NWS Partners' Preferences, Perceptions, and Uses of Probabilistic Winter Forecast Information: Results of a Central Region-wide Survey

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Executive Summary

This report summarizes results from a survey of National Weather Service (NWS) partners about their perspectives on probabilistic forecast information for winter weather. The survey was conducted from May 31, 2022, through July 12, 2022, throughout Central Region (OMB Control Number 0648-0801) and yielded 2503 completed responses. Our analysis focuses on completed responses from three core partner groups: emergency managers, transportation officials, and school officials. Additional responses were received from other NWS partners including but not limited to media, health care officials, and law enforcement. The survey questions investigated partners':

- winter storm decision-making thresholds;
- preferences and uses of winter forecast information;
- preferences and uses of probabilistic winter forecast information in general (i.e., not pertaining to a specific forecast product);
- preference, uses, and understanding of snowfall probability of exceedance graphics;
- preferences and uses of snowfall range graphics; and
- preferences for probabilistic snowfall timing graphics.

This report provides a first look at the results of this survey. Below are highlights from the report by section.

Survey Sample Job Roles and Winter-Storm Decision-Making Thresholds (Section 2)

- As a snow event approaches, partners tend to want higher certainty from forecasters before taking action. And vice versa, they tend to need less certainty at longer lead-times.
    - On average, when an event is less than 24 hours away, certainty needs to be greater than 80% whereas beyond 72 hours, certainty only needs to be at least 10%.
    - Transportation officials want higher certainty at longer lead times for securing staffing resources and materials.

Preferences and Uses Regarding Winter Forecast Information (Section 3)

- Overall, partners ranked wanting to know snowfall location as most important, closely followed by other forecast elements: amounts, start and end timing, and chance of snow. The timing of the heaviest rate was relatively less important. These results suggest that partners first want to know if their area will be affected by winter weather before considering what other forecast elements are useful.
    - Compared to other job roles, emergency managers ranked the amount of snow as more important.
    - Compared to other job roles, transportation officials ranked the start/end of snow as more important.
- Partners want to know the location, amounts, and start-time 12-48 hours before snow begins. They want to know the end-time and timing for the heaviest snowfall at shorter lead-times, within 24 hours.
    - School officials want any information related to snowfall at shorter lead times than other job roles.

Preferences and Uses Regarding Probabilistic Winter Forecast Information in General (Section 4)

- When asked in general about their preferred tradeoff between more advanced notice and lower certainty versus less advanced notice and higher certainty, school officials preferred high certainty rather than longer lead times for snowfall forecasts whereas other partners had only a slight preference for higher certainty. However, partners may have had different interpretations of "advanced notice" and " more (un)certainty", and thus future work should more concretely explore these tradeoffs.
- Given a large snowfall range of 2-8", a majority of partners will prepare for the mid-point amount.
  - More than one-third of transportation officials and emergency managers would prepare for the high-end amount.
  - Only 16% of school officials would prepare for the high-end amount, and 12% would prepare for the low-end amount.
- Providing quantitative, probabilistic information with snowfall ranges resulted in partners preferring the wider range for forecast snowfall.
  - When confidence intervals about forecast snowfall ranges were conveyed qualitatively, a majority of respondents preferred the middle range (i.e., 3-7" forecast with a medium chance of capturing the actual amount) over the wide or narrow range.
  - But, when confidence intervals about forecast snowfall ranges were conveyed quantitatively, a plurality (39%) preferred the wide range forecast (i.e., 80% chance of 2-8"), and partners' second most common preference (36%) was the narrow range plus low- and high-end amounts, similar to what is currently shown on the Weather Forecast Office (WFO) Probability of Weather Precipitation Forecasts (PWPF) web pages.
  - This suggests that partners are engaging in a complex tradeoff of uncertainties in that they would prefer a forecast with snowfall ranges that have higher probabilities of occurring, even if those snowfall ranges are wider and thus more uncertain.

Preferences, Uses, and Understanding Regarding Snowfall Probability of Exceedance Graphics (Section 5)

- Graphics of the probability of exceeding >2" and >4" of snow were found to be very or extremely useful by a majority of partners, but many would seek out additional information based on this forecast.
  - Emergency managers are more likely to contact their local WFO.
  - Transportation and school officials are more likely to seek information from non-NWS sources.
  - Although transportation officials are more likely to seek out additional information, they are also more likely to begin preparing for the storm.
- When evaluating whether partners could accurately interpret the probability of exceedance information, most partners correctly identified the location that had the greatest probability of exceeding 2" of snow, which was explicitly shown in the graphic. However, less than half of partners correctly determined the probability of 1" of snow,

which was not shown in the graphic, suggesting that deducing information from the graphics was a more challenging task.

Preferences and Uses Regarding Snowfall Range Graphics (Section 6)

- When provided with a graphic with a large snowfall range of 3-10”, the vast majority of partners reported the forecast was useful, which challenges thinking that such large snowfall range forecasts are not useful.
    - Most partners indicated they would use this larger snowfall range forecast to monitor the NWS for updated information or to prepare for the storm.
    - When given the large snowfall ranges of 3-10”, most partners reported they would prepare for the mid-point (6-7”) snowfall amount. However, approximately one-third of emergency managers and transportation officials reported they would prepare for the high-end amount of 10”.
    - Partners indicated that a 3-5” forecast with actual snowfall amounts of 10” or more is the most problematic scenario for them, likely because *they do not want to be caught behind.*

Preferences for Probabilistic Snowfall Timing Graphics (Section 7)

- Overall, the vast majority of partners deem probabilistic timing of snowfall to be very or extremely useful.
    - More than 70% of partners said it would be very or extremely useful to know the earliest and the most likely times that snow could begin.
    - Transportation and school officials were more likely to rate timing information about when snowfall will end extremely or very useful compared to emergency managers.

Overall, the survey results indicate that *NWS partners are able to make use of probabilistic information conveyed in different ways and that there are important differences in how different partner groups use and interpret the information. The results also revealed some topics that need to be further explored to better understand partners’ perceptions and uses of probabilistic information.* Additional surveys may be sent over the next 2-3 years to learn if partners’ perspectives and uses regarding probabilistic forecast information is changing over time.

1. Introduction

a. Motivation and background

There has been growing recognition that deriving and effectively communicating uncertainty information has potential to provide important and useful context for a range of audiences. For example, the National Research Council (2006) recommended the increased use of probabilistic information in weather forecasts to provide more complete information to decision makers. The report stated:

> *By partnering with other segments of the community to understand user needs, generate relevant and rich informational products, and utilize effective communication vehicles, the National Weather Service can take a leading role in the transition to widespread, effective incorporation of uncertainty information into predictions (NRC, 2006).*

In the more than 15 years since that report and its recommendations, there have been important technical developments that have aided the explicit quantification of uncertainty, such as new ensemble guidance and post-processing techniques.

In the context of winter weather, during the winter of 2014-2015, the National Weather Service (NWS) Weather Prediction Center (WPC) worked with four NWS offices in the northeastern United States (Boston/Norton, MA, New York, NY, Philadelphia PA/Mount Holly NJ, and Baltimore MD/Washington DC) to create a common methodology to produce probabilistic snowfall forecasts. By the winter of 2016-2017, several NWS offices in the Central Region (CR) began to use probabilistic snowfall information, and it was expanded to include all Central Region offices in the winter of 2018-2019. Termed the Probability of Weather Precipitation Forecasts (PWPF), these probabilistic forecasts are based on both the official NWS forecast and the standard deviation and distribution associated with the 60-member WPC Superensemble[1]. Output from the PWPF includes the probability of exceeding 0.1, 1, 2, 4, 6, 8, 12, and 18 inches of snowfall amounts for a winter event. It also includes the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentile snowfall. All probability of exceedance information, as well as the 10th and 90th percentile, are routinely shared with the public via NWS webpages. As the PWPF spread across the Central Region, offices began to share probabilistic information with NWS partners, such as emergency managers, transportation officials, and school officials. This information was shared via email and incorporated into impact-based Decision Support Service (DSS) Packets.

In response to the development of new probabilistic information, the Central Region conducted a Probabilistic Messaging Testbed during the winter of 2020-2021 to test and evaluate the incorporation of probabilistic data into the NWS information flow for winter weather. More specifically, the testbed goals were to:

1. determine effective messaging strategies in advance of winter precipitation events;
2. investigate efficient and effective ways to collaborate messaging winter precipitation information utilizing probabilistic intelligence;
3. determine the most effective ways to resolve inter-office messaging inconsistencies; and

[1] The Superensemble is a combination of deterministic models, the European Center for Medium-range Weather Forecasts (ECMWF) ensemble, Global Ensemble Forecast System (GEFS), and Canadian Meteorological Center (CMC) ensemble.

4. assess partner comprehension of probabilistic forecast messaging.

The first three goals of the testbed were accomplished by the spring of 2021. A summary of the testbed findings showed that forecasters quickly learned how to use the new tools available. They were also able to adapt their messaging to a messaging funnel that incorporated forecaster confidence with the type of messaging and probabilistic information to deliver to partners. Forecasters found that using a messaging dashboard was helpful in making sure offices were aware of neighboring offices' messaging strategy and to ensure a consistent level of service over a large area. NWS forecasters expressed concerns about the usefulness of some of the data provided to partners—especially information about unusually large snowfall ranges based upon the 25th-75th percentile and 10th-90th percentile snowfall. A full report is available summarizing these results.

The fourth goal, assessing partner comprehension of probabilistic information, was not completed during the testbed period. Instead, results from NWS forecaster surveys and a review of information created by offices within the testbed were used to develop the survey discussed in this report. This important, operationally relevant research with NWS partners is in support of calls from the recent report from the NOAA Science Advisory Board (2021) about Priorities for Weather Research, specifically:

> *ID-4 Recommendation: Prioritize and integrate inter- and trans-disciplinary research on equitable and effective use of hazardous weather information—including both deterministic and probabilistic information—for risk assessment and protective decision-making, including at individual, group, and community levels.*
>
> *Critical action ID-4.1. Examine for whom, in what hazard scenarios, when, and how forecast uncertainty (probabilistic) information is advantageous versus when it is not, including whether and when it's potentially detrimental. Consider characterization, communication, and use of both forecast uncertainty and forecast confidence. Prioritize research on hazard scenarios exacerbated by climate change (e.g., fire weather, drought, heat, extreme precipitation and flooding, winter storms).*

b. Partner survey design and implementation

A group of Warning Coordination Meteorologists (WCMs) collaborated with the National Center for Atmospheric Research to develop the survey in 2021. The survey was submitted to the Office of Management and Budget in September 2021 and was approved in May 2022 (OMB Control Number 0648-0801). It also was approved by NCAR's Human Subjects Committee (HSC #2022-06).

The survey was sent to partners via email by Central Region WCMs or other designated point-of-contact. The survey was open from May 31, 2022, through July 12, 2022. The initial survey invitation was sent along with up to two reminders. In total, 3686 individuals started the survey, and 2503 completed it (completion rate of 67.9%). There were no significant differences by partner group, described below, in incompletes versus completes (p=0.03[2]). Therefore, we analyzed data from those who completed the entire survey (n=2503).

Three partner groups were of particular interest for this survey: emergency managers, transportation officials, and school officials. When winter weather threatens, each of these groups have specific, critical decisions they make that affect the public. Learning how these partners interpret probabilistic information, their preferences for it, and how they may use it in their decision making were the primary goals of the survey. Because the survey was sent to partner lists from each office, other NWS partners were invited and responded to the survey. Based on a preliminary analysis, the "Other" category includes a wide variety of jobs, including partners in the media, health care officials, and law enforcement and emergency services (911, law enforcement, firefighters, etc.). Although we present the results of this "Other" category in all analyses reported here, we do not discuss them in depth and will instead do further, refined analyses of these responses at a later time.

The survey was designed to ask questions that investigate partners':

- winter storm decision-making thresholds (Section 2);
- preferences and uses of winter forecast information (Section 3);
- preferences and uses of probabilistic winter forecast information in general (i.e., not pertaining to a specific forecast product) (Section 4);
- preference, uses, and understanding of snowfall probability of exceedance graphics;
- preferences and uses of snowfall range graphics (Section 5); and
- preferences for probabilistic snowfall timing graphics (Section 6).

The full survey is provided in the Appendix.

The knowledge gained by investigating these topics with partners will help the NWS determine better ways to deliver probabilistic forecast information in ways that are both meteorologically sound and user-relevant. It will guide the development, refinement, and delivery of information in ways that are useful and usable for partners, to enhance their ability to make better decisions.

In this report, we present Central Region-wide results and results stratified by job role. Additional analysis (e.g., by WFO, based on winter weather climatology) will be done in the future. For those who are interested, additional results beyond those shown in this report can be viewed in a supplemental data dashboard that users can interact with to generate results for a single WFO, multiple WFOs, or all of Central Region.

2. Results: Survey Sample Job Roles and Winter-Storm Decision-Making Thresholds

As noted above, all data reported from here onward are based on the set of n=2503 completed survey responses. Note, however, that survey respondents were not forced to respond to every question, and thus there are small numbers of missing data from some questions.

[2] For all tests of statistical significance, we use $\alpha \leq 0.01$ for all ANOVAs and t-tests because there are sufficient Ns in each main group, and we use an $\alpha \leq 0.05$ for the Fisher's p, i.e., for contingency tables because there may be small Ns in some cells.

In our sample of n=2503 respondents, a majority are men (75%). Regarding education, 5% have a high school diploma or GED equivalent; 27% have some college, technical, or associate's degree; 32% have a Bachelor's degree; and 36% have a graduate or professional degree.

a. Job roles of the survey sample

Among completed responses, our sample consists of 37% emergency managers, 22% school officials, 10% transportation officials, and 31% who reported their role as "Other" (e.g., media, health care, law enforcement). Throughout the report, we analyze the survey responses by these four main job role categories (in conjunction with analysis by the full set of completed responses) so we can explore whether and how there are corresponding differences in partners' preferences, interpretations, and uses. Across the job categories, there was a wide range in experience levels, ranging from 0-55 years of experience (mean = 16 years). We also asked the partners to report which WFO serves their area. The spatial distribution of responses is provided in **Figure 1**.

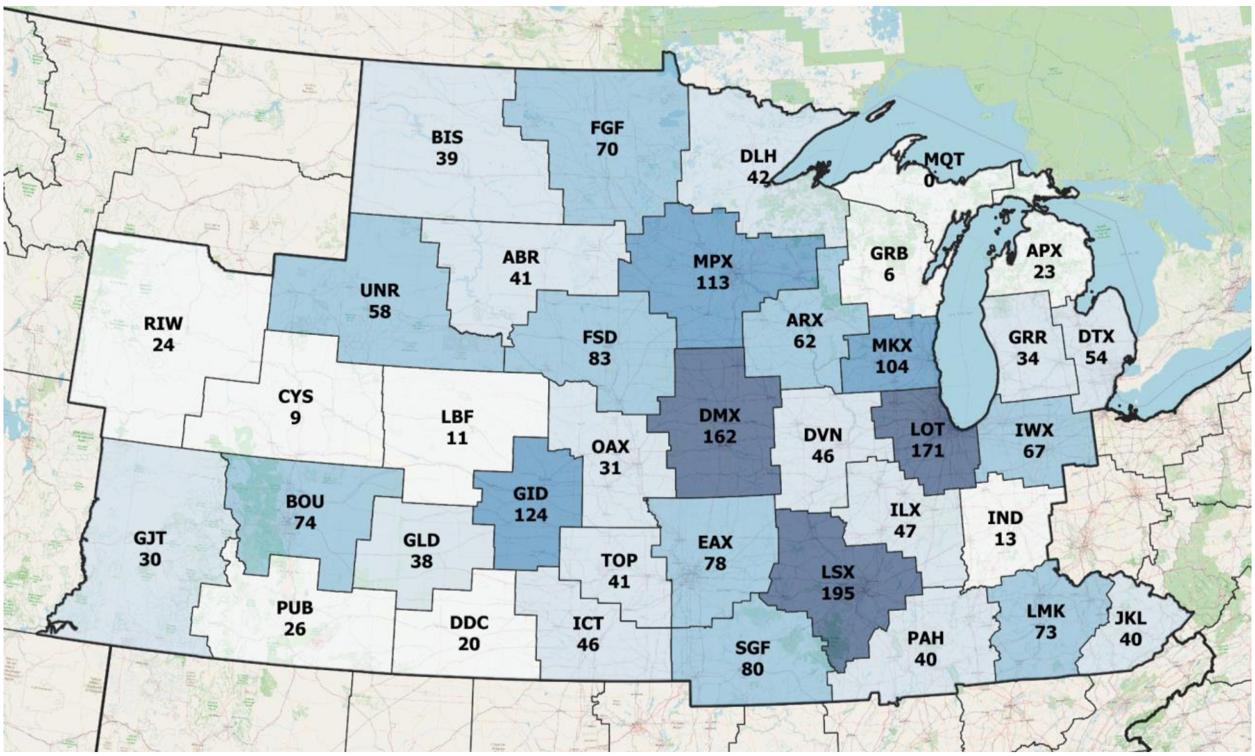

Figure 1. Map of Central region CWAs with the number of respondents who reported being served by each WFO.

b. Decision-making thresholds

This section focuses on decision-making thresholds specific to each type of partner. We asked all partners to imagine that it is mid-January and that there is a forecast for a possible high-impact winter storm to occur on a Wednesday—so they would consider impacts and decisions associated with a weekday—for the area where they work. Then, based on which job category partners identified with, they were branched into a set of questions, each of which asked about a different decision that is commonly made in their job role. The decisions asked for each partner group are listed in **Table 1**.

Table 1. Job-related decisions asked of each partner group.

Emergency Managers	**Transportation Officials**	**School Officials**
Stockpiling and/or prepositioning materials.	Planning for road treatment and/or plowing.	Planning for school closures or delays.
Planning for opening shelters or warming stations.	Securing extra staff, resources, and materials (e.g., snowplows, treatment).	Planning for canceling extracurricular school activities.
Communicating about possible city, county, or state government closures or delays.		

For each of these partner-specific decisions, we asked partners how certain forecasters needed to be that there could be a high-impact winter storm in the area where they worked for them to start making the decision. We asked about this at four different lead-times: < 24, 24-48, 48-72, and > 72 hours before the snow begins. The response options were 0% chance, at least a 10% chance, at least a 30% chance, at least a 50% chance, and at least an 80% chance.

i. Emergency managers

Emergency managers' preferred certainty thresholds are provided in **Figure 2** (mean responses), and **Figure 3** (full distribution). Overall, the results are very similar across the three decisions asked about, and the key differences are by lead-time. The general pattern is that more certainty is needed in the < 24 hour range, and less certainty is needed at longer lead times. More specifically, within 24 hours, the vast majority of emergency managers want high certainty (> 80% chance). In the 24-48 hour range, about half want at least 50% certainty. For the 48-72 hour range, approximately two-thirds want at least 30% or at least 50% certainty, split relatively evenly between the two options. At > 72 hours, emergency managers were split relatively evenly between wanting at least 10% or at least 30% certainty. Although the overall patterns are similar across all decisions, there is one slight difference for decisions about stockpiling. On average, stockpiling required slightly less certainty across the lead times, which is most notable in the 24-48 hour before range.

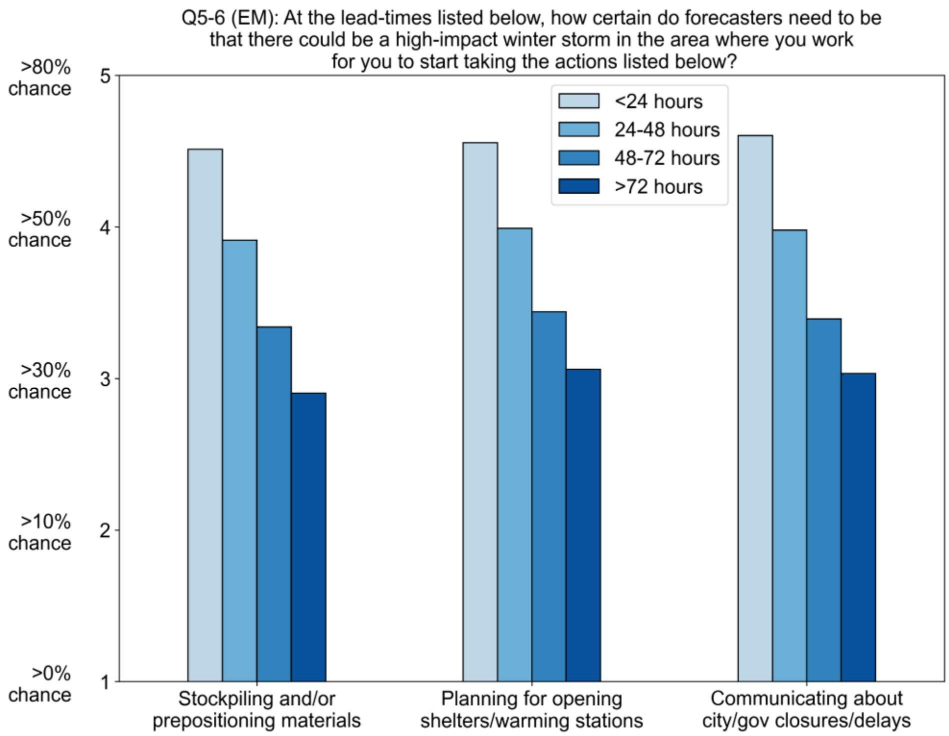

Figure 2. Mean responses of emergency managers' (EM) needed certainty thresholds for three job-related decisions. Means are calculated using the 1-5 values shown along the y-axis next to the percent chance response options.

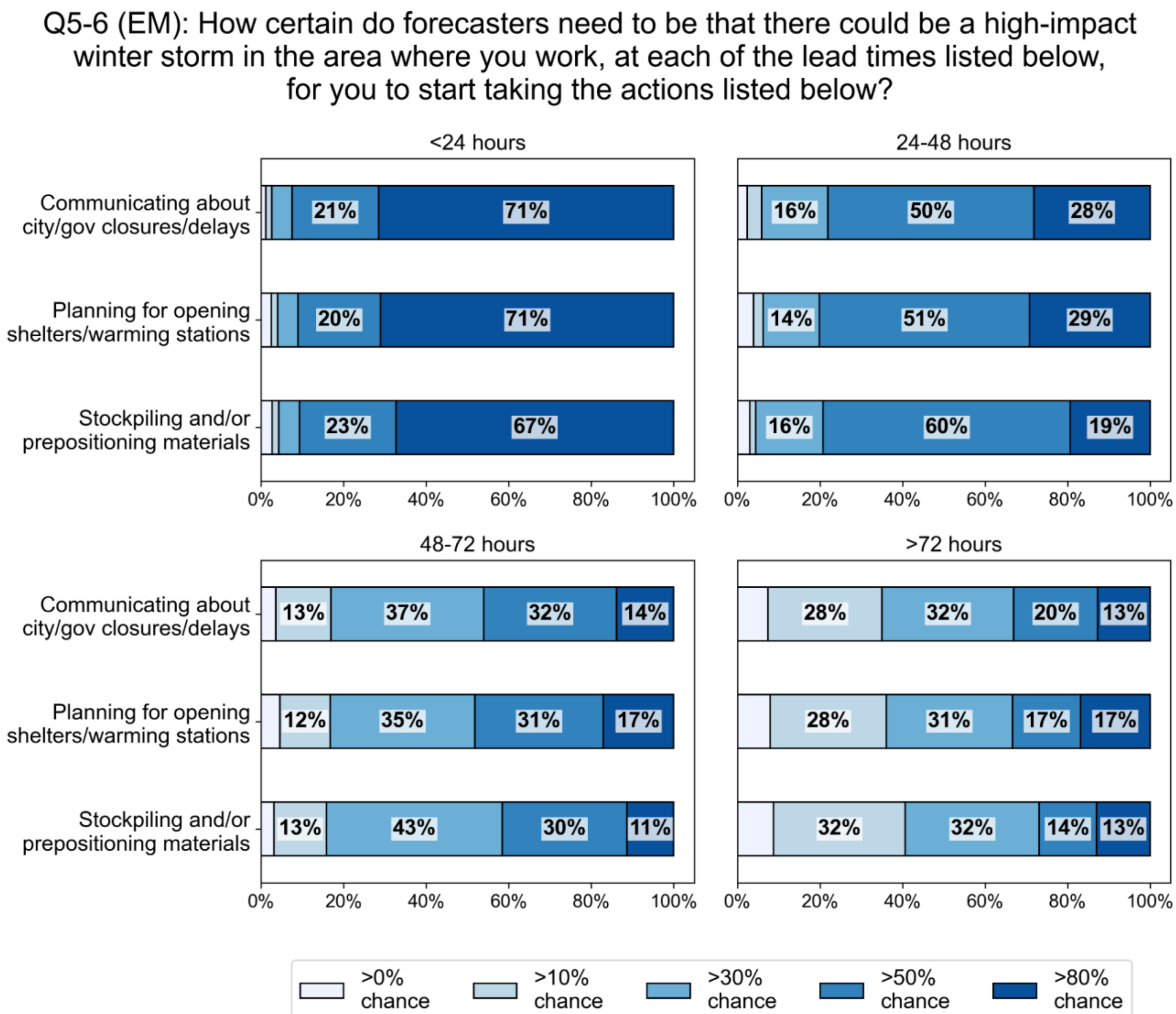

Figure 3. Full distribution of emergency managers' (EM) needed certainty thresholds for three job-related decisions at lead-times of <24 hours (top left), 24-48 hours (top right), 48-72 hours (bottom left), and >72 hours (bottom right).

ii. School officials

School officials' preferred certainty thresholds are provided in **Figure 4** (mean responses), and **Figure 5** (full distribution). Their responses are similar to those of emergency managers. Overall, more certainty is needed < 24 hours before the storm and less is needed at longer lead times, and there are not notable differences between the two decisions asked about. Within 24 hours, roughly three-quarters of school officials want high certainty (> 80% chance) from forecasters to plan for school closures or delays and to plan to cancel extracurricular school activities. In the 24-48 hours before the storm begins, just over half of respondents want at least 50% certainty to make these decisions. The responses for the 48-72 hour and > 72 hour ranges are more variable, with more respondents wanting at least 10% certainty > 72 hours than for the 48-72 hour range. The drop off in the percent of respondents wanting at least 80% certainty is sharper for school officials than for the other job roles.

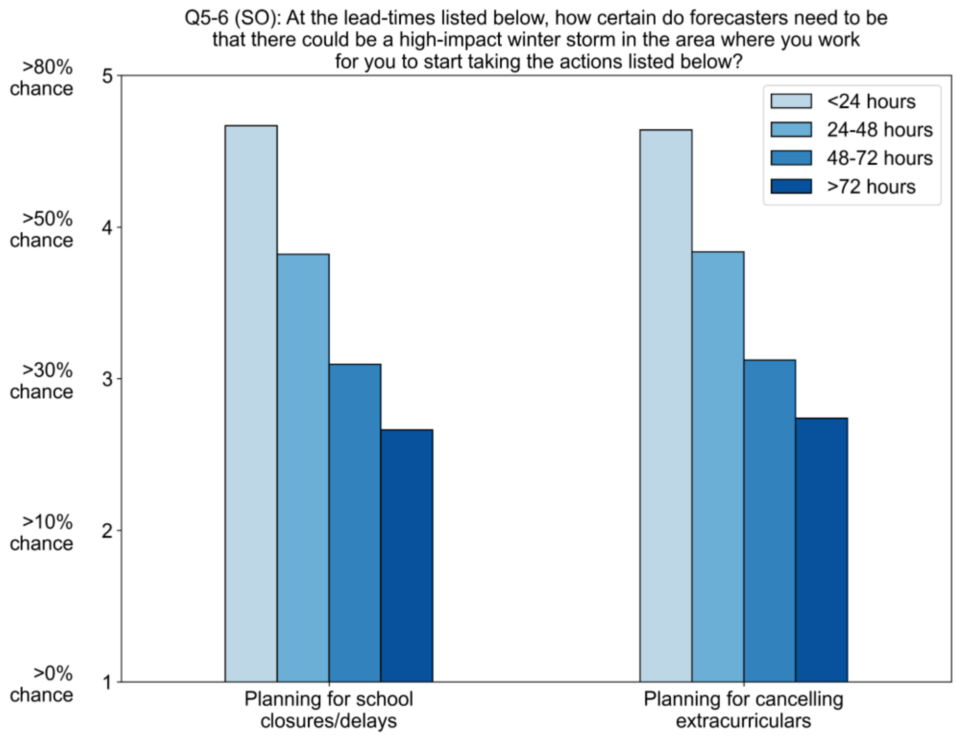

Figure 4. Mean responses of school officials' (SO) needed certainty thresholds for two job-related decisions. Means are calculated using the 1-5 values shown along the y-axis next to the percent chance response options.

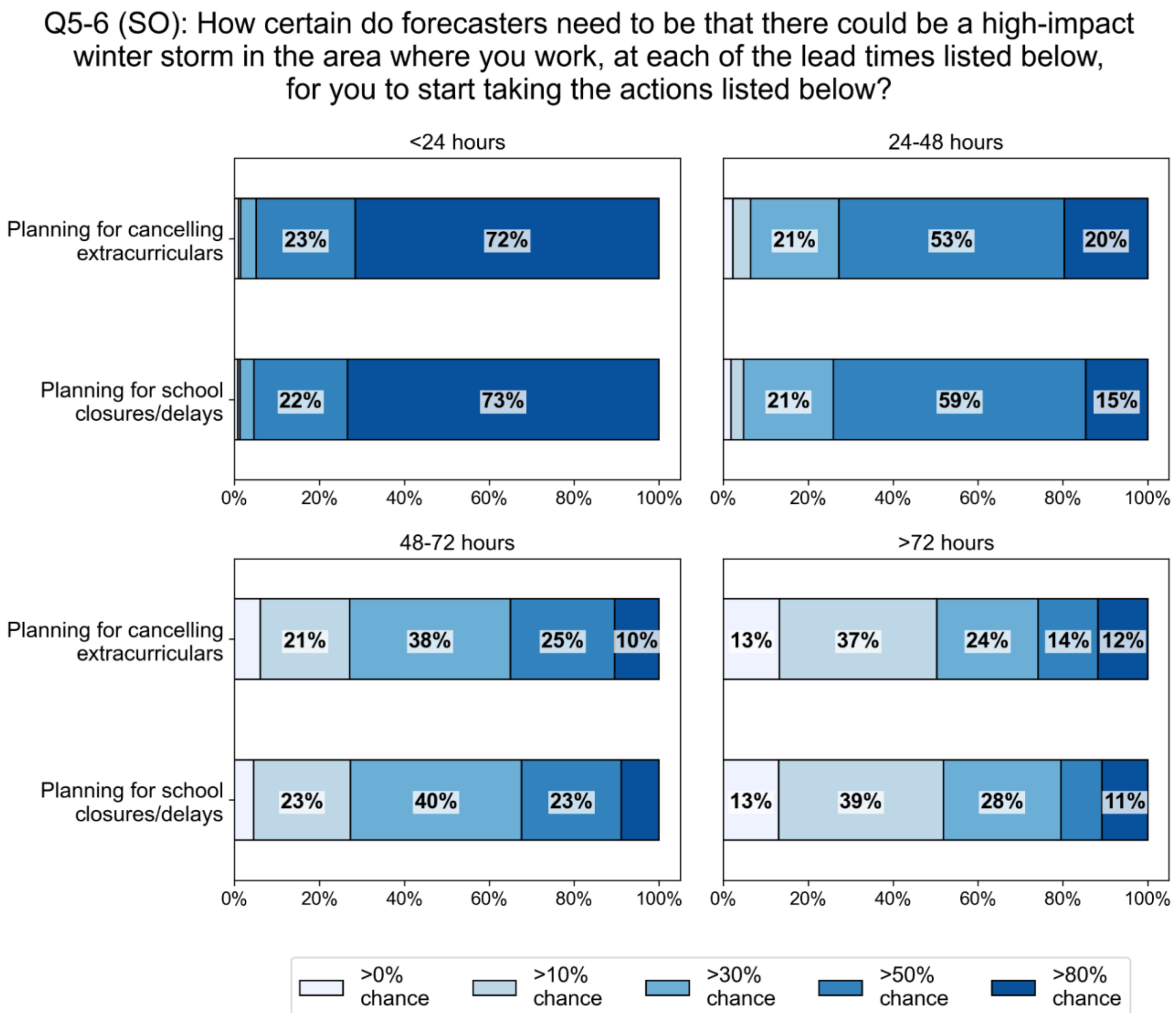

Figure 5. Full distribution of school officials' (SO) needed certainty thresholds for two job-related decisions at lead-times of <24 hours (top left), 24-48 hours (top right), 48-72 hours (bottom left), and >72 hours (bottom right).

iii. Transportation officials

Transportation officials' preferred certainty thresholds are provided in **Figure 6** (mean responses), and **Figure 7** (full distribution). The results follow a similar pattern compared to the emergency managers and school officials. Transportation officials want more certainty < 24 hours before the storm, and they need less certainty at longer lead times. In the 24-48 hours before the storm begins, transportation officials want more certainty for securing extra staff, resources, and materials than for planning for road treatment and/or plowing. The same pattern holds for > 72 hours.

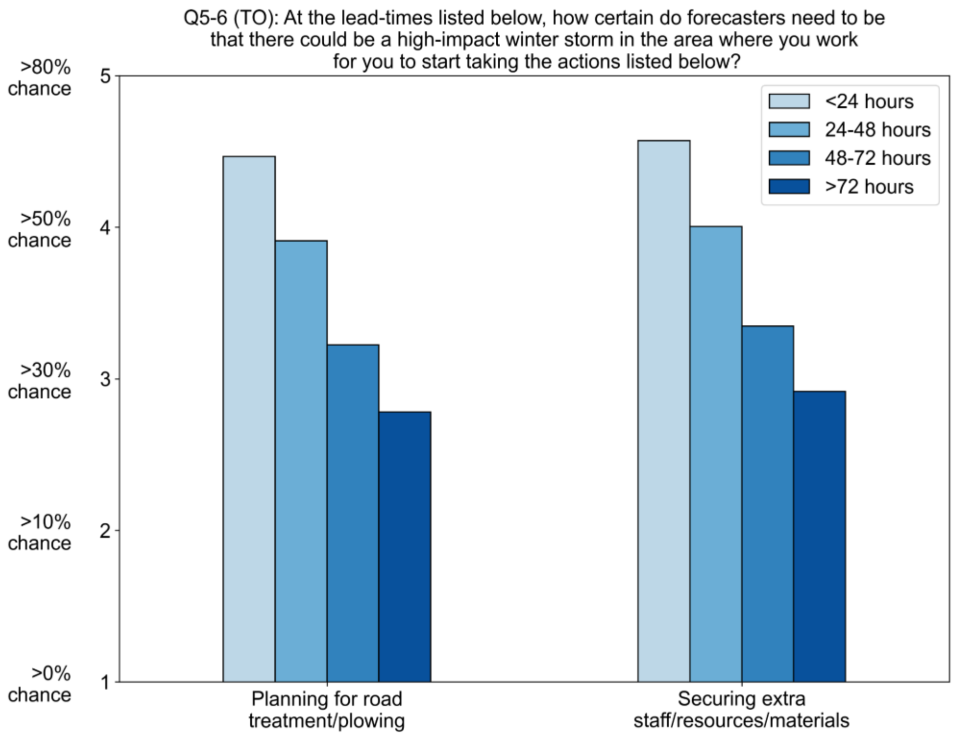

Figure 6. Mean responses of transportation officials' (TO) needed certainty thresholds for two job-related decisions. Means are calculated using the 1-5 values shown along the y-axis next to the percent chance response options.

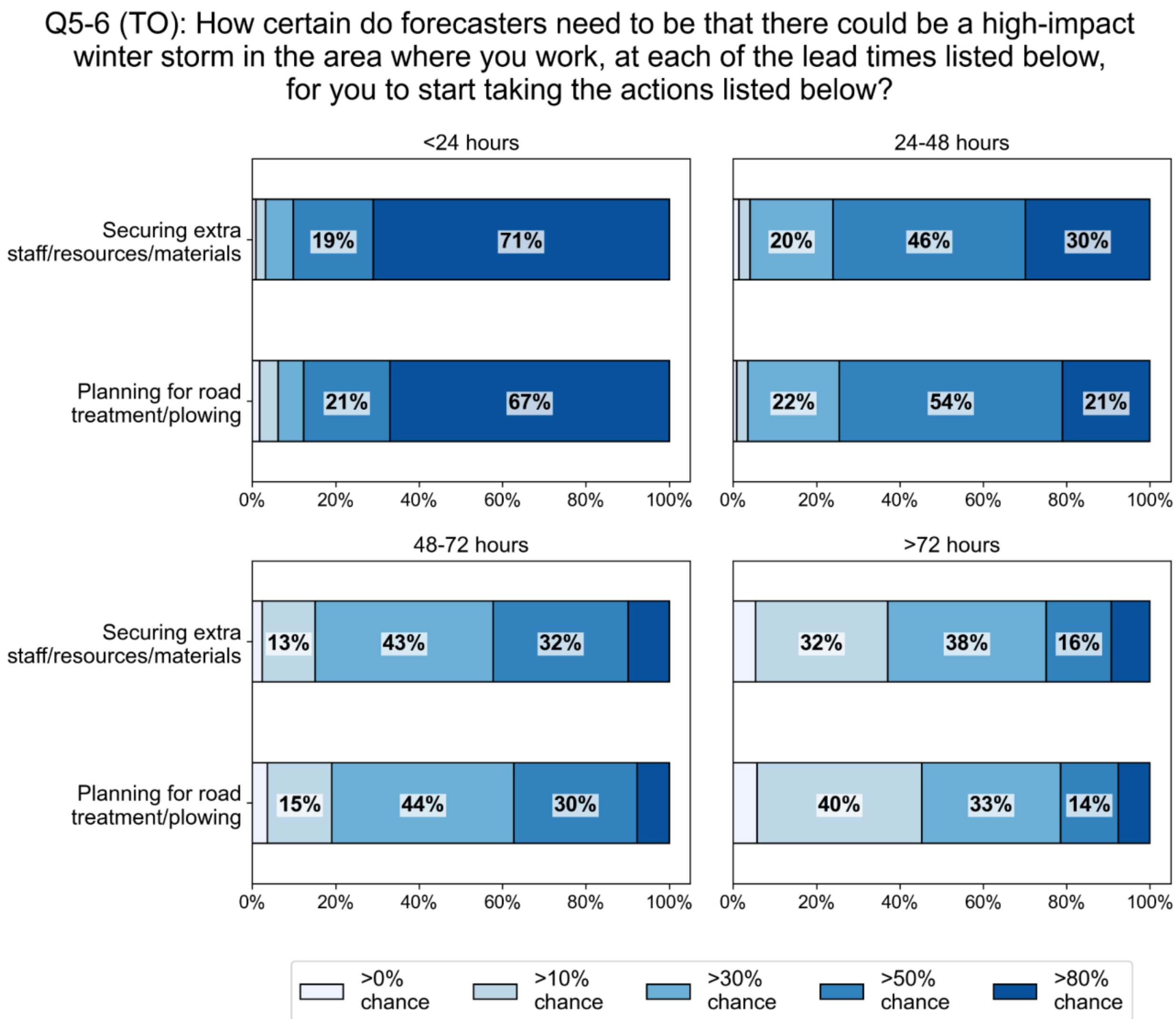

Figure 7. Full distribution of transportation officials' (TO) needed certainty thresholds for two job-related decisions at lead-times of <24 hours (top left), 24-48 hours (top right), 48-72 hours (bottom left), and >72 hours (bottom right).

3. Results: Preferences and Uses Regarding Winter Forecast Information

This section focuses on what different types of winter weather forecast information are important to partners overall and at different lead-times before a winter storm begins.

a. Importance of different forecast elements

To assess the partners' preferences for different types of forecast information, we asked them to rank five winter weather forecast elements from most to least important. Of note, roughly 25% of respondents did not complete this question. We do not know why this question had such a large portion of non-responses, but it could be because ranking is a challenging task or because of the survey interface that respondents used to perform the ranking. Nevertheless, there were no significant differences in non-response to this question by job role. The results for respondents who did complete this question are presented in **Figure 8**.

Overall, the partners ranked the "areas that will get snow", "amount of snow", and "timing of when snow will start or end" as the most important forecast elements, with 67-69% of participants ranking these elements as at least the third most important element. Among these three elements, "areas that will get snow" is most often ranked as the most important element (29%). This perhaps suggests there is a dependency of information utility whereby partners first need to know if their area will be affected by winter weather before considering what other forecast elements are useful. "Chance of snow" is also commonly ranked as the most important element (24%) but, interestingly, is also commonly ranked as the least important element (29%), and thus it is ranked as less important to the partners in aggregate compared to the other forecast elements. Of note, it is possible that partners perceived "areas that will get snow" as a proxy for "chance of snow". The partners ranked the "timing of the heaviest snow rate" lowest, with more than half (53%) of respondents ranking this element fourth or fifth most important.

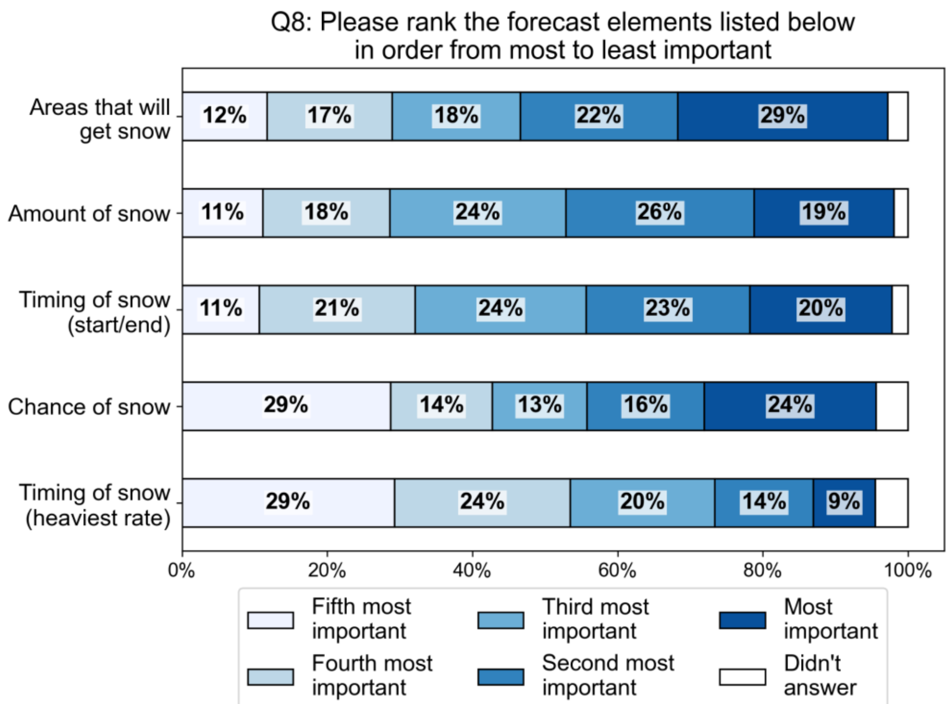

Figure 8. Proportion of respondents who ranked each forecast element (on the y-axis) at each ranking position (e.g., most important, least important). "Didn't answer" refers to respondents who ranked other elements but did not rank the element in question (i.e., not participants who ranked none of the elements, who are not included in this chart).

For the most part, these response patterns are consistent across the different job roles (**Figure 9**), but there are a few key significant differences. Emergency managers rank the "amount of snow" as more important compared to school and transportation officials (**Figure 9b**). Likewise, transportation officials rank the "timing of the start and/or end of snow" as more important than emergency managers and school officials (**Figure 9c**). These results likely reflect the different thresholds and activities for these different job roles. Emergency managers' key decisions about stockpiling/prepositioning resources, communicating about possible closures or delays, and opening shelters/warming stations typically depend on the *amount* of snow that falls, which may explain why they rank this as more important. Meanwhile, transportation officials often must make road treatment decisions when any amount of snow is forecast, but their decisions of when to treat depends on *when* the snow will occur. This may explain why they rank the amount of snow as less important and the timing of impacts as more important.

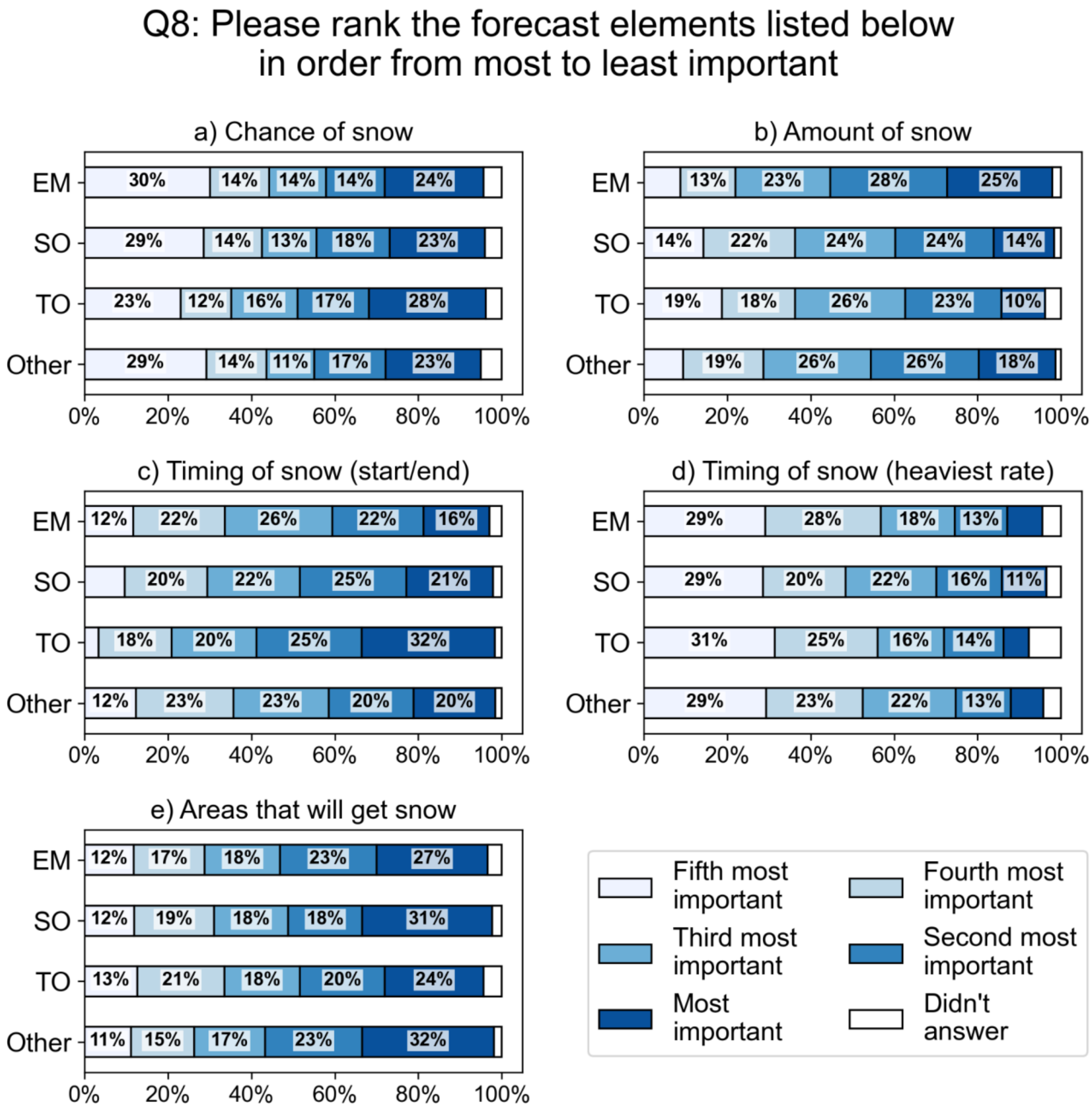

Figure 9. Distribution of importance rankings by job role (y-axis; EM = emergency managers, SO = school officials, TO = transportation officials) for forecasts of a) chance of snow, b) amount of snow, c) timing of snow (start/end), d) timing of heaviest rate of snow, and e) areas that will get snow. "Didn't answer" refers to respondents who ranked other elements but did not rank the element in question (i.e., not participants who ranked none of the elements, who are not included in this chart).

b. *Needed lead-time of different forecast elements*

Next, we asked the respondents to indicate how many hours before snow begins do they need information about five different forecast elements (location, amount, start time, end time, and snowfall rate) to make their critical job decisions. Respondents could also indicate that a forecast element was not important in their decision-making process. The results are summarized in **Figure 10**.

Participants generally desire forecast information about snowfall location and amounts 12-48 hours before snow begins, with 61-67% of respondents preferring information in this timeframe and a smaller contingent (15%) preferring information 0-12 hours before impact. Similarly, most partners want start-time information in the 12-48 hours before snow begins (69%), especially in the 12-24 hours before impacts begin (42%). Among these three forecast elements, there are some differences beyond 48 hours, with a larger proportion of partners preferring location information at these time frames (24%) compared to information about snowfall amounts (17%) and start time (13%). Partners desire information about snowfall rates and end times at shorter lead-times, with 69-70% of respondents needing information about these elements within the 24 hours before snow begins, only 26-27% wanting information beyond 24 hours, and 4-5% indicating the element as not important. Coupled with the results about the forecast element importance rankings discussed above, this further suggests that partners may first assess whether their area will be affected by winter weather before evaluating what other forecast elements are useful as they plan for the event.

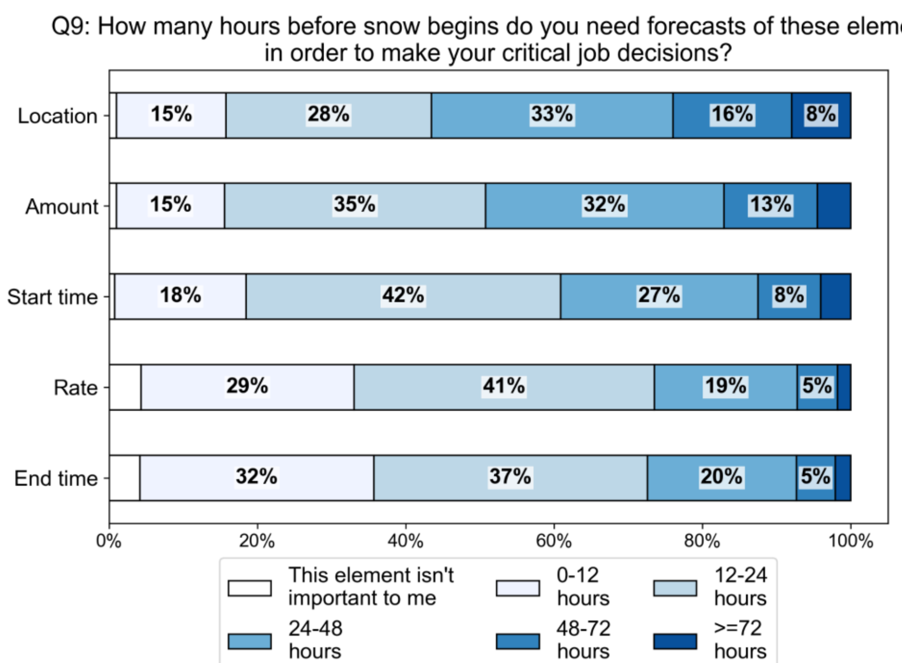

Figure 10. Proportion of respondents who expressed a need for each forecast element (on the y-axis) at each timescale (e.g., 0-12 hours, 24-48 hours) in order to make critical job decisions. Respondents could also select that a forecast element is not important to them, which is denoted in white.

Partners in different job roles expressed significantly different lead-time needs for winter weather forecast information. In particular, school officials need information about snowfall amounts, start time, rate, and location at shorter lead-times (<24 hours) compared to emergency managers and transportation officials, who need information about these forecast elements at longer lead-times. For example, only 34% of school officials need information about snowfall amounts beyond 24 hours before snow begins, compared to 59% of emergency managers and 54% of transportation officials (**Figure 11a**). Further, a sizable contingent (24%) of school officials only need information about snowfall start time (**Figure 11b**) within 12 hours before snow begins, compared to 14% of emergency managers and 17% of transportation officials. We observe similar distributions for snowfall rates (**Figure 11d**) and location (**Figure 11e**). These results reflect the different decision timelines for school officials who generally need less lead-time to make decisions about closing/delaying classes or canceling extracurricular activities, as they typically make these decisions either the night before or the morning of a snow event. There are no significant differences among job roles for snowfall end time (**Figure 11c**), as respondents from all job roles do not require much lead-time for this forecast element.

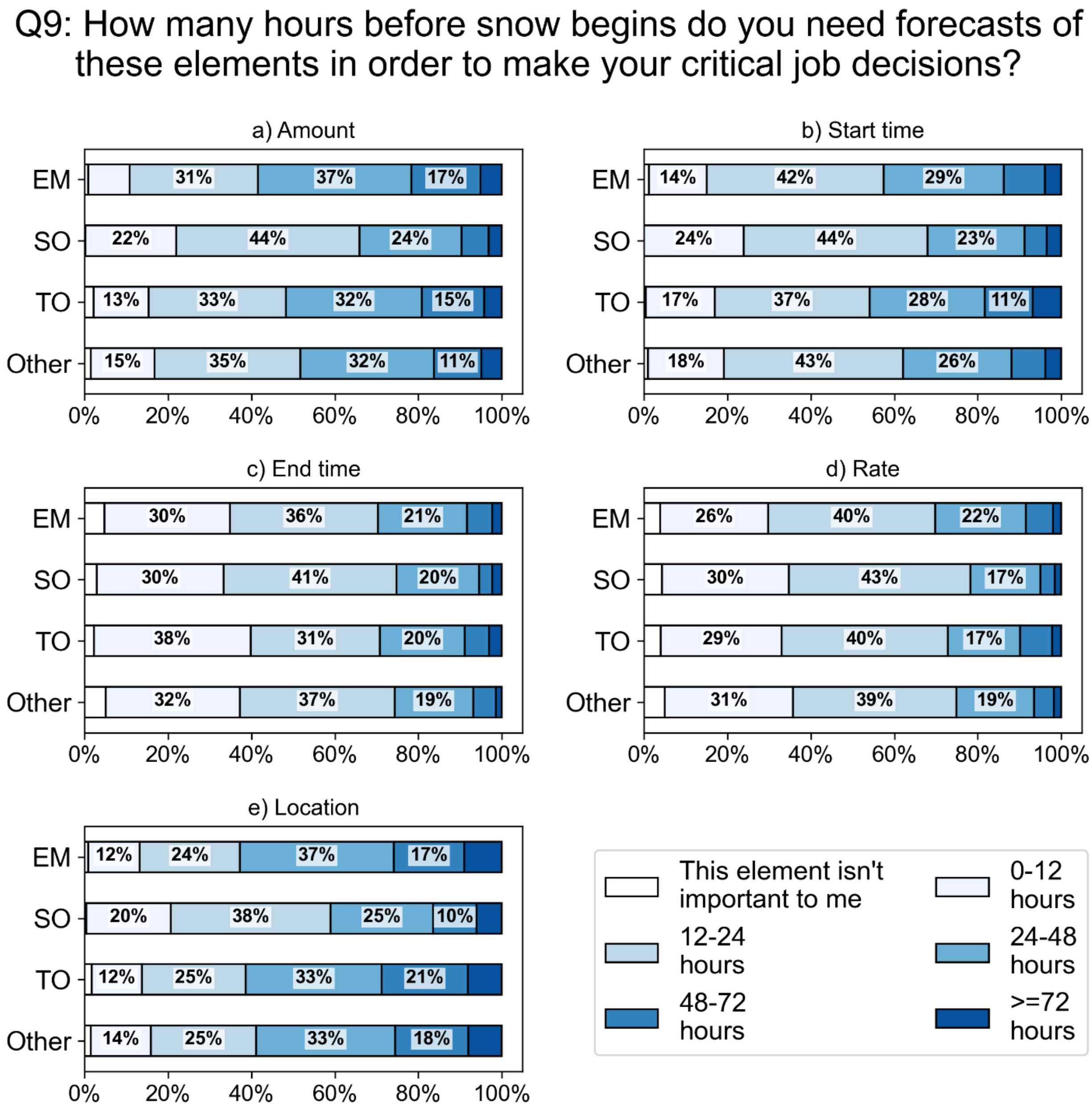

Figure 11. Proportion of respondents within each job role (y-axis) who expressed a need for forecasts of a) snowfall amount, b) snowfall rate, c) snowfall start time, d) snowfall location, and e) snowfall end time, at each timescale (e.g., 0-12 hours, 24-48 hours) in order to make critical job decisions. Respondents could also select that a forecast element is not important to them, which is denoted in white.

4. Results: Preferences and Uses Regarding Probabilistic Winter Forecast Information in General

This section focuses on partners' preferences and uses of probabilistic winter weather information generally, including their preferences for and uses of different types of uncertain snowfall forecasts, such as ranges and probabilities.

a. Preferences for (un)certainty versus lead-time

We asked the respondents to consider the tradeoff between advanced notice (i.e., lead-time) of a winter storm and (un)certainty in the forecast of these hazards. To ensure all participants understood the tradeoff context, the question was asked with this explanation: "Typically, the further in advance of a winter storm, the more uncertainty there is in how much snow will fall. And vice versa, the sooner a winter storm will occur, the more certainty there is in how much snow will fall." With this framing established, we then asked the respondents to choose whether they would prefer more advance notice of a winter weather event even if there is more uncertainty or a forecast with greater certainty even if that means they have less advance notice. Results are provided in **Figure 12**, overall for all respondents and stratified by job role.

Overall, there is a slight preference for greater certainty over more advance notice, with 59% of respondents selecting this option. However, this result is largely driven by school officials, of whom 72% prefer greater certainty. For partners in other job categories, respondents were more evenly split regarding the tradeoff. This suggests that—other than school officials for whom 60% are making their critical job decisions within 0-24 hours of when snow begins (Section 2)—there is no one-size-fits-all solution in resolving this tradeoff. *It also is important to recognize that respondents may have had varying interpretations of what "advance notice" or "greater certainty" means (results in Section 4c further support these varying interpretations of qualitative terms).* Future work could provide more concrete examples for this question, in order to more clearly elucidate decisions about this tradeoff.

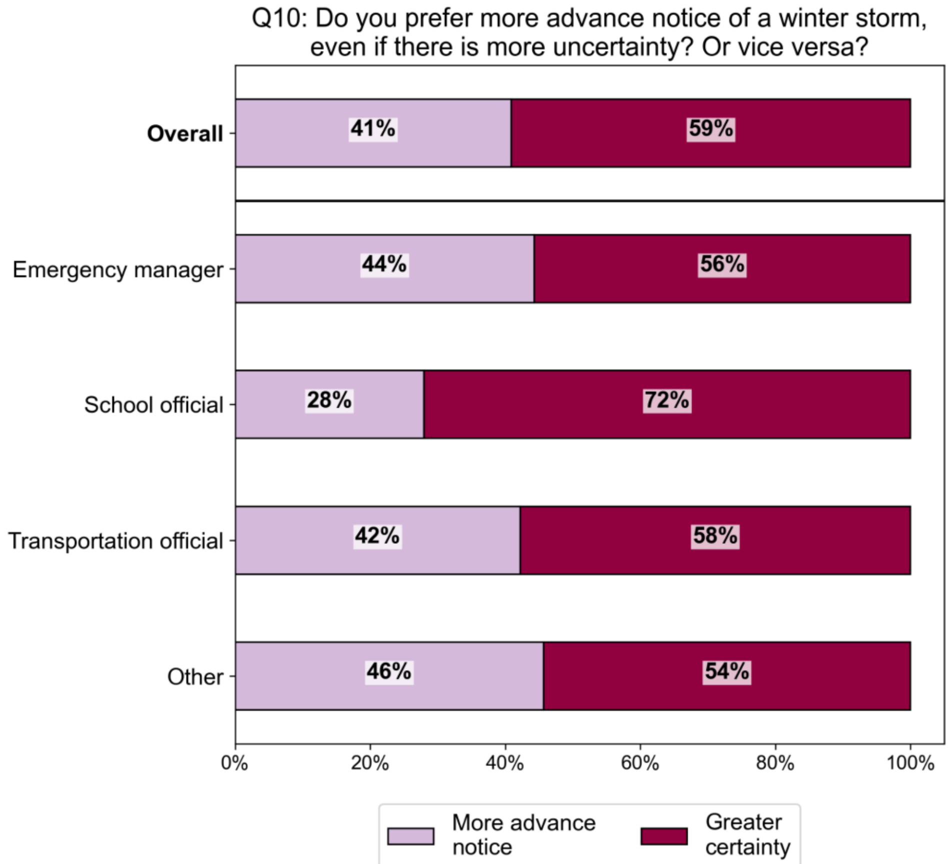

Figure 12. Respondent preferences for forecasts with more advance notice (pink) or greater certainty (red), overall for all of the respondents (top row) and by job role (bottom four rows).

b. Use of snowfall range forecast

The next set of questions asked partners to provide their uses of and preferences for various ways of communicating uncertainty in snowfall forecasts. First, the participants were instructed to imagine that they received a snowfall forecast with a wide range of potential values (2-8 inches). We then asked the participants whether they would prepare for the low-end amount (2 inches), the mid-point amount (5 inches) or the high-end amount (8 inches). Results are provided in **Figure 13**. Overall, more than half of respondents (58%) indicated that they would prepare for the mid-point amount, with another 31% of respondents indicating that they would prepare for the high-end amount. Only 7% of respondents indicated that they would prepare for the low-end amount. Among different job roles, school officials again exhibit a significantly different response pattern, with 70% of school officials indicating that they would prepare for the mid-point amount (compared to 51-57% of respondents in other job roles) and only 16% indicating that they would prepare for the high-end amount (compared to 33-37% of respondents in other job roles). A larger share of school officials (12%) also indicated that they would prepare for the low-end amount, compared to other job roles (5-8%).

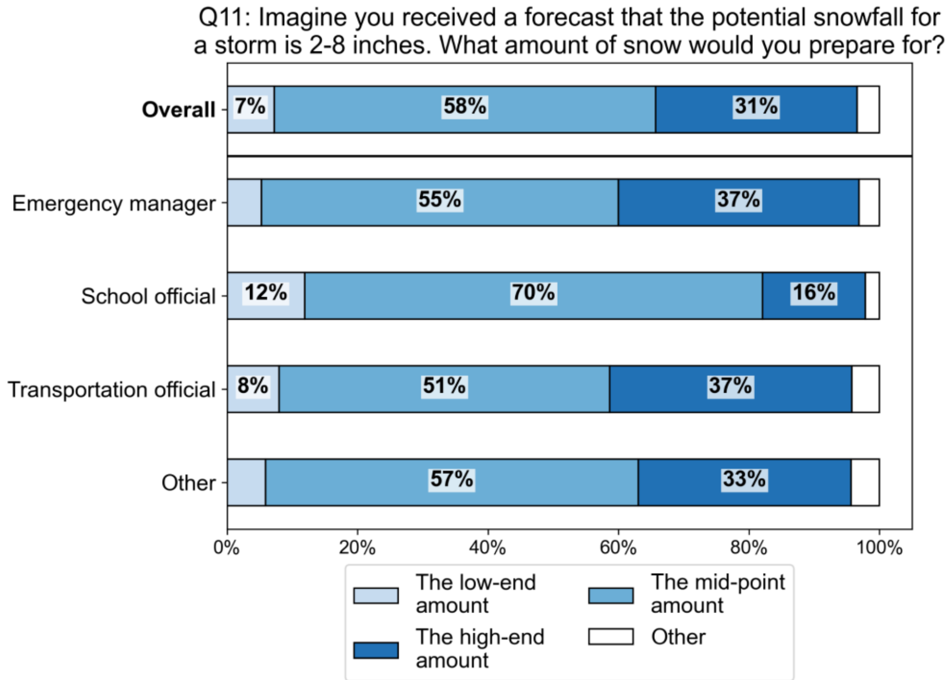

Figure 13. Which part of a forecast snowfall range of 2-8 inches that respondents indicated they would prepare for, overall (top row) and by job role (bottom four rows).

c. Preferences for snowfall range forecasts

After assessing the partners' intended preparatory behaviors with a wide snowfall range, we then asked the partners about their preferences for snowfall ranges of different widths with corresponding confidence intervals conveyed *qualitatively*. Specifically, the partners were asked to consider three snowfall ranges: a "wide range (2-8 inches) and a high chance of capturing the actual amount of snow that will fall", a "middle range (3-7 inches) and a medium chance of capturing the actual amount of snow that will fall", and a "narrow range (4-6 inches) and a low chance of capturing the actual amount of snow that will fall". The subsequent question asked respondents about their preferences for the same snowfall ranges of different widths but with corresponding confidence intervals conveyed *quantitatively*. The response options for this second question were: the wide range conveyed as "80% chance of 2-8", the middle range conveyed as "50% chance of 3-7", the narrow range conveyed as "30% chance of 4-6", and a fourth option of the narrow range with upper and lower bounds of 4-6" plus the possible low-end amount of 2" and the -end amount of 8".

Results of the question asking about the various snowfall ranges with the *qualitative* confidence intervals are shown in **Figure 14.** The majority of respondents (55%) preferred the middle range, 30% preferred the wide range, and 16% preferred the narrow range. This pattern is similar across the different job roles, with the middle range preferred by a majority, followed by the wide range, and then the narrow range. There are modest significant differences, however, in that school officials are more likely than emergency managers to prefer the middle range (59% vs 55%) and narrow range (18% vs 13%) and less likely to prefer the wide range (24% vs 32%).

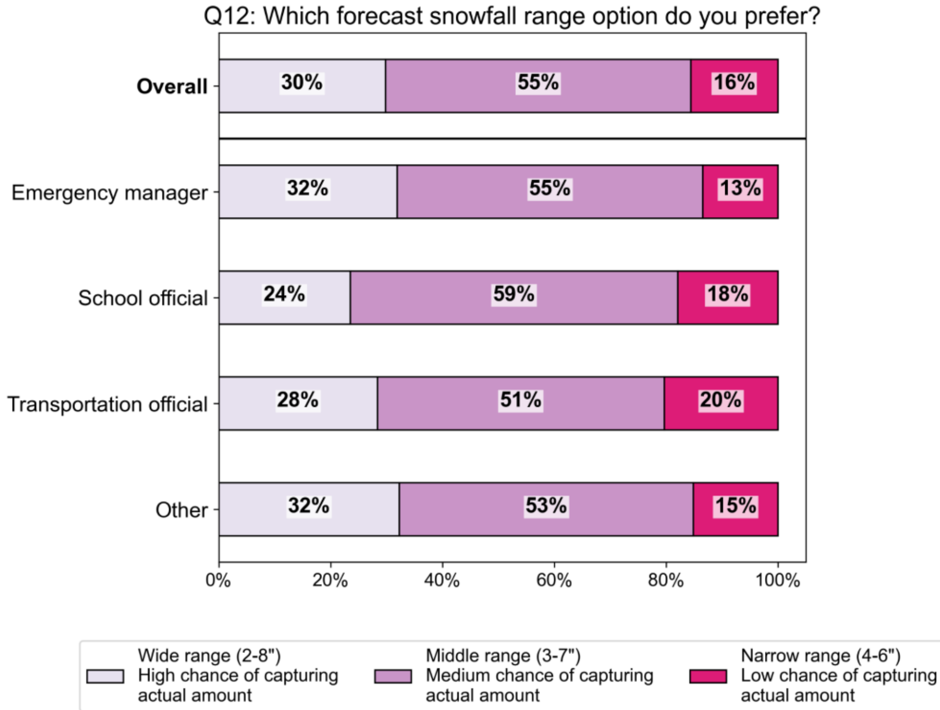

Figure 14. Partner preferences for snowfall ranges of different widths with qualitative confidence intervals, overall (top row) and by job role (bottom four rows).

However, when the partners were provided the various snowfall ranges with the *quantitative* confidence intervals, their response patterns shifted, as shown in **Figure 15**: 39% preferred the wide range with probabilities, 36% preferred the narrow range plus low-end and high-end amounts, 22% preferred the middle range with probabilities, and only 3% preferred the narrow range with probabilities.

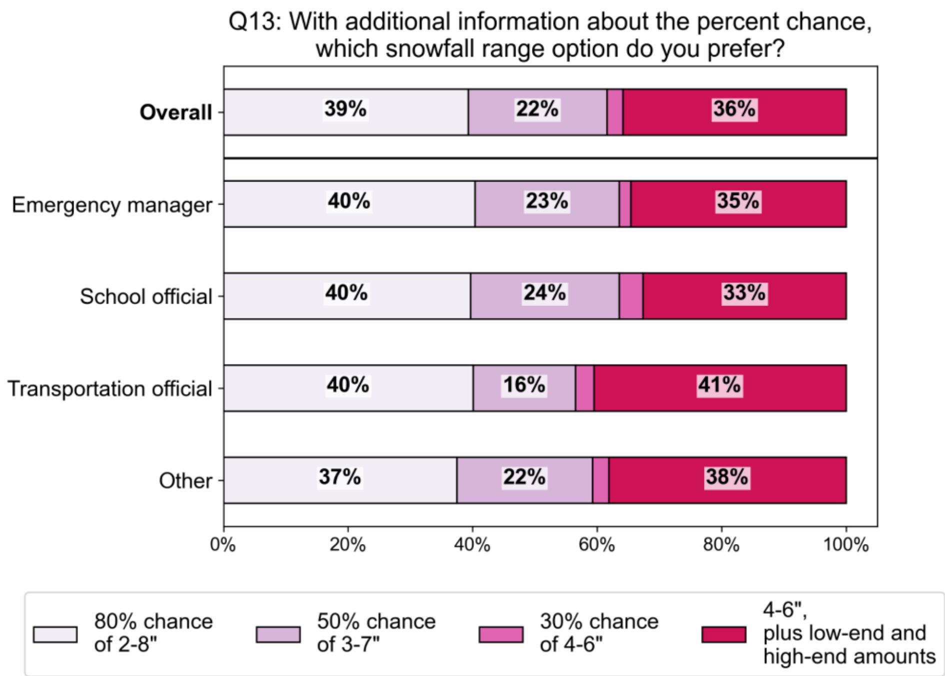

Figure 15. Preferences (as a percent of all responses) for various snowfall ranges with additional probabilistic information, overall (top row) and by job role (bottom four rows).

To understand how the partners' preferences shifted when additional probabilistic information was added, **Figure 16** maps responses to the first question (snowfall ranges with *qualitative* intervals) on the left against their responses to the second question (snowfall ranges with *quantitative* intervals) on the right. This figure illustrates how respondents did or did not change their answers based on how the forecast information was provided.

Of the 740 respondents who preferred the wide range initially, a majority (69%) still preferred the wide range when probability information was included, and a smaller contingent (22%) shifted to prefer the narrow range with low-end and high-end values. In contrast, the 1354 respondents who initially preferred the middle range were more evenly split in the second question, with 37% preferring the narrow range with the high and low end amounts, 33% preferring the middle range with probabilities, and 28% preferring the wide range with probabilities. Only 388 respondents initially preferred the narrow range, but among those who did, most (58%) ended up preferring the narrow range with low and high end amounts, with 21% preferring the wide range with probabilities, and about 10% each preferring the middle and narrow ranges with probabilities.

These results demonstrate that the partners' perceptions of snowfall ranges shifted—in some cases substantially—when quantitative information representing confidence intervals was added. This was especially the case for the middle snowfall range (3-7"), which was the most preferred range when asked initially when the qualitative term "medium" was used but was less preferred when the quantitative "50% chance" information was used. This suggests that the partners may have inferred ideas about the probability of snow associated with the qualitative terms (i.e., "high", "medium", "low" chance of capturing the actual snowfall amount) but that their inferences did not align with the probabilities included in the second question. This mismatch between the probabilities people assign to qualitative terms and what those terms might actually represent has been well documented (Wallsten et al. 1986, Budescu et al. 2014). More specifically, it seems that the partners overestimated what a "medium" chance of snow falling within the provided snowfall range meant, leading to an adjustment in the second question towards ranges that provide higher levels of certainty or that provided bounds for the best and worst-case scenarios. These results also suggest that partners are engaging in a complex tradeoff of uncertainties in that they would prefer a forecast with snowfall ranges that have higher probabilities of occurring, even if those snowfall ranges are wider and thus more uncertain. Whether this result would hold for even wider ranges not presented as part of this survey is not clear and would require additional research.

Finally, these results may also suggest a preference among these partners for uncertainty expressed as low-end and high-end amounts—often termed as "goalposts" or scenarios—rather than probabilities. We see this most clearly for respondents who initially selected the narrow range, as a much larger share of these respondents preferred the narrow range with high-end and low-end amounts versus the narrow range with probabilities. In addition, considerable shares of respondents who selected the wide and middle ranges initially also shifted towards the narrow range with high-end and low-end amounts. These results may suggest that this way of expressing uncertainty is easier to understand or is more actionable for the partners. A follow-up question asked whether the partners preferred the snowfall ranges with or without the percent chance (**Figure 17**). The vast majority of partners (77%) preferred the ranges with the percent chance information, 16% had no preference, and only 7% preferred the ranges without this information. It is important to realize, however, that this question did not offer the option of a snowfall range with low and high-end amounts. Thus, future research still is needed to clarify partners' preferences among these options and in which scenarios.

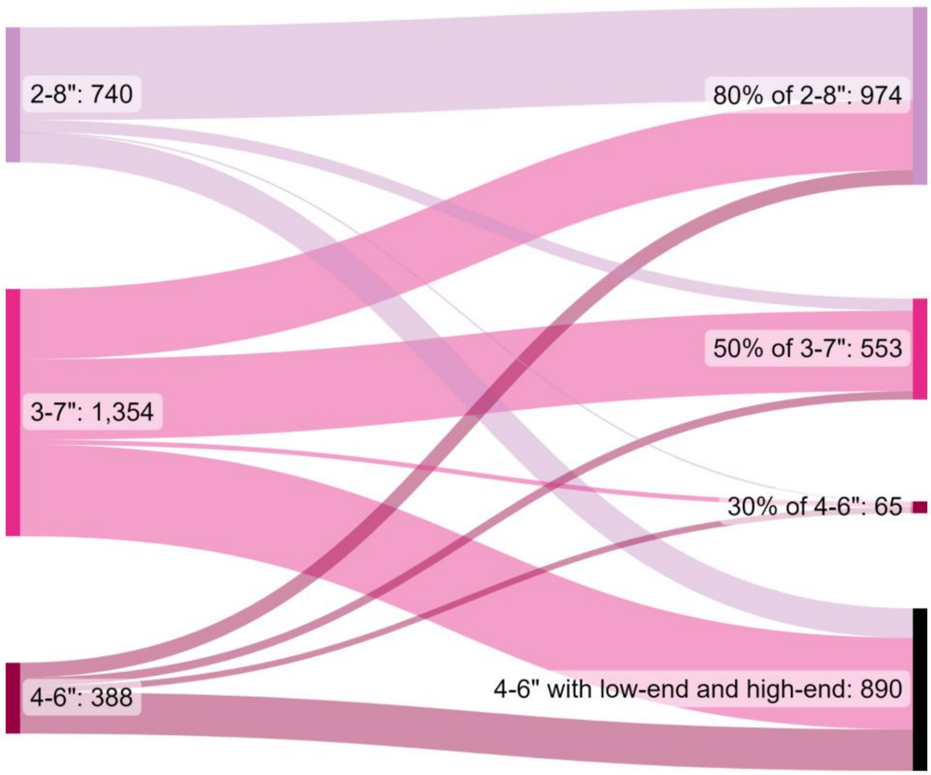

Figure 16. Sankey diagram mapping partner responses to first snowfall ranges question on the left to the second snowfall ranges question on the right.

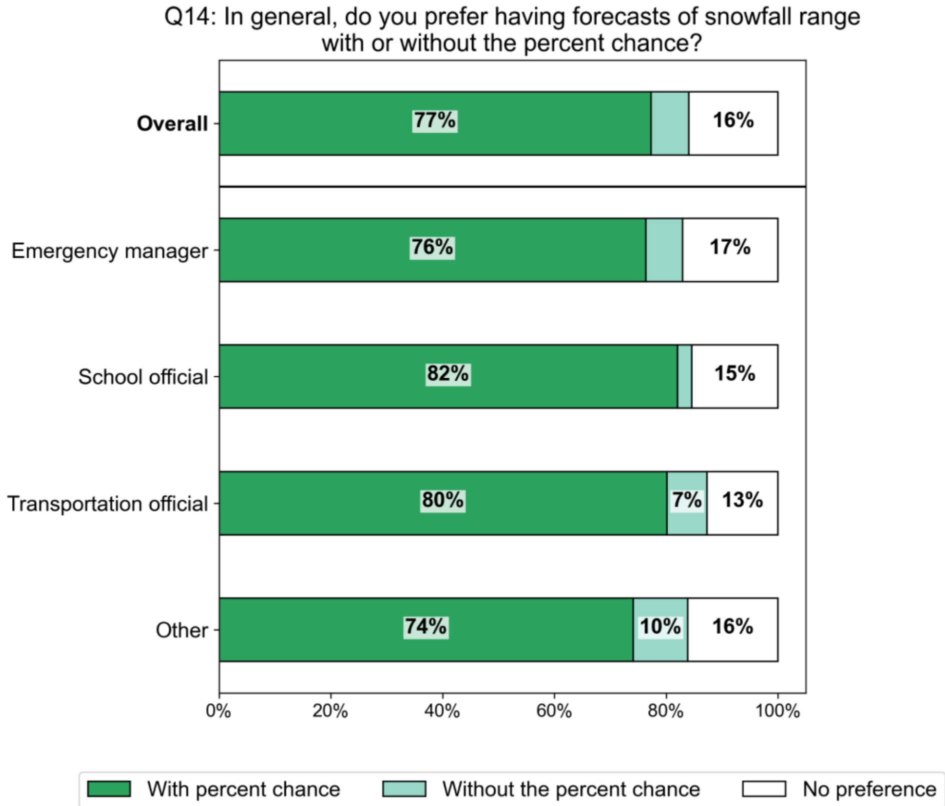

Figure 17. Preferences for snowfall range forecasts with/without percent chance information, overall (top row) and by job role (bottom four rows).

5. Results: Preferences, Uses, and Understanding Regarding Snowfall Probability of Exceedance Graphics

This section focuses on partners' feedback about the snowfall probability of exceedance graphic provided in **Figure 18**. We asked respondents about which aspects of the graphic they found useful, what preparatory actions they would engage in if they encountered such a graphic, and their interpretations of the probabilities on the graphic. We also asked respondents about their color scheme preferences for probability of exceedance graphics, in reference to a different exceedance graphic (**Figure 26**).

a. Usefulness of the information in the graphic

We showed **Figure 18** and told partners to imagine it is Thursday and that this is the forecast for the coming weekend. We then asked partners to imagine that they work in the Sioux Falls region (denoted in the graphic) and to indicate how useful they would find five elements of the graphic: the map on the left that displays the potential for >2" of snow, the map on the right that displays the potential for >4" of snow, the "what is possible" text in the lower left, the "when will it happen" text in the lower middle, and the "what should you do" text in the lower right.

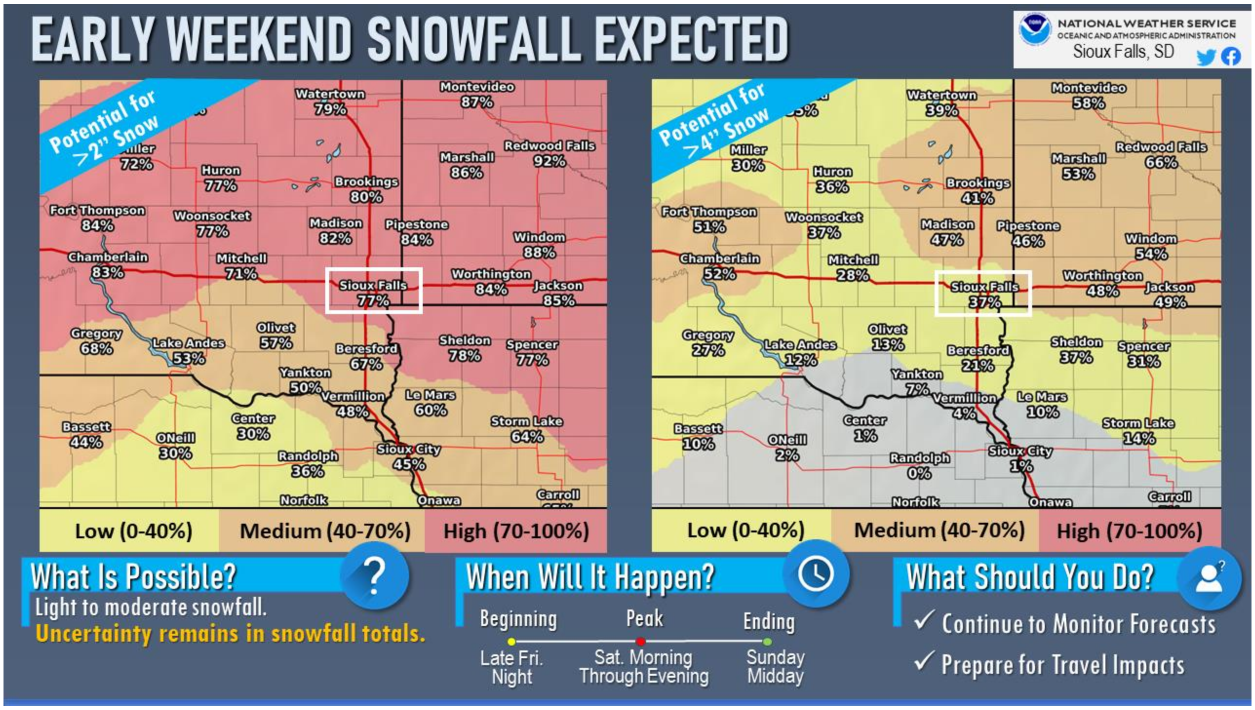

Figure 18. Experimental NWS graphic with snowfall probability of exceedance forecast information that was shown to respondents before asking questions about it. Specific cities are highlighted with white boxes (here, for the one city of Sioux Falls) to minimize the burden of respondents having to find the city in question on the map, so they could instead focus on the forecast information presented.

Figure 19 shows the results for all respondents. Overall, the "when will it happen" text is rated as the most useful part of the graphic, with 88% of respondents ranking it as very or extremely useful. The partners also found both maps highly useful, with 73% finding the potential for >4" snow map very or extremely useful, and 70% finding the potential for >2" snow map very or extremely useful. The other text parts of the graphic are relatively less useful to the partners, with 59% of respondents finding the "what is possible" text very or extremely useful, and only 42% finding the "what should you do" text very or extremely useful (with 28% finding this information not at all or not very useful).

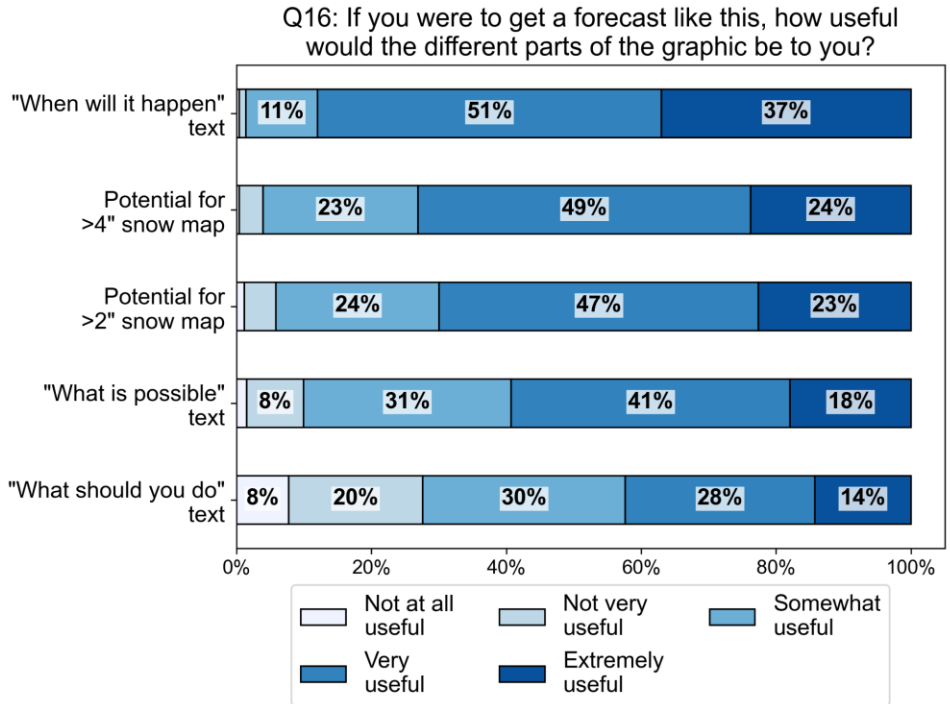

Figure 19. Distribution of respondents' usefulness rankings for each of the elements of the graphic in **Figure 18**.

The analysis of responses by job roles about each of the graphic elements showed no significant differences, with the exception of the "what should you do" text (**Figure 20**); 50% of emergency managers deem this element very or extremely useful, which is significantly more than school officials (38%) who in turn deem this element significantly more useful than transportation officials (32%). It is unclear whether the partners were considering using the "what should you do" information for themselves and decisions pertaining to their job role, or if they may have been considering how they would relay these messages to the users they serve in their respective job roles. Future work could better tease out in what contexts or for which purposes the partners would use this information.

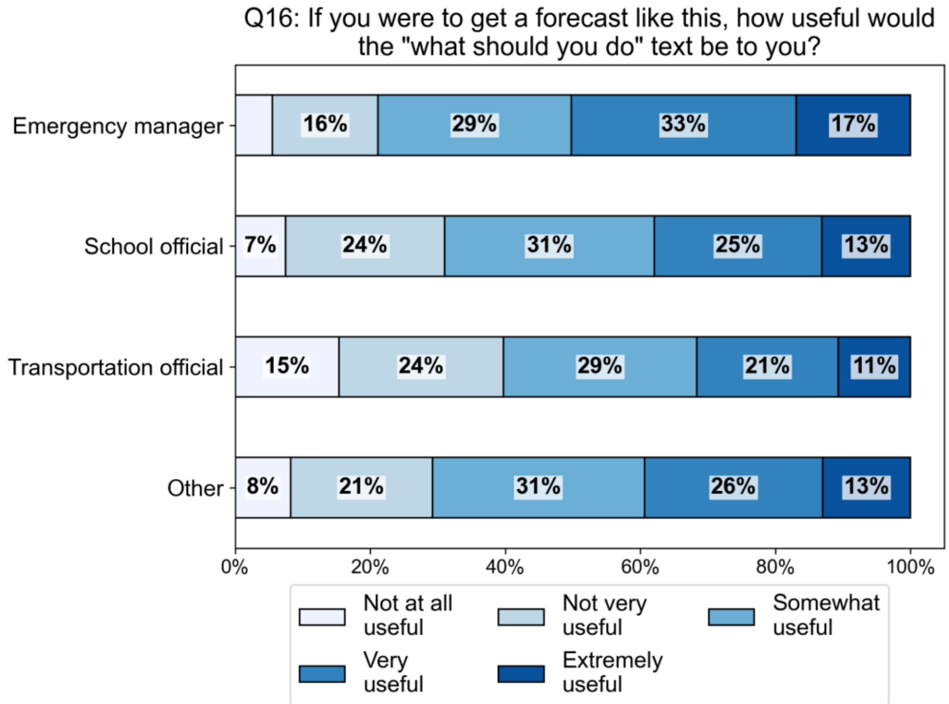

Figure 20. Distribution of usefulness responses for the "what should you do" text, for each job role.

b. Responses based on the information in the graphic

The next question again asked the respondents to imagine they worked in Sioux Falls and then asked them how likely they would be to engage in four preparedness activities if they were to receive the forecast provided in **Figure 18**. The four preparedness activities include preparing for the storm, monitoring the NWS for updated information, contacting their local NWS office in order to talk to someone about the storm, or seeking a forecast from someone other than NWS who could offer them more certain information. **Figure 21** shows that the partners were most likely to monitor the NWS for updated information, with 90% responding that they were very or extremely likely to do so. The partners were also likely to prepare for the storm, with more than half (55%) indicating they were very or extremely likely to prepare. On the other hand, the partners were much less likely to seek a forecast from someone outside of NWS (20% very to extremely likely) or contact their local NWS office (15%).

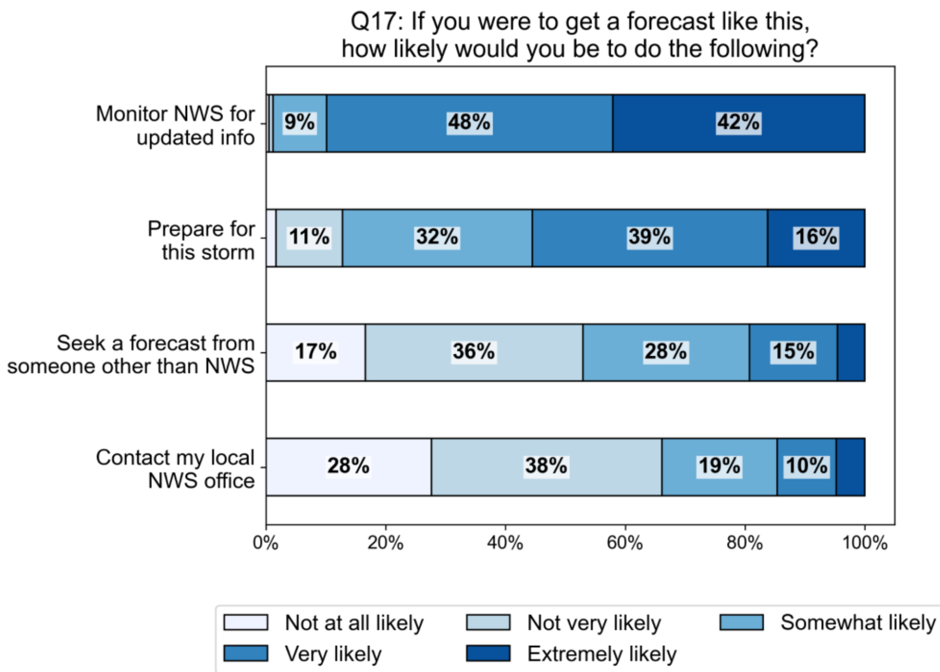

Figure 21. Distributions of responses for how likely respondents would be to engage in preparedness activities after seeing **Figure 19**.

The analysis of responses by job roles is shown in **Figure 22**. Other than monitoring the NWS for updated information (**Figure 22c**), where respondents in all job roles are highly likely to engage in this activity, there are significant differences in the likelihood of engaging in these activities among respondents in different job roles. For instance, all job roles express significantly different likelihoods of seeking a forecast from someone other than NWS (**Figure 22b**), where a larger share of transportation officials (64%) are at least somewhat likely to seek out non-NWS information compared to school officials, and in turn a larger share of school officials (56%) are at least somewhat likely to seek non-NWS information compared to emergency managers (38%). On the other hand, a significantly larger share of emergency managers (44%) are at least somewhat likely to contact their local NWS office to talk about the storm (**Figure 22d**) compared to school officials (30%). These results reflect the various ways partners in different job roles obtain winter weather information; for instance, transportation officials often contract with private companies to provide information in addition to NWS forecasts, which could explain why this group was most likely to seek out non-NWS information. These results may also reflect the degree of partnership between NWS and different partners. Emergency managers, for instance, may have stronger partnerships with NWS WCMs, which could explain why they are more likely to contact NWS and less likely to seek non-NWS information.

Additionally, a significantly higher proportion of transportation officials (79%) indicated they would be very or extremely likely to prepare for the storm (**Figure 22a**), compared to school officials (54%) and emergency managers (49%). These results could be a reflection of the thresholds used in the maps, where a 2” or 4” snowfall would lead to more job-related impacts for transportation officials compared to other partners. This could also offer another explanation for why transportation officials will also use non-NWS information; because these thresholds lead to more job-related impacts, they may be more likely to seek out information from a wider range of sources.

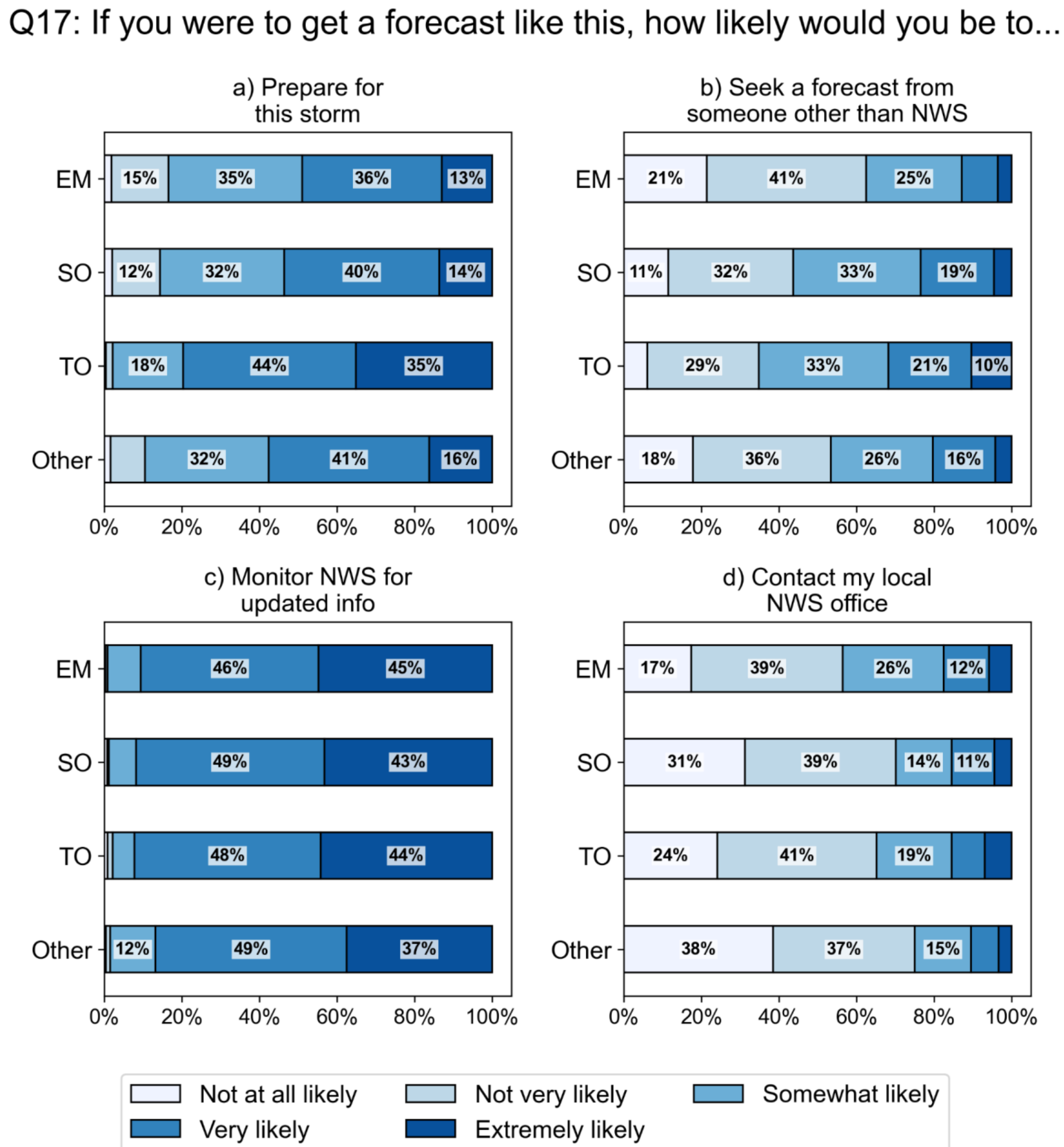

Figure 22. Distributions of responses for how likely respondents would be to a) prepare for the storm, b) seek information from someone other than NWS for more certain information, c) monitor the NWS for updated information, and d) contact the local NWS office to talk about the storm, for each job role.

Among participants who indicated that they were at least somewhat likely to prepare for the storm (n=2166), we asked a follow-up question to assess which aspects of the graphic were helpful to them in preparing. We repeated the same five elements as asked about in **Figure 19**, and we allowed respondents to choose all of the elements that they would find helpful in preparing for a winter storm. These results, summarized in **Figure 23**, closely resemble the usefulness rankings described earlier, with the "when will it happen" text selected as helpful most frequently (79%), followed by the potential for >4" (77%) and >2" (64%) maps, the "what is possible" text (53%), and the "what should you do" text (24%). Of note, more respondents indicated the >4" of snow map is helpful than for the >2" of snow map; this either suggests that 4" is an important threshold or that the chance of more snow is important for partners who indicated they were likely to prepare for the storm.

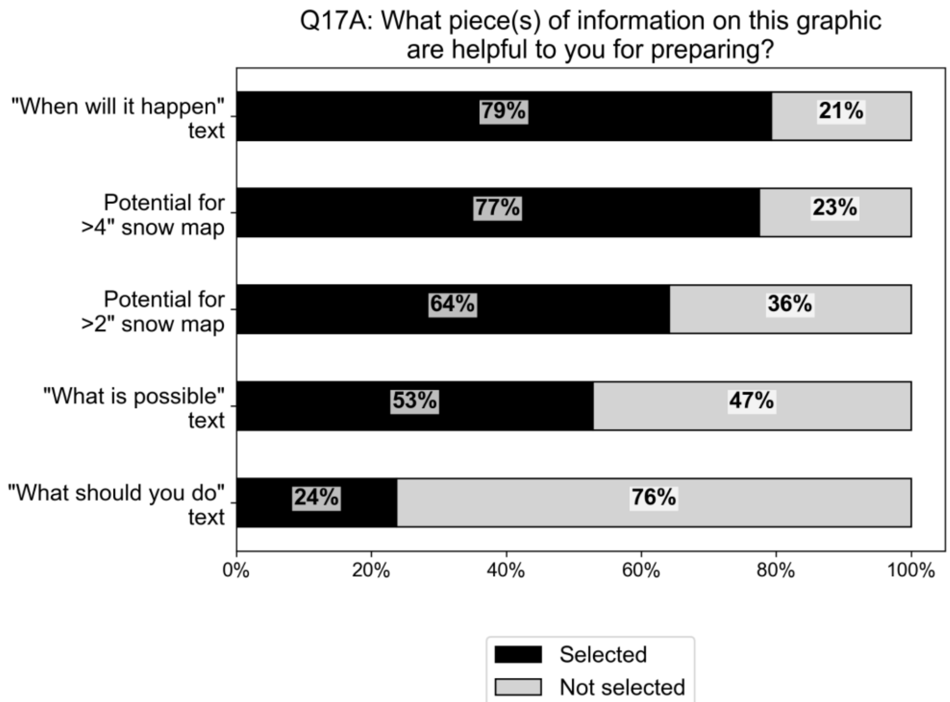

Figure 23. Proportion of respondents who indicated that a graphic element would be helpful in preparing for a winter storm

The analysis by job role (**Figure 24**) shows that much of this pattern is driven by emergency managers, school officials, and other partners, who selected the >4" snow potential map more frequently (77-79%) than the >2" snow potential map (58-66%) (**Figure 24b and a**, respectively). This is not the case for transportation officials, who select the >4" snow potential map at similar rates (**Figure 24b**) but deem the >2" snow potential map even more helpful (81%), significantly more than other job roles (**Figure 24a**). This again highlights the various snowfall thresholds that lead to impacts among different job roles, with transportation officials as more sensitive to low-end snowfall amounts. Elsewhere, there are no significant differences among job roles, except for the "what should you do" text (**Figure 24e**), which repeats a similar pattern observed when all participants were asked to rank the usefulness of the graphic elements.

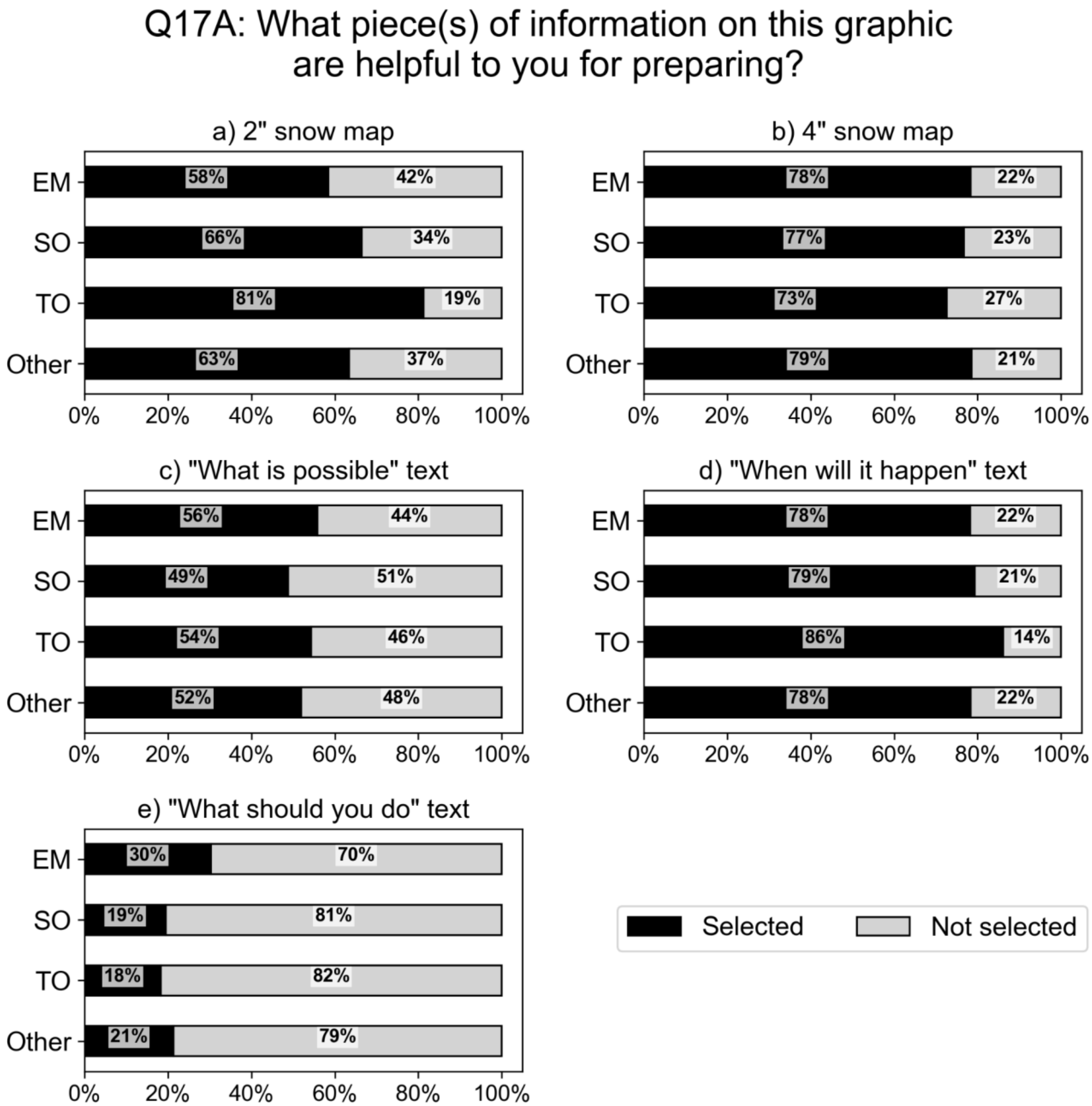

Figure 24. Proportion of respondents who selected a) the potential for >2" of snow map, b) the potential for >4" of snow map, c) the "what is possible" text, d) the "when will it happen" text, and e) the "what should you do" text as helpful in preparing for a storm, by job role.

c. Comprehension of the information in the graphic

After assessing partner preferences of probabilistic snowfall graphics, we asked two questions designed to evaluate partner comprehension of the information included in these graphics. First, we displayed **Figure 18** again, with the four cities of O'Neill, Yankton, Brookings, and Redwood Falls highlighted by white boxes in both maps (image not shown), and we asked the respondents to identify the city with the highest potential for greater than 2" of snow. Second, we again displayed **Figure 18**, this time with only one white box highlighting Vermillion in both maps (image not shown), and we asked the respondents what they thought the potential was of greater than 1" of snow at Vermillion.

Figure 25a displays the results of the first question. The vast majority (91%) of partners correctly identified Redwood Falls as the city with the greatest potential for >2" of snow. The most common incorrect answer was Brookings, which is also in the red-shaded portion of the >2" snow potential map, and is closer to the center of the image. Very few partners (<1%) said they did not know how to answer. There were no significant differences among job roles, either in terms of the distribution of response or in the proportion of respondents who answered the question correctly.

When asked to interpret the graphic and determine the probability of a snowfall amount not indicated on the map, however, more partners reached incorrect conclusions (**Figure 25b**). Less than half of respondents (48%) were able to correctly identify the potential for 1 inch of snow in Vermillion as some percentage that is greater than 48%. Substantial proportions of respondents provided incorrect interpretations, with 28% thinking the 1-inch potential was 48%, and 18% thinking the potential would be less than 48%. Additionally, 4% of respondents indicated that they did not know how to answer the question. These results suggest that deducing information from the maps proved to be a more challenging task than directly interpreting information on the map. This highlights the need to identify key snowfall thresholds and provide probabilities for those thresholds directly when communicating with partners.

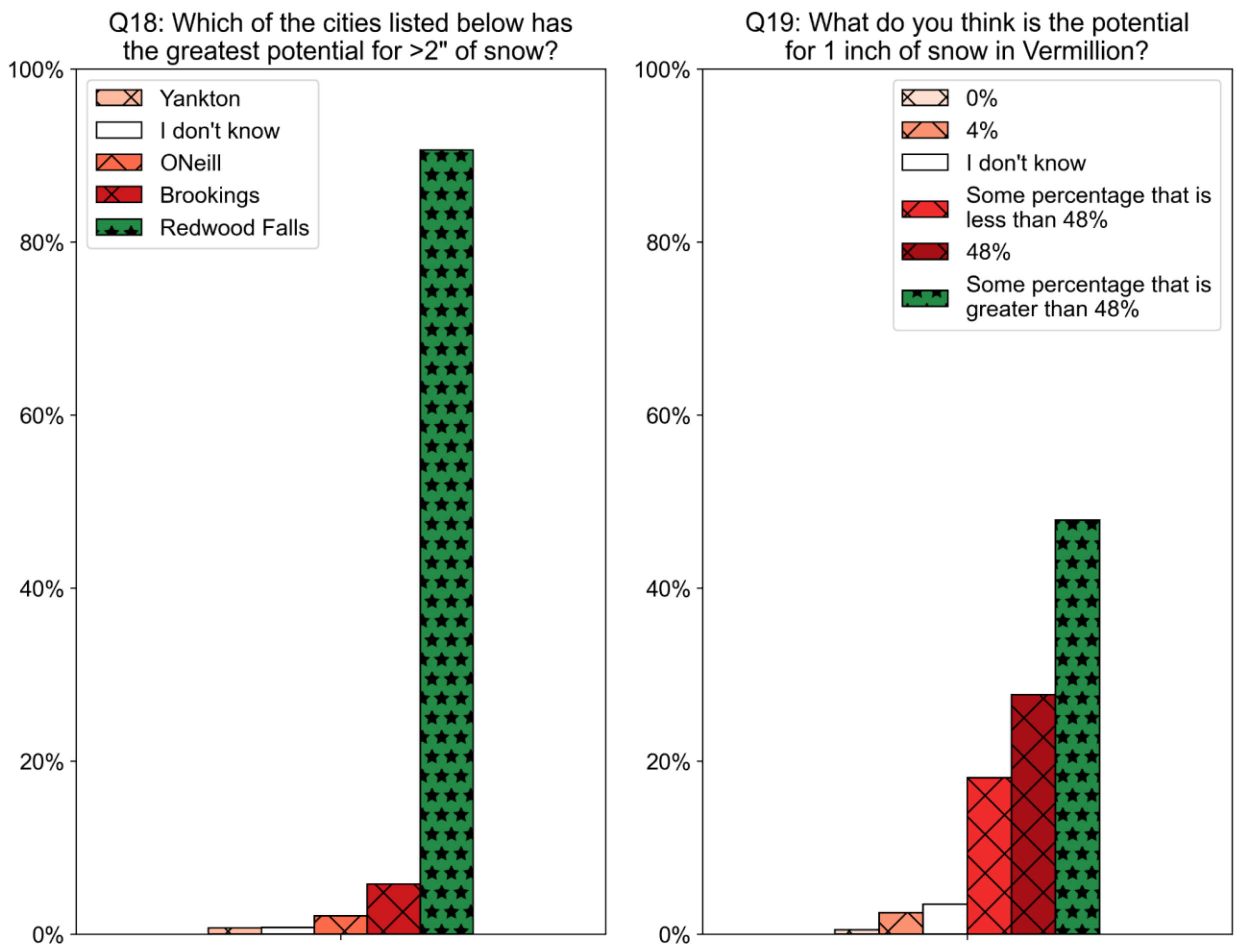

Figure 25. Percentage of respondents (a) who answered which city has the greatest potential for >2" of snow and (b) who answered what the probability was of the potential for 1" of snow in Vermillion. In each plot, the correct answer is denoted in green and hatched with stars as the correct answer, the incorrect answers are denoted in shades of red and cross-hatched to denote incorrect answers, and the white bar denotes respondents who said they didn't know how to answer.

d. Preferences for exceedance graphic visualization

Finally, we provided two different ways of visualizing the probability of exceeding 4 inches of snow or more in Wisconsin (**Figure 26**). One visualization uses a monochromatic scheme, with different shades of blue representing 10% increments where darker (more saturated) colors represent higher probabilities. The other visualization uses a spectral, multi-color scheme, with yellow, orange, and red colors representing different probability ranges (low: 10-40%, medium: 40-70%, and high: >70%, respectively). The two visualizations were presented side-by-side, and partners were asked which they preferred.

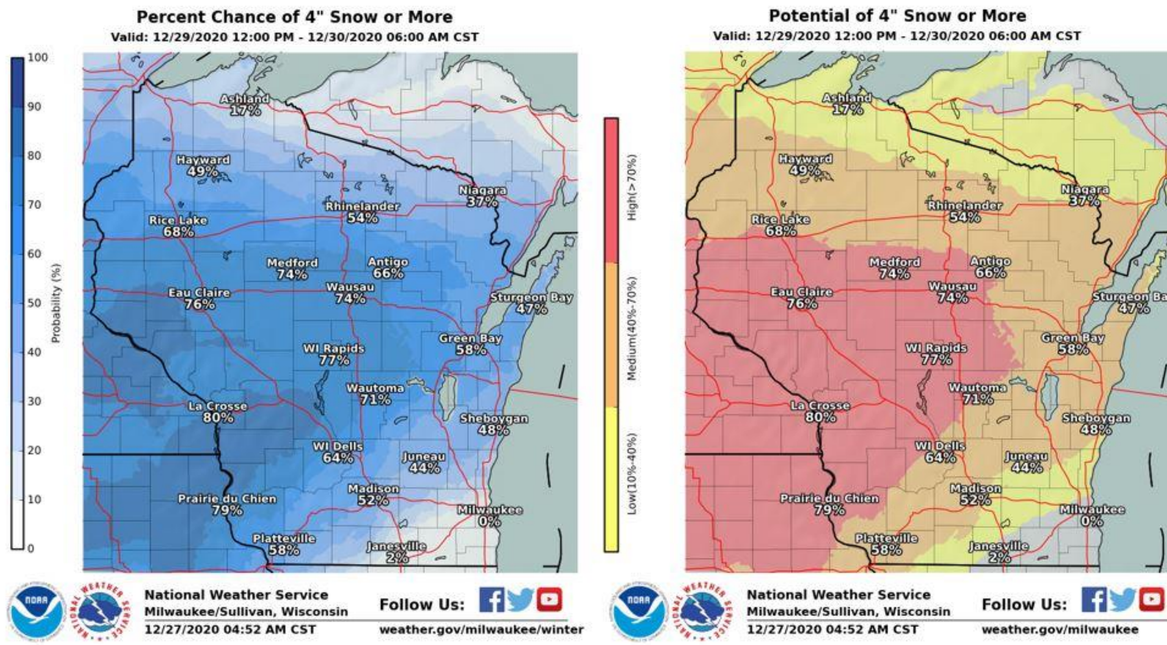

Figure 26. The potential for >4” of snow over Wisconsin, visualized using two color schemes which were presented together to the partners.

Overall, the partners did not express a sweeping preference for one color scheme over the other, with 56% of respondents preferring the red/orange/yellow color scheme and 44% preferring the blue color scheme (**Figure 27**). This pattern was consistent across job roles. However, it is unclear whether the partners’ preferences for the multi-color scheme are due to the colors used or that the probabilities are grouped into three 30-percent bins versus the ten 10-percent bins used in the blue scheme. Thus, more research with partners is needed to understand which visual factors drive partners’ preferences

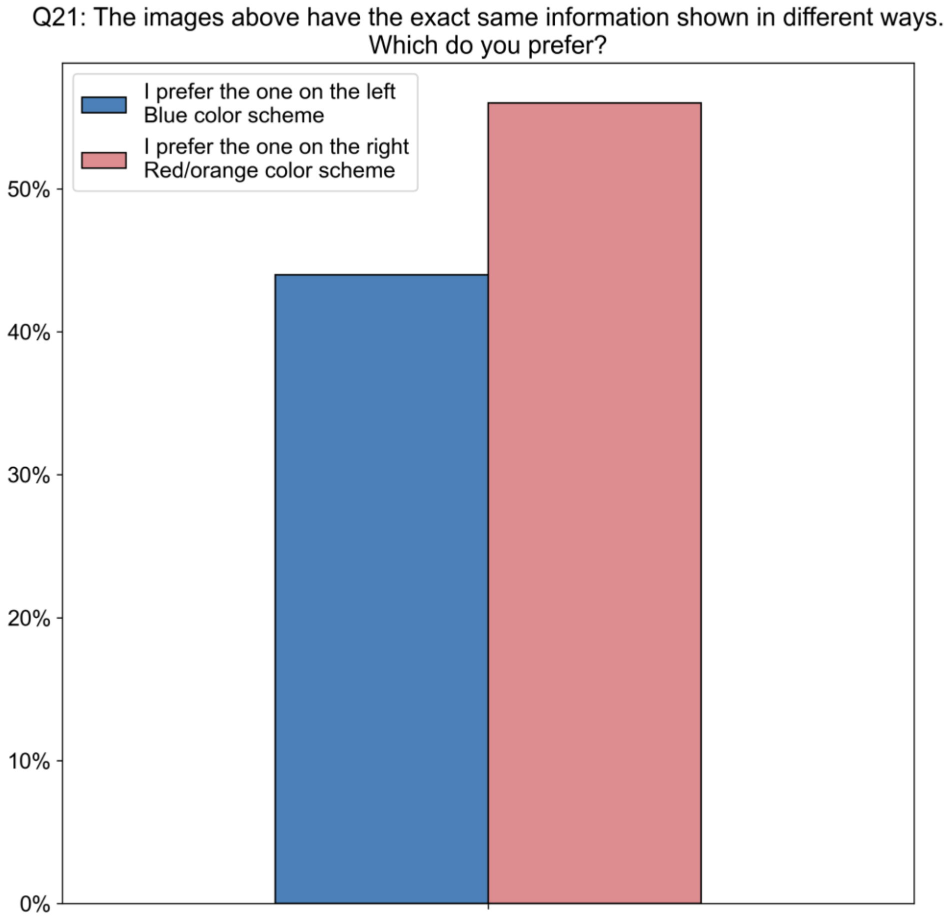

Figure 27. Partner preferences for probability of snowfall information visualized using a blue color scheme (left) or a red-orange-yellow color scheme (right).

6. Results: Preferences and Uses Regarding Snowfall Range Graphics

This section reports on partners' preferences and uses regarding snowfall range forecasts, as shown in **Figure 28**. Two important features of the snowfall ranges shown in this figure are that they are (a) dynamically generated using the 25th-75th percentiles from the Probability of Winter Precipitation Forecast (PWPF) process used by NWS offices and (b) for this particular event, the ensemble-derived forecast yielded large ranges for some areas, such as the 3-10" range for Marshalltown. We displayed **Figure 28**, told partners to imagine that it is Thursday and that this is the forecast for today and tonight, so they would consider impacts and decisions associated with a weekday.

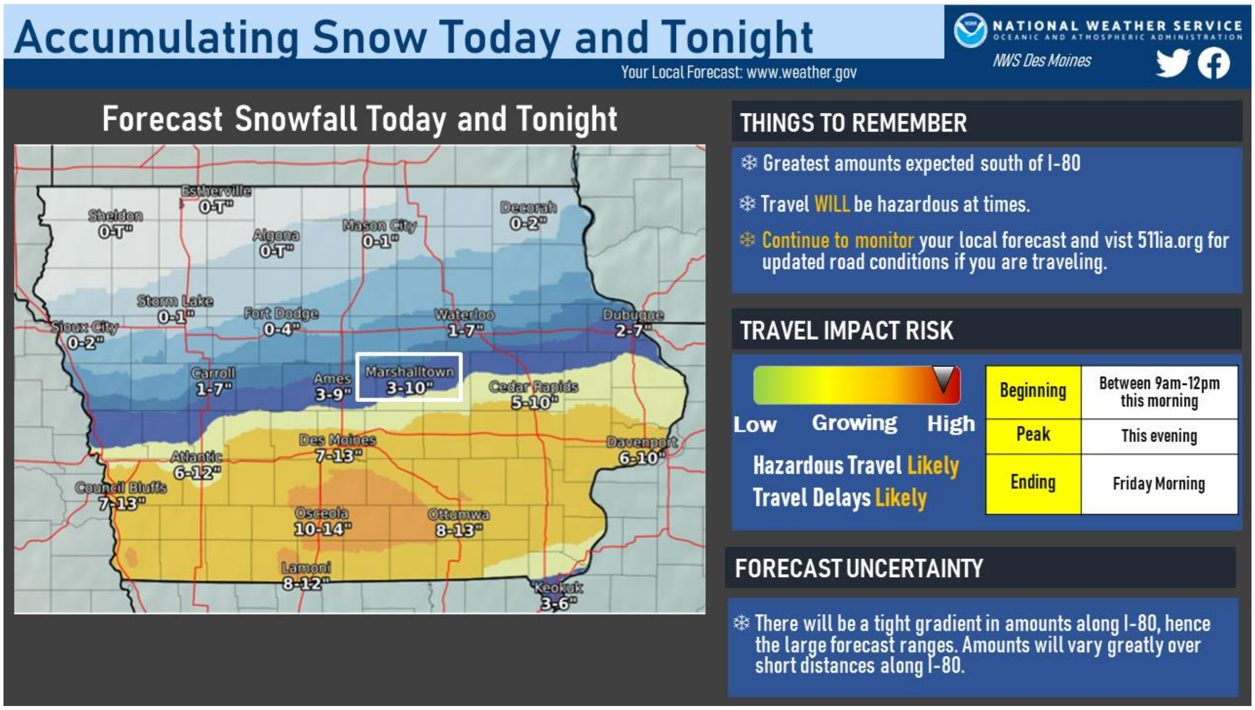

Figure 28. Experimental NWS snowfall range graphic shown to respondents before asking questions about it. All questions about the graphic pertained to Marshalltown, which we highlighted with a white box to minimize the burden of respondents having to find it on the map, so they could instead focus on the forecast information presented.

a. Responses based on the information in the graphic

For the first question, we told respondents to imagine that they work (in their current job role) in Marshalltown, and we asked them how likely they would be to do each of four different actions (**Figure 29**). The vast majority of respondents indicated they are very or extremely likely to monitor the NWS for updated information (92%) or prepare for the storm (82%). Only 21% of respondents indicated they are very or extremely likely to contact their local NWS office to talk with someone about the storm. Twenty-eight percent of respondents indicated they are very or extremely likely to seek a forecast from someone other than NWS who could give more certain information, but 43% indicated they were not at all or not very likely to do this.

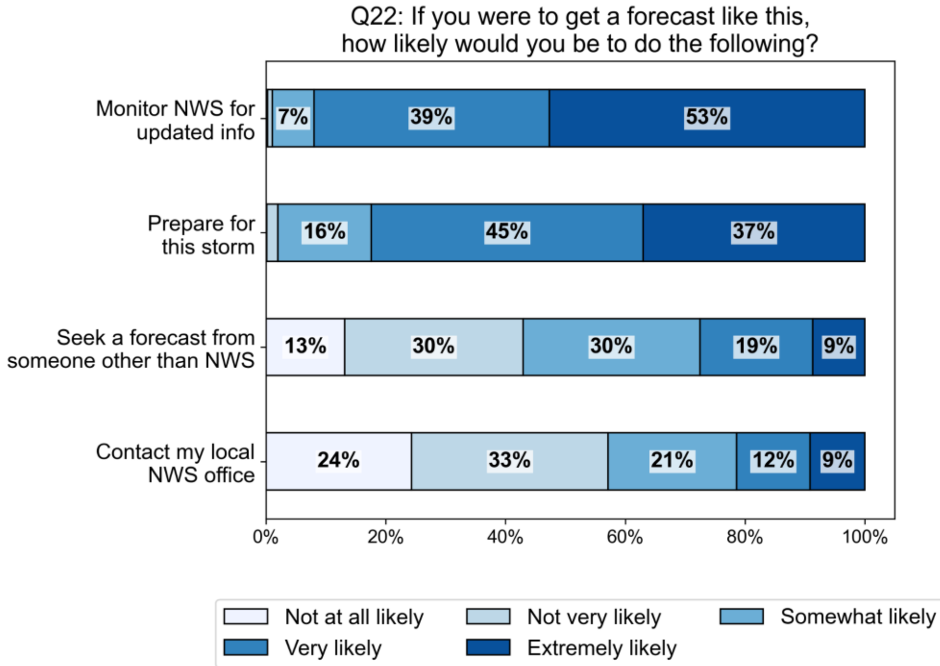

Figure 29. Distributions of responses of how likely respondents would be to do different activities after seeing Figure 28.

The analysis of responses by job roles is shown in **Figure 30**. There are only a few meaningful and statistically significant differences. More transportation officials indicated they are very or extremely likely to prepare for the storm (93%) than school officials (83%) or emergency managers (80%) (**Figure 30a**). More transportation officials (43%) and school officials (36%) were very or extremely likely to seek a forecast from someone other than NWS compared to emergency managers (20%) (**Figure 30b**). And, more emergency managers were very or extremely likely to contact their local NWS office (29%) than school or transportation officials. There are no significant differences by job role in likelihood of monitoring the NWS for additional information.

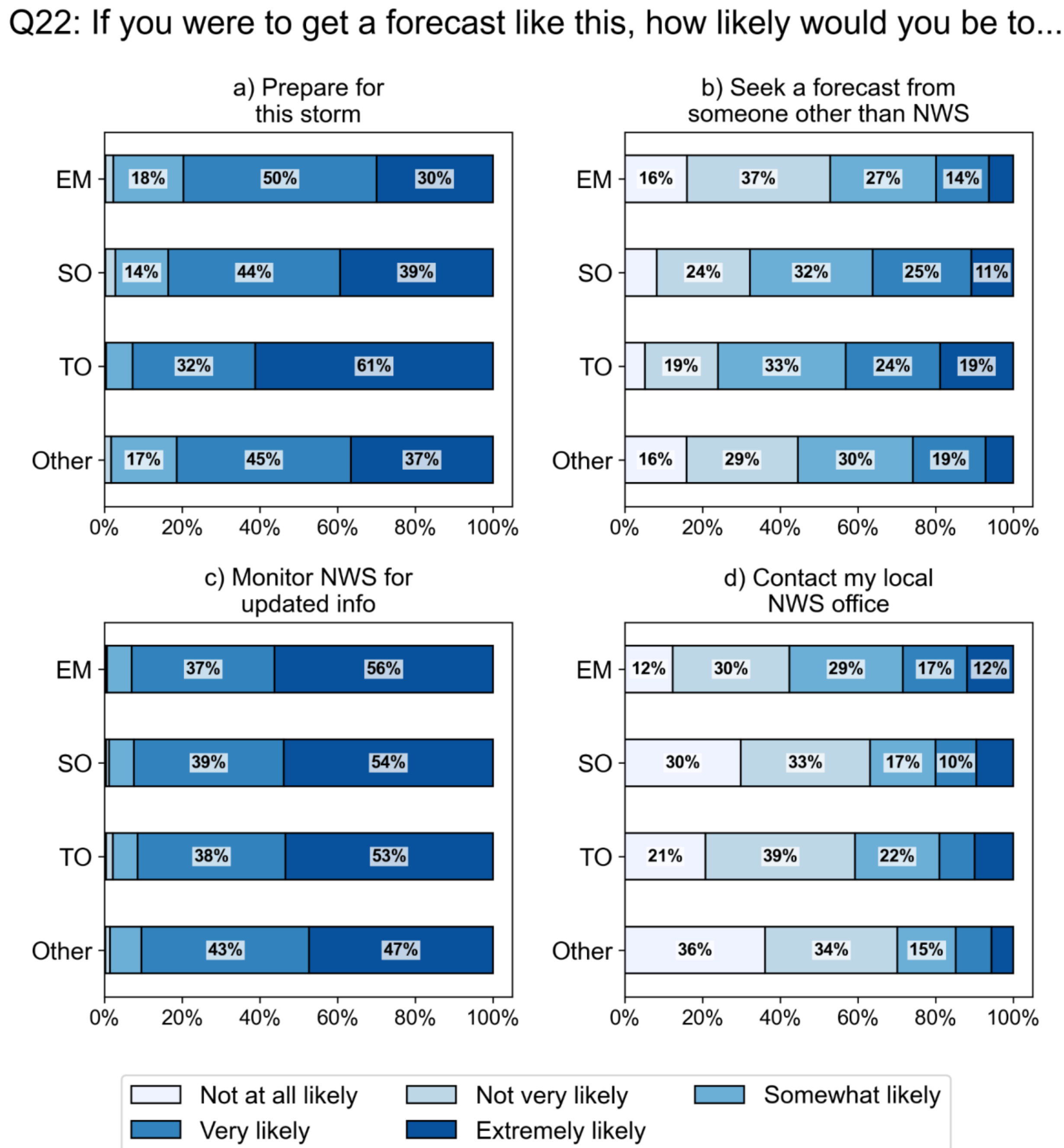

Figure 30. Distributions of responses for how likely respondents would be to a) prepare for the storm, b) seek information from someone other than NWS for more certain information, c) monitor the NWS for updated information, and d) contact the local NWS office to talk about the storm, for each job role.

Respondents who indicated they were somewhat, very, or extremely likely to prepare for the storm (n=2453) were given a follow-up question in which they were asked to select whether or not different pieces of information were helpful for preparation purposes. Results, shown in **Figure 31a**, indicate that the snowfall ranges were helpful to the most respondents (82%), followed by the text boxes on the side of the graphic (64%), the colors on the map (57%), and the upper bound of the snowfall ranges (57%). A minority of respondents indicated that the lower bound of the snowfall ranges was helpful (30%). The only significant difference in response by job role is that a greater percentage of transportation officials indicated that the *lower bound of the snowfall ranges* was helpful to them as compared to the other job roles (**Figure 31b**).

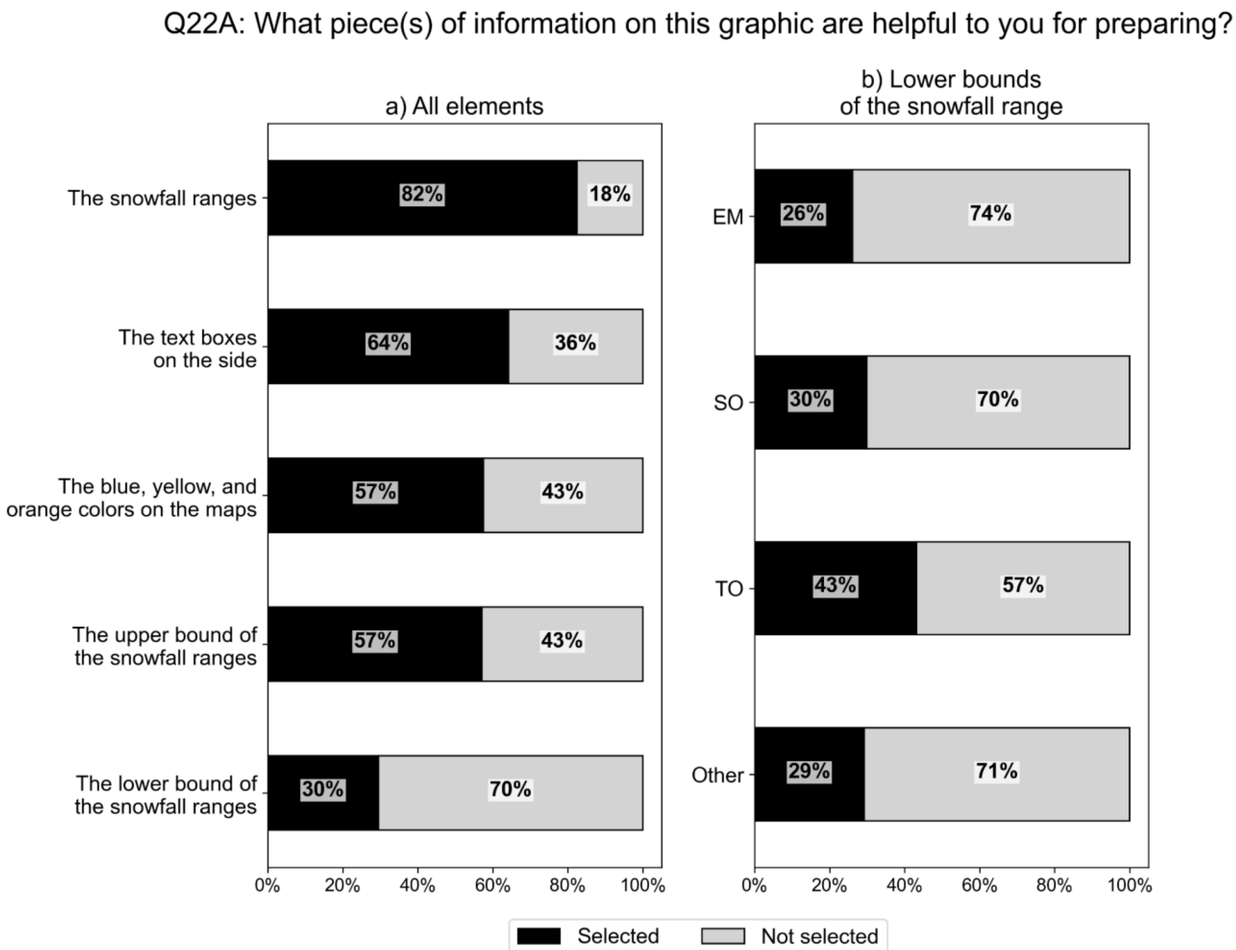

Figure 31. (a) Pieces of information on the snowfall range graphic that were and were not selected as being helpful to respondents for preparing for the storm, and (b) percentages by job role that indicated the lower bound of the snowfall ranges was helpful.

b. Usefulness and use of the information in the graphic

Next, we told partners to again imagine they work (in their current job role) in Marshalltown, and we asked how useful this forecast of 3-10 inches would be to them. Results by job role are shown in **Figure 32**. A majority of respondents in each job category (55-66%) indicated the snowfall range forecast was very or extremely useful, and another 33-38% indicated it was somewhat useful, whereas only 1-8% indicated it was not very or not at all useful. Transportation officials were significantly more likely than each of the other job groups to indicate the forecast was more useful.

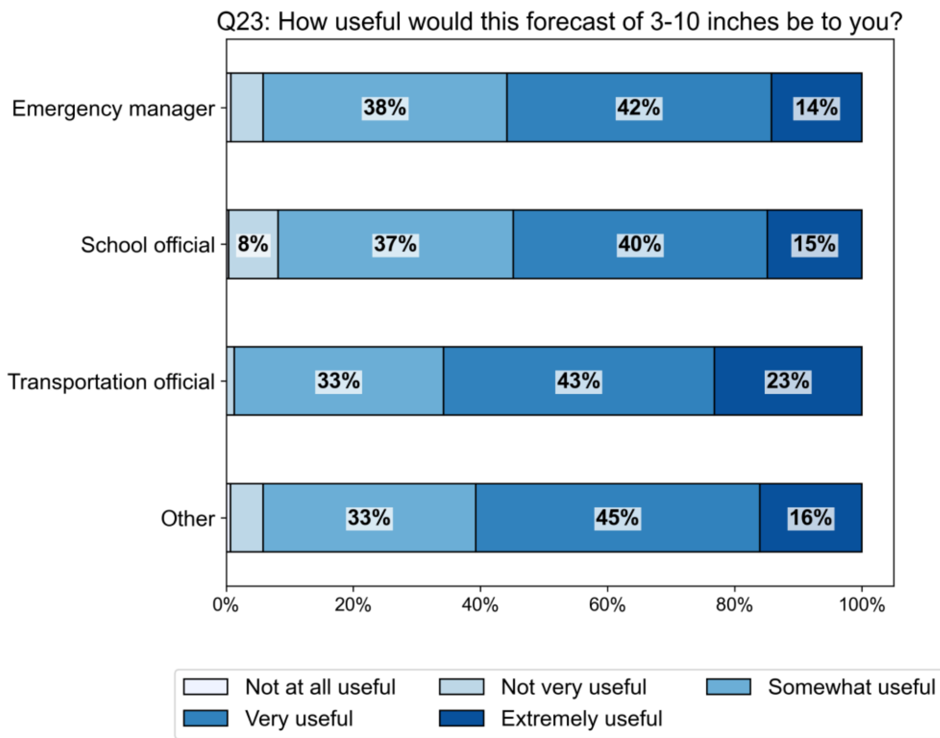

Figure 32. Distribution of reported usefulness of the Marshalltown forecast of 3-10 inches by job role.

Again, we told partners to imagine they work (in their current job role) in Marshalltown, and we asked what amount of snow they would prepare for. Results by job role are shown in **Figure 33**. A majority of respondents in each job category indicated they would prepare for the mid-point amount of 6-7 inches. That said, a significantly greater percentage of school officials selected the mid-point amount (74%) than each of the other job groups (59% of emergency managers, 54% of transportation officials, and 61% of the "Other" category). On the other hand, 33% of emergency managers, 35% of transportation officials, and 28% of the other category indicated they would prepare for the high-end amount, whereas only 11% of school officials indicated this.

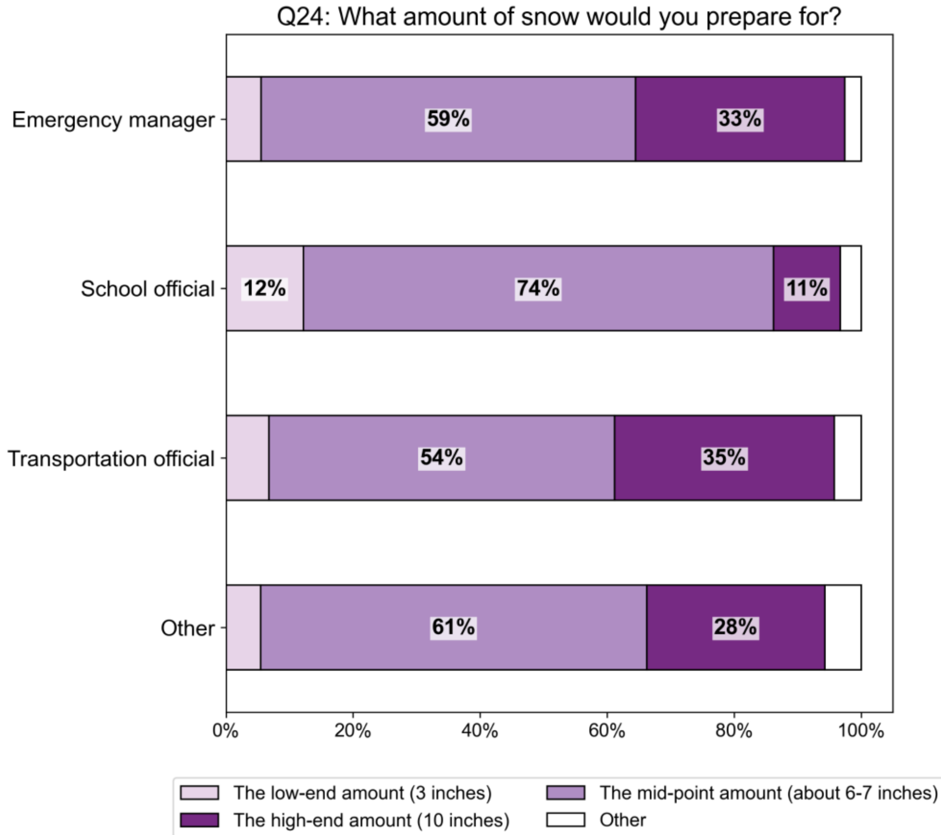

Figure 33. Distribution of the amount of snow respondents would prepare for given the Marshalltown forecast of 3-10 inches for, by job role.

Lastly, we asked partners which scenario would cause the most problems for their work operations. The response options were a 3-10" snow forecast in which the actual snow amount is within that range, a 3-5" snow forecast but the actual snow amount is 10 or more inches, or a 6-10" snow forecast but the actual snow amount is 3 inches or less. Results by job role are shown in **Figure 34**. The vast majority of respondents in each job category indicated that a 3-5" forecast with higher actual amounts would be most problematic (64-81%). However, compared to the other groups, a significantly larger percentage of school officials (23%) indicated that a 6-10" forecast with actual amounts of 3 inches or less would be most problematic. This may be because they would have canceled school or school-related activities without needing to; such cancellations directly and substantially affect a lot of people, and if they are deemed unnecessary by parents, school officials are likely to receive negative feedback about their decision-making.

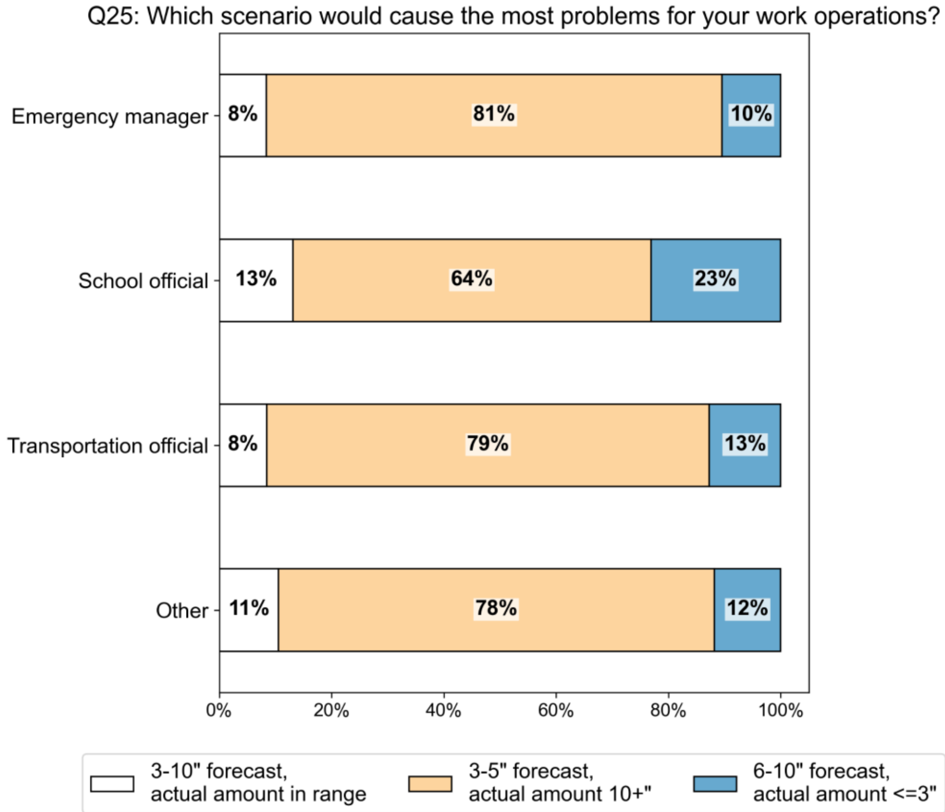

Figure 34. Distribution of responses about which forecast and resultant snowfall scenario would cause the most problems for work operations, by job role.

Taken together, *the set of results about the snowfall range forecast reveals that the 3-10" snowfall forecast is considered useful to the vast majority of partners, which challenges thinking that such large snowfall range forecasts are not useful*. This is true even for transportation officials and school officials who, on average, reported being more likely to seek a forecast from someone other than the NWS if they received a forecast like this (**Figure 30b**). Over 50% of both groups indicated that the larger range was very or extremely useful. Most partners indicated they would use this forecast to prepare for the storm, and although most would prepare for the mid-point snowfall amount of 6-7", approximately one-third of emergency managers and transportation officials would prepare for the high-end amount of 10", presumably because *the possibility of greater snowfall amounts affects these partners' decision-making in important ways, and they do not want to be caught behind*. This is further supported by these partners being more likely to indicate that a 3-5" forecast with actual snowfall of 10" or more is the most problematic scenario for them. Additionally, transportation officials were significantly more likely than the other partner groups to indicate that they would use the lower bound of the snowfall estimate, suggesting that they find the full snowfall range to be useful.

7. Results: Preferences for Probabilistic Snowfall Timing Graphics

The final section of the survey included a few questions that asked about partners' thoughts about the usefulness of probabilistic snowfall timing information. We displayed **Figure 35**, which was derived from the mean time when one inch of snow would accumulate based upon experimental output from the High-Resolution Rapid Refresh Ensemble (HRRR-E)[3]. We told partners to imagine that it is Wednesday and that this is the forecast for tomorrow morning, again so they would consider impacts and decisions associated with a weekday.

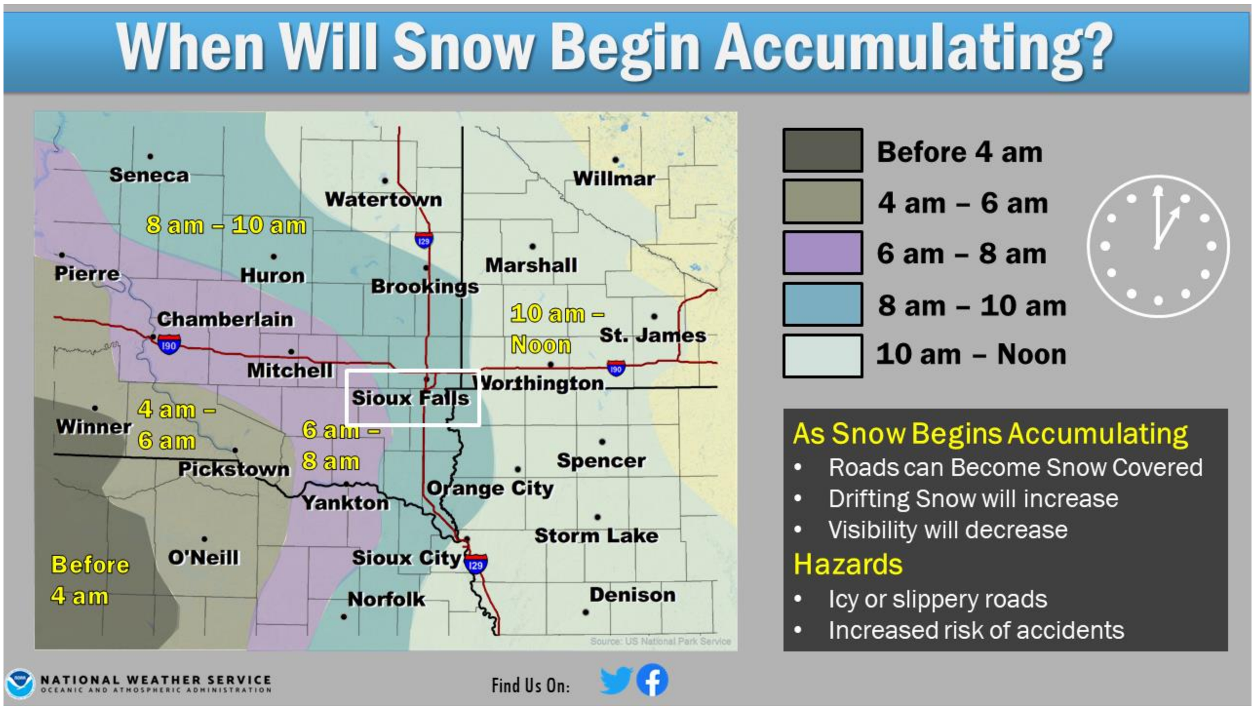

Figure 35. Experimental NWS graphic shown to respondents that displays ranges of times that snow is forecast to begin accumulating. All questions about the graphic pertained to Sioux Falls, which we highlighted with a white box to minimize the burden of respondents having to find it on the map, so they could instead focus on the forecast information presented.

For the first question, we told respondents to imagine that they work (in their current job role) in Sioux Falls and then asked how useful a forecast like this would be to them (**Figure 36**). Between 70-76% of respondents indicated the probabilistic snowfall timing forecast was very or extremely useful, and another 19-23% indicated it was somewhat useful, whereas only 4-8% indicated it was not very or not at all useful. There were no significant differences in perceived usefulness by job role.

[3] This experimental probabilistic timing guidance was developed as part of the NOAA JTTI grant led by NCAR and was made available for evaluation to several CR WFOs.

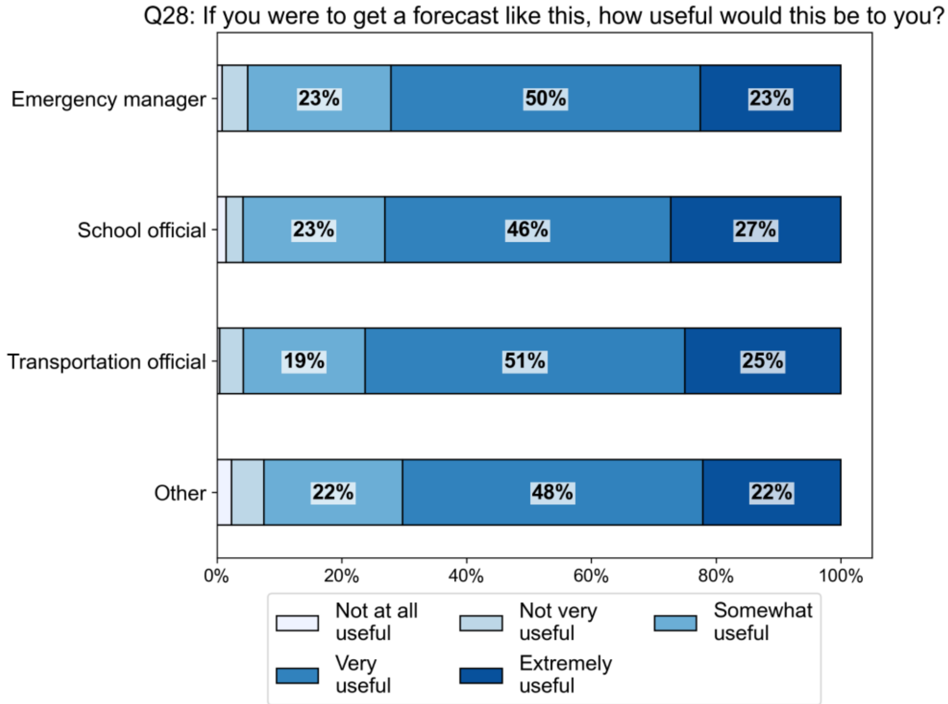

Figure 36. Distributions of reported usefulness of the probabilistic snowfall timing forecast in Figure 35.

Next, we told respondents to imagine the forecast shown in **Figure 35** is when forecasters think the snow is most likely to begin accumulating. Then, we asked how useful it would be to them to know both the earliest (**Figure 37a**) and the latest (**Figure 37b**) that snow might begin accumulating. For the earliest snowfall time, between 80-87% of respondents indicated it would be very or extremely useful, and another 12-17% said it would be somewhat useful. Moreover, school officials and transportation officials were significantly more likely than emergency managers to say the earliest snowfall time would be useful. For the latest snowfall time, 54-63% said it would be very or extremely useful, and another 29-37% said it would be somewhat useful. School officials were significantly more likely than emergency managers to say the latest snowfall time would be useful.

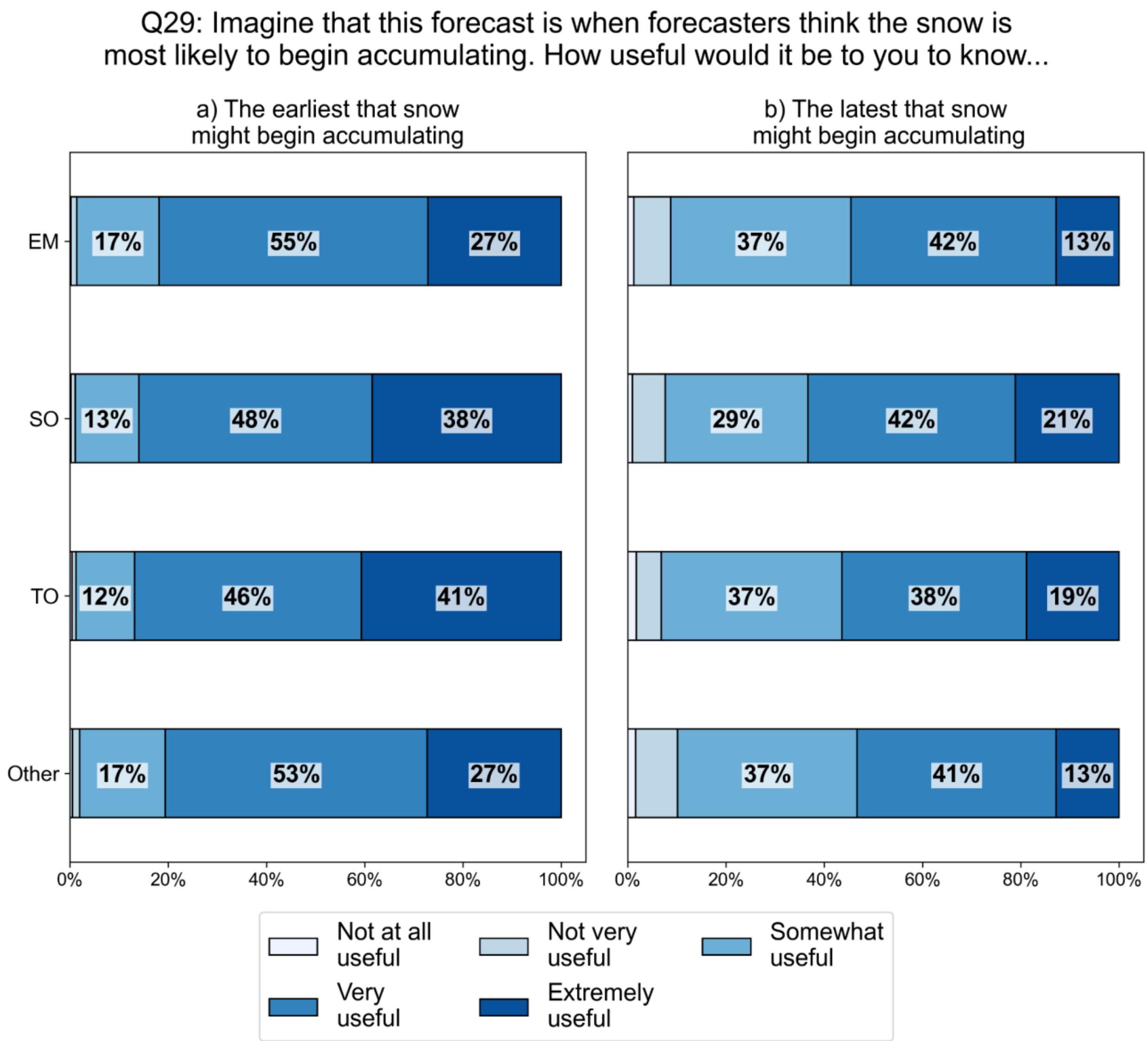

Figure 37. Distributions of reported usefulness of the (a) earliest and (b) latest that snowfall might begin accumulating.

Lastly, we asked respondents how useful it would be to get similar types of forecasts showing when snow accumulation will end (**Figure 38**). Between 48-60% of respondents said such information would be very or extremely useful, and another 34-43% said it would be somewhat useful. Moreover, school officials and transportation officials were significantly more likely than emergency managers and the "Other" job category to say forecasts of the end-time of snow accumulation would be useful.

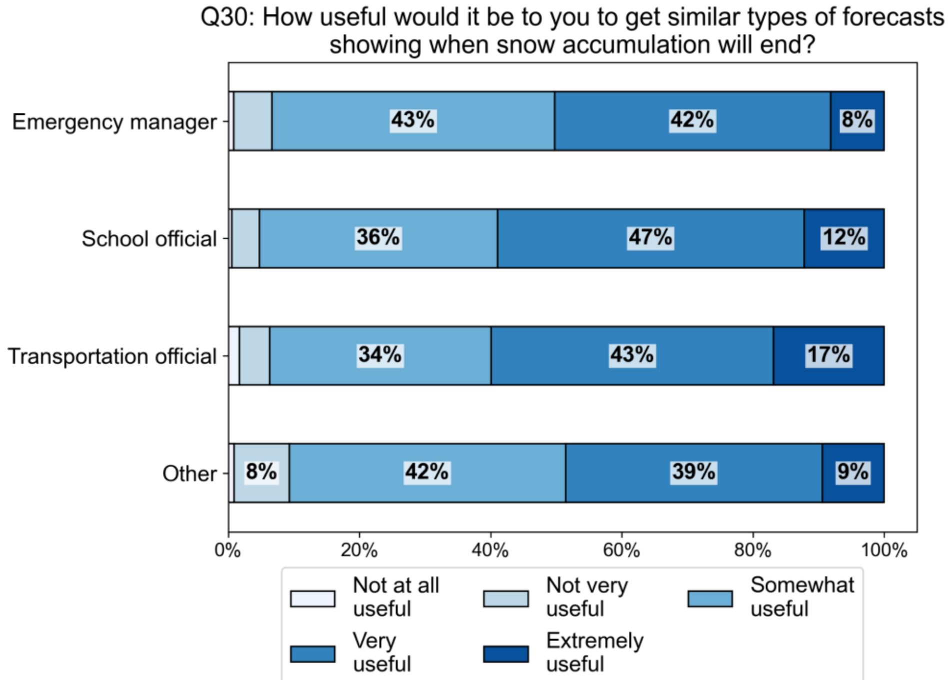

Figure 38. Distributions of reported usefulness of probabilistic forecast of when snow accumulation will end.

Taken together, the set of results about probabilistic snowfall timing forecast information reveals that having information about when snow accumulation will begin and end is tremendously useful to partners. Overall, the earliest time that snow accumulation could start is deemed most useful, but the most likely and latest start-times as well as similar forecasts of the end-time of snowfall accumulation are all considered highly useful by all partners. School officials and transportation officials tend to deem the forecasts of snowfall timing as more useful than their emergency manager and "Other" job category counterparts, presumably because the key job decisions they make are particularly sensitive to timing (e.g., school delays and closures, road plowing and treatment).

8. Future Plans

Findings from this survey are expected to play a pivotal role in shaping the direction of future NWS probabilistic winter weather products, services, and messaging. Over the coming months, the CR Probabilistic Messaging Testbed will review this report and develop best practices for distribution to CR WFOs as soon as the winter of 2023-2024.

Although this report primarily focused on three core partner groups—emergency managers, transportation officials, and school officials—nearly one-third of the n=2503 respondents self-identified into the "Other" category, which consists of media, healthcare officials, law enforcement, and others. Planned future analyses will involve categorizing respondents in this "Other" category and conducting refined analysis to determine the preferences, uses, and understanding of probabilistic winter information of these distinctly different partner groups. In addition, we will conduct spatial analyses, including comparing different climatological regions within the Central Region. Moreover, WFOs will be given access to the supplemental data dashboard that includes the results presented in this report so that plots can be generated at more local levels based on users' interests. Finally, OMB approval was granted for three years. Therefore, the survey may be fielded multiple times to determine changes in partner response over time.

Acknowledgements

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We want to express our tremendous gratitude to many people who supported and contributed to this effort. At CRH, we thank Bruce Smith, Randall Graham, Michael Hudson, and Alexandra Kelly. We thank the CR Northern Plains WCMs, including John Martin, Gregory Gust, and Susan Sanders, and CR Probabilistic Messaging Testbed members, including Michael Fowle, John Gagan, Andrew Just, Paul Nutter, and Jerry Weidenfeld. At NWSHQ, we thank Vankita Brown, Jen Sprague-Hilderbrand, and Valerie Were for their assistance with OMB. At all CR WFOs, we thank the WCMs and other points-of-contact who disseminated the survey to their partners. Last but not least, we thank all of the partners who contributed their time and thoughts in responding to this survey.

References

Budescu, D., H-H. Por, S. Broomell, and M. Smithson, 2014: The interpretation of IPCC probabilistic statements around the world. *Nature Climate Change* 4, 508–512. https://doi.org/10.1038/nclimate2194

National Research Council, 2006: *Completing the Forecast: Characterizing and Communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts*. National Academies Press, 112 pp.

NOAA (National Oceanic and Atmospheric Administration) Science Advisory Board, 2021: *A Report on Priorities for Weather Research.* https://sab.noaa.gov/wp-content/uploads/2021/12/PWR-Report_Final_12-9-21.pdf

Wallsten, T. S., D. V. Budescu, A. Rapoport, R. Zwick, & B. Forsyth, 1986: Measuring the vague meanings of probability terms. *Journal of Experimental Psychology: General*, *115*(4), 348-365.

Appendix: Full Survey Instrument

This survey is being conducted by the National Weather Service (NWS) and the National Center for Atmospheric Research (NCAR). We are reaching out to you because you are a core partner and key user of forecasts from the NWS.

We are conducting this survey to evaluate your thoughts and opinions about winter weather forecasts that NWS provides, including new types of winter forecast information. Your responses will guide what types of winter forecasts we provide in the future. Therefore, your responses are very important because they will have direct impacts on the forecast and decision support services that NWS provides to you.

The survey takes about 15 minutes to complete.

Your participation in this survey is completely voluntary, and you are free to stop at any time. Your individual responses will be anonymous, and your answers will be analyzed and reported in aggregate or in ways that you cannot be identified. Send comments regarding this burden estimate or any other aspect of this information collection, including suggestions for reducing this burden to Peter Rogers at peter.rogers [at] noaa.gov or Julie Demuth at jdemuth [at] ucar.edu. You also may contact the UCAR/NCAR Human Subjects Committee chair, Glen Romine, at romine [at] ucar.edu if you have any questions about your rights as a participant or if you are dissatisfied with any aspects of this study.

A Federal agency may not conduct or sponsor, and a person is not required to respond to, nor shall a person be subject to a penalty for failure to comply with an information collection subject to the requirements of the Paperwork Reduction Act of 1995 unless the information collection has a currently valid OMB Control Number. The approved OMB Control Number for this information collection is 0648-0801. Without this approval, we could not conduct this survey. By clicking "Start", you agree to participate.

1. Please indicate what job position you hold.
   ○ Emergency manager
   ○ School official
   ○ Transportation official
   ○ Other (please specify)

   If "emergency manager" is selected, pipe to Qa

   Qa. You indicated that you're an emergency manager. Please indicate what jurisdiction you serve in this role.
   ○ Local (city or county) emergency manager
   ○ State emergency manager
   ○ Tribal emergency manager
   ○ Federal or regional emergency manager
   ○ College / university emergency manager
   ○ Other (please specify)

   If "school official" is selected, pipe to Qb

   Qb. You indicated that you're a school official. Please indicate what role you serve.
   ○ School principal
   ○ School superintendent
   ○ School transportation director
   ○ School maintenance official
   ○ Other (please specify)

If "transportation official" is selected, pipe to 1c

Qc. You indicated that you're a transportation official. Please indicate what jurisdiction you serve in this role.

○ City transportation official
○ Regional transportation official
○ State transportation official
○ Other (please specify)

2. How many years have you worked in this line of work? *Please round to the nearest year.* (open-ended, force numeric whole number)

3. What are the main ways that you get forecasts from the National Weather Service (NWS) when there is a chance of winter weather? *Select all that apply.*
   - ☐ NWS website
   - ☐ Emailed weather updates from NWS (e.g., situation report, decision support packet)
   - ☐ NWS Twitter account
   - ☐ NWS Facebook page
   - ☐ Other (please specify)

4. What are the main ways that you get forecasts from non-NWS sources when there is a chance of winter weather? *Select all that apply.*
   - ☐ I don't use non-NWS sources of forecast information
   - ☐ TV meteorologists
   - ☐ Paid subscription to a private sector meteorologist
   - ☐ Weather apps on my cell phone
   - ☐ Radio
   - ☐ Newspaper
   - ☐ Social media
   - ☐ Other (please specify)

Imagine that it's mid-January, and there is a forecast for a possible high-impact winter storm to occur on a Wednesday for the area where you work.

Pipe Q1 response here and branch this Q accordingly by partner.

{For EMs}

5. At each of the lead-times listed below, how certain do forecasters need to be that there could be a high-impact winter storm in the area where you work for you to start stockpiling and/or prepositioning materials? (response options: 0% chance, at least a 10% chance, at least a 30% chance, at least a 50% chance, at least an 80% chance)
   a. < 24 hours before the snow begins
   b. 24-48 hours before the snow begins
   c. 48-72 hours before the snow begins
   d. > 72 hours before the snow begins

6. At each of the lead-times listed below, how certain do forecasters need to be that there could be a high-impact winter storm in the area where you work for you to start planning for opening shelters or warming stations? (response options: 0% chance, at least a 10%

chance, at least a 30% chance, at least a 50% chance, at least an 80% chance)

a. < 24 hours before the snow begins
b. 24-48 hours before the snow begins
c. 48-72 hours before the snow begins
d. > 72 hours before the snow begins

6½. At each of the lead-times listed below, how certain do forecasters need to be that there could be a high-impact winter storm in the area where you work for you to start communicating about possible city, county, or state government closures or delays? (response options: 0% chance, at least a 10% chance, at least a 30% chance, at least a 50% chance, at least an 80% chance)

a. < 24 hours before the snow begins
b. 24-48 hours before the snow begins
c. 48-72 hours before the snow begins
d. > 72 hours before the snow begins

GO TO Q8

{For school officials}

5. At each of the lead-times listed below, how certain do forecasters need to be that there could be a high-impact winter storm in the area where you work for you to start planning for school closures or delays? (response options: 0% chance, at least a 10% chance, at least a 30% chance, at least a 50% chance, at least an 80% chance)

a. < 24 hours before the snow begins
b. 24-48 hours before the snow begins
c. 48-72 hours before the snow begins
d. > 72 hours before the snow begins

6. At each of the lead-times listed below, how certain do forecasters need to be that there could be a high-impact winter storm in the area where you work for you to start planning for cancelling extracurricular school activities? (response options: 0% chance, at least a 10% chance, at least a 30% chance, at least a 50% chance, at least an 80% chance)

a. < 24 hours before the snow begins
b. 24-48 hours before the snow begins
c. 48-72 hours before the snow begins
d. > 72 hours before the snow begins

GO TO Q8

{For transportation officials}

5. At each of the lead-times listed below, how certain do forecasters need to be that there could be a high-impact winter storm in the area where you work for you to start planning for road treatment and/or plowing? (response options: 0% chance, at least a 10% chance, at least a 30% chance, at least a 50% chance, at least an 80% chance)

a. < 24 hours before the snow begins
b. 24-48 hours before the snow begins
c. 48-72 hours before the snow begins
d. > 72 hours before the snow begins

6. At each of the lead-times listed below, how certain do forecasters need to be that there could be a high-impact winter storm in the area where you work for you to start securing extra staff, resources, and materials (e.g., snowplows, treatment)? (response options: 0% chance, at least a 10% chance, at least a 30% chance, at least a 50% chance, at least an 80% chance)

a. < 24 hours before the snow begins

b. 24-48 hours before the snow begins
c. 48-72 hours before the snow begins
d. > 72 hours before the snow begins

GO TO Q8

{For "Other" job category}

5a. What is a critical decision that you might make based on this forecast? (open ended)

5. At each of the lead-times listed below, how certain do forecasters need to be that there could be a high-impact winter storm in the area where you work for you to start making or planning for this critical decision? (response options: 0% chance, at least a 10% chance, at least a 30% chance, at least a 50% chance, at least an 80% chance)
   a. < 24 hours before the snow begins
   b. 24-48 hours before the snow begins
   c. 48-72 hours before the snow begins
   d. > 72 hours before the snow begins

GO TO Q8

7. *[Deleted this question but keeping this to keep numbering same as prior programmed versions]*

8. Different elements of forecast information can be provided when there is a threat of snow. Please rank the forecast elements listed below in order from the most important (top) to the least important (bottom). (randomize order of items)
   - Chance (probability or likelihood) of snow occurring
   - Amount of snow that will fall
   - Timing of when the snow will start and/or end
   - Timing of when the snowfall rate will be heaviest
   - Areas that will get snow

9. How many hours before the snow begins do you need forecasts of these elements in order to make your critical job decisions? (response options: This element isn't important to me, 0-12 hours, 12-24 hours, 24-48 hours, 48-72 hours, >72 hours)
   a. Snowfall amount
   b. Snowfall start time
   c. Snowfall end time
   d. Snowfall rate
   e. Snowfall location

10. Typically, the further in advance of a winter storm, the more uncertainty there is in how much snow will fall. And vice versa, the sooner a winter storm will occur, the more certainty there is in how much snow will fall. Which of the statements below best reflects your preference in this tradeoff?
   ○ More advance notice is more important to me, even if there is more uncertainty
   ○ Greater certainty is more important to me, even if that means I have less advance notice

11. One way that NWS can convey the uncertainty in the amount of snow that could fall during a winter storm is to provide a range of snowfall amounts. Imagine you received a forecast that the potential snowfall for a storm is 2-8 inches. What amount of snow would you prepare for?
   ○ The low-end amount (e.g., 2 inches)
   ○ The mid-point amount (e.g., 5 inches)

○ The high-end amount (e.g., 8 inches)
○ Other (please specify)

12. Typically, wider ranges of forecast snowfall amounts have higher chances that the actual snowfall amount will be within the range. And vice versa, narrower ranges of forecast snowfall amounts have lower chances that the actual snowfall amount will be within the range. For example, NWS could provide a forecast of 2-8 inches of snow, which is a wide range but has a high chance of capturing the actual amount of snow that will fall. Or, NWS could provide a forecast of 3-7 inches, which is a middle range but has a medium chance of capturing the actual amount of snow. Or, NWS could provide a forecast of 4-6 inches, which is a narrow range but has a low chance of capturing the actual amount of snow. In general, which option do you prefer?
    ○ I prefer the forecast with the wide range (2-8 inches) and high chance of capturing the actual amount of snow that will fall
    ○ I prefer the forecast with the middle range (3-7 inches) and medium chance of capturing the actual amount of snow that will fall
    ○ I prefer the forecast with the narrow range (4-6 inches) and low chance of capturing the actual amount of snow that will fall

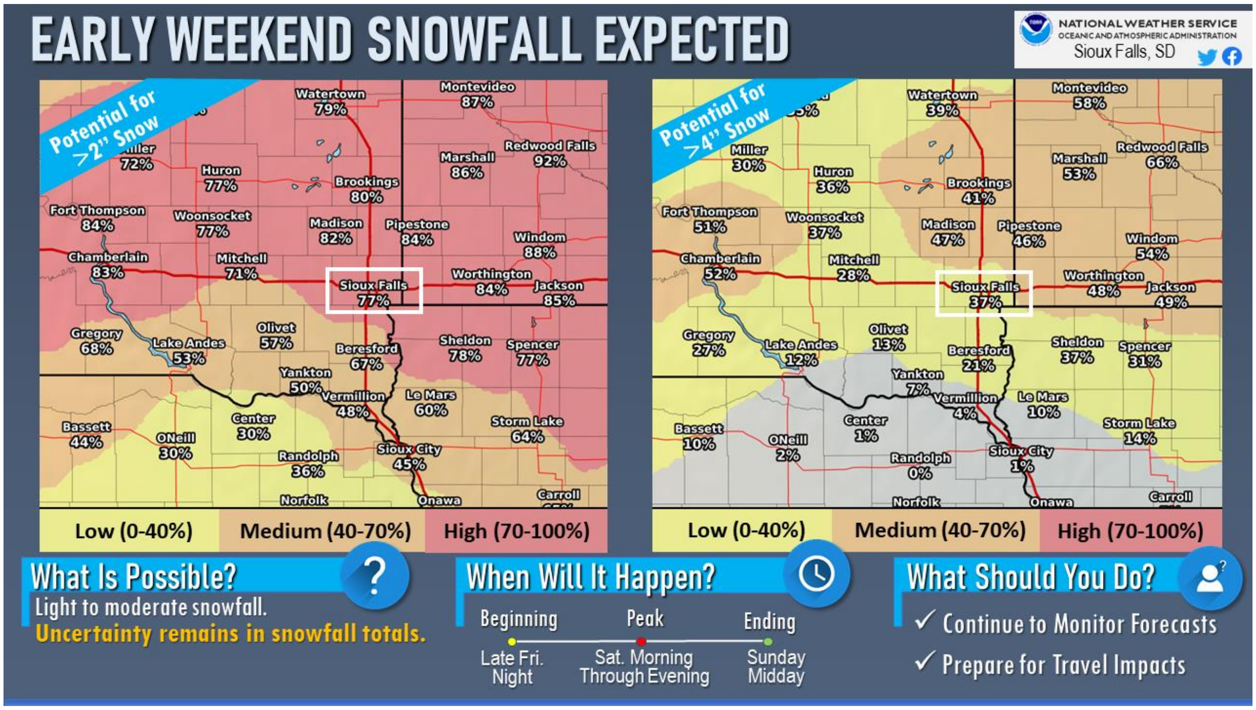
13. NWS also could provide specific information about the percent chance of the different ranges of snowfall amounts. For example, that there's an 80% chance of 2-8 inches, a 50% chance of 3-7 inches, or a 30% chance of 4-6 inches. With this additional information about the percent chance, in general, which option do you prefer?
    ○ I prefer the forecast of an 80% chance of 2-8 inches
    ○ I prefer the forecast of a 50% chance of 3-7 inches
    ○ I prefer the forecast of a 30% chance of 4-6 inches
    ○ I prefer the forecast with the narrow range of 4-6 inches, but I also want to know the possible low-end amount of 2 inches and the high-end amount of 8 inches

14. In general, do you prefer having forecasts of snowfall range with or without the percent chance?
    ○ I prefer the forecast with the percent chance (e.g., 80% chance of 2-8 inches)
    ○ I prefer the forecast without the percent chance (e.g., 2-8 inches)
    ○ I have no preference. I like the forecast both ways.

The NWS is experimenting with different ways of predicting and communicating winter weather forecast information, with a focus on conveying uncertainty in the forecast. NWS is experimenting with this at different lead-times, ranging from forecasts that are issued a few days before a winter storm might begin to the day of.

We will show a few of these experimental forecast products and ask questions about each. There are no right or wrong answers, and your answers will be most helpful if you share what you really think.

Here is the first experimental forecast product. Imagine it's Thursday, and this is the forecast for the coming weekend.



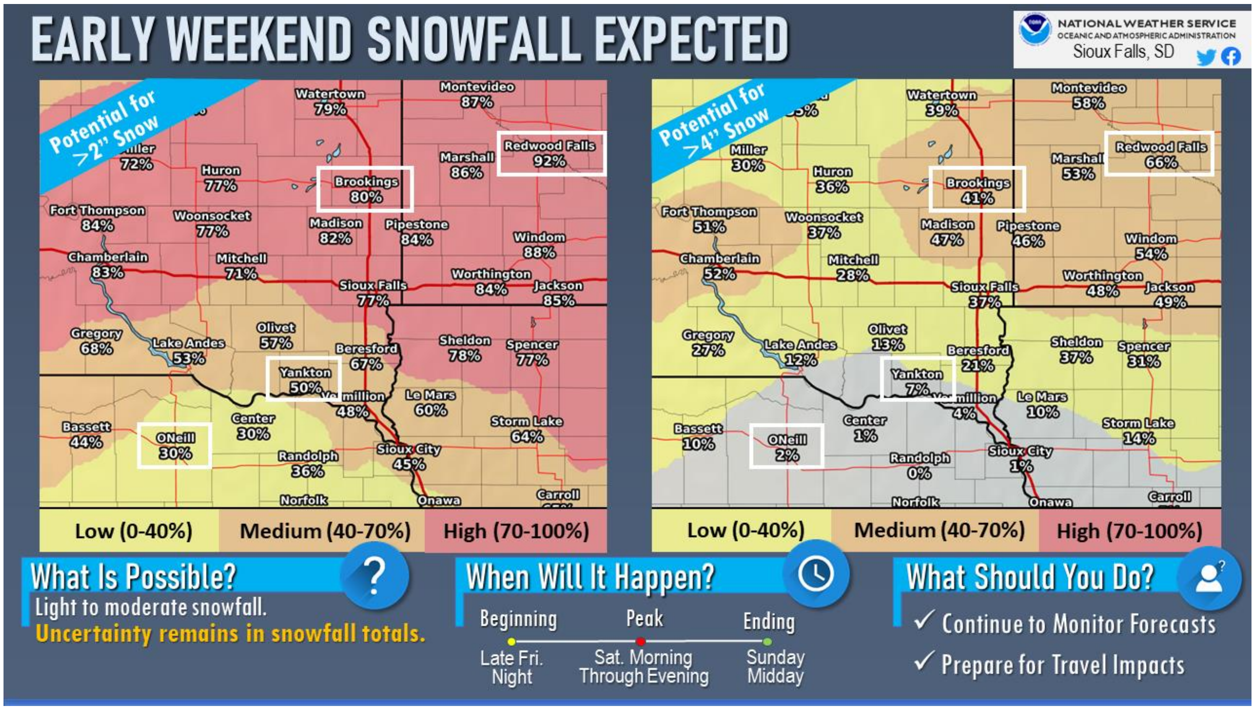
15. *[Deleted this question but keeping this to keep numbering same as prior programmed versions]*

16. Imagine that you work (in your current job role) in Sioux Falls. If you were to get a forecast like this, how useful would the different parts of the graphic be to you? (response options: 1=not at all useful, 2=not very useful, 3=somewhat useful, 4=very useful, 5=extremely useful)
    - ○ The map with the potential for >2" of snow
    - ○ The map with the potential for >4" of snow
    - ○ The "what is possible" text
    - ○ The "when will it happen" text
    - ○ The "what should you do" text

17. Again, imagine that you work (in your current job role) in Sioux Falls. If you were to get a forecast like this, how likely would you be to do the following? (response options: 1=not at all likely, 2=not very likely, 3=somewhat likely, 4=very likely, 5=extremely likely)
    a. Prepare for this storm
    b. Seek a forecast from someone other than NWS who could give me more certain information
    c. Monitor the NWS for updated information
    d. Contact my local NWS office so I can talk with someone about this storm

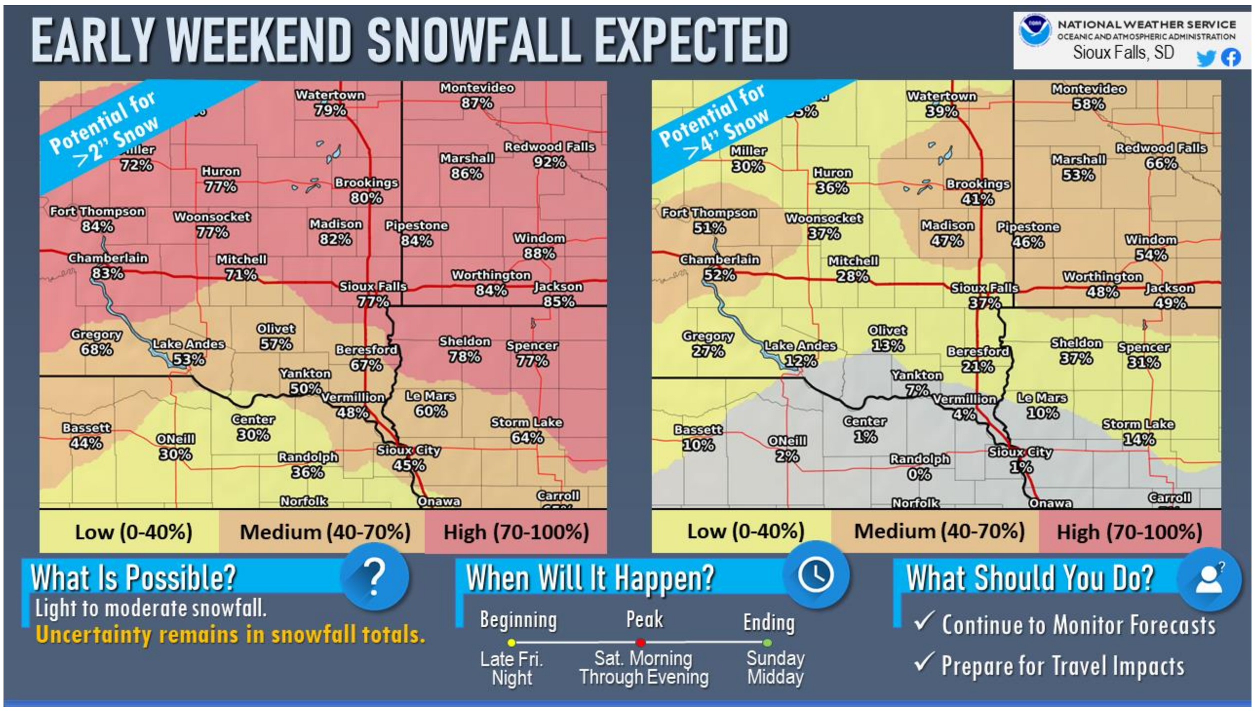
IF response option to item a is >= 3, GOTO Qa, ELSE GOTO next Q

a. You indicated you are likely to prepare for this storm. What piece(s) of information on this graphic are helpful to you for preparing? *Select all that apply.*
   - ☐ The map with the potential for >2" of snow
   - ☐ The map with the potential for >4" of snow
   - ☐ The "what is possible" text
   - ☐ The "when will it happen" text"
   - ☐ The "what should you do" text"

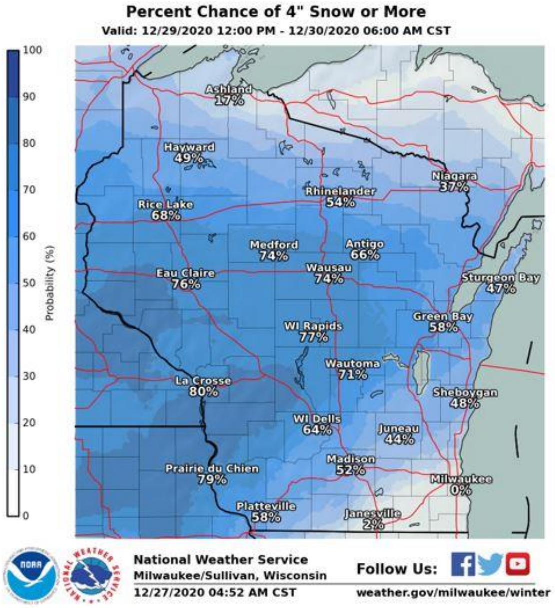


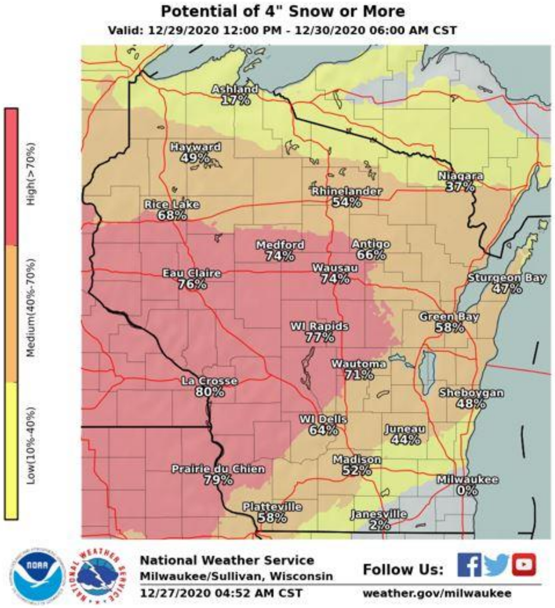
18. Which of the cities listed below has the greatest potential for >2" of snow?
 - ○ Brookings
 - ○ Redwood Falls
 - ○ ONeill
 - ○ Yankton
 - ○ I don't know

19. What do you think is the potential for <u>1 inch</u> of snow in Vermillion?
- ○ 0%
- ○ 4%
- ○ 48%
- ○ Some percentage that is less than 48%
- ○ Some percentage that is greater than 48%
- ○ I don't know



20. If you would like to share any comments about this graphic, please add them here. (Tip: If you're using a smartphone, use voice-to-text to provide your comments.) (Open-ended, do <u>not</u> force response)



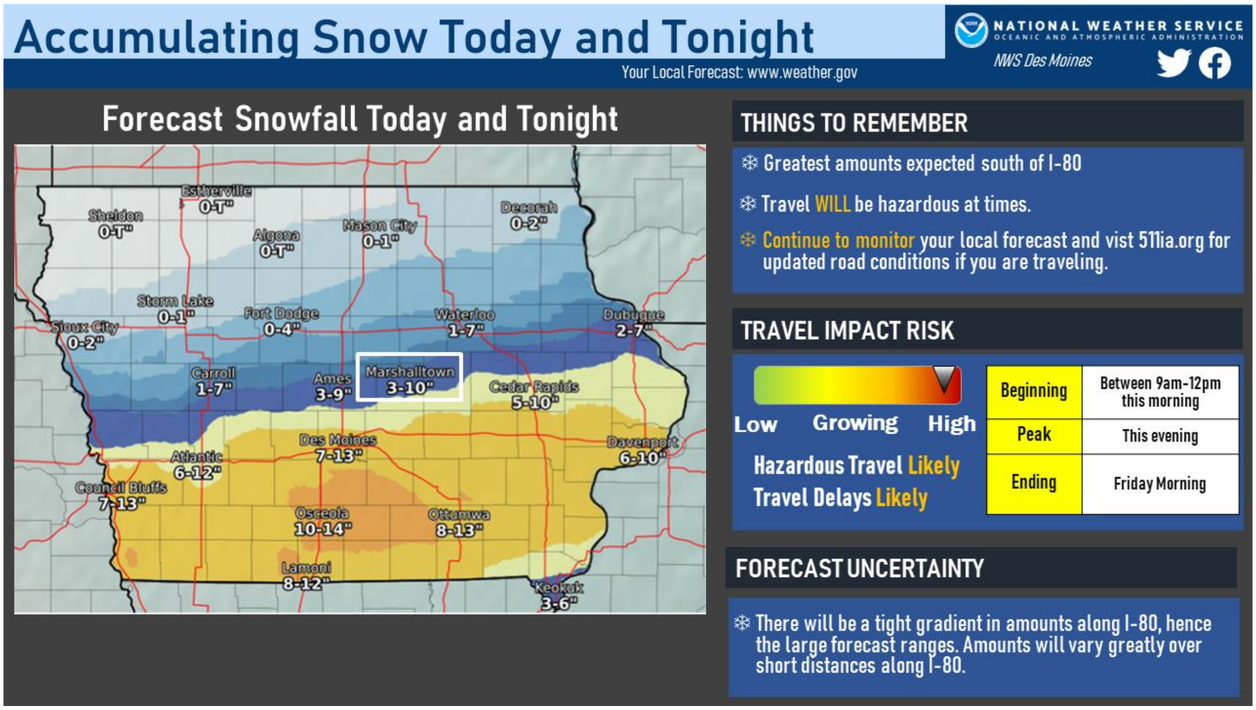


21 Above are two images that show the forecast chance of 4 inches of snow or more. The images have the exact same information shown in different ways. Which do you prefer?

○ I prefer the one on the left

○ I prefer the one on the right

Here is another experimental forecast product. <u>Imagine it's Thursday, and this is the forecast for today and tonight</u>.



22. Imagine that you work (in your current job role) in Marshalltown. If you were to get a forecast like this, how likely would you be to do the following? (response options: 1=not at all likely, 2=not very likely, 3=somewhat likely, 4=very likely, 5=extremely likely)
    a. Prepare for this storm
    b. Seek a forecast from someone other than NWS who could give me more certain information
    c. Monitor the NWS for updated information
    d. Contact my local NWS office so I can talk with someone about this storm

IF response option to item a is >= 3, GOTO Qa, ELSE GOTO next Q

a. You indicated you are likely to prepare for this storm. What piece(s) of information on this graphic are helpful to you for preparing? *Select* *<u>all</u>* *that apply*
    - ☐ The snowfall ranges
    - ☐ The lower bound of the snowfall ranges
    - ☐ The upper bound of the snowfall ranges
    - ☐ The blue, yellow, and orange colors on the maps
    - ☐ The text boxes on the side

23. Again, imagine you work (in your current job role) in Marshalltown. How useful would this forecast of 3-10 inches be to you? (response options: 1=not at all useful, 2=not very useful, 3=somewhat useful, 4=very useful, 5=extremely useful)

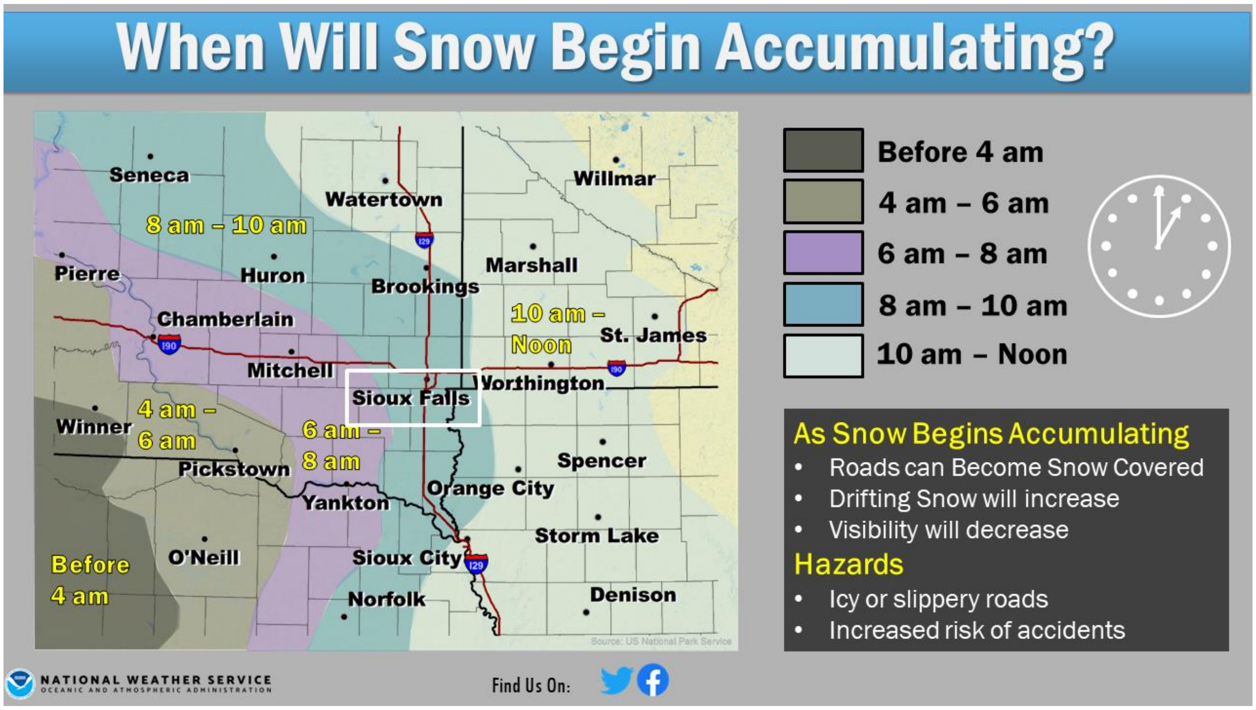
24. Again, imagine you work (in your current job role) in Marshalltown. What amount of snow would you prepare for?
    - ○ The low-end amount (3 inches)
    - ○ The mid-point amount (about 6-7 inches)
    - ○ The high-end amount (10 inches)
    - ○ Other (please specify)

25. Which scenario would cause the most problems for your work operations?
    - ○ A 3-10 inch snow forecast in which the actual snow falls within that range
    - ○ A 3-5 inch snow forecast, but the actual snow amounts to 10 or more inches
    - ○ A 6-10 inch snow forecast, but the actual snow amounts to 3 or less inches

26. *[Deleted this question but keeping this to keep numbering same as prior programmed versions]*

27. If you would like to share any comments about this graphic, please add them here. (Tip: If you're using a smartphone, use voice-to-text to provide your comments.) (Open-ended, do <u>not</u> force response)

Here is one more experimental forecast product. <u>Imagine it's Wednesday, and this is the forecast for tomorrow morning</u>.



28. Imagine that you work (in your current job role) in Sioux Falls. If you were to get a forecast like this, how useful would this be to you? (response options: 1=not at all useful, 2=not very useful, 3=somewhat useful, 4=very useful, 5=extremely useful)

29. Imagine that this forecast is when forecasters think the snow is most likely to begin accumulating. How useful would it be to you to know… *(response options: 1=not at all useful, 2=not very useful, 3=somewhat useful, 4=very useful, 5=extremely useful)*
    a. The earliest that snow might begin accumulating
    b. The latest that snow might begin accumulating

30. How useful would it be to you to get similar types of forecasts showing when snow accumulation will end? (response options: 1=not at all useful, 2=not very useful, 3=somewhat useful, 4=very useful, 5=extremely useful)

31. What NWS office serves your area? (provide drop-down menu, listed alphabetically)

32. What is your gender?
    ○ Male
    ○ Female
    ○ Prefer not to answer

33. What is the highest level of educational training that you have completed?
    ○ Did not complete high school
    ○ High school diploma or GED equivalent
    ○ Some college, technical school, or associate's degree
    ○ Bachelor's degree
    ○ Graduate or professional degree

-- Submit button and thank you message --