300 BILLION SERVED

Sources, Perceptions, Uses, and Values of Weather Forecasts

BY JEFFREY K. LAZO, REBECCA E. MORSS, AND JULIE L. DEMUTH

A nationwide survey indicates that the U.S. public obtains several hundred billion forecasts each year, generating $31.5 billion in benefits compared to costs of $5.1 billion.

Every day, the U.S. weather enterprise collectively disseminates numerous weather forecasts to the U.S. public through various media. Considering the range of forecasts generated at a variety of spatial and temporal scales, the array of forecast providers and communication channels, and the size and diversity of the U.S. population, this equates to an enormous volume and multiplicity of information. The meteorological community knows intuitively that these forecasts are useful and of significant benefit to the public. However, apart from anecdotal evidence and vague notions, the community does not have a clear overall picture of how members of the public obtain, perceive, use, and value weather forecasts.

AFFILIATIONS: LAZO, MORSS, AND DEMUTH—National Center for Atmospheric Research*/Societal Impacts Program, Boulder, Colorado
*The National Center for Atmospheric Research is sponsored by the National Science Foundation
CORRESPONDING AUTHOR: Jeffrey K. Lazo, NCAR SIP, Box 3000, Boulder, CO 80307
E-mail: lazo@ucar.edu

The abstract for this article can be found in this issue, following the table of contents.
DOI:10.1175/2008BAMS2604.1

In final form 19 December 2008

Research on aspects of these issues has been conducted for specific geographical areas (e.g., Saviers and Van Bussum 1997; Lazo and Chestnut 2002), for specific events or weather phenomena and decision-making situations (e.g., Katz and Murphy 1997; Anderson-Berry et al. 2004; Stewart et al. 2004; Call 2005; Drobot 2007; Hayden et al. 2007; Morss and Wahl 2007; Zhang et al. 2007), or for certain demographics (e.g., CFI Group 2005). Private sector marketing studies have likely also investigated these issues, although results from such studies are not readily available. Other work has examined the needs of weather forecast users more generally and emphasized the importance of obtaining input from users (e.g., Pielke and Kimpel 1997; Hooke 2000; Pielke and Carbone 2002; WMO 2003; Morss et al. 2005, 2008a; National Resource Council 2006). These previous efforts bring some elements of the picture into focus, but each contributes only a portion of the montage.

Based on empirical research, this paper seeks to draw a more complete picture of people's attitudes and behaviors regarding day-to-day weather forecast information and how these vary among individuals. Specifically, we investigate the following four interdependent concepts:

- **sources:** where, when, and how often people obtain weather forecast information;
- **perceptions:** how people judge and understand forecasts;

- **uses:** how people use forecasts for activities and decision making; and
- **values:** what dollar value households place on currently available forecasts.

As a simplified model for the purposes of this paper, these interdependent concepts can be thought of as building on each other in the flow and impact of weather forecast information:

Sources → Perceptions → Uses → Values

This model is useful at a broad level, but these four concepts can be—and often are—related in other ways. For example, a person's perception of a forecast from a given source may affect whether or not he or she accesses information from that source in the future.

Knowledge about these four areas is fundamental to better understanding the public's needs for weather forecasts and for providing these forecasts in more beneficial ways to meet those needs. Understanding where people get their weather forecasts helps indicate the broad relative importance and accessibility of different sources and provides insight into constraints and opportunities for developing user-relevant message content. Understanding how individuals perceive forecasts provides an indication of the effectiveness of the information provision and communication processes, and can help identify gaps in these processes. Understanding individuals' use of information across spatial and temporal scales and their use of different components of forecasts can help providers develop better information products to meet the public's needs. Understanding how individuals use forecasts also provides support for the validity of valuation measures; for example, if individuals do not use forecasts, that should be reflected in value estimates. Finally, understanding the monetized value of weather forecasts gives insight into the importance of this information. In economic terminology, value represents the trade-offs people are willing to make to receive this information relative to other information, goods, or services. Expressing these as monetized values can be extremely useful to decision makers and policy analysts.

Building this end-to-end understanding—from sources through values—will help guide product development and investment decisions for the weather community (e.g., on observations, numerical modeling, what forecast information to provide and when and how to provide it) given limited resources. This understanding can also inform other work. For example, understanding how people receive, perceive, use, and value day-to-day weather forecast information builds an important foundation for exploring similar issues related to hazardous weather, such as hurricanes, winter storms, and floods. Improved understanding can also inform work on what type of weather forecast uncertainty information to offer and how to do so more effectively (Morss et al. 2008b). Finally, a true commitment by the weather enterprise to improve the societal benefits derived from forecast information requires a much better understanding of the value-creation process from communication by various sources through to end-user perceptions and their uses of this information.

To explore the four concepts of sources, perceptions, uses, and values, we conducted a nationwide, Internet-based, controlled-access survey of the U.S. public. Although people's attitudinal and behavioral relationships with weather forecast information are sufficiently complex that no one survey can fully assess them, our work does paint an initial picture. When appropriate, we compare our results with previous related research, both to confirm our results and to illustrate how and why they may be different in some ways. After describing our work and results, we offer recommendations for future research.

SURVEY DESIGN AND IMPLEMENTATION.

In applied social science research, surveys are one of the most common and important methods for eliciting information directly from a large number of respondents. Along with assessing people's sources, perceptions, uses, and values of weather forecast information, we investigated other topics in the survey, including interpretations of and preferences for weather forecast uncertainty information (Morss et al. 2008b), weather saliency (Stewart 2006), and use of forecast uncertainty information in decision making. The survey also collected information about respondents' weather-related activities and experiences, as well as basic demographic information.

We followed state-of-the-art methods for developing and pretesting survey questions (Dillman 2000; Tourangeau et al. 2000; Presser 2004). Our initial draft of the sources, perceptions, uses, and value questions were based on questions from a previous survey of households' values for weather forecasts (Lazo and Chestnut 2002). The draft survey instrument was peer reviewed for structure, content, and clarity. A revised hard-copy version of the survey was pretested with recruited nonmeteorologists using one-on-one verbal protocols (known as "think alouds") to evaluate how people understood and interpreted the survey ques-

tions and to assess their motivation for answering the questions (Ericsson and Simon 1993). We iteratively revised the survey content and structure based on these pretests. The full survey is available from the authors.

The survey was implemented online in November 2006 via a survey research company (ResearchExec, Southport, Connecticut) that programmed the online survey and collected the data in a controlled-access forum. Another survey research company (Survey Sampling International, Fairfield, Connecticut) provided the sample.[1] The only people permitted to complete the survey were those invited to do so via an e-mail containing a unique link to the survey Web site. Each person was allowed to complete the survey only once.

Most previous surveys investigating similar issues in weather forecasting have been limited to small convenience samples, specific geographic areas, or weather-related recruiting portals. Using the Internet as a medium for survey implementation unavoidably means that some members of the public are not able to participate, so the respondents are not a completely random population sample. Given our implementation procedure, however, we feel that our sample is more generalizable to the U.S. population than most previous related work. In particular, it avoids some of the representativeness issues that arise in Internet-based surveys hosted on open-access sites with self-selected respondents (who in some cases may respond to a survey multiple times). Our survey population includes respondents from every U.S. state and the District of Columbia. Compared with data from the 2006 American Community Survey (ACS; U.S. Census 2007), our respondent population has a gender and race distribution similar to that of the U.S. public, but it is slightly older and more educated. It also underrepresents people with very low and very high incomes (Morss et al. 2008b).

We received 1,520 completed surveys. Because most of the survey questions focused on people's attitudes and behaviors about specific weather forecast information, some familiarity with weather forecasts was required. Although weather is ubiquitous, we could not assume that *everyone* uses weather forecasts. Therefore, in the first survey question, we defined a weather forecast and then asked respondents whether they ever use them. The vast majority (96.4%) of respondents said yes; the other 3.6% were not asked most of the rest of the survey questions. The remainder of the discussion is based on the responses of the 1,465 individuals who do use weather forecasts, adjusting as appropriate for the 3.6% who do not use forecasts. Because the survey was conducted in 2006, we use economic and population data from that year when making calculations and comparisons.

SOURCES OF FORECASTS. Understanding where, when, and how often people get weather forecasts is basic to beginning to know how best to supply them with such information, yet information about this in the publicly available literature is limited. To assess respondents' sources, we asked them to indicate how often they obtain weather forecasts from each of 10 potential sources. We consider the word "obtain" to represent both active receipt of forecasts (when people seek them directly) and passive receipt (when people get them while engaged in other activities; e.g., when someone is listening to the radio and the weather report comes on). For each source, we offered the six response options given in Table 1. These response options were recoded as shown in Table 1 to develop a conservative, lower-bound frequency by source *per month*. For instance, "rarely or never" was recoded as zero times per month and "once or more a month" as one time per month (even though two or more times per day could actually be many more than 60 times per month for a given respondent). Table 1 shows responses for each source ranked from most to least common sources.

The column labeled "mean times per month" in Table 1 indicates how often the average respondent obtains weather forecasts from each source. For instance, across our population, respondents got forecasts from local TV stations—the most common source—33.7 times per month on average (a little over once a day). More than 70% of respondents obtained forecasts from local TV at least once a day, with cable TV and radio as the next most common sources, respectively. Web pages and newspapers were less common sources overall, but both were a daily or more frequent source of forecasts for 27% of respondents—noting of course that all respondents to the survey had online internet access. On average, respondents obtained forecasts from the National Oceanic and Atmospheric Administration (NOAA) Weather Radio (NWR) a little more than twice per month (with 80% of respondents rarely or never using NWR). This does not mean, however, that NWR is unimportant; emergency managers and other special-

[1] Morss et al. (2008b) provide a more complete description of the survey development and implementation and summarize sociodemographic comparisons of the respondents with the U.S. population.

Table 1. Sources of weather forecasts. The survey question asked "How often do you get weather forecasts from the sources listed below?"; *n* = 1,465. Response columns indicate percent of 1,465 subjects rounded to nearest whole percent. Mean column indicates mean monthly frequency.

Source	Rarely or never	Once or more a month	Once a week	Two or more times a week	Once a day	Two or more times a day	Mean times per month
Recoding to develop conservative lower-bound frequency by source as "times per month"	0	1	4	8	30	60	
Local TV stations	6%	5%	4%	14%	36%	36%	33.7
Cable TV stations	22%	13%	9%	17%	22%	18%	18.9
Commercial or public radio	29%	8%	8%	16%	21%	18%	18.5
Other Web pages	39%	11%	9%	13%	17%	10%	12.7
Newspapers	39%	11%	12%	12%	24%	3%	10.4
NWS webpages	48%	17%	8%	10%	11%	6%	8.3
Friends, family, coworkers, etc.	35%	15%	16%	19%	11%	4%	8.1
NOAA Weather Radio (NWR)	80%	9%	3%	3%	3%	1%	2.1
Cell phone, PDA, pager, or other electronic device	90%	3%	2%	2%	2%	1%	1.6
Telephone weather information source	88%	6%	2%	2%	1%	1%	1.2

ized users obtain information from NWR, particularly in potentially hazardous weather situations (see, e.g., Redmond 1995).

With the exception of National Weather Service (NWS) Web pages and NWR, which provide about 9% of the forecasts the public accesses, it is not possible to quantify what portion of the weather information is "directly" from the NWS. This cannot be quantified because the different sources of weather forecasts sometimes relay unaltered NWS weather forecast information and sometimes furnish value-added information (with varying levels of NOAA/NWS information content). When we look at the results as a whole, Table 1 empirically shows that people can and do obtain weather forecasts from a multiplicity of sources, each presumably chosen to meet individual needs and abilities.

A comparison of these results with two previous related studies supports the validity of our findings and provides information about how sources of weather forecasts may have changed in recent years. Lazo and Chestnut (2002) gathered data in the fall of 2001 using questions similar to ours with similar response categories. Omitting the two Internet-based sources, there is a 0.97 correlation between our results and those in Lazo and Chestnut. The primary difference between the two sets of results is the marked increase in the use of Internet sources in our data. This is probably partly because Internet use increased during the five years between the two surveys and partly because our survey was conducted online, whereas Lazo and Chestnut used hard-copy surveys administered in person. More recently, a Harris Poll (2007) asked respondents "Where are you most likely to get your weather forecasts?" Even though the Harris Poll question is framed differently, the results are consistent with the pattern of our findings: 44% of their respondents indicated local TV; 17% said The Weather Channel; and fewer selected newspaper, radio, and other sources. Also, about 2% of Harris Poll respondents indicated that they did not look at forecasts, similar to the 3.6% of our respondents who reported not using forecasts.

To estimate the total number of weather forecasts obtained per month, for each respondent we summed the times per month each of the 10 sources was used. The average respondent gets weather forecasts across all sources 115 times per month (recall that this is a conservative estimate, because we coded frequencies using the lower bounds of the responses categories). This corresponds to an average of 3.8 times per day, although the number of forecasts an individual obtains probably varies significantly from day to day. The U.S. adult population in 2006 was nearly 226 million.[2] Assuming that our respondents are representative of the U.S. population and accounting for

the 3.62% of respondents who do not use forecasts, this means an estimated *300 billion forecasts are obtained by U.S. adults each year.*[3]

We see significant variability in how often people obtain weather forecasts. A small number of respondents (2.7%) indicated that they get forecasts 305 or more times per month (10 times per day or more on average). Of the respondents who said they use forecasts, 9.2% responded that they get forecasts 30 or less times per month (once per day or less on average). In other words, accounting for those who do not use forecasts, 87.2% of our survey respondents reported getting forecasts on average at least once a day.

Another component in building a picture of the public's use of weather forecasts is what time(s) of day people obtain forecasts. To address this, we asked respondents whether they normally get forecasts at different time periods of the day. Figure 1 shows the percentages of respondents who obtain forecasts during each of the seven time periods offered. Responses ranged from a little more than 20% of people reporting that they get forecasts in the midnight to 6:00 A.M. time period (all times local) to more than 72% saying that they obtain weather forecasts from 7:00 P.M. to midnight. Not surprisingly, a relatively small percentage of people get weather forecasts during the late night and early morning hours (i.e., from midnight to 6:00 A.M.). From 6:00 to 8:00 A.M., as most people wake up and prepare for the day, almost 70% normally get some type of forecast information. This is consistent with results we report in the next section, which indicate that many people use forecasts in planning their daily activities—that is, what to wear or how to get to work or school. The number of people accessing forecasts decreases through the morning and early afternoon, and there is a secondary minimum in the period from 1:00 to 4:00 P.M. Looking overall at the 4:00 P.M. to midnight period, 91.6% of respondents indicate that they obtain forecasts during this time, which is likely connected to people considering forecasts as they plan for the following day. Overall, the peak periods during which people get forecasts are the early morning, early evening, and late evening hours. This is consistent with local TV being the most common source of weather forecasts.

PERCEPTIONS OF FORECASTS. In the previous section, we began to examine from where, when, and how often people obtain their weather forecasts. But another important element—how individuals perceive the information or how they judge and understand forecasts—comes into play between receiving weather forecasts and using them. We assessed people's perceptions of weather forecast information in general, instead of focusing on NWS products and services [which has been done in previous customer studies sponsored by the NWS; see, e.g., CFI Group (2005)]. As we discuss in the "Sources of forecasts" section, it can be difficult to distinguish between products provided directly by the NWS and those that come from broadcast meteorologists or other intermediaries. This suggests that when we look at the overall public arena of weather forecasting—the focus of our study—it is more appropriate to assess people's sources, perceptions, uses, and values of forecasts holistically.

In this context, we consider "perception" to be people's attained judgment or understanding of forecast information, which they usually achieve through their observations or experiences. We explored respondents' perceptions by examining their satisfaction with and confidence in the forecasts they currently receive. Although satisfaction and confidence are related, asking about both yields important distinct

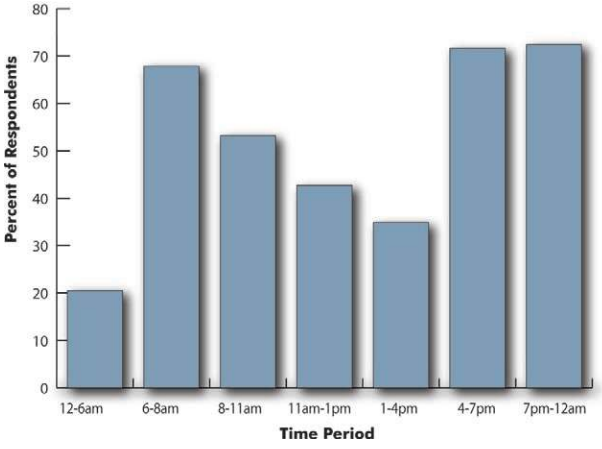

FIG. 1. Percentage of respondents who typically get weather forecasts during different times of the day (*n* = 1,465). The time periods indicated are not of the same temporal length. The survey question asked "Do you normally get weather forecasts during the time periods listed below?" Response options were "yes" and "no."

[2] The estimated 2006 U.S. population is 299,398,485. Of this, 75.4% are 18 years of age and older, which corresponds to an adult population of 225,746,458 [U.S. Census Bureau (2007), Table S0201; Selected Population Profile in the United States].

[3] An adult population of 225,746,458 × 115.374 times per month × 12 months per year × 0.9638 (to account for the 3.62% who do not use forecasts) equates to 301,229,196,054 forecasts a year—about 300 billion forecasts a year.

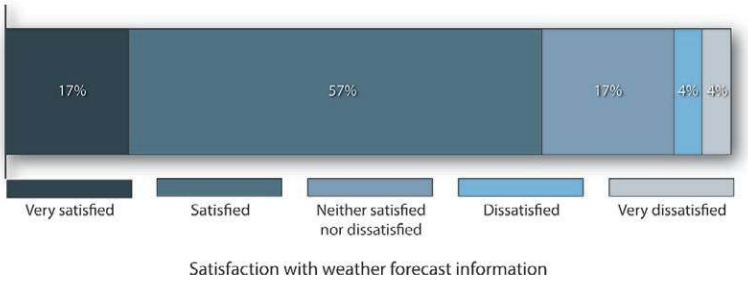

Fig. 2. Respondents' satisfaction with current weather forecasts (note: for all figures percents may not sum to 100% due to rounding; *n* = 1,465). The survey question asked "Overall, to what extent are you satisfied or dissatisfied with the weather forecast information that you currently receive?"

information. People's stated overall "satisfaction" [defined by Merriam-Webster (2005) as "fulfillment of a need or want"] may indicate their perception of the ability of forecasts to meet their needs. People's stated "confidence" ["the quality or state of being certain," Merriam-Webster (2005)] in weather forecasts may reflect their perceptions of the quality, reliability, and accuracy of forecasts. Confidence is discussed in the risk perception literature as "the expectation of not being disappointed" (Siegrist et al. 2005, p. 146) and is intimately tied to trust in the provider of risk information. It is important to note, though, that respondents' actual interpretations of these words may vary from these formal definitions.

To assess satisfaction, we asked respondents how satisfied or dissatisfied they are with the weather forecasts they currently receive. Figure 2 shows response options and results. For most respondents, satisfaction was quite high—almost 75% indicated that they were either satisfied or very satisfied with current forecasts. Only 8% reported that they were dissatisfied or very dissatisfied.

Next, we asked respondents how much confidence they have in weather forecasts for each of six different lead times, ranging from less than 1 day to 7–14 days. Response options and results are shown in Fig. 3. Individuals indicated that they have more confidence in forecasts with shorter lead times, with 85% reporting a high or very high level of confidence in forecasts less than 1 day in advance. People's confidence decreases with increasing forecast lead time, with 78% of respondents indicating low or very low confidence in forecasts 7–14 days in advance. Morss et al. (2008b) discuss these results in further detail, as well as how confidence varies among forecasts of different weather parameters. Specifically, they found that respondents had progressively lower confidence in forecasts of temperature, probability of precipitation, and quantity of precipitation.

These results provide empirical information about people's perceptions of weather forecasts. Our interpretation of these results is that respondents' lower confidence in longer lead-time forecasts reflects their understanding that these forecasts tend to be less accurate. This understanding—which likely comes about through experience with weather and forecasts—coupled with respondents' stated satisfaction levels, suggests that people do have well-formed judgments and understanding about weather forecasts.

Although satisfaction and confidence are useful measures, the meaning of one-time evaluations of these concepts is generally difficult to interpret. Overall satisfaction levels do, however, serve as a useful baseline as new weather forecast information and products become available, and confidence levels form a useful baseline as weather forecasts improve. For these reasons, comparing current results with future survey results using the same question format

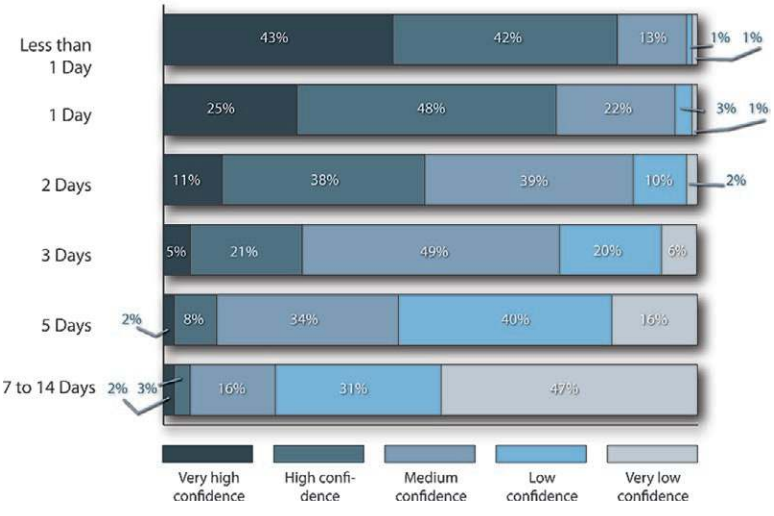

Fig. 3. Respondents' confidence in weather forecasts of different lead times (*n* = 1,465 for each lead time). The survey question asked "How much confidence do you have in weather forecasts for the times listed below?" The times were listed as "Less than 1 day from now, "1 day from now," and so on, out to "7 to 14 days from now."

will be of greater value than a one-time assessment because this will allow changes to be examined over time. In addition to being useful measures on their own, satisfaction and confidence also relate to people's use and value of weather forecasts, as we discuss in the next two sections.

USES OF FORECASTS. We assessed three aspects of how people use weather forecasts: 1) what geographic areas are of concern, 2) what components of forecasts are most important, and 3) for what decisions or activities forecasts are used. The results yield further valuable insight into how and why individuals access weather forecasts, and they also help us understand the link between sources and perceptions of weather forecasts and the value people place on that information.

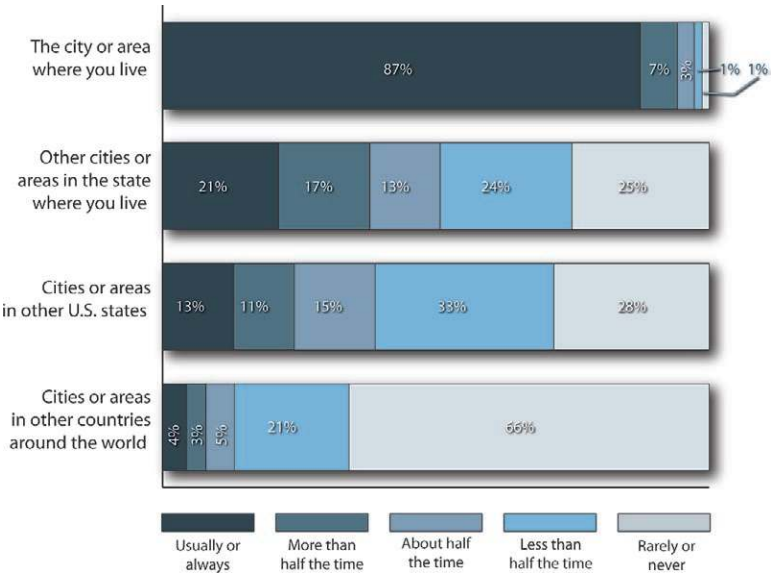

FIG. 4. Respondents' geographic areas of interest for weather forecast information (n = 1,465). The survey question asked "When you get weather forecasts, how often do you get them for the cities or areas listed below?"

To explore the geographic needs and interests of respondents, we asked them how often they obtain forecasts for different geographic areas. Figure 4 shows the response options and results. An overwhelming portion of respondents obtain weather forecasts about the city or the area where they live, with more than 90% saying they do so more than half the time or always. Only about 12% get forecasts for areas outside the United States half or more of the time. These responses are likely connected to the parts of people's lives for which they use weather forecasts to make decisions. For example, statistical analysis of our data shows that those who use forecasts to plan travel were more likely than others to get forecasts for cities or areas in other U.S. states or in other countries.

Weather forecasts comprise multiple components, including different spatial and temporal information, weather elements (e.g., temperature, precipitation, and wind), and meteorological measures (e.g., type of precipitation and high or low temperatures). To better understand needs and interests related to different meteorological elements and measures, we asked respondents how important it is to them to have each of 14 types of information as part of weather forecasts. Respondents were asked to rate each separately using the response options shown in Fig. 5. The figure, which shows the results ranked from most to least important on average, illustrates that precipitation and temperature information are the most important self-reported components of forecasts to respondents. Two of the most important aspects are *when* and *where* precipitation will occur. This information is likely important because people's activities are affected by the weather at specific places and times. As a result, forecasts that have adequate temporal and spatial information are more important (and potentially more valuable). People also reported chance, amount, and type of precipitation as important, as well as high and low temperature, with a majority of respondents indicating that each of these components were very or extremely important.

The time of day when high and low temperatures will occur is of somewhat less importance when precipitation will occur. This may be because people already have a good sense of when high and low temperatures are reached based on personal experience in their locales. The time of day when precipitation occurs tends to be more variable than when high and low temperature occur. Individuals may also place more importance on more specific information about precipitation because precipitation may have a larger personal impact than temperature.

Of those forecast attributes respondents evaluated, the least important were the level of cloud cover and the direction of the wind. Even though wind speed and direction, humidity levels, and cloudiness are less important, on average, than precipitation and temperature information, these were rated as extremely important by 5%–11% of the respondents.

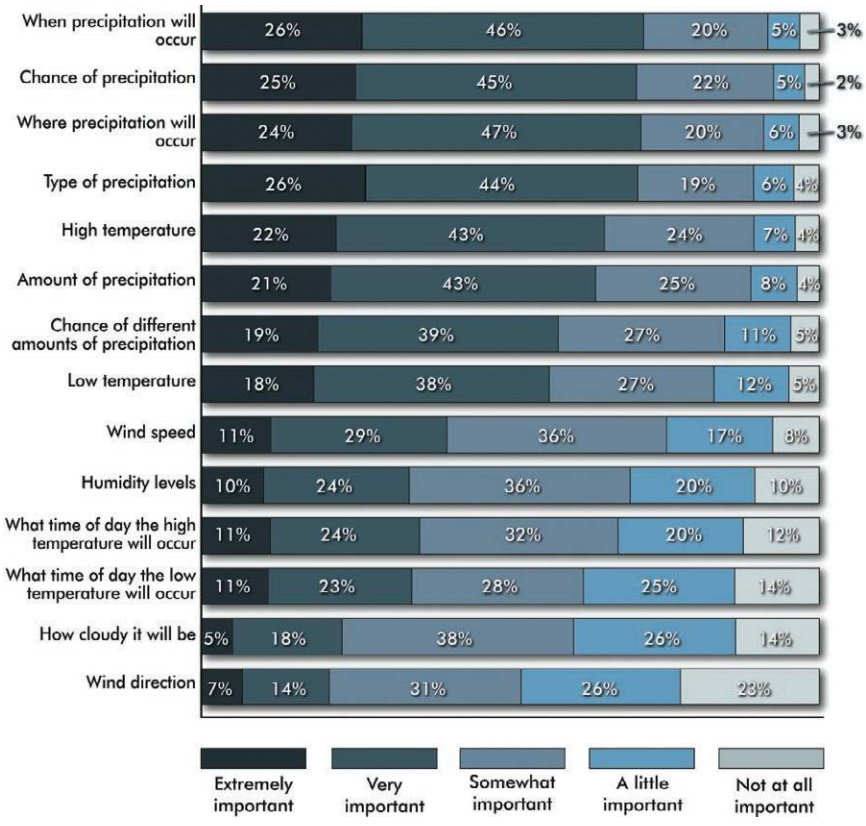

Fig. 5. Respondents' rating of importance for different potential components of weather forecasts (n = 1,465). The survey question asked "How important is it to you to have the information listed below as part of a weather forecast?"

These respondents may have specific uses for these forecast components.

Ultimately, forecasts are intended to give people useful information for making decisions. For this reason, we asked respondents how often, on average, they use weather forecasts for a variety of activities. In previous work, Lazo and Chestnut (2002) developed seven planning and decision-making options. For the current survey we added the option of "simply knowing what the weather will be like." Figure 6 shows the results, ranked according to decreasing use. As the figure illustrates, about 85% of respondents indicated that more than half the time, they obtain forecasts simply to know what the weather will be like. This indicates that people generally have a high level of interest in weather forecasts, regardless of whether they are using this information directly for planning and decision making, and that weather forecasts may have become a form of entertainment for some people. This response may also represent people who monitor weather forecasts to assess weather impacts on future decisions or people who did not (or could not) articulate the specific reasons for which they use weather forecasts, among other possibilities. In part, however, this suggests that daily weather forecasts may be of interest and have value even when they do not appreciably affect behavior or decision making.

Respondents reported using weather forecasts most for those activities for which they likely have the most discretion for decision making (e.g., planning what to wear or weekend activities). Respondents indicated using weather forecasts less for activities for which they likely have less ability to change their behavior (e.g., how to get to work or school or what to do at work). In these cases, forecasts tend to be less relevant. Even for these less common uses and activities, though, 20% or more reported usually or always using forecasts.

VALUES OF FORECASTS. Understanding the economic value of forecasts is vital for policy analysis and for making decisions about priorities for forecast provision. As a result, after eliciting respondents' sources, perceptions, and uses of forecasts, we explored the value households place on the forecasts they currently receive. Through this analysis, we can begin to make an order-of-magnitude quantitative estimate of the dollar value to U.S. households for all weather forecasting services currently provided, across a range of situations. We shift our discussion here to households instead of individuals because the question was framed in terms of household taxes rather than individual costs.

As is necessary for commodities—like weather forecasts—that have a large public good component, we implemented a nonmarket valuation approach. That is, we asked respondents what the commodity is worth (i.e., "stated" preference) rather than using market data as an indication of worth (i.e., "revealed" preference).[4] To do this, we first informed respondents that the NWS is the primary U.S. source for all basic data for weather forecasting and informa-

tion services, including severe weather forecasts, watches, and warnings. The survey was thus designed to elicit household values for all forecast information, including severe weather watches and warnings. We also clarified that all NWS information is disseminated to media and private weather services.

The valuation question then presented or "offered" respondents a hypothetical amount that they are currently paying in taxes for all NWS activities and asked if the services they are receiving are worth more than, worth exactly, or worth less than the amount indicated. Each individual was randomly presented 1 of 11 dollar amounts ranging from $2 a year to $240 a year. By varying the amount that different respondents are told they are paying, we can derive a profile of the percentage of people willing to pay different dollar amounts for weather information. Based on Lazo and Chestnut (2002)—who estimated a median household value of $109 per household per year for all current weather information using a similar question but with lower "offered" amounts—we expected that $240 a year would be high enough that at least 50% of individuals would indicate that NWS weather services were worth less than the amount indicated. However, the range of values we selected did not extend high enough to include the median value, and therefore, we extrapolated the results to derive a median value.

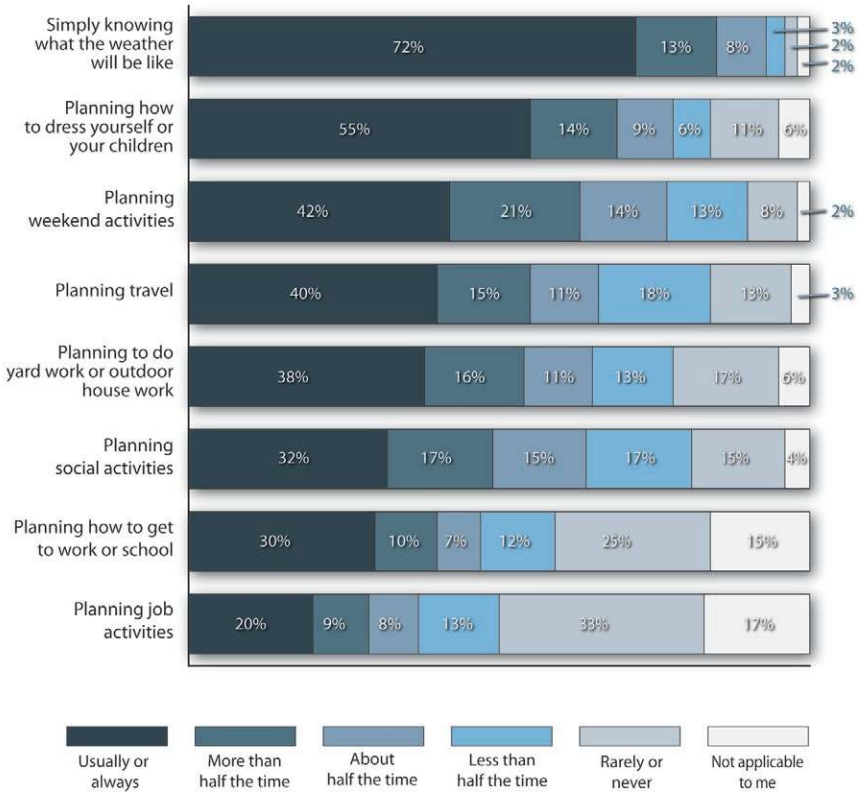

Fig. 6. Respondents' use of weather forecast for decision making (*n* = 1,465). The survey question asked "On average, year round, how often do you use weather forecasts for the activities listed below?"

Figure 7 shows the percentage of people answering that weather forecasts are "worth more than" or "worth exactly" the 11 different dollar levels, as well as the extrapolation to the median fitted value of $286 per household per year (see figure caption for details). This is the dollar level at which we would expect 50% of the respondents to say weather forecast were worth that amount each year and 50% to say they are not worth that amount each year.

Because households' values for forecasts are bounded at zero below and unbounded above, the median value will likely be less than the average value. For this reason, we take the median value extrapolated here as a lower bound estimate of the average value.

It is not clear to what extent members of the public distinguish between NWS-provided information and that offered by other sources. Because most of our respondents receive weather forecasts primarily from nongovernment sources, they may not fully understand how NWS activities contribute to the weather products they receive. Consequently, the value estimate discussed here is probably best interpreted as households' value for all weather forecasts, rather than the portion of forecast services that could be attributed to the activities of the NWS. In that sense,

[4] A public good is one that is 1) nonrival in that others may use the good at zero additional cost and 2) nonexclusive in that once it is provided it is neither possible nor cost effective to exclude others from using the good. Because public goods are not bought and sold in competitive markets, we do not have price information about their value. To determine their value, then, we must use nonmarket valuation methods (Mitchell and Carson 1989; Doering 2007; Morss et al. 2008a).

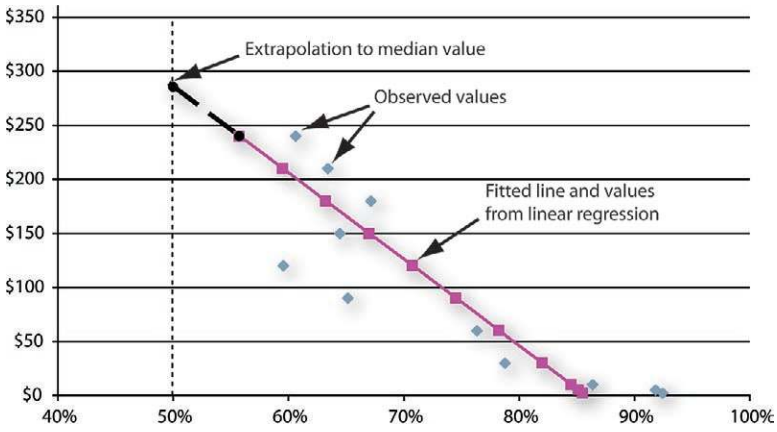

Fig. 7. Assessment of value of all weather forecasting and information services to households (n = 1,465). For each of the 11 "offer" prices (vertical axis) we plot the percent (horizontal axis) indicating worth "more than" or "exactly" that amount. Blue diamonds (♦) show actual responses; solid pink line (— —) shows fitted line from linear regression; dashed black line (—) shows extrapolation to median value of $286 per household per year. Following the convention for graphing demand curves in economics, price (the independent variable) is depicted on the y axis, and the quantity, in this case the percentage of people willing to pay (the dependent variable), is depicted on the x axis. The survey question asked "Do you feel that the services you receive from the activities of the NWS are worth more than, exactly, or less than $N a year to your household?"

it provides an upper bound estimate on the value of NWS services.

We also note that while the survey assessed how respondents use and value forecasts, forecasts are also used in decision making by businesses, government, financial markets, and many other entities. Because we did not ask respondents whether their reported use and value of forecasts was for personal use or other uses, we cannot assume that they were not considering these other uses when responding. Therefore, we cannot simply add the value of other uses for forecasts without the danger of double counting. Future research is needed to explore how often forecasts are used in specific contexts and the values of these forecasts.

In 2006, the United States had an estimated 114,384,000 households (U.S. Census Bureau 2008). Accounting for the 3.6% of households who do not use forecasts (and thus presumably have no value for forecasts), we calculate a total value of $31.5 billion per year to U.S. households for all weather forecast services.[5] When this total amount is divided by the total number of forecasts obtained per year as derived in the "Sources of forecasts" section (301 billion), the average value is 10.5¢ per forecast obtained.

The sum of all federal agency spending on meteorological operations and supporting research in fiscal year 2007 was about $3.4 billion (Office of the Federal Coordinator for Meteorology 2007).[6] Based on a survey and analysis of private sector meteorologists and meteorology companies, Spiegler (2007) estimates private sector expenditures related to weather forecasting at about $1.7 billion.[7] The sum of U.S. public and private sector meteorology expenditures is therefore about $5.1 billion (including all operations and research). Relating this to our estimate of total value to households for weather services, we derive a net benefit of $26.4 billion a year ($31.5 billion in benefits minus $5.1 billion in costs) and a cost–benefit ratio of 6.2 to 1.0 ($31.5 billion in benefits to $5.1 billion in costs).

Although the valuation methodology applied here is relatively simple, our results do begin to reveal households' values for weather forecast information. The approach we employed yields only an initial estimate that needs to be developed further to make it more consistent with in-depth methods for ensuring the validity and reliability of value estimates based on stated preferences (Louviere et al. 2000; Lazo and Chestnut 2002; Adamowicz and DeShazo 2006). These results do, however, strongly indicate that the value of meteorological services in the United States is likely significantly larger than the current costs.

CONCLUSIONS, DISCUSSION, AND FUTURE WORK. Before this study, little publicly available research had explored where, how often, or when people get weather forecast information across a range of contexts (i.e., not just for one weather event or for one provider's products) and how people

[5] That is, 114,384,000 × (1 − 0.0362) × $285.64 = $31.5 billion.

[6] This sum appears to include spending on U.S. Department of Defense weather operations and research.

[7] According to Spiegler (2007, 20–21), "The total current private sector market exceeds $1.5 billion. Based on all the information accessed and analyzed, the margin of error in this estimate may be conservative by 10%–20% or more, resulting in a total market size between $1.65 and $1.8 billion, and perhaps as high as $2 billion."

perceive, use, and value this information. The basic understanding developed here highlights the importance of furthering this knowledge to develop a general picture of how the weather enterprise interacts with members of the public.

Our results show that weather forecasts are a daily part of the lives of the vast majority of the U.S. public. Members of the public obtain 300 billion or more forecasts each year with a total estimated value of $31.5 billion per year. Except perhaps for current news events, there is probably no other type of information that is obtained on such a routine basis from such a variety of sources. It is quite likely that no other scientific information is accessed so frequently (Wilson 2008). As shown in Fig. 6, people use weather forecasts for a variety of activities as well as simply to know what the weather will be like. Weather forecasts can therefore be considered part of the infrastructure of our lives and livelihoods.

Our results also show that people obtain weather forecasts from a variety of sources, but the vast majority obtain them from media sources instead of directly from NWS Web pages or NOAA Weather Radio. Most private sector weather forecasts, however, are either directly or indirectly based on NWS data or forecasts. Moreover, the distinction between the public and private sector components of the weather enterprise probably is not very salient to most members of the public. This suggests that it does not make sense to think of the NWS and the private sector as competing interests. Instead, given that the public and private sectors work in tandem to create and disseminate the forecasts that people obtain from the multiple available sources, the weather enterprise should be developed as a collaborative effort. An integrated, consumer-oriented collaboration between public and private providers can only benefit the public.

Our work also raises several issues for future research. First, the results lead to questions about how best to disseminate weather forecast information across various media. For instance, our survey indicates that as of late 2006, only a minority of respondents were obtaining weather forecasts from cell phones, PDAs, and other portable electronic devices. With new technologies and services developing more content for such devices, location-specific and time-sensitive weather forecasts have growing potential to provide significant societal benefits. It is important to understand and potentially anticipate these changes. This will allow the weather enterprise to provide timely information in useful formats through the most recipient-appropriate channels of communication. For instance, in emergency situations, approaches such as reverse 911 calls using geolocated cell phones may someday distribute timely warning information to people not accessible by conventional systems such as TV or radio. As technologies most people were not even aware of ten years ago continue to evolve into key communications tools, it is important to track these changes over time and accurately assess the potential of new technologies.

In this survey, we neither assess why people use the forecast sources and media they do, nor did we look at how these preferences change depending on the situation. A variety of interesting questions remain to be addressed. For example, do people like TV forecasts because they can get a more in-depth sense of the forecast uncertainty or different weather scenarios, because they prefer receiving forecasts communicated by a human through voice and video, or for other reasons? Do people have confidence in and trust communication from some sources more than from other sources (Peter et al. 1997)? Do people use radio or cellular phones for weather forecasts and information when they are in their cars and detect a weather-related traffic problem? Do people use Web sites for weather forecasts more when they're planning travel outside their local area?

Future research should also investigate how the importance people assign to different forecast components relates to their experience with and understanding of meteorological elements and forecast attributes, as well as to their weather-related activities (see Stewart 2006). Even though a majority of respondents indicated that some forecast attributes, such as humidity levels and wind direction, are of limited importance, this information could be critically important to some subsets of the population. It could also be essential for deriving related information, such as heat index or pollution forecasts, that some people need.

We found that most people were generally satisfied with weather forecasts and had fairly high confidence in forecasts at short lead times. Our assessment, however, has only begun to explore the psychological and social processes underlying how people perceive and interpret weather forecast information. An extensive relevant literature exists in communication (Ajzen 1991; Griffin et al. 1999, 2004), risk communication (Slovic 1987; Morgan et al. 2001; McComas 2006), economics (Lawrence 1999; Letson et al. 2007), and related disciplines such as sociology, journalism, marketing, and mass communications. Based on existing theoretical and methodological approaches from the broad range of relevant disciplines, this body of literature should

be employed to investigate the communication, understanding, and use of weather forecasts more comprehensively. Such knowledge could be a significant help in designing weather forecast products and dissemination mechanisms that enhance forecast interpretation, use, and value.

With respect to the valuation approach, economists have a broad range of methods for eliciting values for information. The simplified approach employed here should be built on, using these methodologies from economics, to develop more reliable and valid estimates for the value of forecast information. Such estimates should include the value of weather forecasts not only in general for the broad public, but also in specific weather contexts (e.g., hurricanes, tornadoes, or heat waves) and for specific user groups (e.g., transportation, energy, health, or agriculture sectors). Studies are also needed to assess the value of improved weather forecasts as well as the value of improved communication and use of forecast information.

As communication technologies become more mobile, as bandwidth increases, and as new generations of users come online, people's sources, perceptions, uses, and values of weather forecasts are changing rapidly. This means that assessments like ours should be performed regularly to understand how the picture is changing with time and to make sure that the knowledge on which weather forecasting decisions are based does not become outdated. Based on our work to date, and to support the weather enterprise's efforts to provide societally beneficial weather information, we advocate for a well-designed and carefully implemented periodic evaluation of the public's sources, perceptions, uses, and values of weather forecasts. One approach would be to undertake a core survey every two years containing a consistent set of questions for basic evaluation of people's sources, perceptions, uses, and values. This would allow for tracking of changes over time and provide indicators to policy makers of improvements or degradation of the value of forecasts and products from the end user's perspective. Additional survey components would focus on more in-depth topics as needed to address key current needs, such as communicating tornado or hurricane warnings, presenting forecast uncertainty information, and supporting potential new products or services. Such an ongoing survey effort should be developed by autonomous researchers in collaboration with survey research experts, and they should be peer reviewed and then implemented with a nationwide representative sample—not a self-selected panel as in some prior satisfaction surveys. The resulting information could be used by public and private sector forecast providers to help them be more responsive to public needs in product and service design and delivery. It would also provide quantitative support of the value of forecast activities. Such a survey would not assess all users or all products or services and thus should be supplemented by additional research and evaluation efforts. Such a research effort would, however, provide solid ongoing evidence of the importance of weather forecasts to the largest and most critical group of users—the general public.

ACKNOWLEDGMENTS. The authors thank Barb Brown, Bill Mahoney, Daniel Nietfeld, Alan Stewart, Rene Howard, and two anonymous reviewers for helpful comments on the paper.

This work is supported by NCAR's Collaborative Program on the Societal Impacts and Economic Benefits of Weather Information (SIP), which is funded by the National Science Foundation and the National Oceanic and Atmospheric Administration through the U.S. Weather Research Program. The views and opinions in this paper are those of the authors.

REFERENCES

Adamowicz, W., and J. R. DeShazo, 2006: Frontiers in stated preferences methods: An introduction. *Environ. Resour. Econ.,* **34,** 1–6.

Ajzen, I., 1991: The theory of planned behavior. *Org. Behav. Human Decision Processes,* **50,** 179–211.

Anderson-Berry, L., T. Keenan, J. Bally, R. Pielke Jr., R. Leigh, and D. King, 2004: The societal, social, and economic impacts of the World Weather Research Programme Sydney 2000 Forecast Demonstration Project. *Wea. Forecasting,* **19,** 168–178.

Call, D., 2005: Rethinking snowstorms as "snow events": A regional case study from upstate New York. *Bull. Amer. Meteor. Soc.,* **86,** 1783–1793.

CFI Group, 2005: National Weather Service customer satisfaction survey: General public. Report to the National Oceanic and Atmospheric Administration, 154 pp.

Dillman, D. A., 2000: *Mail and Internet Surveys: The Tailored Design Method.* 2nd ed. Wiley, 464 pp.

Doering, Otto C., III, 2007: The political economy of public goods: Why economists should care. Presidential Address, American Agricultural Economics Association Annual Meeting, Portland, OR.

Drobot, S. D., 2007: Evaluation of winter storm warnings: A case study of the Colorado Front Range December 20–21, 2006, winter storm. Quick Response Research

Report 192. University of Colorado Natural Hazards Center. [Available online at www.colorado.edu/hazards/research/qr/qr192/qr192.html.]

Ericsson, K. A., and H. A. Simon, 1993: *Protocol Analysis: Verbal Reports as Data.* rev. ed. MIT Press, 443 pp.

Griffin, R. J., S. Dunwoody, and K. Neuwirth, 1999: Proposed model of the relationship of risk information seeking and processing to the development of preventative behaviors. *Environ. Res.,* **80,** 230–241.

——, K. Neuwirth, S. Dunwoody, and J. Giese, 2004: Information sufficiency and risk communication. *Media Psych.,* **6,** 23–61.

Harris Poll, 2007: November 28, 2007. The Harris Poll #118. Local television news is the place for weather forecasts for a plurality of Americans. [Available online at www.harrisinteractive.com/harris_poll/index.asp?PID=839.]

Hayden, M., S. D. Drobot, S. Radil, C. Benight, and E. C. Gruntfest, 2007: Information sources for flash flood and tornado warnings in Denver, CO and Austin, TX. *Environ. Hazards,* **7,** 211–219.

Hooke, W., 2000: Short-term weather prediction: An orchestra in need of a conductor. *Prediction: Science, Decision-Making, and the Future of Nature.* D. Sarewitz, R. A. Pielke Jr., and R. Byerly Jr., Eds., Island Press, 61–83.

Katz, R. W., and A. H. Murphy, 1997: *Economic Value of Weather and Climate Forecasts*. Cambridge University Press, 222 pp.

Lawrence, D. B., 1999: *Economic Value of Information.* Springer-Verlag, 416 pp.

Lazo, J. K., and L. G. Chestnut, 2002: Economic value of current and improved weather forecasts in the U.S. household sector. Report to the NOAA Office of Policy and Planning, U.S. National Oceanic and Atmospheric Administration. [Available online at www.economics.noaa.gov/library/library.html.]

Letson, D., D. Sutter, and J. K. Lazo, 2007: The economic value of hurricane forecasts: An overview and research needs. *Nat. Hazards Rev.,* **8,** 78–86.

Louviere, J. J., D. A. Hensher, and J. D. Swait, 2000: *Stated Choice Methods: Analysis and Applications.* Cambridge University Press, 402 pp.

McComas, K. A., 2006: Citizen satisfaction with public meetings used for risk communication. *J. Appl. Commun. Res.,* **31,** 164–84.

Merriam-Webster, cited 2005: Online dictionary. [Available online at www.merriam-webster.com/dictionary.]

Mitchell, R. C., and R. T. Carson, 1989: *Using Surveys to Value Public Goods: The Contingent Valuation Method.* Resources for the Future, 463 pp.

Morgan, M. G., B. Fischhoff, A. Bostrom, and C. Atman, 2001: *Risk Communication: The Mental Models Approach.* Cambridge University Press, 351 pp.

Morss, R. E., and E. Wahl, 2007: An ethical analysis of prediction and decision making: The case of the Red River flood of 1997. *Environ. Hazards,* **7,** 342–352.

——, O. V. Wilhelmi, M. W. Downton, and E. Gruntfest, 2005: Flood risk, uncertainty, and scientific information for decision making: Lessons from an interdisciplinary project. *Bull. Amer. Meteor. Soc.,* **86,** 1593–1601.

——, J. K. Lazo, B. G. Brown, H. E. Brooks, P. T. Ganderton, and B. N. Mills, 2008a: Societal and economic research and applications for weather forecasts: Priorities for the North American THORPEX program. *Bull. Amer. Meteor. Soc.,* **89,** 335–346.

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

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

Office of the Federal Coordinator for Meteorology, 2007: The federal plan for meteorological services and supporting research: Fiscal year 2007. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 295 pp. [Available online at www.ofcm.gov/fp-fy07/fedplan.htm.]

Peters, R. G., V. T. Covello, and D. B. McCallum, 1997: The determinants of trust and credibility in environmental risk communication: An empirical study. *Risk Analysis,* **17,** 43–54.

Pielke, R. A., Jr., and J. Kimpel, 1997: Societal aspects of weather: Report of the sixth prospectus development team. *Bull. Amer. Meteor. Soc.,* **78,** 867–876.

——, and R. E. Carbone, 2002: Weather impacts, forecasts, and policy: An integrated perspective. *Bull. Amer. Meteor. Soc.,* **83,** 393–403.

Presser, S., 2004: *Questions and Answers in Attitude Surveys.* SAGE Publications, 388 pp.

Redmond, J. W., 1995: NOAA weather radio as an emergency communication vehicle in west Tennessee. *Wea. Forecasting,* **10,** 485–497.

Saviers, A. M., and L. J. Van Bussum, cited 2008: Juneau public questionnaire: Results, analysis, and conclusions. NOAA Technical Memorandum NWS AR-44. [Available online at http://pajk.arh.noaa.gov/info/articles/survey/intro.htm.]

Siegrist, M., H. Gutscher, and T. C. Earle, 2005: Perception of risk: The influence of general trust and general confidence. *J. Risk Res.,* **8,** 145–156.

Slovic, P., 1987: Perception of risk. *Science,* **236,** 280–285.

Spiegler, D. B., cited 2007: The private sector in meteorology—An update. [Available online at www.ametsoc.org/boardpges/cwce/docs/DocLib/2007-07-02_PrivateSectorInMeteorologyUpdate.pdf.]

Stewart, A. E., 2006: Assessing the human experience of weather and climate: A further examination of weather salience. Preprints, *AMS Forum: Environmental Risk and Impacts on Society: Successes and Challenges,* Atlanta, GA, Amer. Meteor. Soc., 1.6. [Available online at http://ams.confex.com/ams/Annual2006/techprogram/paper_101916.htm.]

Stewart, T. R., R. Pielke, Jr., and R. Nath, 2004: Understanding user decision making and the value of improved precipitation forecasts: Lessons from a case study. *Bull. Amer. Meteor. Soc.,* **85,** 223–235.

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

U.S. Census Bureau, cited 2007: 2006 American community survey. [Available online at www.census.gov/acs/www/.]

——, cited 2008: The 2008 statistical abstract. Table 58: Households, families, subfamilies, and married couples: 1980 to 2006. [Available online at www.census.gov/compendia/statab/cats/population/households_and_families.html.]

Van Bussum, L., Jr., 1999: A composite look at weather surveys: Using several weather surveys to get an estimate of public opinion. Western Region Technical Attachement 99-20. [Available online at www.wrh.noaa.gov/wrh/99TAs/9920/index.html.]

Wilson, K., 2008: Television weathercasters as science communicators. *Public Understand. Sci.,* **17,** 73–87.

WMO (World Meteorological Organization), 2003: Socio-economic benefits of meteorological and hydrological products and services. *WMO Bull.,* **52,** 354–359.

Zhang, F., and Coauthors, 2007: An in-person survey investigating public perceptions of and response to Hurricane Rita forecasts along the Texas coast. *Wea. Forecasting,* **22,** 1177–1190.