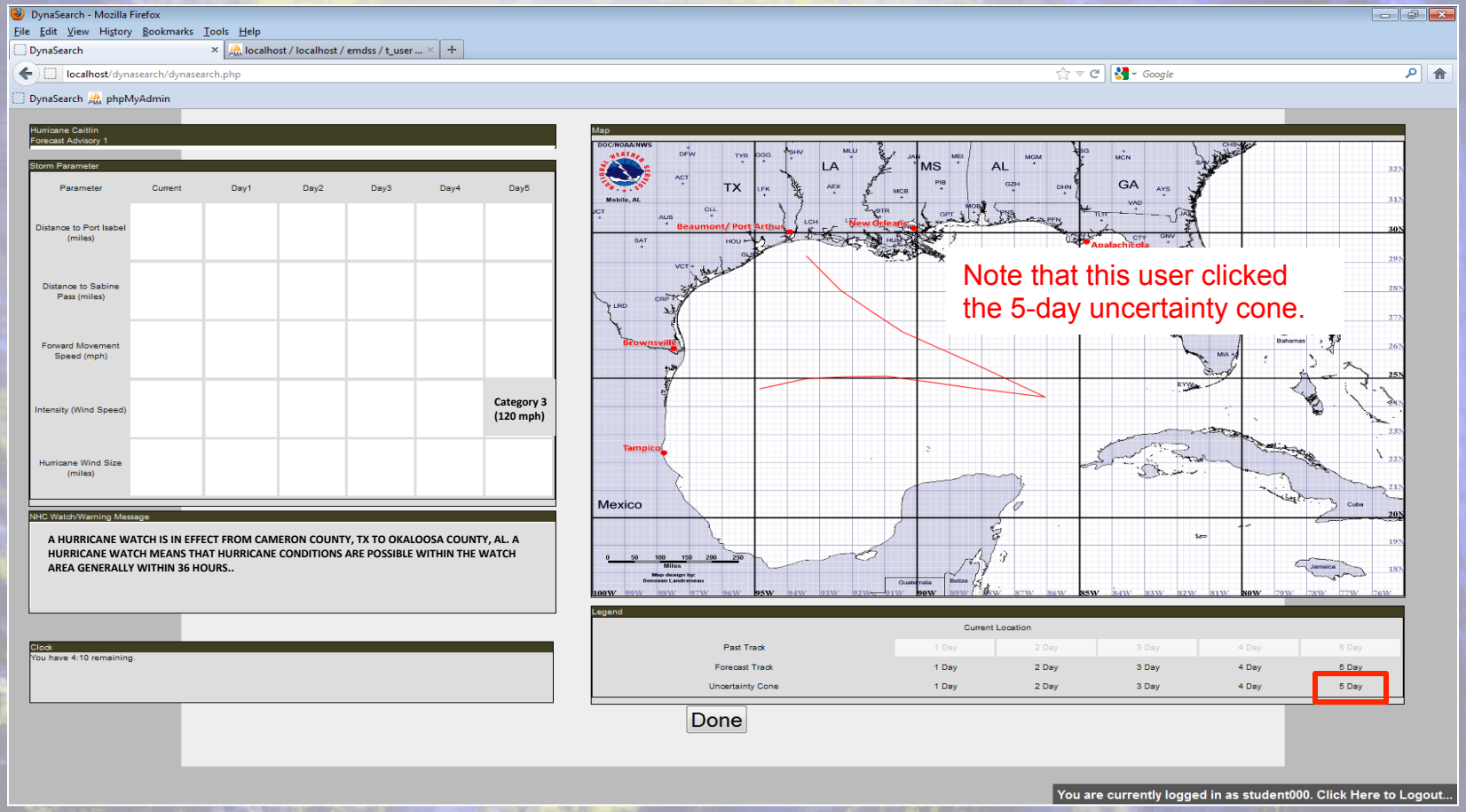
Ruginski et al. (2015)

- Assigned participants to five display conditions—track, cone, track + cone, fuzzy cone, and track ensemble.
- Participants made damage judgments at 12 locations along two transects defined by the hurricane's expected position 24-hr and 48-hr from its current location.
- There were some statistically significant, but small, differences among the displays, but all revealed declining damage judgments with distance from the track centerline.

Wu et al. (2015, a, b)

- *DynaSearch* is a computer system for studying people's information search strategies in dynamic decision tasks.
  - > *DynaSearch* can display graphics (e.g., maps), tables, and text boxes.
  - > Display content is made visible by clicking/holding on the desired information element.
  - > *DynaSearch* is a useful alternative to eye-tracking methods because it can be used to conduct Internet experiments.

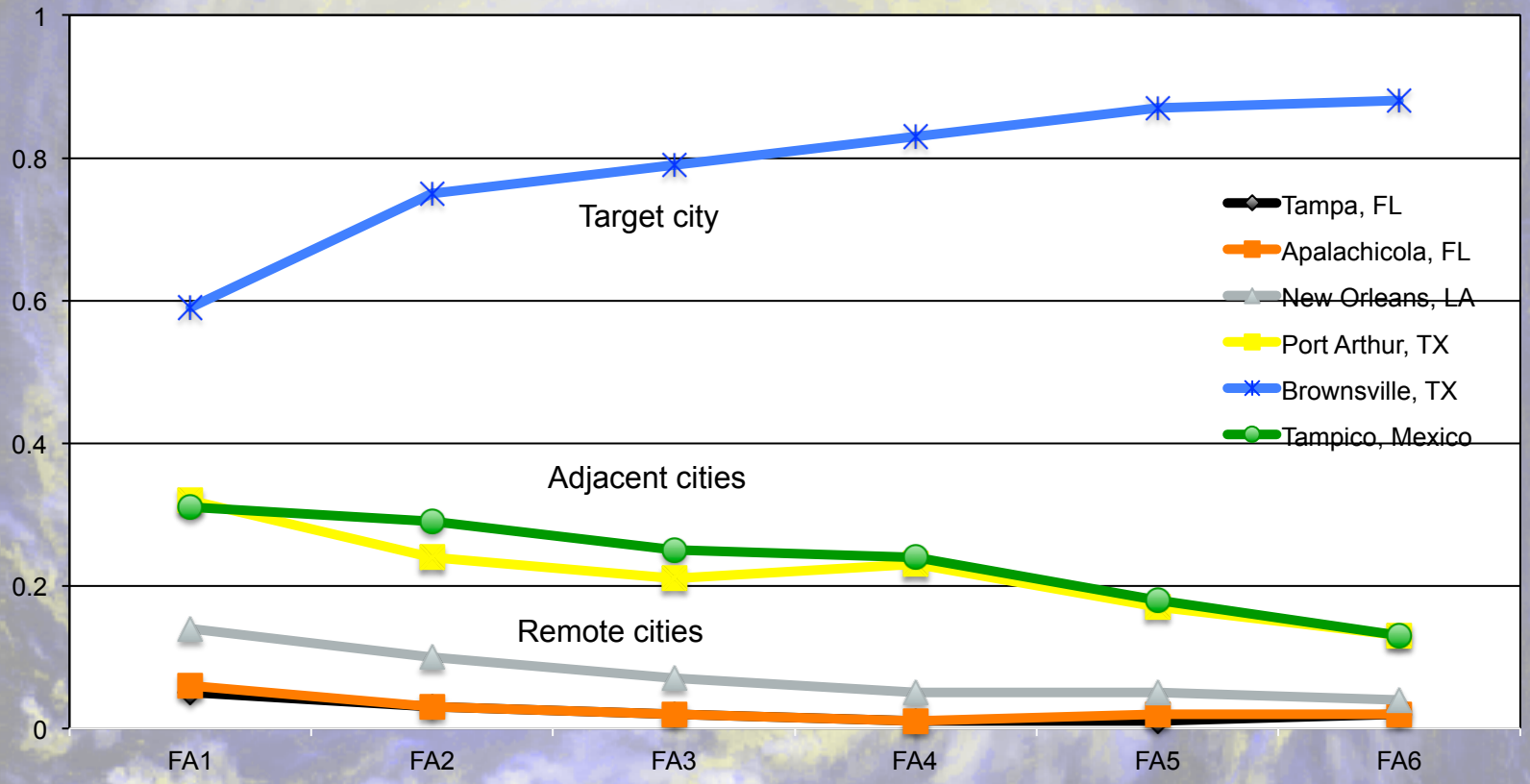
DynaSearch Forecast Advisory Information Display



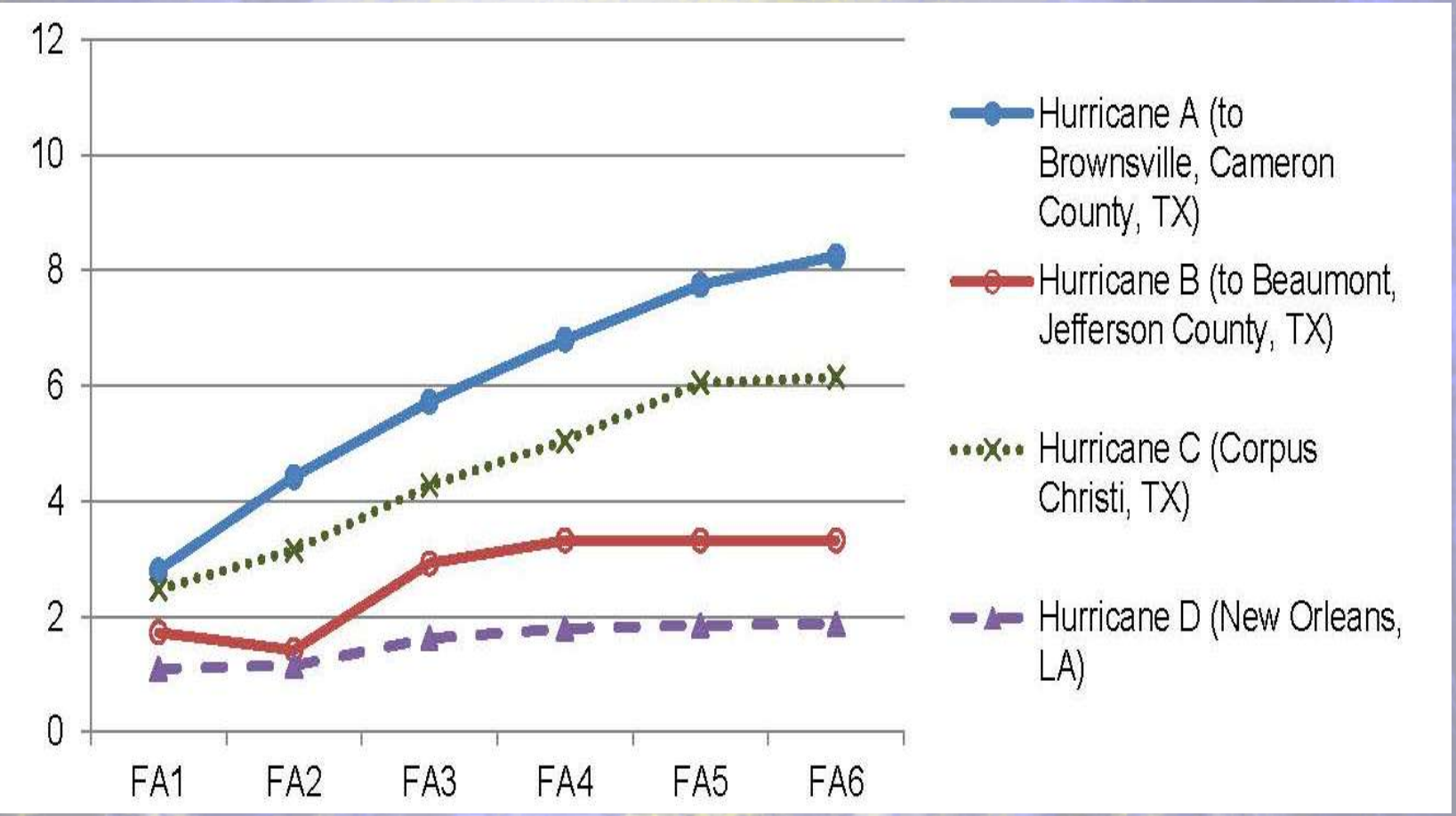
Wu et al. (2015, a, b)

- After each information display, participants provided p_s judgments for six cities around the Gulf of Mexico and made protective action recommendations for their jurisdictions.
  - > For target cities, p_s judgments were high after Forecast Advisory 1 and increased.
  - > For adjacent cities, p_s judgments were moderate after Forecast Advisory 1 and decreased.
  - > For remote cities, p_s judgments were low after Forecast Advisory 1 and decreased for remote cities.
- Protective action recommendations were highly correlated (r = .40-.53) with p_s judgments.

Mean p_s for Hurricane A (Brownsville)



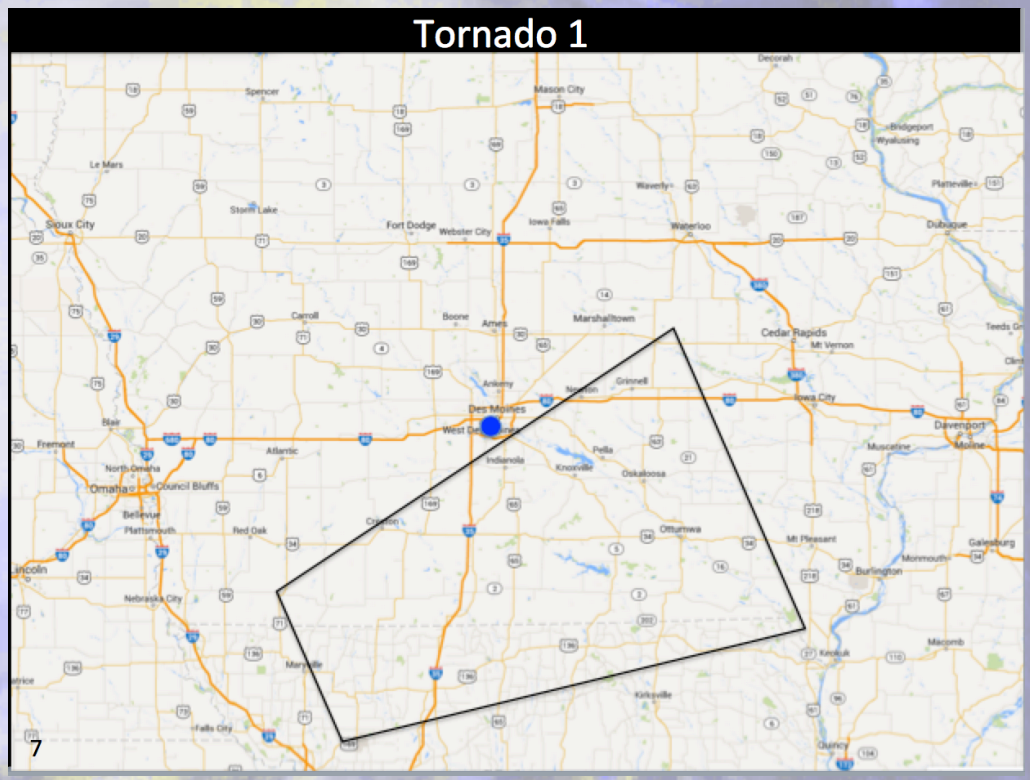
Protective Action Recommendations for Cameron County (Brownsville)



Tornado Warning Polygons

A tornado warning polygon

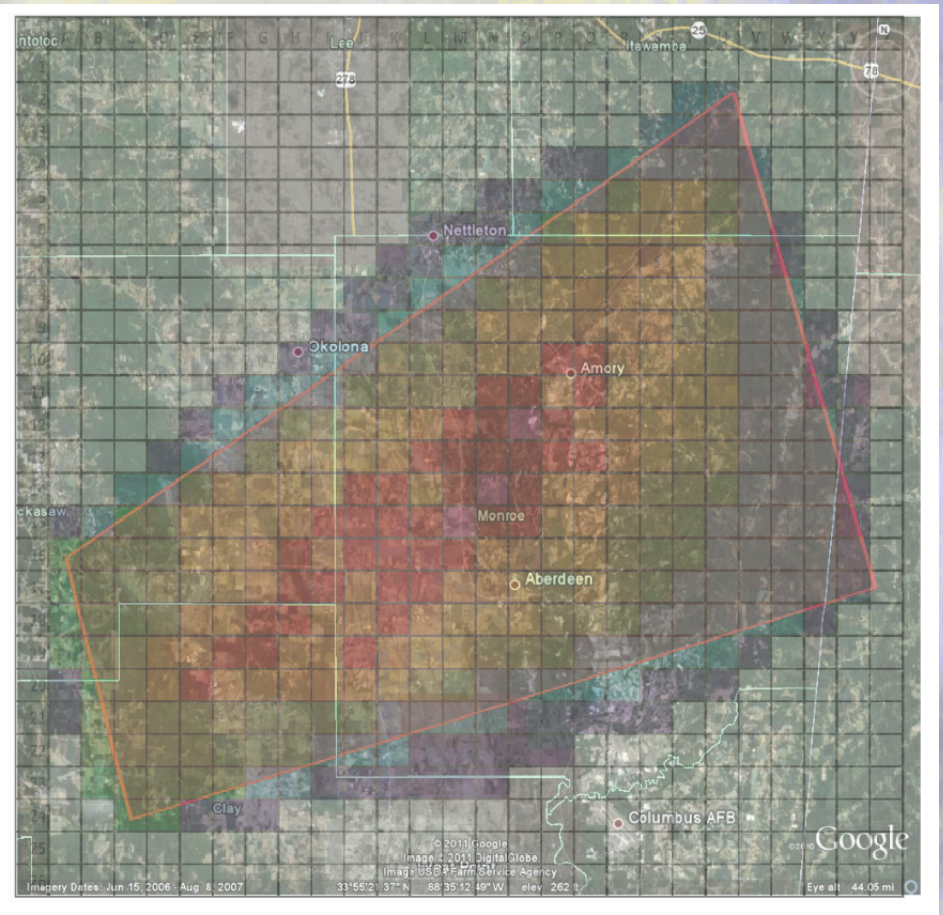
- Depicts the area that a warning meteorologist thinks is at risk of being struck by a tornado
- Is based on expert judgment rather than historical data.



Tornado Warning Polygons

- Mason and Senkbeil (2015) asked people to describe a warning polygon.
  - > Only 26.3% (10/38) were able to provide a correct explanation.
- Sherman-Morris and Brown (2012) asked participants to identify areas in a warning polygon that were likely to be struck.
  - > Respondents tended to judge the area of highest risk to be an ellipse located in the center of the polygon whose vertices on the semi-major and semi-minor axes are approximately equidistant from the polygon's four edges.

Sherman-Morris and Brown (2012)



Nagele and Trainor (2012)

- This study surveyed respondents who lived in areas that had recently been issued a tornado warning.
  - > Being inside the polygon was positively correlated with information seeking and sheltering, but was not significant in a subsequent regression analysis.
  - > However, protective action was more likely when a polygon's area was less than 50% of the county being warned.

Ash et al. (2014)

- Ash et al. (2014) compared three forms of tornado warning polygons.
  - A standard polygon, which had no internal differentiation of risk areas.
  - A spectral polygon, which was divided into nine regions that indicated the highest risk area in dark red, the lowest risk area in light blue, and intermediate risk areas in corresponding hues of the color spectrum.
  - A red gradient polygon, which was divided into five regions that indicated the highest risk area in dark red and the remaining risk areas in increasingly lighter shades of red.

Ash et al. (2014)
Three Forms of Polygons

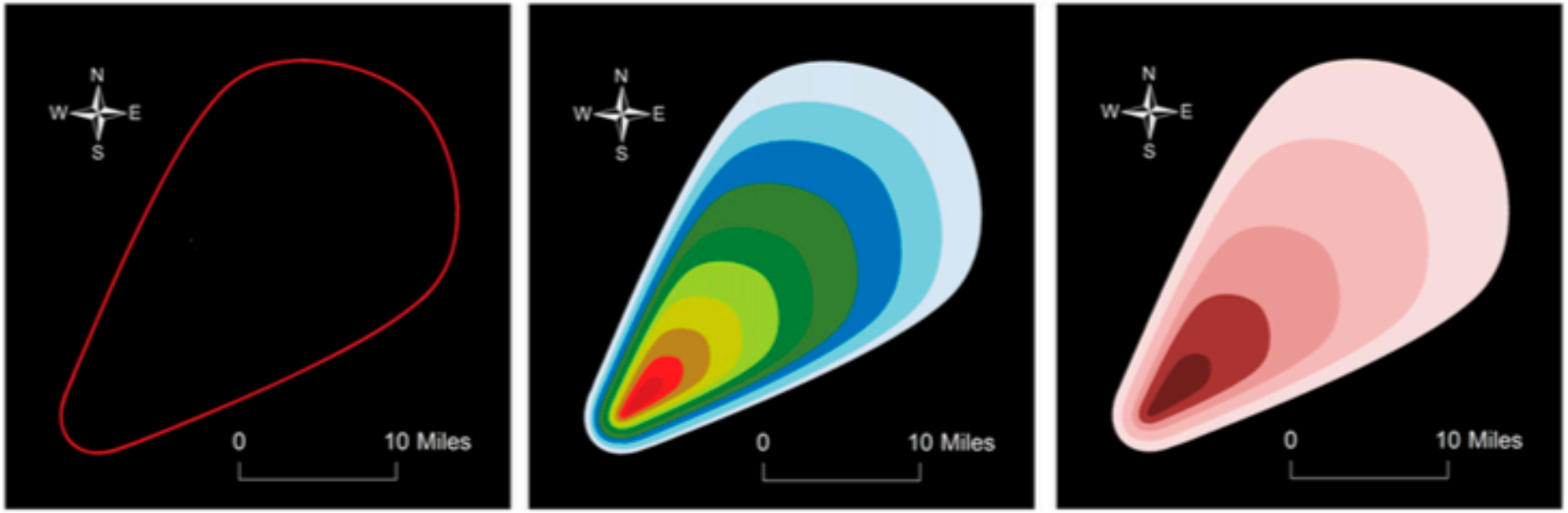
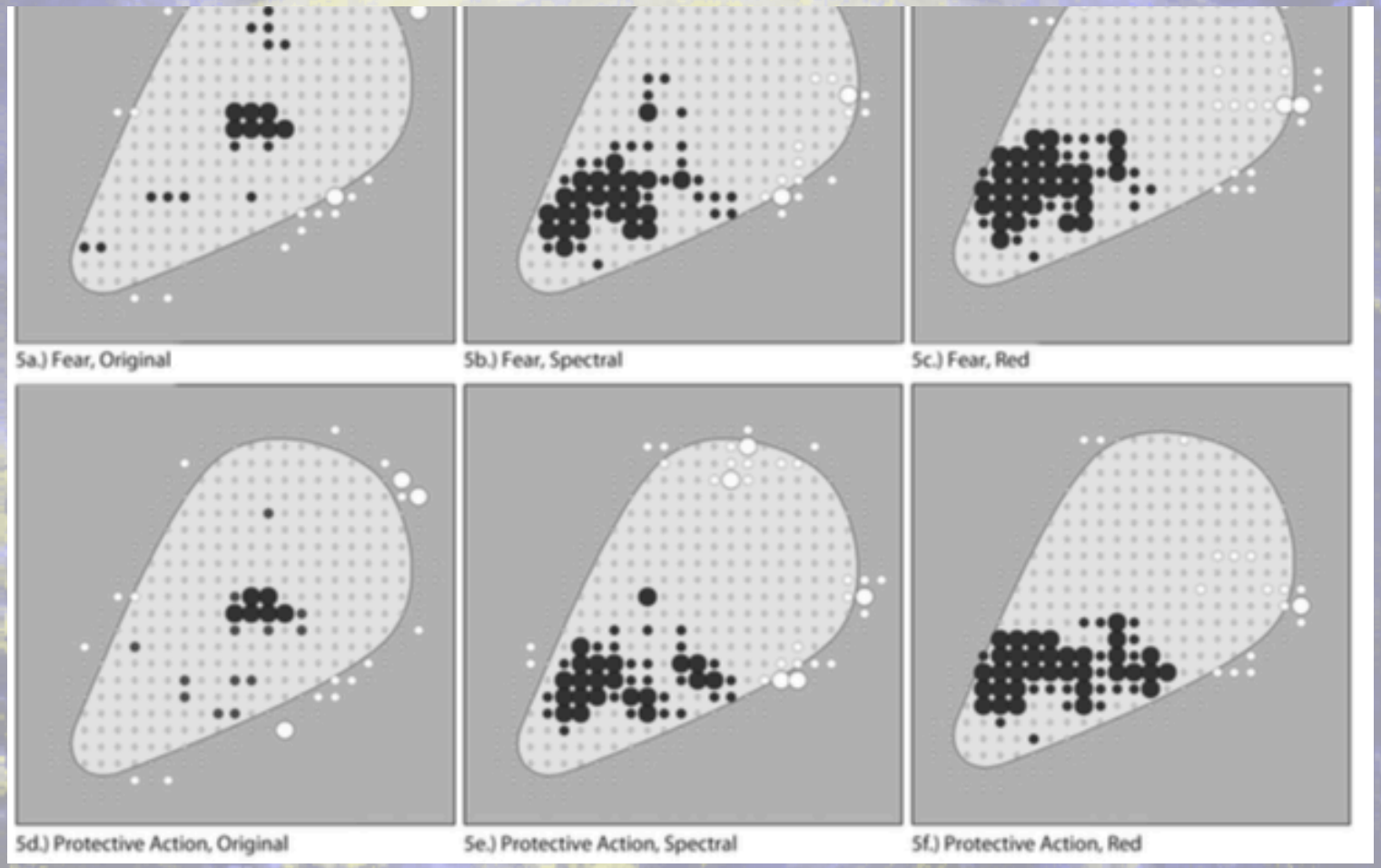


FIG. 1. Three warning designs tested in this study.

Ash et al. (2014)

- The standard polygon
  - > Elicited the highest overall ratings of fear and protective action, especially in a small area at the centroid.
  - > There was a sharp decline in both DVs near the edges.
- The spectral and red gradient polygons
  - > Had much larger areas of high ratings for both DVs and these were located close to the storm front in the polygon.
  - > Had DV ratings that tended to decline more gradually toward the outer contour than did the standard polygon.

Ash et al. (2014) Results



Lindell et al. (2015) Experiment

- Participants viewed 15 tornado polygons that varied in their proximity to their location.
  - > p_s judgments were highest at the polygon's centroid and declined in magnitude at the edge.
  - > p_s judgments were lower just outside the polygon than just inside and were lower still farther away.
- p_s judgments were
  - > strongly correlated with adaptive protective actions such as seeking information from social sources and sheltering in-place (r = .35-.65), but
  - > not significantly correlated with maladaptive actions (r = .12 with going outside to observe and also r = .12 with evacuation).

Lindell et al. (2015)

	A	B	C	D	E	F	G	H	I
5					2.38/ 3.34				
4	2.49/ 3.15	3.00/ 4.03						3.11/ 3.87	1.46/ 1.61
3	1.39/ 2.15	2.57/ 2.81			4.55/ 4.85		3.30/ 3.88		
2		1.39/ 1.44		2.99/ 4.13	3.09/ 4.03	2.76/ 3.35	1.93/ 2.10		
1									

Note: *Extremely unlikely* = 1; *Extremely likely* = 5

Overall Conclusions

- People can infer more differentiated representations of risk from a dichotomous display (uncertainty cone or warning polygon) than is actually depicted in it.
  - > The hurricane studies generally showed that people not only provided nonzero p_s estimates outside the uncertainty cone boundaries; they provided estimates that declined with distance from it.
  - > The tornado studies generally showed that people not only provided higher p_s estimates inside the figure boundaries; they provided estimates that decreased laterally away from the centroid.

Overall Conclusions

- More generally, these studies suggest that people evaluate graphical uncertainty displays using a *distance-decay heuristic.*
  - > This generates a perceived risk gradient (Lindell and Earle 1983) in which p_s judgments decrease with distance from the expected impact location (also see Montello, Fabrikant, Ruocco and Middleton 2003, for a discussion of the *distance similarity metaphor*).
- In addition, some of these studies, together with others (see Huang et al., in press), indicate that expected and actual protective actions are correlated with p_s judgments.

Overall Conclusions

- However Nagele and Trainor (2012), together with other post-impact surveys dating back to Mileti and Beck (1975) and Perry et al. (1981), suggest caution in applying these results.
  - > There can be a major difference between reactions to a single graphic display and the totality of information encountered between the first warning and protective action implementation.
- Moreover, research is needed to determine if these results also apply to floods and lahars—hazards in which topographical features affect the geographical risk.

References

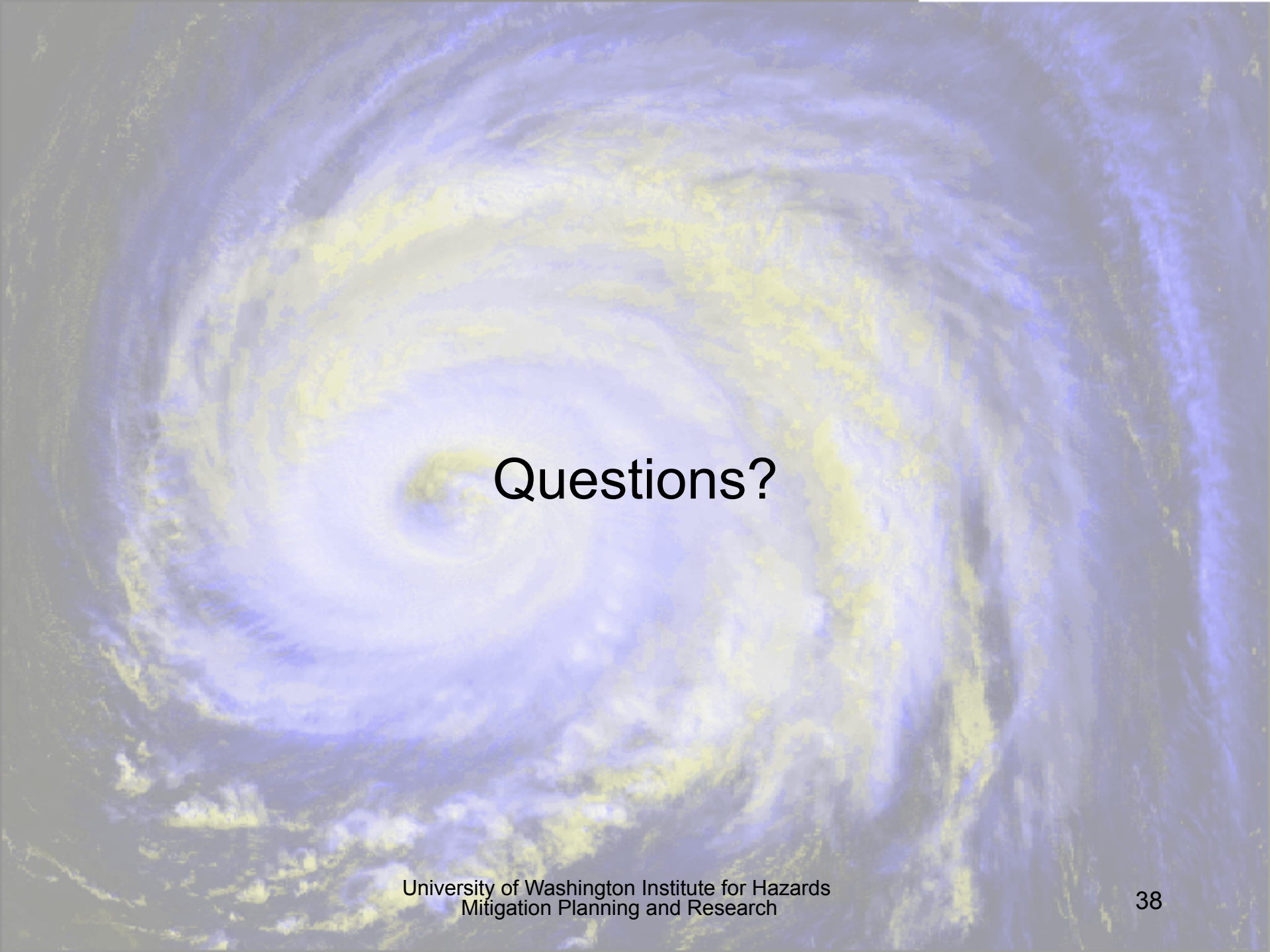
- Ash, K.D., R.L. Schumann III, and G.C. Bowser, 2014: Tornado warning trade-offs: Evaluating choices for visually communicating risk. *Weather, Climate, and Society*, *6*(1), 104-118.
- Broad, K., A. Leiserowitz, J. Weinkle, and M. Steketee, 2007: Misinterpretations of the “cone of uncertainty” in Florida during the 2004 hurricane season. *Bulletin of the American Meteorological Society*, 88(5), 651-667.
- Cox, J., D. House, and M.K. Lindell, 2013: Visualizing uncertainty in predicted hurricane tracks. *International Journal for Uncertainty Quantification,* 3, 143-156.
- Huang, S-K., M.K. Lindell, and C.S. Prater, in press: Who leaves and who stays? A review and statistical meta-analysis of hurricane evacuation studies. *Environment and Behavior*.
- Lindell, M.K. and T.C. Earle, 1983: How close is close enough: Public perceptions of the risks of industrial facilities. *Risk Analysis, 3,* 245-253. Reprinted in S. Gerard, R. K. Turner and I. J. Bateman (eds.) *Managing the Environment for Sustainable Development Vol. 4, Environmental Risk Planning and Management*, Northampton, MA: Elgar (2001), pp. 449-457.

References

- Lindell, M.K., S-K. Huang, H-L. Wei, and C.D. Samuelson, 2015: *Perceptions and Expected Immediate Reactions to Tornado Warning Polygons.* Seattle WA: University of Washington Department of Urban Design and Planning.
- Mason J.B. and J.C. Senkbeil, 2014: Implications of the 2011 Tuscaloosa EF4 tornado for shelter and refuge decisions. (Natural Hazards DOI: 10.1007/s11069-014-1230-4)
- Meyer, R., K. Broad, B. Orlove, and N. Petrovic, 2013: Dynamic simulation as an approach to understanding hurricane risk response: Insights from the Stormview lab. *Risk Analysis, 33,* 1532–1552.
- Mileti, D.S. and E.M. Beck, 1975: Communication in crisis: Explaining evacuation symbolically. *Communication Research*, 2, 24-49.
- Montello, D.R., S.I. Fabrikant, M. Ruocco, and R.S. Middleton, 2003: Testing the first law of cognitive geography on point-display spatializations. In W. Kuhn, M.F. Worboys, and S. Timpf (Eds.): *COSIT 2003*, LNCS 2825 (pp. 316–331).

References

- Nagele, D.E., and J.E. Trainor, 2012: Geographic specificity, tornadoes, and protective action. *Weather, Climate, and Society*, *4*(2), 145-155.
- Perry, R.W., M.K. Lindell and M.R. Greene, 1981: *Evacuation Planning in Emergency Management.* Lexington, MA: Heath Lexington Books.
- Sherman-Morris, K., and M.E. Brown, 2012: Experiences of Smithville, Mississippi residents with the 27 April 2011 tornado. *National Weather Digest, 36*(2), 93-101.
- Wu, H-C., M.K. Lindell, and C.S. Prater, 2015, a: Process tracing analysis of hurricane information displays. *Risk Analysis*. doi: 10.1111/risa.12423
- Wu, H-C., M.K. Lindell, and C.S. Prater, 2015, b: Strike probability judgments and protective action recommendations in a dynamic hurricane tracking task. *Natural Hazards*. doi: 10.1007/s11069-015-1846-z
- Wu, H-C., M.K. Lindell, C.S. Prater, and C.D. Samuelson, 2014: Effects of track and threat information on judgments of hurricane strike probability. *Risk Analysis,* 34, 1025-1039.


Questions?