In a perfect world, we would expect that providing better road and weather warning information would lead to increased protective action on the part of the traveling public. However, there is a rich library of social science literature indicating that people do not respond to warnings and weather information in a linear manner (e.g., Sorensen 2000). Information systems comprise both scientific technologies and the people who use them. Importantly, people bring significant perceptual and behavioral histories to the decision-making table.

A whole suite of information—including people’s sources, perceptions, and experiences relating to weather and road conditions—needs to be understood and carefully addressed to maximize the possible benefits of scientific advances and technologies. However, there is limited information about people’s knowledge and actions regarding weather in general, and even less is known about people’s preferences for in-vehicle weather and road condition information, or their willingness to share data originating from their vehicle.

Using an Internet survey, this project therefore examined weather information-gathering tendencies and preferences, with a focus on road weather conditions. In addition, we included questions on people’s comfort level with sharing vehicle data and examined how much they are willing to pay, given that this is a relatively new venture, for new types of road and atmospheric weather data.

DATA COLLECTION. We conducted an Internet survey of U.S. residents during October and November 2010, associated with the American Meteorological Society (AMS) Annual Partnership Topic (APT) focused on mobile observations (Mahoney and O’Sullivan 2013). Prior to sending out the survey, we pretested all questions with several verbal protocol analyses to ensure that questions were being interpreted as planned; additionally, some of the questions used here were asked on other surveys that also used more extensive pretesting (e.g., Hayden et al. 2007;
Lazo et al. (2009). The complete set of questions is available from the authors.

Working through Survey Sampling International (SSI; www.surveysampling.com/), we obtained 1627 responses. Internet sampling is an attractive option for this type of exploratory study because it can facilitate gathering data quickly and allows for better control over respondents' access to the questions (i.e., they cannot jump ahead or go back and change their answers based on information in a subsequent question).

Estimates of Internet access vary widely but, based on the 2010 Pew Internet Report (Smith 2010), about 66% of U.S. households (~62 million) have Internet access at home. As such, using the Internet to conduct the survey inevitably excludes some populations from responding: namely, those that have limited Internet access. SSI does recruit panelists that do not have such access and provides facilities to take the survey, but the anonymous nature of the survey respondents means we cannot know how many of the respondents are from this group. Disadvantaged persons, including those without ready access to transportation, may be further inhibited from taking the survey. Thus, it is important to note that the results presented here are not representative of the entire population of the United States. Moreover, future research may warrant using other research methods that can better access hard-to-reach populations. In comparison with U.S. Census information, the response pool for this survey contained a higher proportion of females, was better educated, and was slightly wealthier.

RESULTS. This section outlines the main survey results, highlighting information-gathering tendencies, preferences for in-vehicle information, and concerns related to the sharing of vehicle data. Also included are breakdowns of these responses in relation to each other, age, and geographic location.

Information-gathering tendencies. Adverse weather conditions remain a considerable hazard to the U.S. motoring public, leading to over 7,000 fatalities and more than 670,000 injuries in a given year (Federal Highway Administration 2010). Advances in the physical and technological sciences will soon allow for the provision of high-fidelity weather and road condition data and forecasts, which could ameliorate these losses. Extensive social science research provides clues into the effective use of that information; for instance, Miletli and Sorensen (1990) highlight “hearing the warning” as the first key step in an effective warning chain. Just over 91% of survey respondents reported obtaining weather forecasts either via active or passive measures, slightly lower than previous reports (e.g., Lazo et al. 2009). Of those that do obtain weather forecasts, the primary information source while not in a vehicle was a local television station, accessed on average 26 times per month (Fig. 1). “Fixed” Internet (i.e., Internet access not via smart phones) was the second most popular choice, viewed roughly 20 times per month. Local radio (17 times per month) and cable television (15 times per month) were also
popular information sources. The remaining options were much less frequently used. These results roughly parallel previous research (e.g., Hayden et al. 2007; Drobot 2007; Lazo et al. 2009). The major difference is that Internet sources have become more popular; for instance, they ranked below radio in Hayden et al. (2007). Whether the Internet ever surpasses local TV is debatable, but it clearly has risen in prominence over the past few years. Similarly, smart phone Internet usage is up from previous studies, and it too likely will continue to climb in importance.

While in the vehicle, access to weather information was more limited and passive, relying mostly on local radio stations (Fig. 2). None of the other options rated at higher than 5 times accessed per month. Nonetheless, smart phones clearly are being used by some people. Given the negative connotations of distracted driving, it may be that smart phone use was underreported as well. The paucity of people using telephone (dial in) sources suggests the 511 network is not being used very much for weather information. Analysis of state 511 usage rates would be useful to confirm or contradict this finding.

Weather forecast and information preferences: General comments. Overall, survey respondents were generally satisfied with temperature, precipitation, and severe weather information they currently receive from a variety of sources (Fig. 3). Roughly three in four respondents were either “satisfied” or “very satisfied,” with temperature information rating the highest and precipitation information rating as the least satisfying of the three measures. This is important, as precipitation is probably the biggest threat to drivers. When provided with a list of new information types that we anticipate as being available in the vehicle in the near future, respondents showed overwhelming interest for most of the proposed information types (Fig. 4). Road closure information is marginally ahead of local weather conditions and local weather forecasts in terms of responses in the “very” and “extremely” interested categories. Weather conditions rated higher in interest than traffic conditions, accident information, and routing suggestions. Parking and points of interest were not highly desired by the respondents. When looking at the responses for “not at all interested,” local weather conditions and local weather forecasts had the lowest totals, with only 8% of the respondents showing no interest.

Stratifying the weather information into specific weather conditions continues to provide compelling information on the public desire for road and weather data and forecasts. Nearly two in three respondents were “very” or “extremely” interested in icy road warnings (Fig. 5). Snow-covered road information was also highly desired. A variety of other precipitation measures, as well as low visibility and a general warning on whether or not weather will slow a trip, were "very" or "extremely" desired by about 57% of the survey respondents. Only lightning ranked somewhat low, with only 40% of respondents being "very"
or “extremely” interested. Although the sample sizes are low, respondents that operated motorcycles daily or once a week tended to be more interested in these warnings (not shown).

The warning community stresses an effective response goes beyond hearing the warning, through to understanding it and ultimately taking action. Although the survey did not present respondents with particular warning messages, it did ask to what extent people felt that they would take protective action based on a warning. Owing to social desirability, which is the tendency of respondents to reply in a manner that will be viewed favorably by others, the responses may be overly positive for this question. However, numerous studies demonstrate the survey design used here should minimize social desirability, compared with telephone or in-person interviews (e.g., DeMaio 1984; Aquilino 1994). The responses should provide a reasonable measure of which hazards people are more likely to respond to relative to one another. In this respect, flooded roadways are the most likely hazard that if warned ahead of time, drivers would take protective action1 (Fig. 6). Tornado, black ice, and hail warnings would engender a strong protective response as well. Falling rain and lightning are less likely to elicit any behavioral changes. As above, motorcycle riders were slightly more likely to indicate that they would take protective action against all hazards.

Despite an overwhelming interest in enhanced weather information, the public remains somewhat wary of sharing data (Fig. 7). This may be because the concept of vehicle-based data and its privacy rules are not well known. For some variables, such as air temperature, headlights, wipers, anti-lock braking systems (ABS), and time, more than half of all respondents are “very” or “extremely” comfortable with sharing the data. However, even for these variables, roughly one in five respondents were “not at all” or only “a little” comfortable. Moreover, approximately one in three respondents are “not at all” or only “a little” comfortable with sharing vehicle heading, speed, and direction, with more people falling into the “not at all” or only “a little” comfortable than “very” or “extremely” categories for location reporting.

Not surprisingly, the public’s concern over data sharing is magnified when asked about what specifically concerns them. Just over 60% of respondents are “very” or “extremely” concerned about being tracked (Fig. 8), with just under 60% “very” or “extremely” concerned with respect to cybersecurity and the potential cost. The least concerning item is privacy. However, even here, two in four respondents are “very” or “extremely” concerned, and only one in four are “not at all” or “a little” concerned. The lower privacy concerns may be related to a previous question where the respondents were told that the connected

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1 Protective action was self-defined by the respondents and may include, for example, a change in driving behavior or seeking shelter.
vehicles program is being designed to ensure privacy. These results point out a clear need to emphasize that the program is designed as a public benefit; respondents overwhelmingly want more information but remain wary of the data sharing that is needed for the development of the desired products. This result seems at odds with the fact that cell phone use has been widely adopted, yet many cell phones can now track the users’ locations.

A final question queried respondents on their willingness to pay for enhanced road and atmospheric weather data. Business models for the development of these advanced services are still under consideration, and these results shed some light on the public viewpoint. Nearly half of all respondents were unwilling to commit to paying anything for these enhanced products (Fig. 9). Qualitative answers associated with half of the responses suggest that many people think that these services should be freely provided; a smaller portion feels that the existing information is already sufficient. The latter finding is consistent with the previous question on satisfaction with existing weather information, but it also further points out the need for a public campaign to quantify and explain the benefits of the proposed new systems. Only 18% of the respondents were willing to pay at least ten dollars per month. It is likely that weather hazard information may need to be bundled with other in-vehicle capabilities to make it more affordable or at least to increase its perceived worth.

**Weather forecast and information preferences: Stratifications.** Each survey question was stratified by responses to every other question in order to identify relationships between different types of information given in the survey. These individual stratifications were compared with both the overall distribution of answers for a question as well as each other to
determine what, if any, dependencies existed in the data.

The major interaction observed in the stratifications was that survey respondents who frequently used more sources of weather information while driving also tended to have more interest in receiving larger amounts of information in their vehicles, were more likely to take action in more types of weather hazards, and were more comfortable sharing a larger number of data types from their vehicles. To generalize, those who already consume more weather information from more sources while driving have an existing interest in being informed of road weather conditions and therefore have a higher interest in receiving more road weather-specific data in their vehicles. In turn, they are willing to share more information from their vehicles in order to improve the information they could receive while driving. As more informed drivers, they are also more likely to take protective action in the event of adverse weather conditions along the roadways.

Willingness to pay was also associated with the interest in receiving and sharing information, with those who expressed the desire to receive and willingness to share information also willing to pay a larger amount. Those who were comfortable sharing less than half of the data types presented in the survey had a median willingness to pay of $0, with a 75th percentile of $5–$10. In contrast, those who were comfortable sharing over half of the presented data types had a median willingness to pay of less than $5 and a 75th percentile of $20–$25, indicating a much larger proportion of willingness to pay amongst those more comfortable sharing information. Likewise, those interested in receiving less than half of the data types presented in the survey had a median willingness to pay of $0 and 75th percentile of $5–$10, while those interested in over half had a median willingness to pay of less than $5 and a 75th percentile of ≥$30. However, as described in the previous subsection, the majority of respondents felt the information should be freely available. As expected given the interest and comfort results above, those who were willing to pay more were also more likely to take action in the advent of adverse weather conditions with the same median and 75th percentile as with comfort sharing.

Of those who were comfortable sharing information from their vehicle, comfort with one type of information corresponded with comfort in sharing:

Table 1. Tally of responses to survey questions about likelihood to take action in the event of the given road weather hazard. Red (green) highlights an unusually high (low) number of responses (relative to the expected mean) in the “very likely” category.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Not sure</th>
<th>Very unlikely</th>
<th>Unlikely</th>
<th>Likely</th>
<th>Very likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Falling rain</td>
<td>49</td>
<td>238</td>
<td>474</td>
<td>496</td>
<td>359</td>
</tr>
<tr>
<td>Hail</td>
<td>59</td>
<td>100</td>
<td>182</td>
<td>546</td>
<td>727</td>
</tr>
<tr>
<td>Falling snow</td>
<td>64</td>
<td>157</td>
<td>252</td>
<td>526</td>
<td>616</td>
</tr>
<tr>
<td>Tornado</td>
<td>93</td>
<td>101</td>
<td>84</td>
<td>268</td>
<td>1071</td>
</tr>
<tr>
<td>Black ice</td>
<td>75</td>
<td>113</td>
<td>95</td>
<td>361</td>
<td>975</td>
</tr>
<tr>
<td>Snow on road</td>
<td>59</td>
<td>141</td>
<td>184</td>
<td>486</td>
<td>750</td>
</tr>
<tr>
<td>Low visibility</td>
<td>58</td>
<td>100</td>
<td>206</td>
<td>596</td>
<td>657</td>
</tr>
<tr>
<td>Flooded road</td>
<td>72</td>
<td>79</td>
<td>53</td>
<td>398</td>
<td>1014</td>
</tr>
<tr>
<td>Lightning</td>
<td>65</td>
<td>215</td>
<td>499</td>
<td>433</td>
<td>404</td>
</tr>
<tr>
<td>High winds</td>
<td>52</td>
<td>118</td>
<td>349</td>
<td>546</td>
<td>551</td>
</tr>
</tbody>
</table>

Fig. 10. Respondents’ willingness to share multiple types of information.
all other types. Figure 10 shows that the two most common categories were comfort with sharing all options or comfort with none. Also evident in Fig. 10 is the tendency for more respondents to be comfortable with most, but not all, the information types, rather than comfortable with only a very few. The outlier from this analysis, as seen in the coloring of Fig. 10, was location. Except for respondents comfortable with all or all but one option, over half were only neutrally comfortable, or less, with location, even among those comfortable with sharing a majority of the data types. As mentioned previously, those who were more comfortable sharing information also appeared more interested in receiving weather and driving information in their vehicle.

In terms of driver behavior given adverse weather conditions, those that described themselves as more likely to take action in response to a particular type of weather hazard were more likely to take action for all the other hazard types. This is shown in Table 1, where columns of the number of responses seem to be consistent for many of the hazards. However, as seen in Table 1, not all hazards followed this pattern. In particular, the more extreme hazards of tornadoes, black ice, and flooded roads (colored red) were more likely to elicit an action regardless of the respondents’ likelihood of taking action for other conditions. In contrast, hazards that may seem more mundane or not immediately life threatening, specifically falling rain and lightning (colored green), had fewer respondents likely to take action, as was described in the section titled “Weather forecast and information preferences: General comments.”

One final stratification of note was the differences related to age, with respondents that used a larger number of sources for weather information, were more interested in receiving information in their vehicle, and were more comfortable sharing information having a lower mean age. The mean ages for these categories can be found in Table 2. The younger mean age was statistically significant for home and driving sources of weather use and interest in receiving information in the vehicle. There was little age difference in comfort with sharing information and likelihood to take action in adverse road weather conditions, and these differences were not statistically significant. However, the difference in means was small in a practical sense (4 to 5 years) for both use of home sources of weather information and interest in receiving information while driving. The only practically significant age difference was seen in the use of a larger number of weather sources while driving, which was 18 years. To further explore this large difference in relation to the smaller age differences, age was categorized into generational groups.

The four generational age groups are presented in Fig. 11 and were defined from those used by the U.S. Census Bureau in their age and sex composition 2010 report (U.S. Census Bureau 2011). The same pattern present in the overall analysis can be seen with comparing the age groups and average numbers of affirmative responses to each information category in Fig. 11, where the number of sources used, both at home and when driving, and interest in receiving data in the vehicle decrease with increasing age. Comfort with sharing sources and likelihood to take action in adverse weather conditions is flat across the age groups.

**Table 2. Mean age for groups that frequently (2 times per week or more) use more or less than half of the data sources presented in the survey, are at least very interested in receiving more or less than half of the data types in their vehicle, are comfortable sharing more or less than half of the vehicle data presented in the survey, and are likely to take action in more or less than half of the hazardous weather conditions.**

<table>
<thead>
<tr>
<th></th>
<th>Over half</th>
<th>Under half</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home sources of weather</td>
<td>44</td>
<td>49</td>
</tr>
<tr>
<td>Driving sources of weather</td>
<td>30</td>
<td>48</td>
</tr>
<tr>
<td>Interest in receiving information while driving</td>
<td>46</td>
<td>50</td>
</tr>
<tr>
<td>Comfort sharing information</td>
<td>47</td>
<td>48</td>
</tr>
<tr>
<td>Likelihood to take action</td>
<td>48</td>
<td>47</td>
</tr>
</tbody>
</table>

**Weather and forecast information preferences by geographic region and population density.** In an effort to determine whether preferences vary according to location within the United States, the respondents were grouped into nine geographic regions roughly based on climate zone regions developed by the U.S. Forest Service (U.S. Forest Service 2012), and then the results were analyzed to determine any significant differences between regions. There were several regional differences, in satisfaction with both the weather information currently being received and interest in various types of information that will likely be available in the future.

Residents of Pacific California seemed to be more dissatisfied than residents of other regions with.
both the temperature and the severe weather information they are currently accessing by various means. For example, 65.3% of respondents in Pacific California reported being “satisfied” or “very satisfied” with severe weather information compared to 85.0% of those in the Gulf Coast and 79.9% of those in the upper Midwest (Fig. 12). In addition, residents of Pacific California appeared to be less interested in receiving local weather conditions and forecasts while traveling, but they had a greater desire to access all of the traffic information. Specifically, 43.1% of respondents in this region would be “very” or “extremely” interested in having access to local weather conditions, while 70.4% of residents in the Pacific Northwest and 65.3% of residents in the upper Midwest desired the same information (Fig. 13).

After stratifying weather information into specific weather conditions, it is evident that respondents in Pacific California, the Gulf Coast, and the Southwest desert regions were less interested in having access to the type of precipitation that is likely to fall (Fig. 14). This is most likely because the type of precipitation does not vary greatly in these regions. The regional responses to interest in road conditions (e.g., the likelihood of icy or snow-covered roads) were consistent with this finding. A significant variation in the response distributions from each region was found for all of the questions concerning interest in specific weather conditions. The only question that elicited responses that remained consistent among the regions was interest in the possibility of travel delay due to weather conditions. More than half of those surveyed in every region were “very” or “extremely” interested in receiving this information. It is possible that the public is more concerned with the effects of current weather

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**Fig. 11.** Average number of home and driving sources used, information types respondents are interested in receiving and are comfortable sharing, and adverse weather conditions in which respondents are likely to take action, stratified by age group.

**Fig. 12.** Respondents’ satisfaction with currently available severe weather information.
hazards as opposed to obtaining detailed information about a specific weather event.

When analyzing regional variation in the extent to which the respondents would take protective action when presented with a weather warning, significant differences were observed only when the questions referred to snow or ice. The Gulf Coast and the Southwest desert rarely experience these events, so it makes sense that these residents would respond as less likely to take action. Approximately two out of three residents in Pacific California would be “likely” or “very likely” to take action to avoid or minimize the impact on their vehicles during all of the specific weather events listed, yet less than 42% of those surveyed desired information about a specific weather occurrence or road condition, and only 47% were interested in receiving local forecasts in general. The only exception to this was interest in the threat of flooded roads, with 51% of those surveyed in this region “very” or “extremely” interested in receiving this information while traveling. In fact, in every region, the number of respondents that reported they would be “likely” or “very likely” to take protective action during adverse weather was much greater than the number who would be “very” or “extremely” interested in receiving information about that specific weather event. Again, this could indicate a desire to understand how travel plans or a vehicle might be affected, or to receive decision support, versus a desire for more information on the circumstance creating the need to take protective action.

This study also assessed the impacts of urban versus rural residential environments on the respondents’ preferences for receiving weather and traffic-related information while traveling. Rural and urban groups were based on the

In the next few years, you will be able to get more information while in your vehicle. How interested are you in the following types of information while you are travelling?

Percent “Very Interested” or “Extremely Interested” in receiving LOCAL WEATHER CONDITIONS

![Fig. 13. Respondents’ interest in receiving local weather condition information by region.](image)

In the next few years, numerous types of weather information could be provided to you while you are travelling in your vehicle. How interested are you in the following types of information while you are travelling?

Percent “Very Interested” or “Extremely Interested” in WHAT TYPE OF PRECIPITATION WILL OCCUR

![Fig. 14. Respondents’ desire, by region, to receive information concerning the type of precipitation that is likely to fall.](image)
U.S. Census Bureau’s definitions of these terms (U.S. Census Bureau 2013). Urban residents were more interested in obtaining traffic-related information, even more so than in receiving local weather conditions (Table 3). Rural residents appeared to be significantly more interested not only in accessing local weather conditions, but also in the availability of information related to each specific weather condition (Table 4).

**CONCLUSIONS.** This survey was intended to provide some basic insights into drivers’ preferences for in-vehicle weather and road condition hazard information and their attitudes about sharing vehicle data. The overall results indicate that drivers are quite interested in knowing about road weather hazards while traveling, but are wary of sharing data from their vehicles and largely unwilling to pay for the in-vehicle weather information. A solid business case (return on investment) and a campaign to explain benefits and privacy policy will need to be made before most drivers will pay for these services or share necessary data from their vehicles.

Within these overall results, respondents who already consume more weather information had a higher interest in receiving the in-vehicle information as well as being more willing to pay for it and more likely to take action based on the presence of a hazard. They tended to be younger and would likely not be the main audience of the outreach activity to explain the benefits and privacy policy of in-vehicle weather information.

When developing a program to provide weather information to drivers, it will also be important to consider geographic variations. Those in locations with less variable weather likely have less interest in, and less need for, the type of weather information posed in the survey. Likewise, residents of rural areas may have different information needs than those in urban areas, and both sets of needs must be addressed for a nationwide product.

Moving forward, developers of in-vehicle weather information (both public and private) and decision support services can use the results presented here to guide their service products to provide the traveling public with the most pertinent and desired weather impacts on the roadway.

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