The Impact of Forecast Uncertainty on Decision Making

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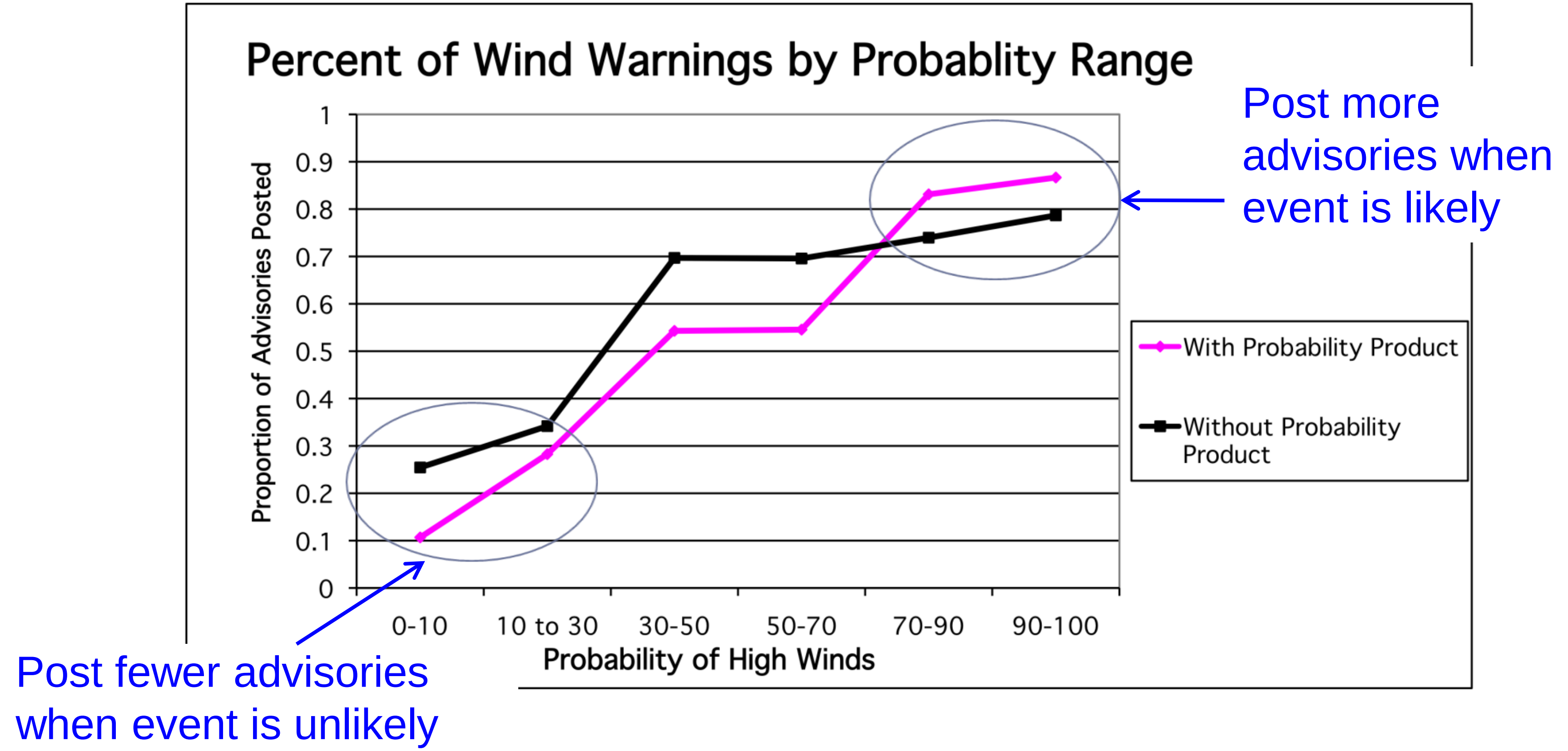
Research Program

- How do people understand uncertainty forecasts?
  - Compare communication formats
- Do forecasts with uncertainty estimates improve decisions?
  - Compare decisions based on deterministic forecasts to decisions based on uncertainty forecasts
  - Which are better?
  - Weather forecasters & general public

Study 1: Forecasters make better decisions with uncertainty products

- Forecasters decided whether to post small craft advisory
  1. 8 decisions with products (satellite imagery, model output) they usually use
  2. 8 decisions with products they usually use + probability product



Joslyn, S., Pak, K., Jones, D. Pyles, J. & Hunt, E., (2007)

Does general public make better decisions with uncertainty forecasts?

- Non-expert end user (general public)
- Can they understand uncertainty?

Study 2: People anticipate uncertainty in deterministic forecasts

- Survey of 1,340 residents of Pacific Northwest
  - 98% west of Cascades
- Given 52 forecasts & asked what they expected to observe
- Wide range of expectations
  - Forecast: Night time low in December: 32ºF
  - Participants expect: 28.5---I----36ºF
- Significantly wider ranges with longer lead times
- Extreme forecasts
  - Forecast: Daytime high in August: 100ºF
  - Participants expect more normal values: 90----------I--102ºF
- Contrary to verification
  - observed values for extreme forecasts tend to be slightly MORE extreme

Study 2: Survey of general public users

- People understand that forecasts involve uncertainty
- When no uncertainty estimate provided
  - Estimate it on their own
  - Anticipate wide ranges and unjustified biases
    - PROBLEM: discounting extreme values could put them in danger
- Good uncertainty forecasts could
  - improve people's understanding of future weather events
  - acknowledging and specifying the uncertainty

Can general public use uncertainty forecast to make better decisions?

- Evidence suggests that
  - People ignore uncertainty estimates
  - People make errors in interpreting and using uncertainty information

- Uncertainty information is difficult for general public to process

Study 3: # Do non-experts make better decisions with uncertainty forecasts?

Decide whether to salt the roads to prevent ice

Study 3: Computer based simulation

Manager of company: in charge of treating the roads in the winter to prevent icy conditions-Treatment BEFORE freezing

- Monthly budget: $36,000
  - Cost of treating roads 1 day = **$1,000**
  - Each day: temperature forecast for relevant time
    - real forecasts within the normal range
  - Penalty (if no treatment & temp ≤ 32ºF) = **$6,000** cost to city disrupted AM commute
  - Feedback: observed temperature after each trial/balance adjusted
  - 2 simulated months (60 trials)
  - Balance forwarded to next month
- Reward cash prize: commensurate with performance (about $10)

Study 3: Compared forecasts with and without uncertainty estimates

Deterministic	Uncertainty
Night time low temperature 36ºF	Night time low temperature 36ºF 20% chance the temperature will be equal to or less than 32 F

Study 3: Deterministic Condition

Month 1, Day 1

The expected night time low temperature for tomorrow is **35°F**

Would you like to salt the roads?

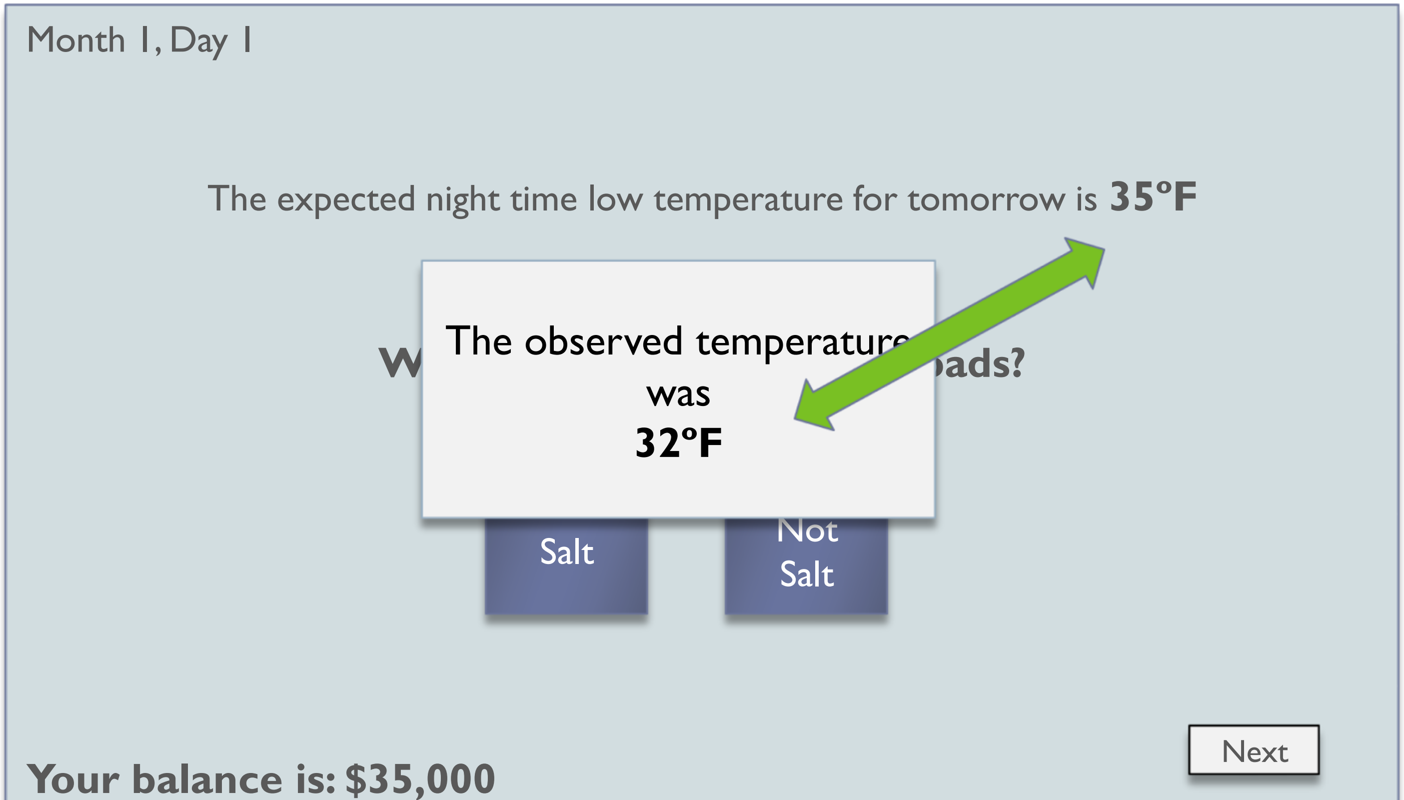
Salt

Not Salt

Next

Your balance is: $36,000

Study 3: Deterministic Condition



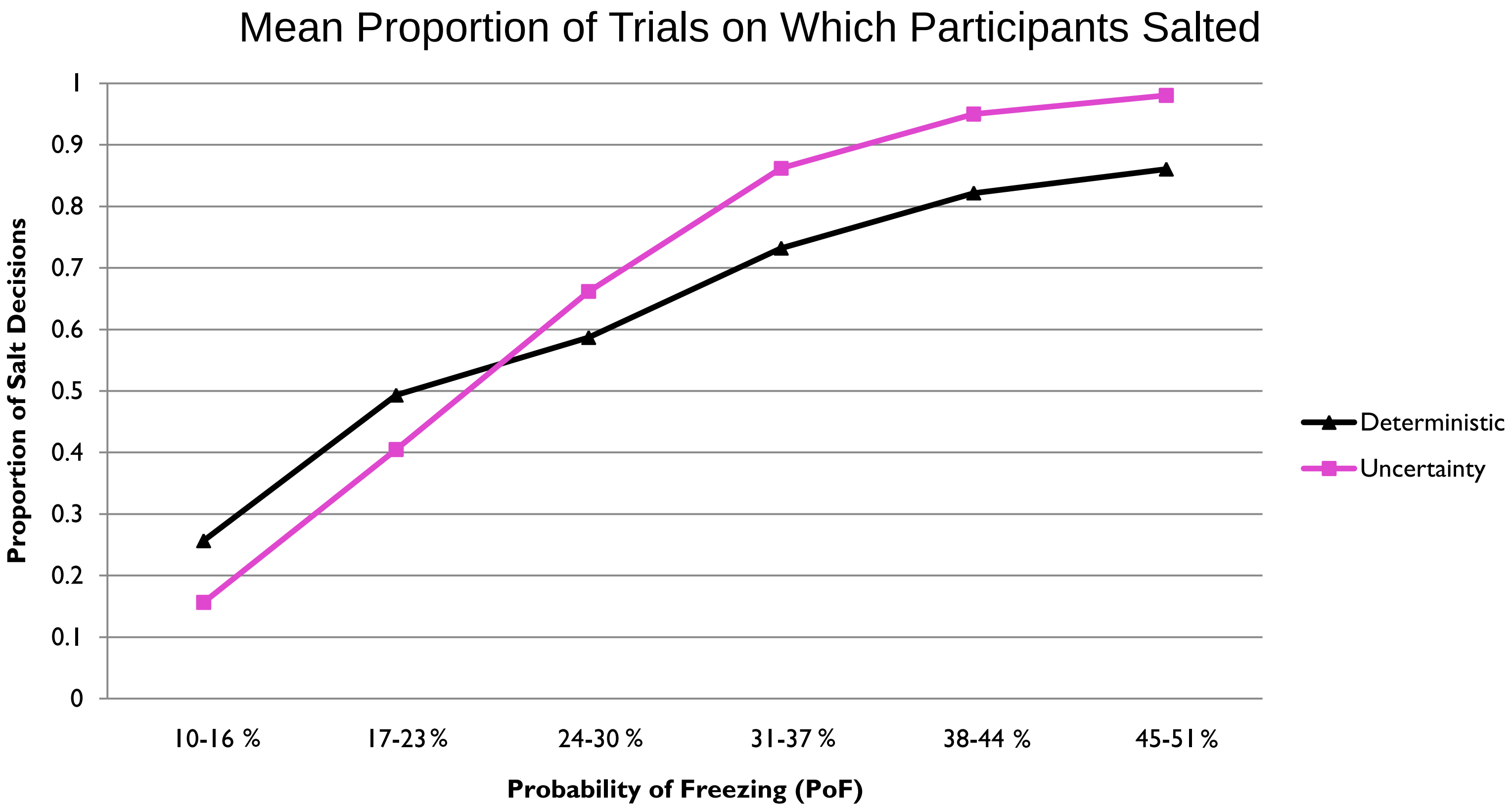
Study 3: People with uncertainty estimates did better

Mean Ending Budget

Deterministic Night time low temperature 36ºF	Uncertainty Night time low temperature 36ºF 20% chance the temperature will be equal to or less than 32 F.
$6,742	$11,171

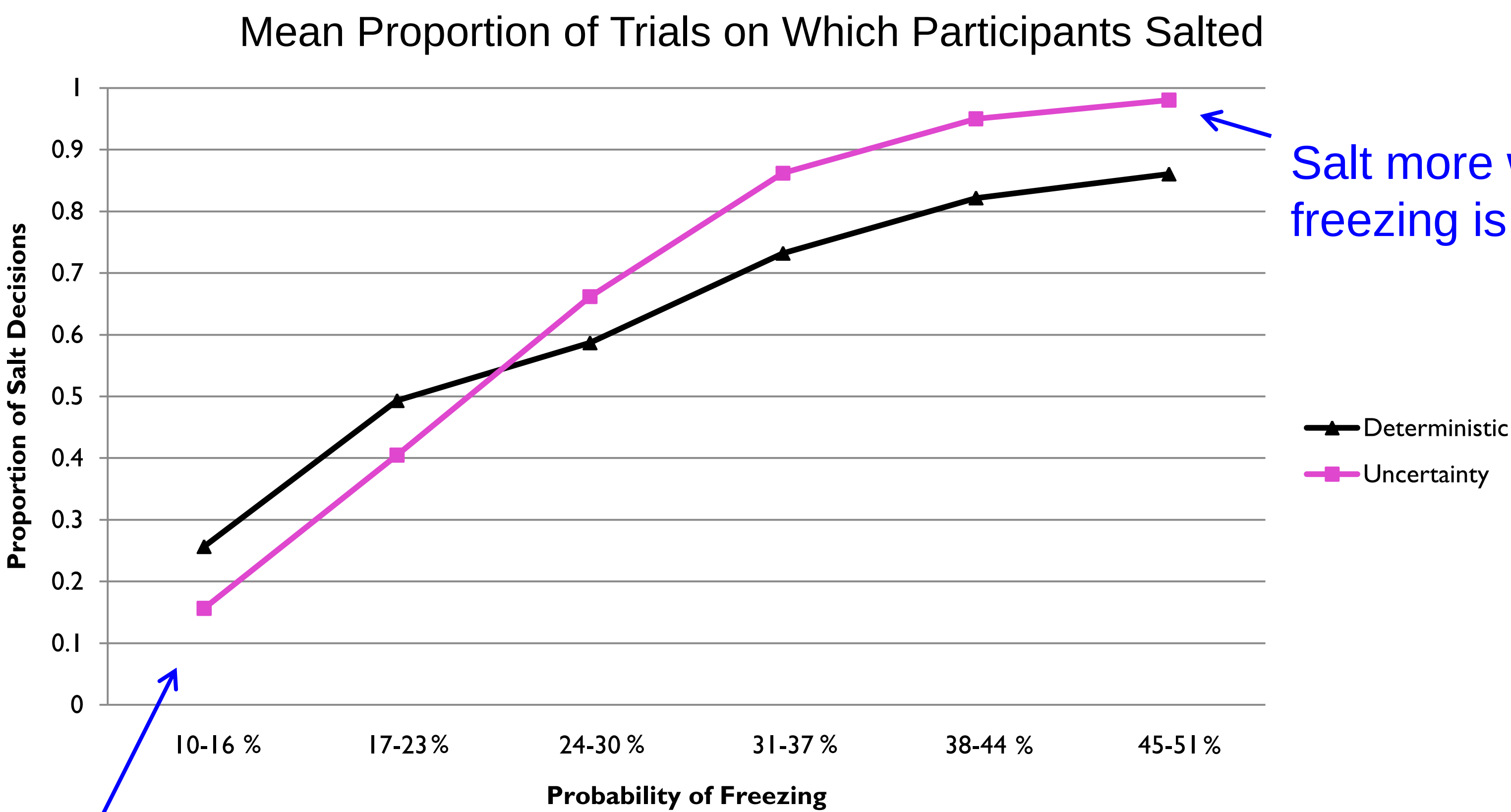
Larger ending balance

Study 3: How did decision improve?



Everybody salts more as PoF increases suggesting that those in the deterministic condition estimated the uncertainty

Study 3: Advantage for uncertainty similar to that seen among forecasters

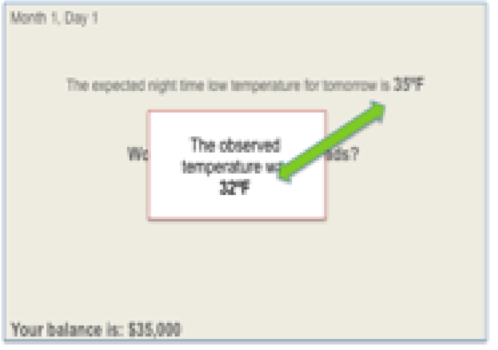


Salt more when freezing is likely

Salt less when freezing is unlikely

Study 3: What happens when forecast error increases?

- Forecast Error: Difference between the deterministic forecast & observation



- Does uncertainty help when error increases?
  - Perhaps people will stick with the forecast if the uncertainty has been acknowledged
  - Leading to better performance

Study 3: People with uncertainty did better even when error increased

Mean Ending Budget

Forecast Error	Deterministic Night time low temperature 36ºF	Uncertainty Night time low temperature 36ºF 20% chance the temperature will be equal to or less than 32 F.
Low error SE = 3ºF	$6,742	$11,171
High error SE = 6ºF	-$7,057	$-250
	$13,800	$ 11,421

Everybody does worse

Did better

Study 3: Similar pattern in trust ratings

Mean Trust Rating
scale: 1 (very little)----5(very much)

Forecast Error	Deterministic Night time low temperature 36ºF	Uncertainty Night time low temperature 36ºF 20% chance the temperature will be equal to or less than 32 F
Low error SE = 3ºF	2.6	3.5
High error SE = 6ºF	1.7	2.5

Lower trust
In high error
forecasts

Study 3: Similar pattern in trust ratings

Trust scale: 1 (very little)----5(very much)

Forecast Error	Deterministic Night time low temperature: 36ºF	Uncertainty Night time low temperature 36ºF 20% chance the temperature will be equal to or less than 32 F.
Low error SE = 3ºF	2.6	3.5
High error SE = 6ºF	1.7	2.5

People had more trust in forecasts with uncertainty estimates
Continue to use them, even when error increases

Optimal Strategy

$1,000 / $6,000 = .1667

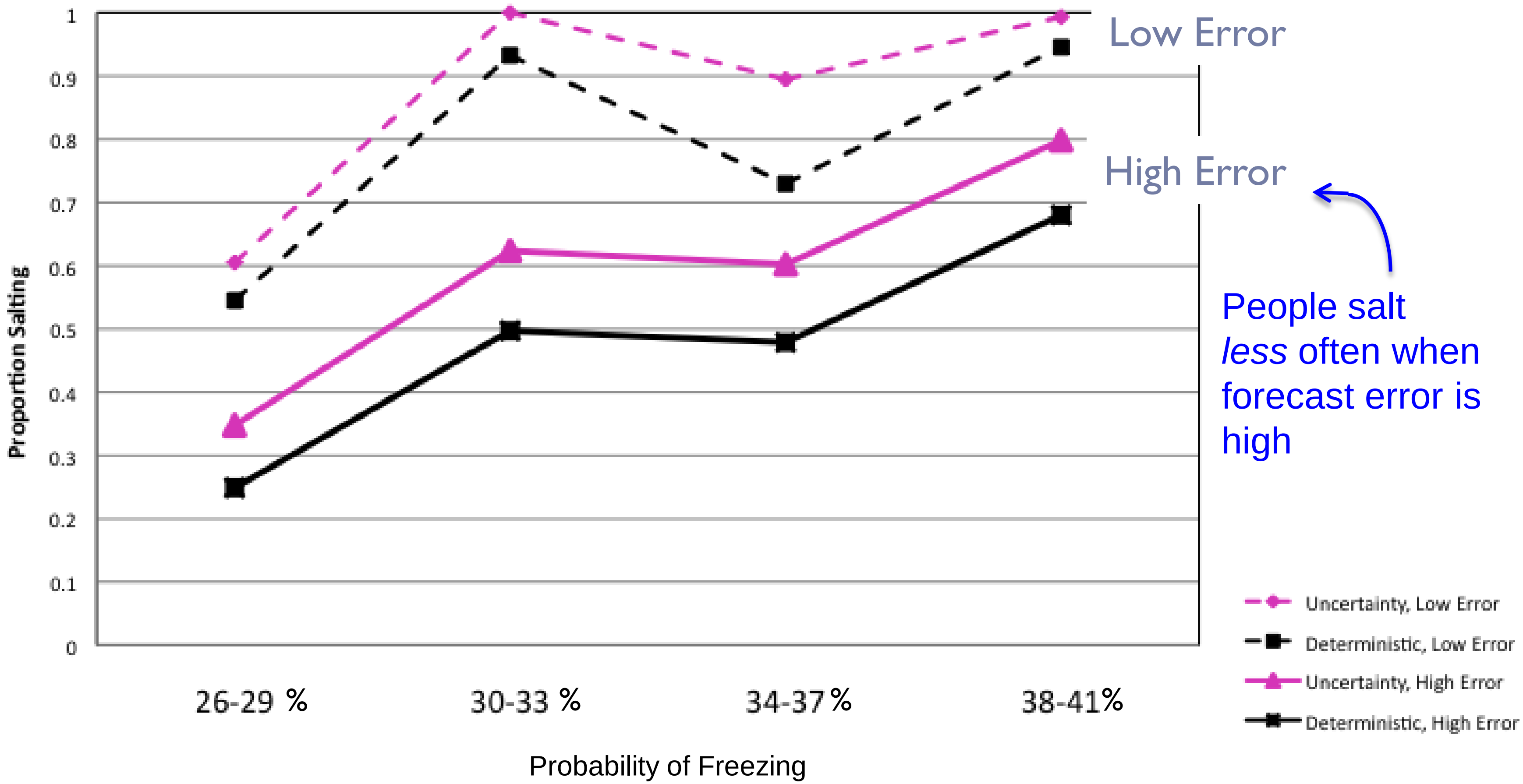
probability of freezing

Cost to treat roads -$1,000 vs. -$6,000 x **16.67%** = -$1000

Expected Value

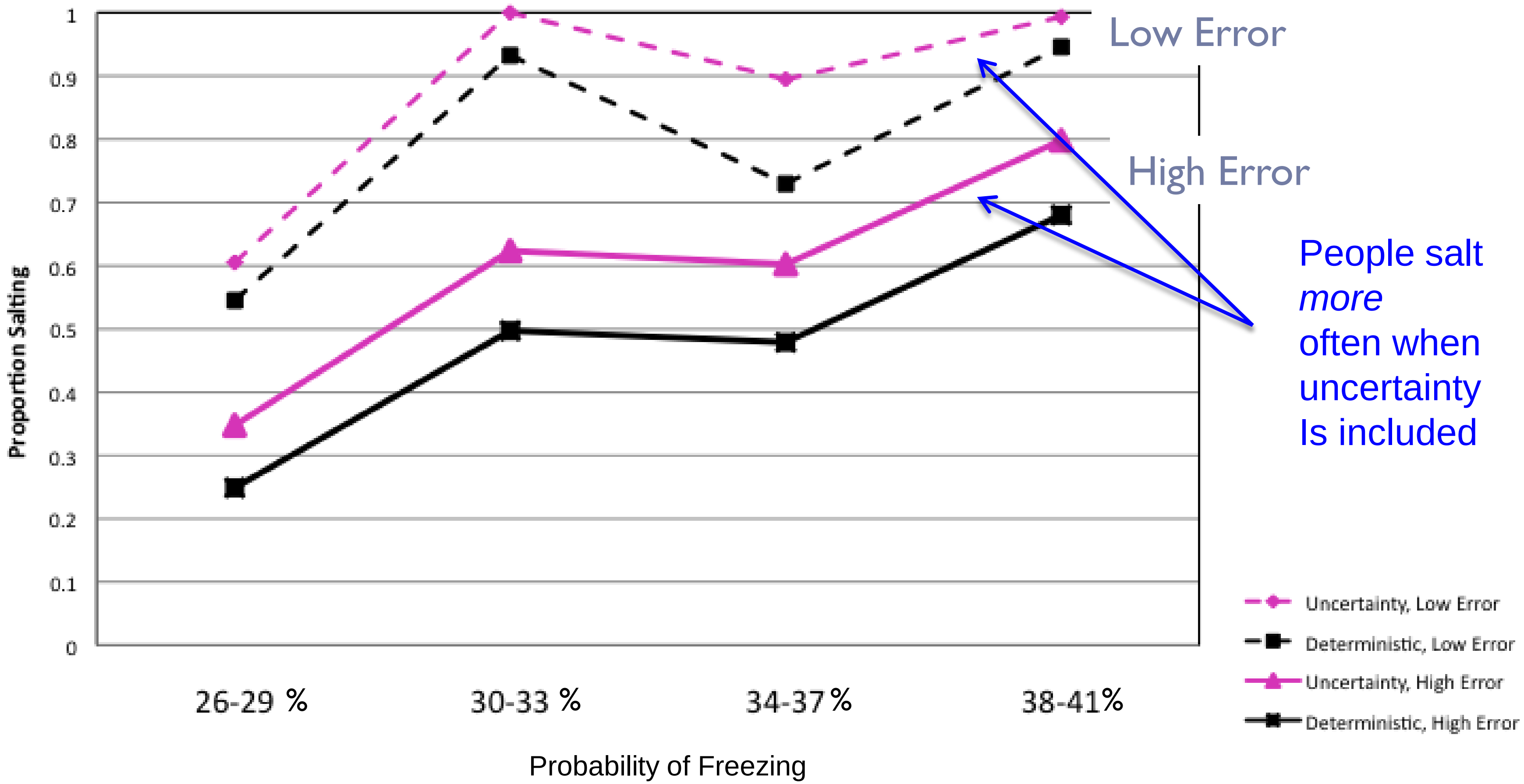
- Salt whenever PoF $\geq$ 17%

Study 3: Strategy change in high error trials



Optimal Decision is to salt (PoF > 17%)

Strategy change in high error trials



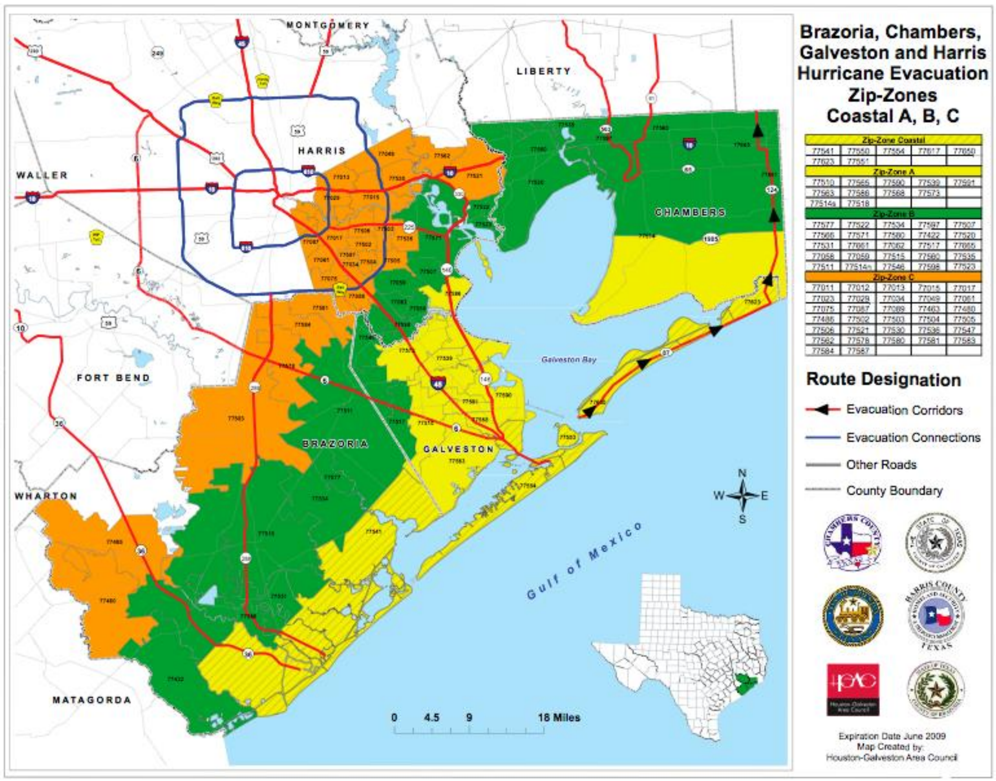
Optimal Decision is to salt (PoF > 17%)

Scenario is similar to weather warning

- Precautionary action is required at low probability
  - Optimal choice: Salt whenever PoF $\geq$ 17%

- Similar to weather warning (e.g. Hurricanes)
  - Evacuation when chance of hurricane force winds at any given location < 30%
  - People make risk seeking errors: fail to take action when appropriate

Appropriate to take action at low probabilities: Hurricane Ike



September, 2008

- Mandatory evacuation
  - Galveston area
  - 2 days before
  - Chance of hurricane force winds 18%
- “certain death”
- 1,000’s stayed

Why do people fail to evacuate?

- They know there is uncertainty
  - Estimate it themselves
  - Discount extreme forecasts
  - Think hurricane is unlikely
  - They are reluctant to act when they distrust the forecast

- Road Salt simulation task
  - Forecast with uncertainty helps
  - Is it better than being told the “right thing” to do?
  - Evacuation: user is told what decision to make

Study 3: Decision Advice

- Condition comparable to evacuation:
  - Tells the user what to do
  - "Decision Support Aid"

"advanced weather modeling computer system, which incorporates the most recent weather forecast available, the uncertainty involved, and the costs associated with salting or not salting, and provides you with a decision recommendation for each day's forecast."

- It told them to salt when probability of freezing $\geq$ 17%

Study 3: Telling People the "right thing" to do did not help

Mean Ending Budget

	Deterministic Night time low temperature 36ºF	DSA Night time low temperature 36ºF *Decision Support Aid: "Applying salt brine is recommended under these circumstances."*	Uncertainty Night time low temperature 36ºF 20% chance the temperature will be equal to or less than 32 F.
Low error	$6,742	$7,538	$11,171

Not significantly different than deterministic forecast

Study 3: Telling People the "right thing" to do did not help

Mean Ending Budget

	Deterministic Night time low temperature: 36ºF	DSA Night time low temperature: 36ºF *Decision Support Aid: "Applying salt brine is recommended under these circumstances."*	Uncertainty Night time low temperature 36ºF 20 % chance the temperature will be equal to or less than 32 F.
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Significantly worse than forecast that included uncertainty

Study 3: Telling People the "right thing" to do did not help

Mean Ending Budget

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Low error	$6,742	$7,538	$11,171
High error	-$7,057	-$4,358	$-250

Significantly worse than forecast that included uncertainty

Study 3: Telling people the "right thing" to did not inspire trust in the forecast

Mean Trust Rating

	Deterministic Night time low temperature 36ºF	DSA Night time low temperature 36ºF *Decision Support Aid: "Applying salt brine is recommended under these circumstances."*	Uncertainty Night time low temperature 36ºF 20% chance the temperature will be equal to or less than 32 F.
Low error	2.6	2.6	3.5
High error	1.7	1.8	2.5

Trust scale: 1 (very little)----5(very much)

Significantly worse than forecast that included uncertainty

Conclusions

- People realize there is uncertainty in weather forecasts
  - If uncertainty is not specified, they estimate it themselves
  - Discount extreme forecasts
- When they perceive the error in the forecast
  - People are reluctant to act
  - Telling them the right thing to do does not help

Conclusions

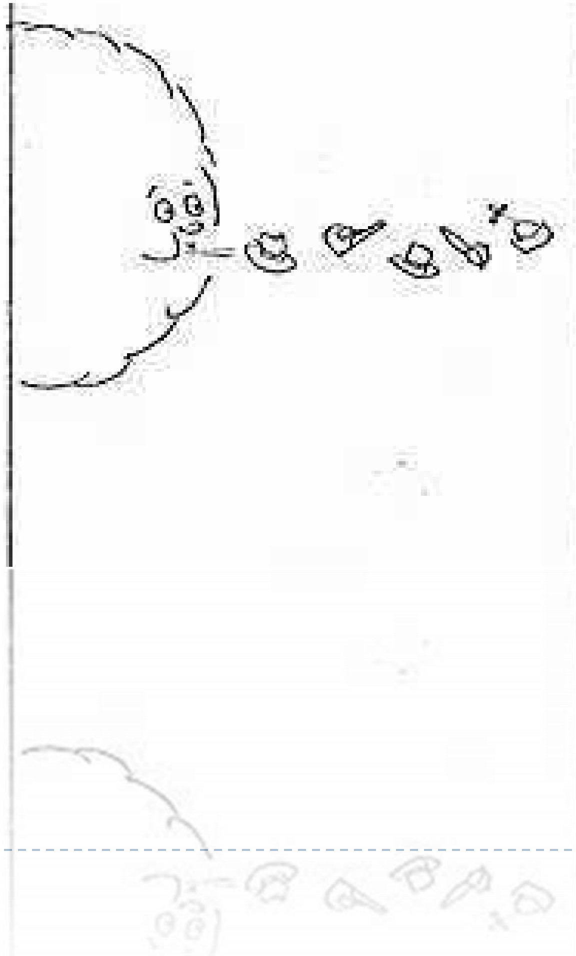
- People realize there is uncertainty in weather forecasts
  - If uncertainty is not specified, they estimate it themselves
  - Discount extreme forecasts
- When error in the forecast increases
  - People are reluctant to act
  - Telling them the right thing to do does not help

Conclusions

- People make better decisions when forecasts include uncertainty estimates
  - Forecasters as well as general public
  - Pattern of improvement is remarkably similar
- Uncertainty estimates increase trust in the forecast
  - Acknowledging the uncertainty may make the the forecast seem less “wrong” when it fails to verify
  - People continue to use the forecast even when error increases

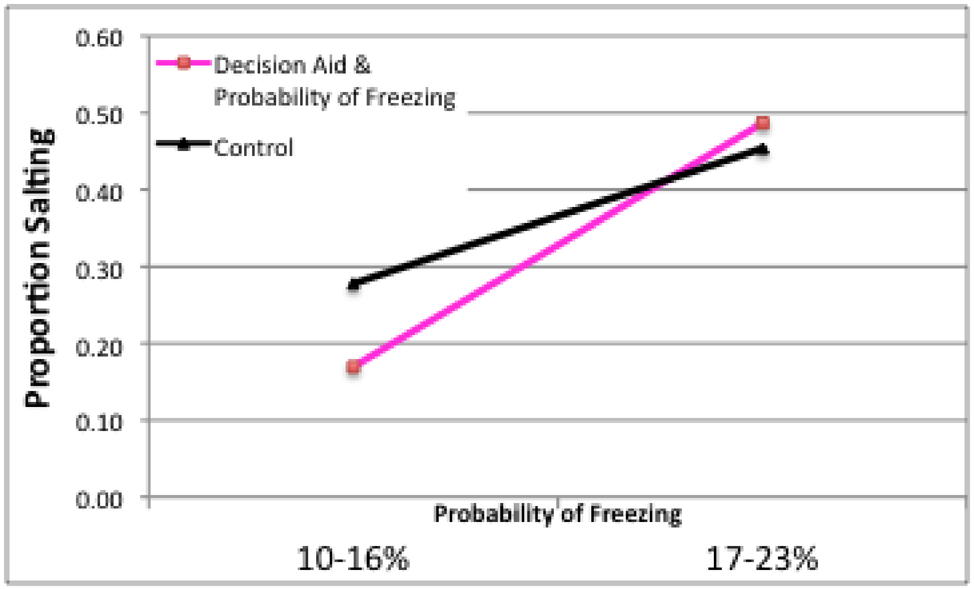
Next Steps: More research is needed

- Good data base of compliance rates and related variables
- Experimental research
  - Captures basic cognitive characteristics
    - Many factors that influence decisions are unconscious
  - Ethically manipulate variables
    - communication format
    - decision threshold
    - forecast error
- Next questions
  - Same pattern of behavior when decision threshold involves extreme values?
  - Optimal communication formats
    - Increase in odds over climatology
    - Worst case scenario
    - Frequency vs Probability
    - Consequences to end user



The End

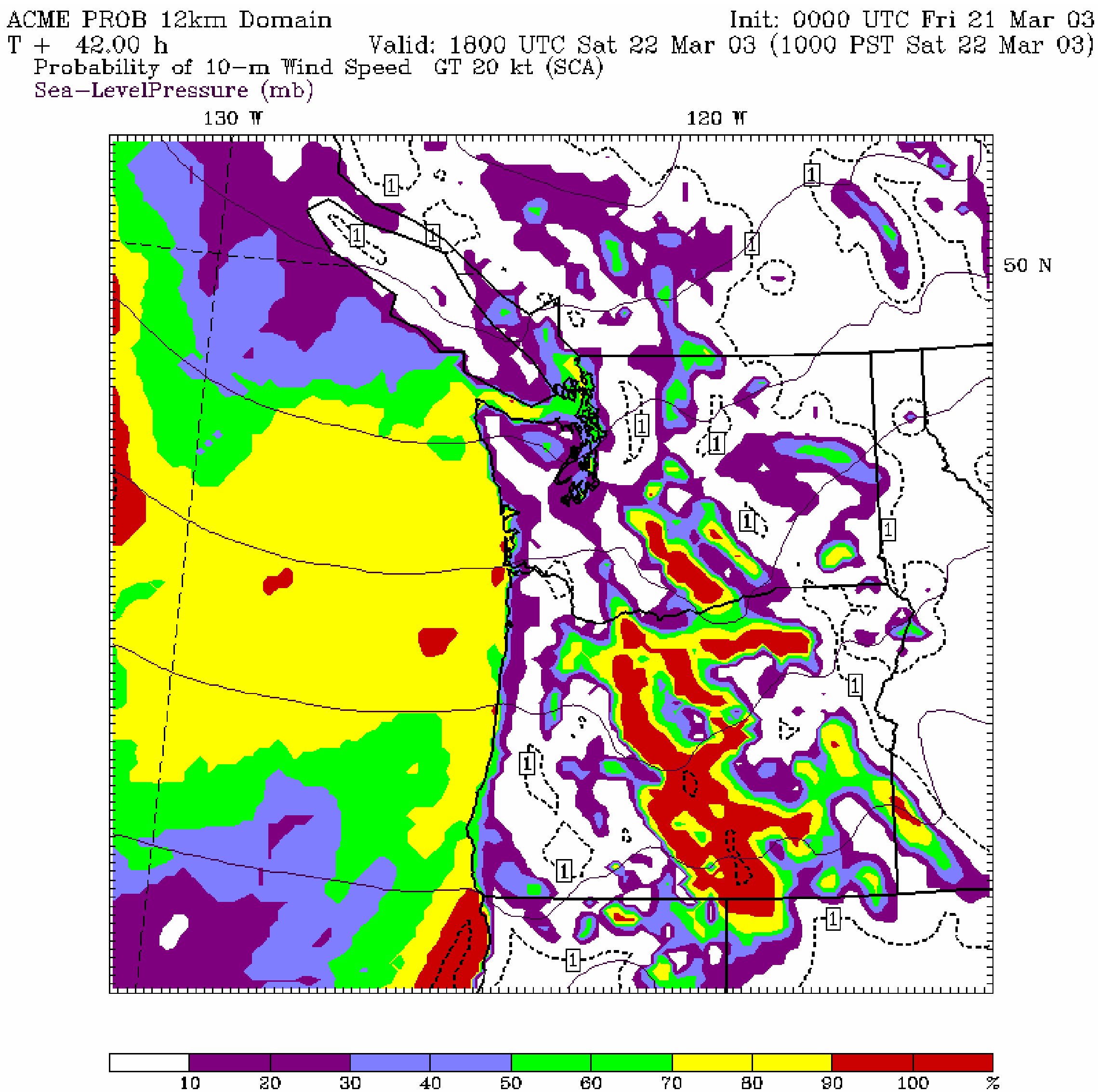
Next Steps

- Low probability range, around optimal threshold (1-23%)
- 

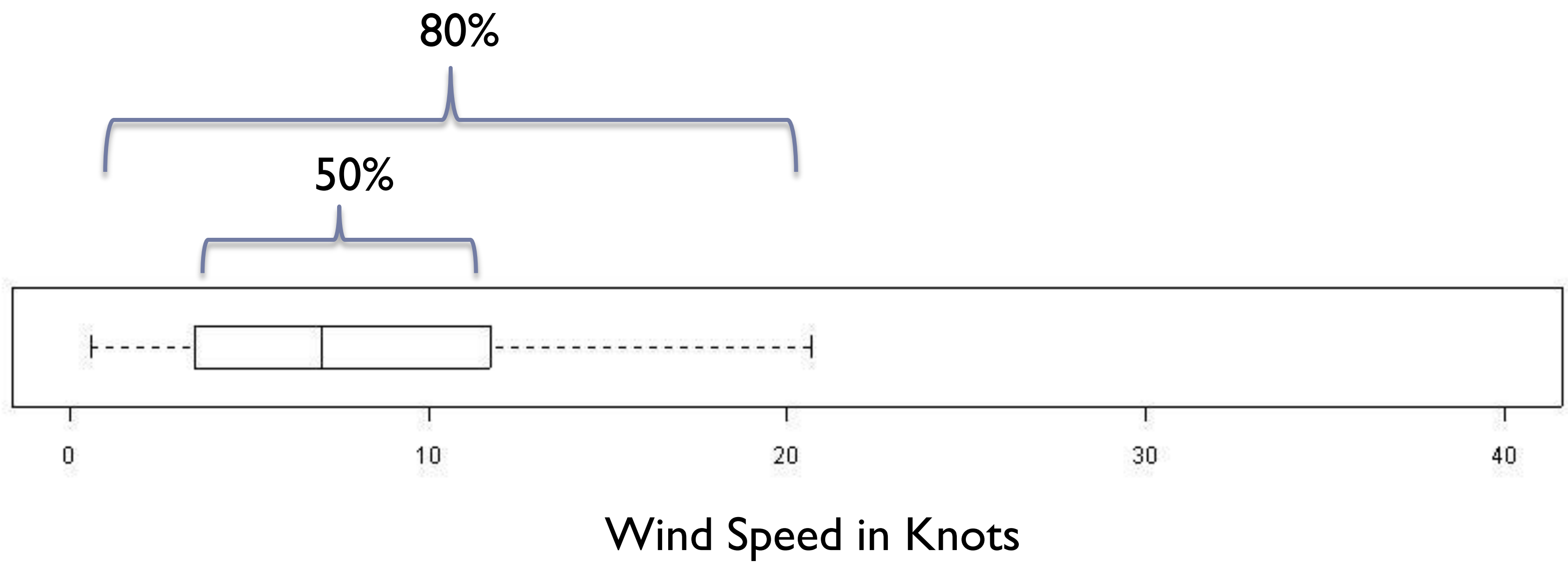
combination of an uncertainty estimate explicit decision advice leads to better decisions

- Introducing extreme event

Probability Product: MM5 ACME Ensemble
Probability of winds greater than 20 knots



Box plot better for point forecast



Nadav-Greenberg, L., Joslyn, S., & Taing, M.U. (2008). The effect of weather forecast uncertainty visualization on decision-making. *Journal of Cognitive Engineering and Decision Making*, 2 (1), 24-47.

Interpretation errors: Deterministic conversion error

Probability of precipitation

- 70 % chance of precipitation-----> 70 % time
  70 % area

(Murphy et al., 1980; Gigerenzer, et al., 2005)

- Error only reduced by
  70% chance rain & *30% chance of no rain*

(Joslyn, et al., 2008)

Similar error with predictive interval

Communicate uncertainty in a form that conforms to expectations of user.

- If the user is concerned with high winds
  - 10% chance wind speed will be greater than 20 knots

    is better than

  - 90% chance less than 20 knots

|---10%----->

<----90%-----|

5kts 10kts 20kts 30kts

- Even though the 2nd expression describes the more likely outcome because that is what the user is concerned with and expect to hear about

Communicate uncertainty in a form that conforms to expectations of user.

- If the user is concerned with low temperature
  - 10% chance temperature will be less than 32 degrees

    is better than

  - 90% chance greater than 32 degrees

|---90%---------->

<----10%--|

28º 30º 32º 34º 36º 38º 40º

- Even though the 2nd expression describes the more likely outcome because that is what the user is concerned with and expect to hear about

Why is uncertainty is difficult to process?

- Increases processing load:
  - Consider both outcomes & the probability for each