3.3 UNDERSTANDING THE USE OF FORECAST UNCERTAINTY INFORMATION IN DECISION MAKING: RESULTS FROM A SURVEY

Rebecca E. Morss*, Jeffrey K. Lazo, Julie Demuth
National Center for Atmospheric Research, Boulder, CO

1. INTRODUCTION

Weather forecasts are unavoidably uncertain, and meteorologists have information about forecast uncertainty that is not readily available to most forecast users. Consequently, there is growing interest in the hydrometeorology community in more effectively communicating forecast uncertainty (e.g., Ryan 2003; NRC 2003, 2006; AMS 2008). Yet in many situations, it is not clear whether communicating forecast uncertainty is desirable, or how to best do so. Thus, communicating weather forecast uncertainty poses a number of open research questions.

The ultimate goal of most forecast provision is to provide information that people can use beneficially. Thus, an important aspect of effectively communicating uncertainty is understanding how intended recipients interpret and use different types of forecast information. This includes comparing interpretation and use of single-value (deterministic) forecasts with those presenting uncertainty in different ways. Although studies in idealized contexts suggest that uncertainty information has potential to benefit users (e.g., Richardson 2000; Zhu et al. 2001; Mylne 2002; Palmer 2002), a variety of constraints limit effective communication and use of forecast uncertainty information in the real world (e.g., Murphy et al. 1980; Katz and Ehrendorfer 2005). Here we examine how members of the U.S. public use different types of forecasts, including those containing uncertainty information, in simulated decision contexts.

The analysis is based on questions incorporated into a nationwide, controlled-access Internet survey with approximately 1500 respondents. One set of questions asked respondents their threshold, in terms of a percentage chance of rain or temperature below freezing, for deciding whether to move a picnic indoors or protect garden plants. The remaining questions examined here asked respondents to use various precipitation or temperature forecasts to make decisions to take or not take protective action in potential flood or frost scenarios. The protection component of the scenarios involves monetary costs, and the impact component (flood or frost) involves monetary losses. In the scenarios, respondents were asked what decisions they would make given deterministic forecasts and forecasts that conveyed uncertainty in different ways. These scenario questions are similar to experimental economics and psychology approaches that empirically assess how individuals use information.

* *Corresponding author address*: Rebecca E. Morss; National Center for Atmospheric Research; P.O. Box 3000; Boulder, CO 80307-3000. e-mail: morss@ucar.edu

Here we present preliminary results examining 1) individuals' thresholds for decision making using probabilistic forecasts; and 2) how subjects responded to different types of forecast information in the decision scenarios. The results provide information about respondents' understanding of forecast uncertainty information, inferences of forecast uncertainty, and ability to use the uncertainty information in decision making. Results of this type can serve as a starting point for policy decisions about whether and in what formats to communicate forecast uncertainty to the public, and perhaps to specialized forecast users. Because weather forecasting is a common form of risk communication, the results may also inform risk communication more generally.

The survey included a number of questions in addition to those discussed here. One set of questions, closely related to those examined here, analyzed respondents' perceptions, interpretations, and preferences for weather forecast uncertainty information; results from these are presented in Morss et al. (2008). A second set examined the U.S. public's sources, perceptions, uses, and values of weather forecasts in general; these results are discussed in Lazo et al. (2009). The questions discussed here — the decision threshold questions and the decision scenarios — are exploratory work. Thus, the primary goal of implementing these questions in the survey was to generate preliminary findings and test a methodology that could be built on in future work.

2. METHODOLOGY

2.1 *Survey implementation*

The survey was developed by the authors in 2006 using standard principles for developing survey questions and conducting survey research (Dillman 2000; Schuman and Presser 1996; Tourangeau et al. 2000). The survey questions, including those discussed here, were developed iteratively, including review by peers and a pretest with several non-meteorologists. The survey was implemented on the Internet in November 2006. It was programmed and hosted by a survey research company (ResearchExec), who also managed data collection. The sample, which was designed to be representative of the U.S. population reachable online, was provided by a second company (Survey Sampling International (SSI)). Only people invited by SSI (via e-mail) were permitted to access the survey.

We received 1520 completed surveys. Our respondent population has similar gender and race characteristics to the U.S. public, but it is somewhat older and more highly educated, and it under-

Table 1. Overview of decision scenario questions

			Scenario 1	Scenario 2	Scenario 3	Scenario 4
Decision context			*Reservoir*	*Reservoir*	*Fruit*	*Fruit*
Cost of taking protective action ($)			10,000	20,000	10,000	20,000
Potential damage ($)			100,000	100,000	100,000	100,000
Damage threshold			4 in. or more of rain		low temperature below 32°F	
Forecast conditions (randomized)	*Single-value forecasts*	#1	1 in. of rain		low temperature of 37°F	
		#2	2 in. of rain		low temperature of 35°F	
		#3	3 in. of rain		low temperature of 33°F	
	Range forecasts	#4	2 to 4 in. of rain		low temperature of 32°F to 34°F	
		#5	1 to 5 in. of rain		low temperature of 31°F to 35°F	
	Percentage chance forecasts	#6	5% chance of 4 in. or more of rain		5% chance of 32°F or lower	
		#7	10% chance of 4 in. or more of rain		10% chance of 32°F or lower	
		#8	20% chance of 4 in. or more of rain		20% chance of 32°F or lower	
		#9	40% chance of 4 in. or more of rain		40% chance of 32°F or lower	
Number of respondents before removing all-yes and all-no responses (total 1465)			362	367	363	373
Number of respondents after removing all-yes and all-no responses (total 1233)			307	300	315	311

represents people with very low and very high incomes. It is also geographically diverse, with respondents from every U.S. state. Further detail about the survey development, implementation, and respondent population can be found in Morss et al. (2008).

Because many of the questions assumed some familiarity with and use of weather forecasts, the first question asked whether the respondent ever uses weather forecasts. Fifty-five respondents (3.6%) said "no" and were not asked most of the remaining questions, including those examined here. Thus, the analysis presented here is based on data from 1465 respondents.

2.2 *Decision Threshold Questions*

The survey included two decision threshold questions, referred to as the picnic and garden situations. Each respondent was randomly assigned to receive one of the two questions (picnic or garden).

In the picnic situation, respondents were told they have an outdoor picnic planned for tomorrow. They were then asked: "At what forecast chance of rain for tomorrow would you decide today to move your picnic indoors?" There were 11 response options: forecast chance of rain from 10% to 100%, in intervals of 10%, or not moving the picnic indoors (i.e., take no action).

In the garden situation, respondents were told they have a garden with plants that will die if the temperature drops below freezing (32°F). They were then asked: "At what forecast chance that the temperature will be below freezing (32°F) tonight would you decide today to cover your plants?" There were 11 response options: forecast chance of temperature below freezing (32°F) from 10% to 100%, in intervals of 10%, or not covering the plants (i.e., take no action).

In both questions, respondents were asked to select 1 of the 11 options.

2.3 *Decision Scenario Questions*

The survey included four decision scenarios, summarized in Table 1. The four scenarios are a combination of two decision contexts (referred to as reservoir and fruit) and two conditions for the cost of taking protective action ($10,000 or $20,000). The potential damage ($100,000) remained the same in all four scenarios. Respondents were randomly assigned to one of the four scenarios, in other words, to one of the decision contexts (reservoir or fruit) and one of the cost conditions ($10,000 or $20,000). The respondents receiving the reservoir decision scenarios were the same as those receiving the picnic threshold question (described in section 2.2), and those receiving the fruit decision scenarios were the same as those receiving the garden threshold question.

Each scenario contained two decision alternatives: 1) no protective action, or 2) protective action at a cost ($10,000 or $20,000); and two possible outcomes: 1) no damage, or 2) $100,000 damage. Two cost conditions were used to explore how respondents' decisions varied (between subjects) based on the expected value of taking protective action. Respondents were not given information about which outcome (damage or no damage) occurred.

In the reservoir scenarios, respondents were told: "Suppose you are a manager of a local water reservoir. If there are 4 inches or more of rain tomorrow, your reservoir will overflow and flood the town, causing $100,000 in damages (but no injuries or deaths) that your company must pay for. You can prevent a potential flood by releasing water from your reservoir today, but releasing water will cost your company {$10,000 or $20,000}." The four possible combinations of decisions (action or no action) and outcomes (damage or no damage) were explained. Respondents were then presented nine forecast conditions, one at a time, in random order. For each forecast condition, they were asked whether they would spend the {$10,000 or $20,000} to release water from their reservoir. The response options were "yes" or "no". After making a decision in each forecast condition, respondents were not allowed to return to the previous question.

In the fruit scenarios, respondents were told: "Suppose you are a fruit grower and your crop is nearly ripe. If the temperature drops below freezing (32°F) tonight and your crop is unprotected, it will be damaged and you will lose $100,000. You can prevent potential freeze damage by protecting your crop today, but protecting your crop will cost you {$10,000 or $20,000}." As in the reservoir scenarios, the four combinations of decisions and outcomes were explained, and respondents were presented nine forecast conditions, one at a time, in random order. For each forecast condition, they were asked whether they would spend the {$10,000 or $20,000} to protect the crop.

For the reservoir scenarios, the damage threshold was 4 inches or more of rain, and for .the fruit scenarios, the damage threshold was temperature below 32°F. The nine forecast conditions presented to respondents for each decision context are shown in Table 1.

Note that while the two decision contexts are related, they are not directly parallel. Differences include: the content of the scenarios (e.g., flood vs. frost, rain vs. temperature forecast, impact for one's company and a town vs. impact on one's crops); the framing of the decision in terms of releasing water from the reservoir vs. protecting the crop; the positive vs. negative framing of the damage thresholds (4 inches or more of rain vs. temperatures below 32°F); and the different numerical values in the scenarios. Given these differences, the goal is not to compare results between the two decision contexts. Rather, we aim to explore results that are consistent across the two. Nevertheless, the results indicate that individuals did respond differently to the two decision contexts; this is discussed briefly in section 4.1.

Following the decision scenario questions, respondents were asked how confident they were that they were able to use the forecast, damage, and cost information to answer the questions about whether or not to release water from their reservoir (for those given the reservoir scenarios) or protect their crop (for the fruit scenarios). Given the exploratory nature of this work, we included this question to assess respondents' confidence in their ability to understand and make decisions in the scenarios. Response options were a 5-point scale ranging from 1 (not at all confident) to 5 (extremely confident). Respondents reported an average confidence of 3.07 with a standard deviation of 0.92; in other words, they were on average somewhat confident in their ability to respond to the scenario questions.

The decision scenario questions contain elements of experimental economics and psychology approaches (e.g., Davis and Holt 1992; Kagel and Roth 1995; Camerer 1999; Ariely and Norton 2007), implemented in a survey. The presentation of monetary costs and damages and the expected value framing is similar to experimental economics, but subjects received no direct incentives. The contextual nature of the scenarios has similarities to psychology experiments. The survey implementation differs from the usual implementation of these types of experiments in a laboratory setting. A potential disadvantage of the survey implementation is that the inclusion of these questions within a long survey may have led to subject fatigue and increased difficulties with subjects' comprehension of the scenarios. However, the survey implementation allows a much larger, more diverse respondent population than typical experimental approaches, which generally involve tens of subjects, generally students. Further, the study design employed here allows within-subject comparisons of the use of different forecast information as well analysis across the subject pool.

Scenarios and experiments of this general form are a common methodology employed by economics and psychologists to examine how people use information in decisions, particularly under uncertainty. However, there have been only a few implementations of this methodology to examine use of weather forecast information. Examples include: Patt and Schrag (2003), Roulston et al. (2006), and Joslyn et al. (2007, 2009). These previous studies asked somewhat different research questions to those examined here. Thus, one goal of this exploratory work was to test using an experimental-type methodology in a survey to compare how respondents interpreted and used several different types of forecast information.

3. PRELIMINARY RESULTS: DECISION THRESHOLDS

This section presents preliminary analysis of data from the decision threshold questions (described in section 2.2). Figure 1 shows the probability thresholds selected by respondents in the picnic (N = 729 respondents) and garden (N = 736) situations.

As the results show, different individuals can have very different probability thresholds for decision making. A portion of these differences is likely due to people's different tolerances for risk. Note also that a small percentage of people (in both situations) chose to take no protective action.

Figure 1 also indicates that the respondent population exhibited differences in probability thresholds between the two situations. On average, respondents selected a higher threshold for taking protective action in the picnic situation than in the garden situation. The reasons for this require further investigation. However, this result is consistent with the result in section 4 that people were less likely to take protective action in the reservoir scenarios (which, like the picnic situation, involve a precipitation forecast) than in the fruit scenarios (which, like the garden situation, involve a freezing temperature forecast).

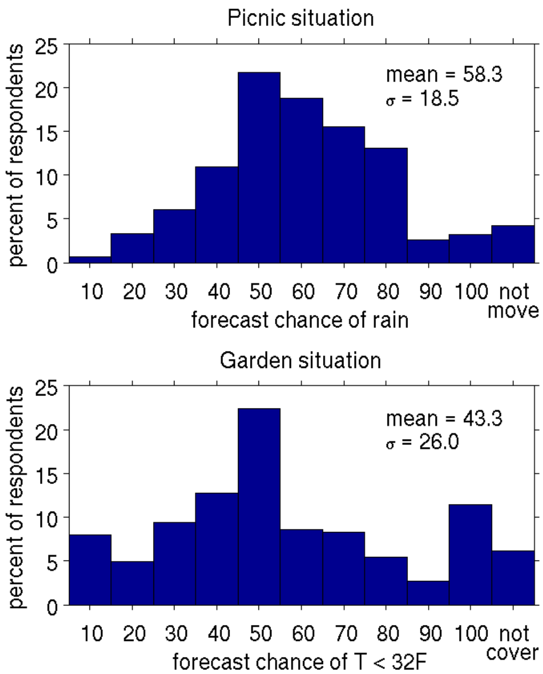

Figure 1. Percent of respondents who selected different thresholds for percentage chance of rain in the picnic scenario (upper, N=729) or percentage chance of temperature below freezing in the garden scenario (lower, N=736). Also shown is the percent of respondents who selected not moving the picnic or not covering garden plants. The mean and standard deviation shown are for the respondents who selected one of the 10 percentage chance options.

Responses to the picnic situation also show a more normal distribution than responses to the garden situation, which exhibit secondary peaks at the lowest (10%) and highest (100%) percentage change options. It is possible that people responded more consistently in the picnic situation because they are more familiar with probability of precipitation forecasts (since these have been regularly provided to the public for decades) than percentage chance of temperature forecasts (which are generally not currently available).

4. PRELIMINARY RESULTS: DECISION SCENARIOS

This section presents preliminary analysis of data from the decision scenario questions (described in section 2.3 and summarized in Table 1). Of the 1465 respondents, 183 answered "no" (take no action) to all nine forecast conditions, and 49 answered "yes" (take action) to all nine conditions. There was a larger frequency of all-no responses in the reservoir scenarios and a larger frequency of all-yes responses in the fruit scenarios. Consistent with this, respondents were overall more likely to choose to take no action in the reservoir than in the fruit decision context; this will be discussed in section 4.1.

Because the repeated yes or no responses suggest that these respondents may not have understood the scenario or may not have responded to the forecast conditions as intended, these 232 respondents (15.8%) were removed from the analysis of data shown below. The number of respondents for each of the four scenarios, before and after removal of these respondents, is shown at the bottom of Table 1.

While the results are discussed using the order of the nine forecast conditions presented in Table 1, recall that each respondent received the forecast conditions one at a time, in random order. Thus, to the extent that individuals ordered their responses in a seemingly logical manner, they were not doing so because the nine forecast conditions appeared in order. Most of the results presented are for comparisons across the entire panel, although a few within-subject comparisons are discussed.

4.1 *Use of "Single-Value" Forecasts*

First, we compare respondents' decisions in the first three forecast conditions: 1 inch, 2 inches, or 3 inches of rain in the reservoir scenarios, and low temperature of 37°F, 35°F, or 33°F in the fruit scenarios. These are referred to as the "single-value" (or deterministic) forecast conditions. The percentage of respondents saying "yes" to taking protective action given the three different forecast conditions is shown in Fig. 2.

We start by discussing two general patterns in Fig. 2 that appear throughout the decision scenario results. The first pattern is that, for any given forecast condition, respondents were more likely to choose protective action in the fruit scenarios than in the reservoir scenarios. As discussed in section 2.3, while the two sets of decision scenarios are parallel in many ways, there are several differences that we did not control for. It is not clear which of these differences was most influential in leading respondents to be more likely to protect in the fruit scenarios. One difference that may have played a role is the presentation of the reservoir decision as releasing water from the reservoir, which is not as clearly a protective action as the presentation of the garden decision as protecting the crop. However, recall from section 3 that respondents tended to select a higher percentage-chance threshold for taking protective action in the picnic situation than in the garden situation. This suggests that people may have a higher threshold for protection given forecasts of chance or amount of rain than they do for low temperature forecasts, and thus be overall less likely to protect given rain forecasts.

The second pattern is that, for any given forecast condition, the respondent population generally chose to protect with similar frequency in the two cost conditions. We expected people to be more likely to protect when the cost was lower, in other words, when it was $10,000 rather than $20,000. As Fig. 2 shows, this did not generally occur. In other words, the respondent population generally had limited response to the cost component of the scenario. This is particularly true when compared with the differences in responses between the two decision contexts or among the different forecast conditions. Possible reasons include our between-subject comparison (each subject received only one of the two cost conditions) or the lack of incentives directly connected with the cost (given our survey implementation). In discussing most of the remaining results, we therefore average across the $10,000 and $20,000 cost conditions (although results for the two are still depicted separately).

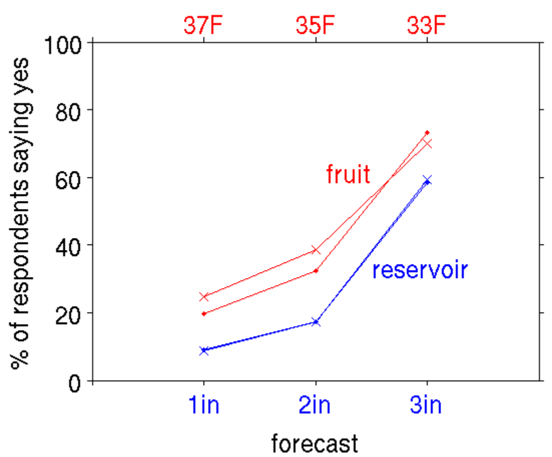

Figure 2. Percent of respondents who said they would take action to protect against possible flooding or frost in the reservoir (blue) or fruit (red) scenarios, respectively, given the three different single-value forecast conditions. The forecast conditions for the reservoir and fruit decision contexts are presented along the bottom and top of the figure, respectively. Results are shown separately for the $10,000 (•) and $20,000 (×) cost conditions, for each of the two decision contexts. There are N=1233 respondents for all four scenarios, with approximately 300 respondents for each (see Table 1 for details).

Regarding decisions in the three single-value forecast conditions, Fig. 2 indicates that in both scenarios, respondents were more likely to choose to protect as the forecast grew closer to the damage threshold. Within-subject comparisons indicate that this pattern held for 92% of individual respondents; in other words, most respondents either chose to take or not take action in all three single-value forecast conditions or changed their response from no action to action as the forecast grew closer to the damage threshold. This suggests that most respondents may have been able to interpret the single-value forecasts and the scenarios well enough to make decisions.

The results in Fig. 2 also provide some indication of the level of uncertainty respondents inferred into the single-value forecasts. For example, 72% of respondents said they would take action in the fruit scenarios given a forecast of 33°F. Since the damage threshold is 32°F, this suggests that these respondents inferred at least 1°F of uncertainty into the deterministic forecast. In other words, as discussed in Morss et al. (2008), most respondents believed that deterministic temperature forecasts contained some uncertainty. Based on Fig. 2, one can likely say the same for quantitative precipitation forecasts.

More specifically, if one imagines that respondents infer some distribution about a deterministic forecast, the 72% who decided to take action with a 33°F forecast in the fruit scenarios inferred a sufficiently wide distribution that they believed there was some chance the temperature would drop below 32°F. What that chance had to be for that person to take action likely depends on the cost and potential damage in the scenario and their individual tolerance for (aversion to) risk. The 28% who decided not to take action with a 33°F forecast may also have believed there was some chance of temperatures below 32°F, but that chance was not sufficiently large to warrant protection. In addition, note that the 72% of respondents who said they would take action with a 33°F forecast is similar to the 72% of respondents who said they inferred more than 1°F of uncertainty into a high temperature forecast (Morss et al. 2008; their Fig. 2).

As shown in Fig. 2, 35% of respondents chose to take protective action given a low temperature forecast of 35°F, suggesting they believed the forecast could be in error by at least 3°F, and 22% of respondents chose to take action given a forecast of 37°F (an inferred error of at least 5°F). Similar inferences can be drawn from subjects' decisions given single-value forecasts in the reservoir scenarios. Further analysis and interpretation of these results is left for future work.

4.2 *Use of "Range" Forecasts*

Next, we compare respondents' decisions in the third through fifth forecast conditions: 3 inches, 2 to 4 inches, or 1 to 5 inches of rain in the reservoir scenarios, and low temperature of 33°F, 32°F to 34°F, or 31°F to 35°F in the fruit scenarios. This compares decisions for a single-value forecast with those for two forecast ranges symmetric about the single-value forecast. Results are shown in Fig. 3.

Figure 3 indicates that the respondent population did not make substantially different decisions when range forecasts were provided than when the mean of that range was provided. The size of the range, at least within the two ranges tested, also did not make a substantial difference. A within-subject comparison indicates that 59% of respondents (70% in the fruit decision context and 47% in the reservoir decision context) selected the same response (action or no action) in all three conditions shown in Fig. 3. In other words, presenting the ranges rather than the single-value forecasts did not alter nearly two-thirds of respondents' decisions.

The range forecasts may not have had a clear effect on decisions across the population because, as discussed in section 4.1 and Morss et al. (2008), most respondents already infer some uncertainty around single-value forecasts. For example, Morss et al. (2008) found that when given a high temperature forecast of 75°F, more than two-thirds of respondents expected the actual high temperature to be 73-77°F or a larger range. People's inferences of uncertainty of high and low temperature forecasts may be somewhat different. However, given that most people already appear to infer two or more degrees of uncertainty around a deterministic temperature forecast, ranges of the type presented in the fruit scenarios may not have provided many respondents with information that altered their decision.

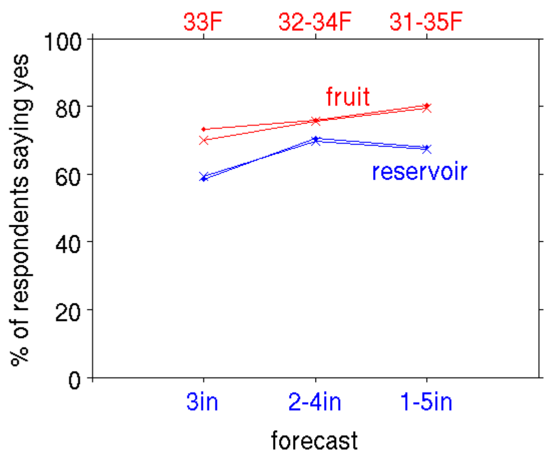

Figure 3. As in Fig. 2, for a single-value forecast and two range forecasts symmetric about the single-value forecast.

Given that the precipitation ranges tested were a much larger fraction around the single value than the temperature ranges, one might expect these ranges to have a more noticeable effect on decisions. The fact that the ranges altered more respondents' decisions in the reservoir scenario indicates that this occurred to some extent, but not with a consistent effect across the population. This suggests that some people may have focused as much on the part of the range away from the damage threshold as the part at or above the threshold. For example, in the 1 to 5 inches of rain forecast condition, they may have focused as much on the possibility of 1 inch of rain as on the possibility of 5 inches of rain.

Note again that, as in Fig. 2, people were more likely to take protective action in the reservoir decision context, and there is little difference between responses to the two cost conditions within each decision context (see section 4.1 for discussion).

4.3 *Use of "Percentage Chance" Forecasts*

Finally, we compare respondents' decisions in the sixth through ninth forecast conditions: a 5%, 10%, 20%, or 40% chance that there will be 4 or more inches of rain (in the reservoir scenarios) or that the low temperature will be 32°F or lower (in the fruit scenarios). Results are shown in Fig. 4.

Figure 4 indicates that in both scenarios, respondents were more likely to take action as the forecasted chance of exceeding the damage threshold increased. To test this statistically, we performed preliminary analysis using a Probit model, with yes/no response as the dependent variable and percentage chance, scenario (reservoir or fruit), and cost as the dependent variables. As expected from Fig. 4, percentage chance and the scenario were highly significant predictors. Further, a within-subject comparison indicates that (across the four scenarios) 85% of individuals ordered their responses in an apparently logical way, in other words, they either said yes (take action) or no (no action) to all four forecast conditions or their response changed from no to yes as the chance of exceeding the damage threshold increased.

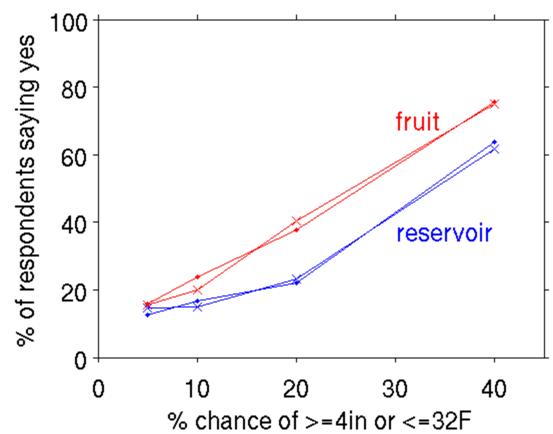

Figure 4. As in Figs. 2-3, for the four percentage-chance forecast conditions. The x-axis represents the forecasted chance that there will be four or more inches of rain (in the reservoir scenarios) or that the low temperature will be 32°F or lower (in the fruit scenarios).

The other 15% of respondents did not provide ordered responses; in other words, they chose to protect at a lower chance and not to protect at a higher chance. These respondents may not have understood the scenario or the percentage-chance forecasts, or they may have been making decisions using other criteria. Recall from section 2.2 that respondents were asked how confident they were (on a scale from 1 to 5) that they were able to use the information provided to answer the decision questions. The average confidence of those who provided unordered responses was 2.9, slightly lower than the 3.1 average confidence of those who provided ordered responses.

Averaged across the four scenarios, 7% of respondents chose to protect in all four percentage-chance forecast conditions, in other words, had a decision threshold below a 5% chance. The percents of respondents who changed their response from no to yes at the 10%, 20%, and 40% chance thresholds were 6%, 13%, and 36%, respectively. A further 23% chose not to protect in all four forecast conditions, in other words, had a decision threshold above a 40% chance. (As discussed above, the remaining 15% did not provide ordered responses.) As discussed in section 3, this illustrates how different people have different percentage-chance thresholds for decision making, based on their risk tolerance and other factors.

Recall that these were four of nine forecast conditions, presented in random order. This means that most respondents did not receive these four forecast conditions in order of increasing chance. Although some respondents could have recalled their decisions in earlier forecast conditions and provided ordered responses to satisfice, it seems unlikely that most respondents were able to do so. Consequently, these results suggest that many of the respondents were able to interpret the percentage-chance forecasts sufficiently to use the information in decision making. Further analysis of this data is needed, however, and further work is needed to investigate to what extent people are able to use percentage-chance forecasts across situations.

The expected value of taking protective action and not taking action are equal when there is a 10% chance of exceeding the damage threshold in the $10,000 cost condition, and when there is a 20% chance in the $20,000 cost condition. Thus, if respondents were making decisions using expected value as the criterion, one would expect them to decide to act (not act) when the forecast chance was above (below) this level. Some respondents decided to take protective action at lower percentage chances, suggesting they are risk averse. However, even when a 40% chance of exceeding the damage threshold was forecast, 37% and 25% of respondents chose not to protect in the reservoir and fruit scenarios, respectively (Fig. 4). In these cases, the expected value of protecting is much higher than the expected value of not protecting. This, combined with the fact that the respondent population exhibited limited response to the cost component of the scenario, suggests that many respondents are not acting as expected-value decision makers in these scenarios. This will examined further in future work.

5. SUMMARY

An important component of providing useful weather forecast information is understanding how people interpret forecast uncertainty and how they use forecasts that include uncertainty information. To begin building this knowledge empirically, we incorporated questions about a probabilistic decision threshold and weather-related decision scenarios into a nationwide survey with approximately 1500 respondents. In the threshold questions, respondents were asked at what percentage chance of rain or temperature below freezing they would decide to move a picnic indoors or cover garden plants. In the scenario questions, respondents were asked to use different precipitation or temperature forecasts to make decisions to protect or not protect from a potential reservoir-related flood or a fruit-damaging frost. Preliminary results are presented on respondents' thresholds for decision making in the picnic and garden situations and their use of different types of forecasts (including those containing uncertainty information) in the reservoir and fruit decision scenarios.

The analysis to date suggests that in the picnic and garden situations, respondents have a variety of forecast probability thresholds for decision making. On average, respondents selected a higher probability threshold for taking action in the picnic situation (forecast of chance of rain) than in the garden situation (forecast of chance low temperature would be below freezing). In the decision scenarios, the cost component of the scenario had minimal effect on respondents' decisions. The subject pool also responded to the two decision contexts differently: overall, they were more likely to take protective action in the fruit decision context than in the reservoir decision context.

When given single-value forecasts, the majority of respondents decided to take action even when the forecasted value did not reach the damage threshold. This suggests that most respondents inferred a range around single-value forecasts, in other words, they interpreted the deterministic forecasts as uncertain. The extent to which respondents decided to take action given different single-value forecasts provides some information about their inferences of uncertainty in forecasts of low temperature and rain amount.

Based on their decisions, it is not clear how respondents interpreted forecasts that explicitly provided precipitation or temperature ranges. Many respondents did not alter their decisions when given ranges symmetric about a single-value forecast. Thus, further investigation of how people interpret and use range forecasts is needed.

When given forecasts of the percentage chance of exceeding the damage threshold, the respondent population was more likely to take protective action as the percentage chance increased. However, many respondents did not make decisions as expected-value maximizers. Further examination of these results is required within the context of previous findings on how people make decisions under risk and uncertainty.

These findings are preliminary; further analysis and interpretation of the data is needed. The results suggest that questions of this type, implemented in a survey or an experimental laboratory, have potential to enhance knowledge about how people interpret and use different types of forecasts, including forecasts containing uncertainty information. Such knowledge can help the meteorology community learn to communicate uncertainty more effectively, in ways that enhance interpretation and beneficial use.

5. REFERENCES

AMS (American Meteorological Society), 2008: Enhancing weather information with probability forecasts. *Bull. Amer. Meteor. Soc.*, **89**, 1049–1053.

Davis D. D., and C. A. Holt, Eds. 1992: *Experimental Economics*. Princeton University Press, 572 pp.

Dillman, D.A., 2000: *Mail and Internet Surveys: The Tailored Design Method*. 2d ed. John Wiley & Sons, Inc., 464 pp.

Joslyn, S., L. Nadav-Greenberg, and R. M. Nichols, 2009: Probability of precipitation: Assessment and enhancement of end-user understanding. *Bull. Amer. Meteor. Soc.*, in press.

Joslyn, S., K. Pak, D. Jones, J. Pyles, and E. Hunt, 2007: The effect of probabilistic information on threshold forecasts. *Wea. Forecasting*, **22**, 804–812.

Kagel J. H., and A. E. Roth, Eds. 1995: *Handbook of Experimental Economics*. Princeton University Press, 721 pp.

Katz, R. W., and M. Ehrendorfer, 2006: Bayesian approach to decision making using ensemble weather forecasts. *Wea. Forecasting*, **21**, 220-231.

Lazo, J. K., R. E. Morss, and J. L. Demuth, 2009: 300 billion served: Sources, perceptions, uses, and values of weather forecasts. *Bull. Amer. Meteor. Soc.*, in press.

Morss, R. E., J. Demuth, and J. K. Lazo, 2008: Communicating uncertainty in weather forecasts: A survey of the U.S. public. *Wea. Forecasting*, **23**, 974–991.

Murphy, A. H., S. Lichtenstein, B. Fischoff, and R. L. Winkler, 1980: Misinterpretations of precipitation probability forecasts. *Bull. Amer. Meteor. Soc.*, **61**, 695-701.

Mylne, K., 2002: Decision-making from probability forecasts based on forecast value. *Meteor. Appl.*, **9**, 307–315.

NRC, 2003: *Communication Uncertainties in Weather and Climate Information*. National Academy Press, 68 pp.

NRC, 2006: *Completing the Forecast: Characterizing and Communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts.* National Academy Press, 124 pp.

Palmer, T. N., 2002: The economic value of ensemble forecasts as a tool for risk assessment: From days to decades. *Quart. J. Roy. Meteor. Soc.*, 128, 747–774.

Patt, A., and D. P. Schrag, 2003: Using specific language to describe risk and probability. *Climatic Change*, 61, 17–30.

Richardson, D. S., 2000: Skill and economic value of the ECMWF ensemble prediction system. *Quart. J. Roy. Meteor. Soc.*, **126**, 649–668.

Roulston, M. S., G. E. Bolton, A. N. Kleit, and A. L. Sears-Collins, 2006: A laboratory study of the benefits of including uncertainty information in weather forecasts. *Wea. Forecasting*, **21**, 116–122.

Ryan, R. T., 2003: Digital forecasts: Communication, public understanding, and decision making. *Bull. Amer. Meteor. Soc.,* 84, 1001–1003.

Schuman, H., and S. Presser, 1996: *Questions and Answers in Attitude Surveys: Experiments on Question Form, Wording, and Context*. Sage Publications, 372 pp.

Tourangeau, R., L. J. Rips, and K. Rasinski, 2000: *The Psychology of Survey Response*. Cambridge University Press, 415 pp.

Zhu, Y., Z. Toth, R. Wobus, D. Richardson, and K. Mylne, 2001: On the economic value of ensemble-based weather forecasts, *Bull. Amer. Meteor. Soc.*, **83**, 73–83.