THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF METEOROLOGY AND ATMOSPHERIC SCIENCE

# EVALUATING THE USEFULNESS AND RESPONSE TO GRAPHICAL INFORMATION USED TO COMMUNICATE UNCERTAINTY-DRIVEN AND PROBABILISTIC WINTER WEATHER FORECASTS

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# ABSTRACT

Hazardous winter weather events cause significant impacts on daily life, but the ways these events are currently communicated, especially with the graphical information that is used, varies greatly across the weather enterprise. Important forecast information can sometimes be misleading or confusing due to the way it is displayed or the way that people interpret it. Previous studies have shown that including uncertainty and probabilistic information in weather messaging is an effective means of conveying risks and aiding in decision-making. Therefore, several National Weather Service (NWS) offices have begun using some probabilistic information in their messaging strategies for winter weather. For instance, based on probabilistic data, forecasters will create three-category "risk probability" graphics to communicate the inherent uncertainty of snowfall accumulations. However, despite their utility across the weather enterprise, very few studies exist that examine the interpretation or effectiveness of this messaging strategy. In this study, we will analyze a variety of uncertainty-driven and probabilistic messaging strategies for hazardous winter weather, including the "risk probability" graphics, to examine what strategies are easiest to interpret and most effective at communicating important forecast information. A variety of online surveys and focus groups for emergency managers, broadcast meteorologists, NWS meteorologists, and the public were used to identify their relative understanding and likely responses to the different messaging strategies. One survey of the public amassed over 800 responses, generating several conclusions. One significant result of this research focuses on how core partners of the NWS as well as most of the public want more probabilistic and uncertainty information incorporated into the forecasts they receive, while keeping the graphics used to communicate this information simple and easy to understand.

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# Chapter 1

# Introduction

Forecasting winter weather will always be a challenge because every forecast has some level of inherent uncertainty. Small changes to the track of a storm, for instance, can drastically change where the most snow will fall. Therefore, it is important for meteorologists to recognize this uncertainty and incorporate this information into forecasts that can benefit the end user. However, this information must be communicated to the end user in a way that they will easily understand and find valuable to their decision-making processes. One of the best ways that a forecaster can incorporate uncertainty into a forecast is by using probabilistic information to convey the likelihood of a weather event occurring or a threshold being surpassed.

In fact, meteorologists should use probabilistic information in place of deterministic information whenever possible (Joslyn & LeClerc 2012; Grounds & Joslyn 2018). In practical terms, this means that instead of saying that a particular weather event will or will not occur, a forecaster should mention that there is a high chance, perhaps an 80% probability, that a weather event will occur. Some meteorologists fear this type of information will confuse the public as they think many people will not be able to understand it properly (Pappenberger et al. 2013). However, past studies indicate that people make better decisions, have higher trust in information, and display a greater understanding of forecast information when they are shown a probabilistic forecast instead of a deterministic one (Ash et al. 2014; Bolton and Katok 2018; Joslyn and Demnitz 2019; Joslyn et al. 2007; LeClerc and Joslyn 2012; Marimo et al. 2015; Roulston and Kaplan 2009; Roulston et al. 2006; Joslyn and Grounds 2015). Without probabilistic information, people can only guess the underlying uncertainty of forecasts, so communicating probabilistic forecasts is critical to support informed decisions by users with varying needs (Fundel et. al 2019). It is, however, very important to tailor probabilistic information to different audiences' needs to increase their impact on the audience's decision-making processes, as forecasters should frame messages and forecasts that contain probabilistic information in a way that the end user can easily interpret (Connelly and Knuth 1998; Fundel et. al 2019).

Past research has determined that probabilistic information is most effective when displayed with numbers, as categorical expressions of uncertainty, for instance using descriptor words such as "unlikely," "possible," and "likely," have been shown to be vague and open to interpretation among users (Windschitl and Wells 1996). Additionally, categorical expressions of uncertainty can be interpreted differently based on their context (Weber and Hilton 1990). Therefore, there is strong evidence that using categorical expressions and numerical expressions in conjunction with each other, for example saying, "snow squalls are possible this evening with a 20% to 30% chance," is better than just using the word "possible" alone (Budescu et. al 2014). Purely categorical expressions of uncertainty should generally be avoided, so numeric information should be prioritized, and used alone if necessary, such as "there is a 60% to 70% chance of thunderstorms this evening," because these expressions are interpreted more consistently (Budescu et. al 1988, Jaffe-Katz et. al 1989). People also tend to be more comfortable with, and trusting of, purely numeric information as opposed to purely categorical information, and that purely categorical statements often lead people to overestimate risks (Gurmankin et. al 2004, Knapp et. al 2010). Point estimates, such as just "a 20% chance," can be used in some situations as well, but confidence intervals, such as "there is a slight, 10% to 20%, chance that more than 10 inches of snow will fall," gives users additional information they might find useful (Grounds et. al 2017, Løhre et. al 2019). The size of the confidence interval can influence how people interpret a forecast, as people seem to implicitly understand that smaller confidence intervals mean that a forecast is more certain versus wider ranges indicating more uncertainty (Løhre et. al 2019).

Prior research has also shown that communicating probabilistic information in the form of visualizations is an effective way for groups of people who are less numerate or who may have difficulty with probabilities expressed as numbers or words to understand this type of information (Johnson and Slovic 1995, Gerst et. al 2020, Okan et. al 2015). In the domain of weather, visualizing probabilities often comes in the form of maps, and studies suggest that people understand basic probability information about forecasts when presented with a map (Wu et. al 2014). In addition to maps, other types of visualizations have been used to improve the understanding of probability information in weather forecasts, including ensemble plots (Toet et al. 2019).

However, not many studies have been completed to address how to present this probabilistic and uncertainty-driven information in a clear and concise manner for communicating forecast information for winter weather events, especially in terms of getting the public's opinions on how these types of forecasts should be communicated. This research aims to answer some of these questions that are currently unknown by analyzing many different types of graphics that National Weather Service (NWS) offices currently use to communicate hazardous winter weather events and determining the most effective ways of incorporating this valuable uncertainty-driven and probabilistic information into forecasts, especially in a graphical framework.

There are two main objectives of this research study, which aims to improve winter weather messaging and make it more consistent across the weather enterprise. Objective one is to determine which graphic types are most effective at communicating the threat of an upcoming winter storm. Objective two is to determine how to best incorporate more uncertainty-driven and probabilistic forecast information into these graphics used to communicate hazardous winter weather events, based on the past research that was previously discussed.

# Chapter 2

## Methods Overview

To reach these objectives, we will collect and analyze forecast graphics that convey probabilistic information. We will then subdivide these graphics into three categories for analysis:

1. Long-range graphics, which are used to communicate winter weather events three to seven days before the event begins, will be studied to determine if a certain graphic type is preferred.
2. Probability of exceedance graphics, sometimes called risk probability graphics, which are used to communicate potential snowfall amounts two or three days before the winter storm begins, will be studied in detail to determine if a specific graphic type is preferred. These graphics are created by taking the Weather Prediction Center's (WPC) Super Ensemble model with about 44 members to estimate an initial probability distribution for predicting snowfall amounts. The WPC's deterministic snow forecast is the mode of the distribution, shifting the distribution of the ensemble members (Figure 1). Then, each NWS Weather Forecast Office (WFO) uses their own deterministic snow forecast to again shift the distribution one way or another (Figure 1). The distribution probability of the ensemble members now gets turned into the risk probability graphics based on the probabilities of exceeding specific snowfall threshold values (Figure 1). To simplify this map depiction, some NWS offices have placed the specific threshold values into three categories, from 10-40%, 40-70%, and 70-100%, as shown in the red/orange/yellow color scheme graphic

(Figure 1). The data used for risk probability graphics is available to meteorologists for forecasting 72 hours into the future.

3. Snowfall forecast map graphics are the third category and they will be analyzed to determine how uncertainty-driven information can be incorporated into these as well.

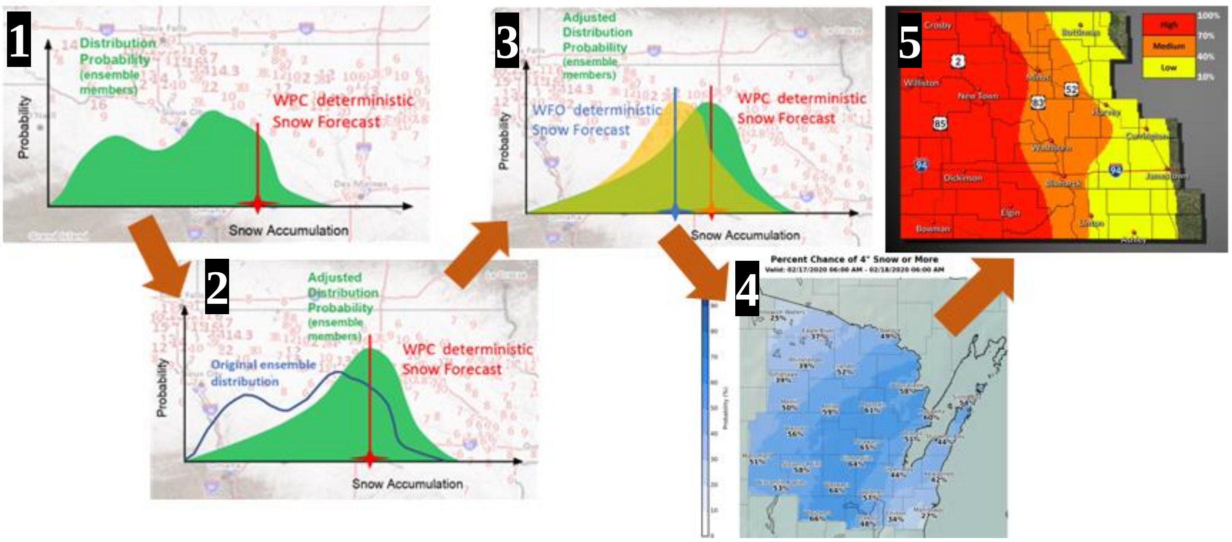



**Figure 1.** General sequence of how the WPC Super Ensemble distribution gets turned into risk probability graphics that NWS offices utilize and distribute to users.

Feedback was received from NWS meteorologists, broadcast meteorologists, emergency managers, and the public through surveys and focus groups to allow for a variety of perspectives from those with different backgrounds and opinions. Results from this work will not only benefit NWS offices as they communicate hazardous winter weather events to the public and to their core partners in the future, but the entire weather enterprise will be able to see how uncertainty-driven and probabilistic information can be effectively incorporated into graphics and forecasts.

To determine which types of forecast information and what graphic types are most effective at communicating the threat of an upcoming winter storm, over 500 graphics were collected to get a comprehensive perspective of how winter weather forecasts are currently communicated by NWS offices across the country. Graphics were collected from Twitter and

Facebook from the 2019-2020 winter season that over 25 different NWS offices across the country used to communicate upcoming winter storms. The date and time that the graphic was posted was noted, along with the anticipated onset date of the winter storm that was being forecasted.

These graphics were then organized based on graphic type, grouping all the long-range graphics together, all the snow maps that communicated some uncertainty together, all the risk probability graphics together based on the color scheme, and all the risk probability graphics that were used for other purposes besides snowfall accumulation together. This organization process was helpful for separating the research into three distinct categories. For high-impact snow events, the general messaging sequence usually starts three to seven days before the event with some long-range graphics communicating the risks and uncertainties associated with a possible upcoming winter storm. Within two to three days, risk probability graphics are created and used to communicate that uncertainty that is still present, even though the area of highest impact is becoming clearer to forecasters. And then, finally, deterministic snow maps with specific snow ranges are created one to two days before the event begins, however, circled areas on the snow maps are used to communicate any remaining uncertainty that is present in the forecast.

Surveys and focus groups were chosen to be the primary modes of getting feedback on these graphic styles, so that conclusions about which graphics were most effective at communicating an upcoming winter storm could be determined. Due to restrictions from within the National Oceanic and Atmospheric Administration, getting feedback from the public across the United States would not be possible on a short timeline due to their approval process. Therefore, it was agreed to ask non-meteorologists who work at NWS offices in the NWS Central Region for their feedback on these graphics via a survey (Figure 2).

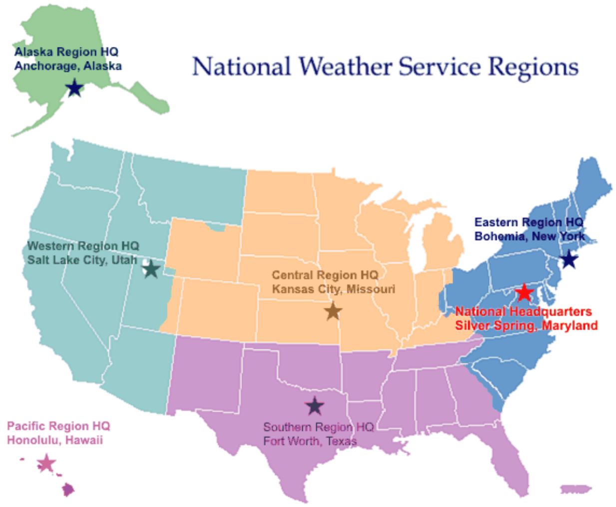



**Figure 2.** Map of NWS regions. The survey for NWS meteorologists and the survey for NWS non-meteorologists were distributed to NWS offices in the Central Region, which is highlighted in the orange/tan color.

Additionally, a different survey was created for meteorologists who work at NWS offices in the NWS Central Region to get their perspective on these graphics. It was important to get feedback from both groups since meteorologists have plenty of experience creating these graphics for upcoming winter storms, whereas non-meteorologists must interpret these graphics and try to apply the information these graphics provide to the decisions they make in their lives to stay safe.

To get feedback from other groups of people that rely on information from the NWS and use these graphic styles in a different way, focus groups were also organized with emergency managers and broadcast meteorologists from North Dakota. These core partners of the NWS use information from the NWS, which is distributed to them for communicating important weather hazards to the public. Therefore, it was very important to include these people in the conversation about these winter weather graphics since they use the graphics and information in different ways than the general public does, and it is very important that the NWS is presenting them with information that they can understand and that is helpful to them.

Social media analytics were also studied associated with two large snowstorms that impacted North Dakota during the final few months of 2019. Information from the NWS Bismarck's Facebook and Twitter pages was sorted based on the number of impressions and engagements that each post containing a graphic ahead of these winter storms received. This information was helpful to determine what types of graphics got the most attention on social media at each of the lead time categories that were investigated.

Once the research shifted from working under the NWS to being done under Penn State protocols, a survey with a larger sample size of the general public could be conducted. A new survey was designed with input from many different people, and this was distributed to predominately non-meteorologists, but those who had a background in meteorology were also allowed to complete the same survey.

Results were analyzed to determine the key takeaway points and the key conclusions from each phase of this research and from the research project overall.

# Chapter 3

# Survey Research Completed with 40 Meteorologists in NWS Central Region

## 3.1 Methods

The survey designed for NWS meteorologists in the Central Region was focused on determining these meteorologists' opinions on the winter weather forecasting graphics that many of them are familiar with creating. As meteorologists on the creation side of the graphics, they do not know exactly how the targeted end user will interpret them and act based on the information in the graphic, but they can make inferences about this behavior. Additionally, these meteorologists have an understanding about the different products and maps used in the graphics that are produced by NWS offices as well as why some graphical choices are made. Meteorologists at NWS offices might also have opinions about specific graphics that are different from the graphic styles that are currently being used, and this survey gave them the opportunity to voice their suggestions and ideas.

The survey was split up into two parts: one focusing solely on risk probability graphics and the other dealing with long-range winter weather messaging and communicating uncertainty on snow maps. In total, 15 questions were created, 10 of which were multiple choice and 5 that were open-ended questions. All multiple-choice questions were required to be answered, while the open-ended questions could be skipped. This survey was created in Google Forms under my NOAA, or National Oceanic and Atmospheric Administration, secure email account, with all the responses to the survey and the data being stored in my NOAA secure email Google Drive.

The primary distribution method of this survey was through emails from Chauncy Schultz, my NOAA Hollings Scholarship mentor. He sent the survey out to meteorologists in the Central Region of the NWS, an area loosely defined as encompassing the Central and Northern Plains and the Midwest (Figure 2). These meteorologists could be asked to fill out a survey without the survey obtaining NWS approval because the people who were filling out this survey were federal employees, and I was operating under the NWS as a part of the NOAA Hollings Scholarship. This survey was distributed during the month of July 2020, with 40 meteorologists completing the survey and submitting their responses.

**3.2 Results**

Several key conclusions can be drawn about the differences that are currently present with risk probability graphics and the opinions that meteorologists have about them. When asked about the preferred color scheme of the risk probability graphics, 21 meteorologists, which is slightly more than half of those surveyed, said they preferred the three-tiered red, orange, yellow color scheme (Figure 34 and Table 1). It should also be considered that many NWS offices in the Central Region already utilize this three-tiered red-orange-yellow color scheme, so there is some familiarity among the meteorologists surveyed and they are not as familiar with the other color schemes possibly altering their answer choice. In terms of the preferred title of these risk probability graphics, there was a clear preference to use the word “potential” in the title, with 63% of meteorologists surveyed selecting the “potential for at least ‘x’ inches of snow” title (Table 1).

There was more disagreement with some of the other aspects of these graphics that were in question, as 38% of meteorologists surveyed preferred color scale option 2 (Figure 40), while 35% thought that color scale option 4 (Figure 42) was the best suited for these risk probability graphics (Table 1). Additionally, when asking about adding probability percentages to the color scale at each color interval, 55% thought that this would improve the graphic and help users interpret it better, while 45% did not think it would help (Figure 10) (Table 1). Because this question had a component that allowed respondents to type in their reasoning, some common reasoning supporting the addition of these probability percentages included citing past research which has shown that users make better decisions with numbers and the percentages provide important context by making the graphic less subjective. On the other hand, common reasoning in opposition of these probability percentages included the additional confusion that is possible for users with these numbers and the fact that it implies greater precision and certainty than forecasters have.

There were also a wide variety of opinions when asked about adding specific probability percentages at each location on the map of the risk probability graphic (Figure 44). While 28% of meteorologists thought that the probability percentages would help users interpret and understand the graphic better, 30% said that the percentages at each location make the graphic more confusing and 30% also thought that having the percentage on the color scale was enough (Table 1). Meteorologists could type their own answer to this question and some of the responses in favor of including the probability percentages at each location was that it would help color blind people and they can be used to highlight areas of highest confidence within the “high” confidence area. Common responses in opposition of including these probability percentages at each location was that these specific numbers imply more skill than meteorologists have, and that people might become too reliant on the exact number with a slight change to the number in a future forecast update possibly altering their preparedness actions before the winter storm. A compromise that was mentioned by a couple of meteorologists was to round the percentages to the nearest 5% or 10% so that the precise percentages down to the ones of a percent are not used.

Adding additional text to the risk probability graphic was also considered and generally well received by meteorologists that were surveyed, with 68% selecting that this additional text gives users important information they might not have seen if they were not seeking it out elsewhere (Table 1). However, some respondents pointed out that there is a limit to how much text should go on a graphic. As an example, Figure 45 possibly crosses a line by having too much text and makes the graphic too busy or confusing.

There was a split opinion on whether including two risk probability maps on the same graphic (Figure 46) was a good practice or not, with some meteorologists saying that having two maps gives a good sense of what the “floor” and “ceiling” are of the snowfall potential and that higher-end users in the public would benefit from this practice, along with emergency managers and other NWS partners. Concern about users being confused and not being able to interpret this graphic layout (Figure 46) was also a common response, with a variety of reasoning such as not being able to comprehend the graphic quickly and the inability of users to distinguish the differences between the two maps without an additional explanation. One suggestion that was made was to just use one risk probability map on the graphic and then add in some brief text explaining the potential for higher amounts throughout the area or by using a circled area on the map to pick out a certain region that might see higher amounts.

Overall, the meteorologists that were surveyed understand the value of the risk probability graphics in the messaging timeline before a winter storm as they serve as an important bridge from long-range graphics to snow maps since they can be posted when too much uncertainty remains for a snow map to be released. Many meteorologists also said that the risk probability graphics allow users to prepare differently based on their specific needs because each user has different risk tolerances, and the risk probability graphics give them information about the confidence in the forecast as well as the spatial coverage of the threat. Additionally, many of the meteorologists surveyed also thought that the risk probability graphic style, particularly with the three-tiered red, orange, yellow color scheme, could be easily implemented to communicate the risk of other hazards besides snow. 60% of meteorologists surveyed said that they would use this style of graphics to communicate blowing and drifting snow (Figure 47), 68% would use it for travel impacts (Figure 48), and 85% would use it for communicating an icing or freezing rain potential (Figure 49 and Table 1).

When selecting what long-range style graphic style the meteorologists' thought was most effective at communicating an upcoming winter storm, there was not a particular option that stood out as being widely preferred given the large number of options. However, about 38% picked the graphic style where a region of snow potential is highlighted and/or circled on a map (Table 1). When asked how long-range winter weather messaging can improve, many pointed towards trying to achieve a more consistent messaging strategy across the NWS as well as continuing to keep these graphics at this lead-time simple and not getting too detailed with the forecast, such as by talking about specific snow amounts. It should also be mentioned that there is not one solution or graphic that will work for all situations as each storm is different, so it is important to use more than one graphic style at this lead time while maintaining consistency between the types of messaging methods used as well as among NWS offices. Going along with the simplistic theme for graphics at this lead time, meteorologists also believed that a long-range threat matrix graphic (Figure 56) would be too confusing for users with 48% of respondents thinking that this graphic is not a good way communicating long-range risk (Table 1).

Communicating uncertainty on snow maps can be important, especially when a tight gradient in snowfall amounts is present or if a lot of uncertainty remains in a particular part of the forecast region. Communicating this uncertainty can be effectively achieved by drawing a circled region on the snow map and indicating that this is the region of greatest uncertainty. 73% of meteorologists surveyed thought that users would understand this circled area of uncertainty, while only 20% thought that users would also prepare differently if they lived in the circled area (Table 1). Forecasters generally said that they choose to circle a region of greatest uncertainty when there is a very tight gradient in snowfall amounts, possibly due to a rain/snow transition zone, or when models disagree, possibly due to an uncertain storm track. A few meteorologists, however, noted that these circled areas of uncertainty should not be overused, which could decrease credibility. Additionally, another suggestion was for the circled area to sometimes be titled "potential for higher snow totals," or something along those lines, that would give more of a description as to why the circled area has an elevated level of uncertainty. Finally, half of the meteorologists that were surveyed thought that using a combination of a circled area of uncertainty on a snow map and a text-based description of the uncertainty would be most effective and easiest for the user to understand. A more in-depth, text-based description that would explain why a particular region on the snowfall forecast map is circled may help clear up any confusion that users would have and help them better understand how the forecast could change.

**Table 1.** Results from the multiple-choice questions asked of NWS meteorologists in the Central Region (40 respondents total). Refer to Appendix A for full questions, option choices, and answers as they were shown on the survey. The questions are in the first column, with the options and the number of respondents for each option in the other columns.

| Question | Options for Each Question and Number of Respondents for Each Option | | | | |
|---|---|---|---|---|---|
| Q1 – Risk Probability Color Scheme Preference | Three-tiered (red, orange, yellow) | Blue shadings | Brown, Yellow, Green, Blue, Red | Grey, Blue, Yellow, Orange, Red (WPC Scale) | No preference for color scale |
| | **21** | **6** | **7** | **6** | **2** |
| Q2 – Risk Probability Title Preference | Potential for at least "x" inches of snow | Chance of at least "x" inches of snow | Risk of greater than "x" inches of snow | Probability of "x" Inches or greater snowfall | No preference for title |
| | **25** | **4** | **2** | **9** | **0** |
| Q3 – Three-tiered Risk Probability Color Scale Preference | Option 1: “Lowest potential” & “Greatest potential” descriptors | Option 2: “Low,” “Medium,” & “High,” with percentages | Option 3: “Slight,” “Moderate,” & “High” with percentages | Option 4: “None,” “Low,” “Medium,” & “High” descriptors | No preference for color scale |
| | **9** | **15** | **2** | **14** | **0** |
| Q4 – Does Adding Percentages to Color Scale Improve Risk Prob. Graphics | Yes | No | Note: this question was technically open-ended, but respondents had to state “yes” or “no” at the beginning of their response | | |
| | **22** | **18** | | | |
| Q5 – Adding Probability Percentages at Each Location on Risk Prob. Graphics (select all that apply) | Would help users interpret and understand the graphic easier | Users would be able to understand the discrete percentages at each location | Percentages at each location make the graphic more confusing | Percentages not necessary at each location – on the color scale is enough | Percentages do not make a difference if they are included on the graphic |
| | **11** | **6** | **15** | **15** | **5** |
| Q6 - Text on the Risk Prob. Graphics Help the User Interpret Them (select all that apply) | Additional text helps users interpret the graphic better | Additional text gives users info. they might not have seen if not looking elsewhere for it | Additional text makes the graphic too busy and confusing | Additional text should instead be a part of the post's text on social media | |
| | **12** | **27** | **9** | **3** | |

| | | | | | |
|---|---|---|---|---|---|
| Q9 – Utilizing Risk Probability Graphics to Communicate Other Hazards (can select multiple) | Blowing/ Drifting Snow | Icing/ Freezing Rain Potential | Travel Impacts | Wind Gusts | Wind Chill |
| | **24** | **34** | **27** | **15** | **20** |
| Q10 – Long-Range Winter Weather Graphic Style Preference | Circling one or more areas for snow potential | List of dates/ timeline w/ potential for snow highlighted | "What we know," "what is uncertain," "what you can do" | Using track of storm to communicate timing and impact area | No preference for the graphic style used at this lead time |
| | **15** | **6** | **11** | **5** | **3** |
| Q11 – Long-Range Threat Matrix Graphic Example. Does it communicate the storm risk effectively? | Effective, and users will understand it | Effective, but improvements need to be made to help the user understand it better | Unsure whether users will be able to interpret and understand it easily | Not a good way of communicating long-range winter storm risk | Other (type own response) |
| | **0** | **3** | **14** | **19** | **4** |
| Q13 – Circled Area of Uncertainty on Snow Maps – User Understanding and Preparing Differently | User understands the circled area of uncertainty and will prepare differently | User understands circled area, but will not prepare differently if they live in the circled area | User does not understand the circled area, but will prepare differently | User does not understand the circled area, and with not prepare differently if they live in the circled area | I don't know what the user will think of the circled area or how they will prepare |
| | **8** | **21** | **0** | **0** | **11** |
| Q15 – Communicating Uncertainty on Snow Maps with Circled Area Versus with Text on the Graphic | Circling area of uncertainty is more effective and easier to understand | Discussion of uncertainty in text is more effective and easier to understand | I think some combination of the two should be used on the same graphic | I do not have an opinion on this | |
| | **16** | **1** | **20** | **3** | |

## 3.3 Discussion

Meteorologists in the Central Region that were surveyed understand the value that the risk probability graphic provides to users, but these graphics must be kept simple so that they can be used in a way in which the public will understand them. When collecting graphics on social media for this research project, there was a noticeable difference in the amount of risk probability graphics that were posted from offices in the Northern Plains and Upper Midwest compared to the rest of the country. Because this graphic style was developed by these regional NWS offices, forecasters throughout most of the Central Region are comfortable using risk probability graphics when messaging winter weather hazards. I think this familiarity with the graphic style influences how meteorologists become comfortable using this graphic style for other hazards, such as for blowing snow and freezing rain.

Keeping these risk probability graphics simple was a common thread among many meteorologists who were surveyed. Many forecasters were hesitant about using specific numbers to communicate the probabilistic information on these graphics. However, as mentioned previously, past research has shown that numeric expressions of uncertainty, such as “there is a 60% chance of exceeding 6 inches of snow,” should be prioritized over purely categorical statements, because these expressions are interpreted more consistently (Budescu et. al 1988, Jaffe-Katz et. al 1989). It is worth noting that just over 50% of meteorologists surveyed thought that adding probability percentages to the color scale improves the risk probability graphics, so this was a very divisive topic among the meteorologists (Table 1). Adding probability percentages at each location on these risk probability graphics was also a disputed topic, and what needs to be considered is whether adding probability percentages at each location takes the usage of numeric expressions of uncertainty too far and could overwhelm or confuse the end user. What was not a disputed topic among forecasters that were surveyed was the fact that additional text should be added to risk probability graphics as it would most likely benefit the end user in their interpretation of the graphic, but the text needs to be kept short to avoid overwhelming the user. Based on these responses, a risk probability graphic similar to Figure 3 seems to be preferred by meteorologists who were surveyed utilizing the three-tiered red/orange/yellow color scheme, having the word "potential" in the title, using the low/medium/high color scale with probability percentages (10%, 40%, 70%, 100%) on the color scale, not having probability percentages at each location on the map, only using one risk probability map on the graphic, and including some text-based information - but not too much for it to be overwhelming.

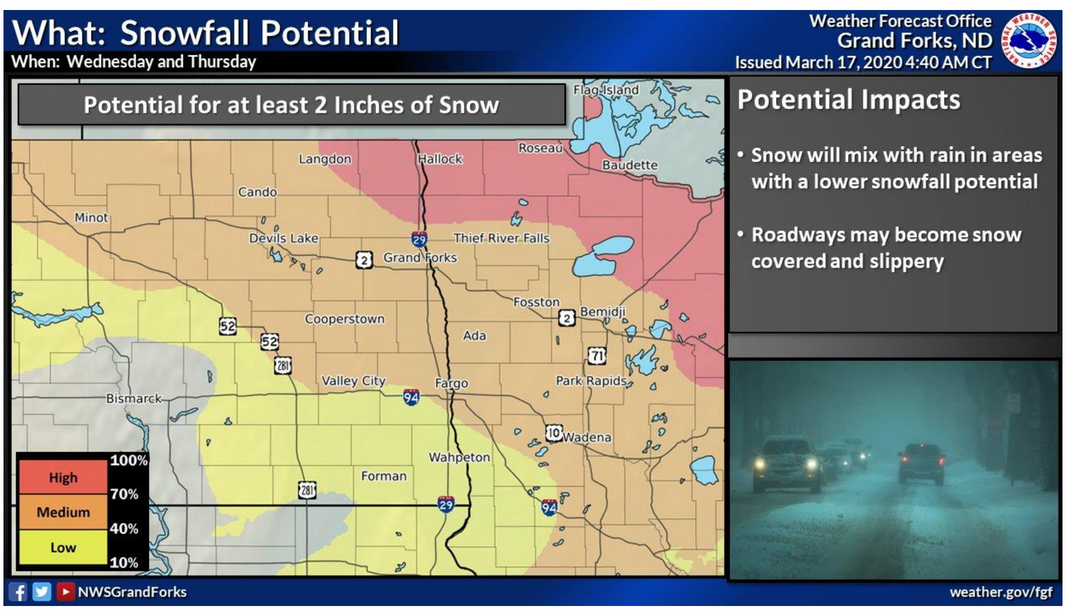


**Figure 3.** Graphic posted by NWS Grand Forks on 3/17/20 with a three-tiered red, orange, yellow risk probability map communicating the potential for 2" or more of snow and some text-based impact information on the graphic as well.

The desire for simplistic messaging also carried over to meteorologist's preferences for long-range winter weather forecast graphics. Even though there was not a clear preference for one graphic type used at this lead time, most meteorologists selected the option where a circled area is drawn on a map to communicate where the potential impacts from a winter storm are expected to occur (Figure 52). This approach is more simplistic than some of the other graphic styles used at this lead time, in particular the ones that are very text heavy and the threat matrix example (Figure 56). There was a strong agreement among forecasters that a more consistent messaging strategy needs to be found at this lead time before a winter storm, particularly when coordinating with nearby NWS offices. The possibility of using model data to achieve this consistent message was mentioned by a few meteorologists.

Finally, circling areas of uncertainty on snow maps is well-liked among meteorologists who were surveyed, as almost three-quarters of them thought that users understand the circled areas of uncertainty. Adding a short description to the graphic to explain why the area is circled was also thought to help users understand the meaning of the circled area. Overall, this feedback suggests that meteorologists should continue to use circled areas of uncertainty on snow maps, but feedback from the public survey discussed later will reveal if users actually understand the circled areas of uncertainty and how they say they will act in response to it.

# Chapter 4

# Survey Research Completed with 32 Non-Meteorologists in Central Region

## 4.1 Methods

The survey designed for non-meteorologists who work at NWS offices in the Central Region was focused on determining how someone without a degree in meteorology interprets forecast information about upcoming winter storms and to compare results with the assumptions that meteorologists have about the public's perceptions of these forecasts. This survey aimed to give a perspective at a small sample size of how the public interprets graphics distributed by NWS offices, with the possibility that these results would be representative of the opinions of a larger sample size of the public.

This survey was mainly focused on determining if non-meteorologists make better decisions when presented with probability of exceedance graphics, otherwise known as risk probability graphics, three days before a winter storm. To accomplish this, a scenario-based survey was created where respondents were asked to imagine that they were the leader of their local town's public works department and they had to make decisions about staffing before a winter storm could impact their town. If the snow accumulates more than 4 inches, they need at least 10 people on staff to plow the roads. If the snow accumulates less than 4 inches, they need less than 10 people on staff. Overstaffing would cause their department to lose money because too many people were called into work. Understaffing would cause the roads in their town to not be plowed in a timely manner and would cause delays for their residents who want to travel. A scenario like this one was chosen because it eliminates some of the respondents' personal biases and choices that they would make if they had to decide how the winter storm will impact their personal life. For instance, it was considered when creating this survey to create a scenario where respondents would have to decide if the upcoming winter storm would impact their travel plans based on the forecast. However, there are many more variables at play in a scenario like this one because each person is going to be comfortable driving in a different amount of snow. By placing respondents in a position where they must decide about staffing based on a snow forecast, with their decision having consequences if they overstaff or understaff their department, biases are less likely to enter the equation. The goal of this aspect of the survey was to determine if people were expecting more or less than a certain amount of snow based on the forecast, or if they thought the forecast was too uncertain to decide. This scenario-based section of the survey consisted of three separate scenarios, but all of them had the same guidelines where respondents were the leader of their local town's public works department. For each scenario, a different graphic was given to them three days before the hypothetical winter storm, some of which were risk probability graphics, and then a snow map was given to them one day before the hypothetical winter storm to simulate an update to the forecast. The same set of questions was asked when respondents were presented with each of the graphics, to determine their decision about staffing, their confidence level, and their understanding of the graphic. Only one graphic was displayed per page of the survey so that respondents could not refer to a prior forecast or graphic.

The second part of the survey for the non-meteorologists asked three of the same questions that were asked to the NWS meteorologists in their survey to compare results. These questions were about the long-range graphics, risk probability graphics, and communicating uncertainty on snow maps.

In total, the survey consisted of 27 questions. Twenty-one (21) were required multiple choice or short answer questions and six (6) were optional open-response questions where respondents had the opportunity to explain their decision about staffing for each scenario. This survey was created in Google Forms under my NOAA secure email account, with all the responses to the survey and the survey data being stored in my NOAA secure email Google Drive.

This survey was distributed to all Meteorologists In-Charge at NWS offices in the Central Region via email, asking them to pass the survey along to non-meteorologists who worked at their office, such as electric technicians and administrative support assistants. These people could be asked to fill out a survey without the survey obtaining approval because the people who were filling out this survey were federal employees, and I was operating under the NWS as a part of the NOAA Hollings Scholarship. Distribution of the survey occurred during the month of July 2020, with 32 non-meteorologists completing the survey.

## 4.2 Results

Several key conclusions can be drawn from this survey about the way that people with a meteorology degree perceive risk probability graphics and their opinions on other probabilistic messaging strategies for winter storms. In terms of the demographics of the sample size, 94% were between the ages of 35 and 62 (Table 2). 63% of respondents primarily get their weather information from the NWS in the winter season, indicating that most of them probably have some familiarity with the graphics that were used in this survey (Table 2). Additionally, 59% of respondents said that they are usually aware about an upcoming winter storm 3-4 days before the onset of that storm, which is usually around the time when risk probability graphics start to be created and distributed by NWS offices (Table 2). Therefore, many respondents are familiar with forecast information about upcoming winter storms at this lead time and might make decisions in their life based on these forecasts, similar to how they will make decisions three days before the onset of a theoretical winter storm using graphics presented to them in this survey. When respondents were asked how many inches of snow they consider to be “impactful,” 56% of them said either four or six inches. Results from this question will be compared to how many inches of snow the public thinks is considered “plowable” when asked about it in their survey in Chapter 5.

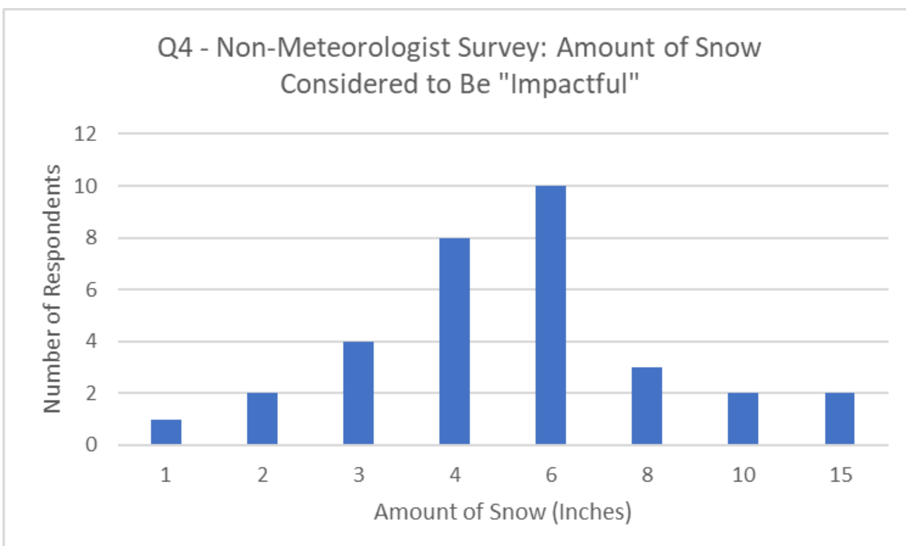



**Figure 4.** Results from question 4 of the survey (Appendix A) distributed to non-meteorologists in the Central Region. This question asked how many inches of snow respondents consider to be “impactful.”

**Table 2.** Results from some of the multiple-choice questions asked of non-meteorologists who work at NWS offices in the Central Region (32 respondents total). Refer to Appendix B for full questions, option choices, and answers as they were shown on the survey. The questions are in the first column with the options and the number of respondents for each option in the other columns of this table.

| Question | Options for Each Question and Number of Respondents for Each Option | | | | |
|---|---|---|---|---|---|
| Q1 – Age Group | 18-26 | 27-35 | 36-44 | 45-53 | 54-62 |
| | **1** | **1** | **7** | **7** | **16** |
| Q2 – Primary Source of Weather Info. in the Winter | NWS | Broadcast Meteorologists | Radio | Newspaper | Phone Weather Apps |
| | **20** | **2** | **1** | **1** | **8** |
| Q3 – When Do You Usually Know About the Threat of an Upcoming Winter Storm | 1-2 Days Before | 3-4 Days Before | 5-6 Days Before | 7+ Days Before | |
| | **4** | **19** | **6** | **3** | |
| Q25 – Long-Range Winter Weather Graphic Style Preference | Circling one or more areas for snow potential | List of dates/ timeline w/ potential for snow highlighted | “What we know,” “what is uncertain,” “what you can do” | Using track of storm to communicate timing and impact area | No preference for the graphic style used at this lead time |
| | **13** | **2** | **7** | **8** | **2** |
| Q26 – Risk Probability Title Preference | Potential for at least "x" inches of snow | Chance of at least "x" inches of snow | Risk of greater than "x" inches of snow | Probability of "x" Inches or greater snowfall | No preference for title |
| | **7** | **5** | **1** | **15** | **4** |
| Q27 – How Do You Interpret Circled Area of Uncertainty on Snow Maps If You Live Within It (select all that apply) | Check the forecast again before the storm starts to see if anything has changed | Prepare for higher snowfall amounts in case the forecast changes | Actions do not change compared to if I lived in an area that was not circled | I do not understand what the circled area means | |
| | **22** | **16** | **2** | **1** | |

Generic graphics were created in Adobe Illustrator for this survey to resemble actual graphics that NWS offices used to communicate winter storms, but they were hand drawn to control the forecast and make comparisons between scenarios easier. The region of where the snow was forecasted to fall on the maps was shifted around for each scenario to avoid respondents confusing one scenario with another, but the overall distribution of snowfall amounts remained the same to allow for a fair comparison.

In all three scenarios for the forecast graphics used three days before the winter storm, the "X" on the graphic indicated the location of the respondents' town and was placed at approximately the location where there was a 45% chance of that location receiving 4" of snow or more. This probability value was chosen to indicate that the forecast was still fairly uncertain at this lead time. For scenario 1 that used a three-tiered, red/orange/yellow risk probability graphic, this placed the town in the orange "moderate" contour, slightly closer to the low contour than the high contour (Figure 59). For scenario 2 that used a blue gradient risk probability graphic with probability percentages plotted at various locations, this placed the town right next to a 45% label on the map (Figure 61). And for scenario 3 that used a snow map three days before a winter storm, this placed the town in the 2-4" contour since there was a greater chance of this snowfall range verifying at the town's location (Figure 63). When asked to choose how many people respondents thought they should have on staff three days from now for the storm, most of them recognized the uncertainty present with this forecast when presented with the risk probability graphics. 69% said it was too early to make a staffing decision when given the three-tiered, red/orange/yellow graphic and 63% said it was too early when given the blue gradient risk probability graphic (Figure 5). However, when presented with the snow map three days before the winter storm, 50% said it was too early to make the staffing decision while the other 50%

chose to make the decision at this lead time and bring in less than 10 people since they were not expecting more than 4” of snow in their town (Figure 5).

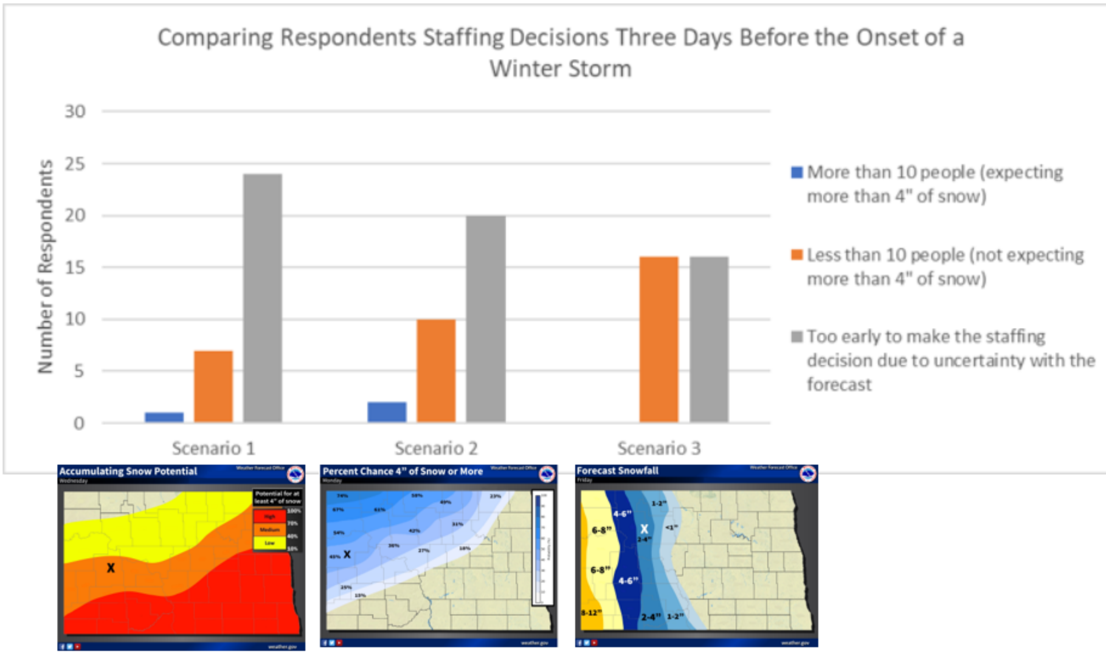



**Figure 5.** Results from the non-meteorologist survey presented with a bar graph comparing respondents’ staffing decisions using the graphic in each scenario presented to them three days before an upcoming winter storm. Graphics that were presented in the survey for each scenario are included in this figure for easy reference. See Appendix B for the full-size graphics.

When asked to explain why they chose an option and how they made their decision, many respondents cited that there is too much uncertainty present in the forecast at this lead time in all three scenarios and that the forecast could still change. However, for scenario three, a few more respondents said that they decided to bring less than 10 people on staff for the winter storm because their town was in the 2-4” range on the snow forecast map. Respondents’ confidence level with their decision was generally about the same for all three scenarios at this lead time with a mean of around 81% for all three (Figure 6).

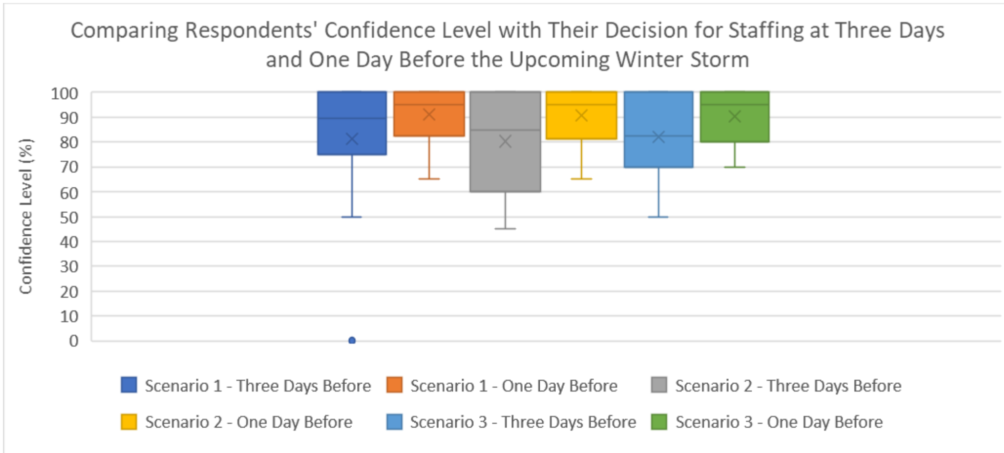



**Figure 6.** Results from the non-meteorologist survey presented with a box and whiskers plot comparing respondents' confidence level with their staffing decision for all three scenarios both three days and one day before an upcoming winter storm.

Respondents were also asked to say if they understood the graphic that was presented to them three days before the upcoming winter storm and if they found it useful when making their staffing decision. Most non-meteorologists understood both the risk probability graphics, with slightly more understanding the blue gradient color scheme graphic used in scenario 2, and the highest level of understanding was with the snow map (Figure 7).

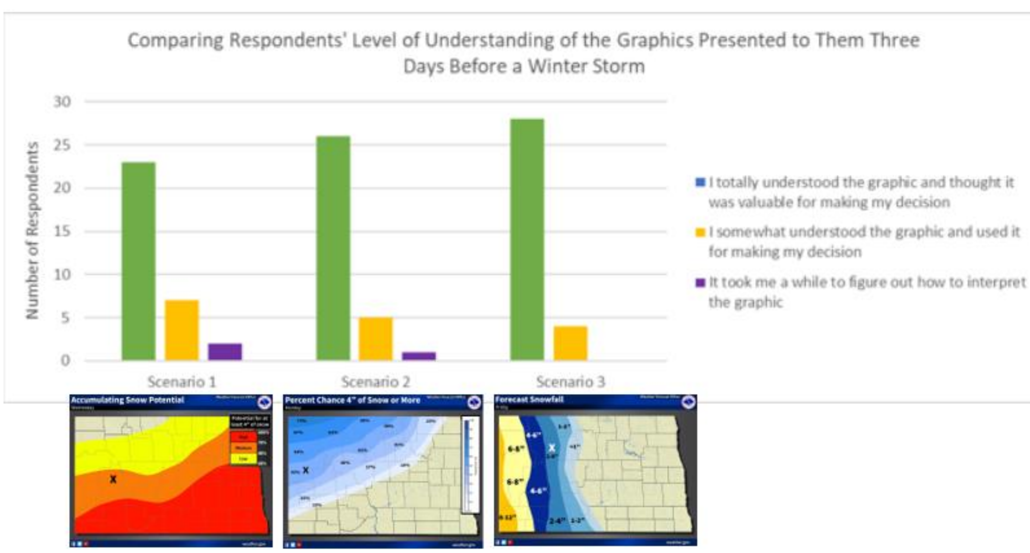



**Figure 7.** Results from the non-meteorologist survey presented with a bar graph comparing respondents' level of understanding of the graphics presented to them in the scenarios three days before an upcoming winter storm. Graphics that were presented in the survey for each scenario are included in this figure for easy reference. See Appendix B for the full-size graphics.

When providing a forecast update one day before the winter storm, respondents' decisions changed drastically to strongly favor the more than 10 people staffing option, with more than 90% of respondents selecting this option, as the snow map presented in all three scenarios showed the respondents' town in the 4-6" contour (Figure 8). When asked to provide the reasoning behind their decision, many respondents said that the forecast is much more reliable at this lead time and the fact that the graphic now clearly indicates more than 4" of snow is expected in their town. Respondents' confidence level with their staffing decision also increased compared to their confidence level three days before the winter storm, with a mean confidence level of approximately 91% for all three scenarios (Figure 6).

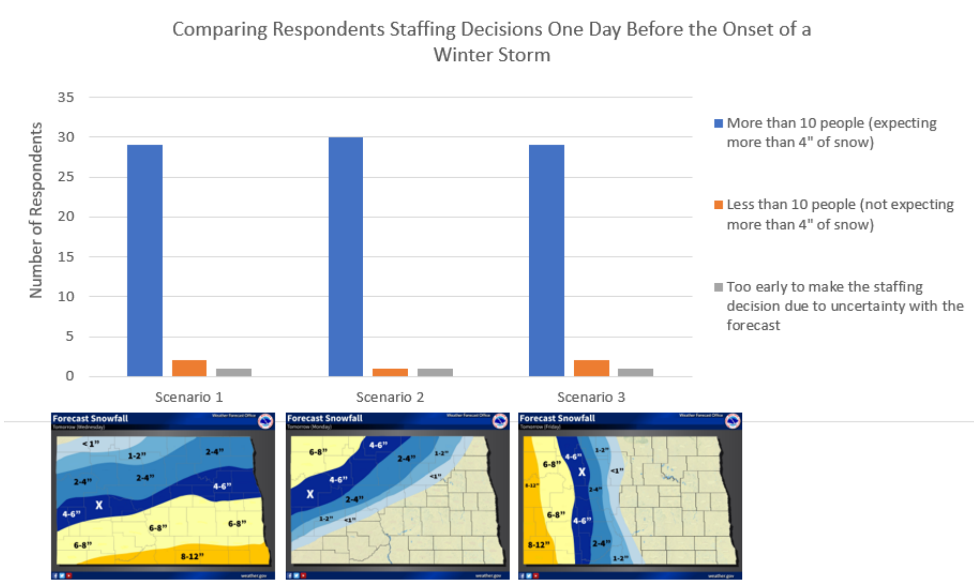



**Figure 8.** Results from the non-meteorologist survey presented with a bar graph comparing respondents' staffing decisions using the graphic in each scenario presented to them one day before an upcoming winter storm. Graphics that were presented in the survey for each scenario are included in this figure for easy reference. See Appendix B for the full-size graphics.

Finally, the last few questions of the survey addressed graphics used to communicate winter storms at a variety of lead times. When asked which graphic style they prefer several days, usually three through seven days, before a winter storm to communicate this upcoming storm threat, 41% chose the graphic style that circles one or more areas on a map that have the potential for accumulating snow (Table 2). However, many non-meteorologists also selected the "what we know"/"what we don't know" graphic style as well as the graphic style that uses the track of the storm to communicate the timing and impact area as their preferred graphic style (Table 2). When asked about what title should be used for the risk probability graphics, 47% chose the option that uses the word "probability" in the title (Table 2). And when asked how they will interpret the circled area of uncertainty that they were theoretically located in, 66% said they will check back for forecast updates to see if anything has changed and 50% of respondents said they will prepare for higher snowfall amounts in case the forecast changes (Table 2).

### 4.3 Discussion

Non-meteorologists who work at NWS offices that were surveyed were able to understand the risk probability graphics presented to them three days before an upcoming winter storm and use them in their decision-making process for staffing. Additionally, when presented with the risk probability graphics in scenarios 1 and 2 three days before the winter storm, respondents were more likely to recognize the uncertainty that is present in the forecast at this lead time compared to when they were given a snow map three days before a winter storm. Therefore, respondents made better decisions with the risk probability graphics since they understand the uncertainty at this lead time instead of anchoring onto a deterministic forecast presented on the snow map, which could change. A deterministic snow map was used in scenario 3 for this survey to compare how respondents' answers would differ compared to when they were given probabilistic information on the risk probability graphics. Results from this survey indicate that the risk probability graphics are a valuable tool to communicate the uncertainty that is still present with a snow forecast before a snowfall forecast map should be issued.

Respondents of this survey showed a preference for the circled areas on a map for snow potential as an effective graphic style to communicate the threat of an upcoming winter storm at longer lead times, generally three through seven days before a winter storm. This is consistent with the preference among NWS meteorologists as well, with 41% of respondents in the meteorologist survey and 38% in the non-meteorologist survey choosing this as the best graphic style (Tables 1 & 2). However, in both surveys the distribution of respondents was spread out among multiple different graphic types likely indicating that a variety of graphic styles should be used at this lead time and vary based on the specific winter storm type and situation.

The non-meteorologists that were surveyed preferred using the word “probability” in the title of the risk probability graphics, which is different from the strong preference that meteorologists had towards using the word “potential” in the title of these graphics. Future work should explore if non-meteorologists understand the terms that can potentially be used in the titles of these graphics correctly before a recommendation can be made to use the word probability, or any of the other word choices, in the title of these graphics.

Finally, non-meteorologists seemed to understand and like the circled area of uncertainty on snowfall forecast maps as 68% of them said that if they lived in a circled area of uncertainty, they would check back for forecast updates to see if anything has changed (Table 2). This agrees with the 73% of meteorologists who thought that users would understand the circled area of uncertainty on snowfall forecast maps. These results suggest that the circled area of uncertainty on snow maps should continue to be used and more NWS offices should adopt this practice when it is deemed necessary, as this additional piece of forecast information is helpful for users.

# Chapter 5

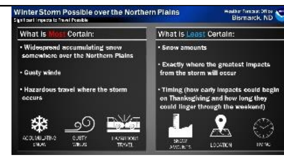
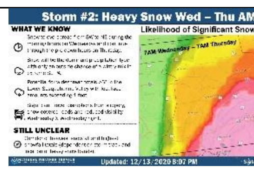
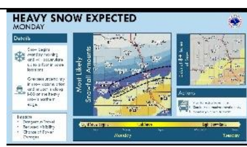
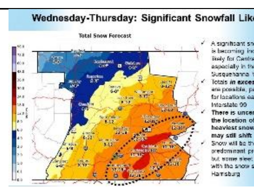
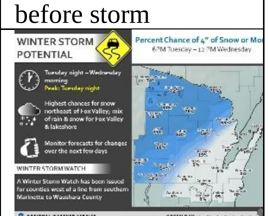
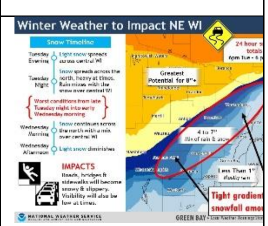
# Survey Research Completed with the 833 Members of the Public Across the U.S.

## 5.1 Methods

The survey for the public was designed to complement the previous surveys conducted as a part of this research project. Its goal was to achieve a much larger sample size than the previous surveys and include a wider spectrum of respondents. This survey will provide insight into how the public interprets probabilistic and uncertainty-driven winter weather forecast information, as respondents were asked about their preferences for different graphical styles and elements at all lead times before a winter storm as well as how easy specific graphics are to interpret. The survey also included questions to determine how well people think specific graphics communicate the uncertainty that was present in the forecast.

To accomplish these goals while also keeping the survey at a reasonable length (~10 minutes to complete) four scenarios were created, and respondents were randomly placed in one of them by the survey software. This created in a fairly even distribution of respondents for each scenario. Within each scenario, a series of graphics used to message winter storms that were posted to Twitter and Facebook by NWS offices during the 2019-2020 or 2020-21 winter seasons were presented to respondents individually with a series of questions asked about each graphic. Sequences of three or four graphics were selected based on the types of graphics used to message the upcoming winter storm, with the goal to include as many different types of graphic styles at the long-range lead time and as many different types of risk probability graphics in the survey. Additionally, for the aspect of communicating uncertainty on snowfall forecast maps, graphic sequences were selected to get the public's feedback on how circled areas of uncertainty were used on snow maps. Based on these objectives, a series of graphics used by NWS Omaha from January 22-24, 2021 to communicate an upcoming winter storm were used as the first scenario in this survey (Table 3). A series of graphics used by NWS State College from December 15-17, 2020 were used as the second scenario in this survey, a series of graphics used by NWS Bismarck from November 24-28, 2019 were used as the third scenario in this survey, and a series of graphics used by NWS Green Bay from November 23-25, 2019 were used as the fourth scenario in this survey (Table 3). Many of the same questions were asked across all four scenarios to allow for easy comparison of the results.

**Table 3.** Sequence of graphics presented to respondents in each of the four scenarios for the survey of the U.S. public. The date that these graphics were posted to social media by their respective NWS office is listed as well as how many days this was before the upcoming winter storm would impact the area. Four graphics were presented to respondents in the NWS Omaha, NWS State College, and NWS Green Bay scenarios. Three graphics were presented to respondents in the NWS Bismarck scenario. For the full-size graphics, see Appendix C – the figure numbers are indicated on this table for each graphic.

| | **Scenario #1 – NWS Omaha** | **Scenario #2 – NWS State College** | **Scenario #3 – NWS Bismarck** | **Scenario #4 – NWS Green Bay** |
|---|---|---|---|---|
| **First Graphic Presen-ted** |   (Figure 67) Posted 1/22/21 – three days before storm |   (Figure 72) Posted 12/11/20 – five days before storm |   (Figure 77) Posted 11/24/19 – five days before storm |   (Figure 81) Posted 11/23/19 – three days before storm |
| **Second Graphic Presen-ted** |   (Figure 68) Posted 1/23/21 – two days before storm |   (Figure 73) Posted 12/13/20 – three days before storm |   (Figure 78) Posted 11/27/19 – two days before storm |   (Figure 82) Posted 11/24/19 – two days before storm |
| **Third Graphic Presen-ted** |   (Figure 70) Posted 1/23/21 – two days before storm |   (Figure 75) Posted 12/14/20 – two days before storm |   (Figure 80) Posted 11/28/19 – one day before storm |   (Figure 83) Posted 11/24/19 – two days before storm |
| **Fouth Graphic Presen-ted** |   (Figure 71) Posted 1/24/21 – one day before storm |   (Figure 76) Posted 12/15/20 – one day before storm | |   (Figure 85) Posted 11/25/19 – one day before storm |

Before survey respondents went through the scenario assigned to them in the survey, they answered several general background questions to gain insight into their demographics, if they are a meteorologist or not, where do they get their weather information, and what types of forecast information they think are most important. Eight questions were a part of this section of the survey, six of which were multiple choice, one where a number had to be entered into a text box, and one where respondents had to rank the order of several different choices.

After the preliminary questions, the respondents began responding to their randomly assigned scenario where they had to imagine they lived in their assigned region where the forecast information was being given. Nine or ten questions were asked in each of these scenarios, most of which were multiple choice where respondents had to select a number from 0 to 10 (Figure 66). One question in each scenario asked respondents to enter a number into a text box and there were a few "heat map" questions in each scenario where respondents had to click on a part of a graphic that was presented to them based on their opinion.

Finally, respondents answered five final questions that addressed their preferences about the long-range graphic styles, risk probability graphic color schemes, using the circled area of uncertainty on snow maps, and using probabilistic snowfall ranges on snow maps. Some of these questions were the same or very similar to questions asked in the previous surveys of this thesis allowing for comparison of the results.

In total, this survey consisted of 54 questions, but due to the random assignment of only one of the scenarios, respondents only saw 22 or 23 questions total, depending on the scenario they were given. All questions did not force a response, but all requested one by popping a message up on the screen if someone did not answer a particular question. However, the respondents could close this message and skip over questions if they wanted to. People who were under the age of 18 or who were not current residents in the United States could not fill out this survey. This survey was created on the Qualtrics survey creator website, utilizing my secure Penn State login credentials to create the survey and access the survey results.

This survey was granted approval by the Penn State Institutional Review Board on March 10, 2021 and distribution of the survey occurred through an anonymous survey link where no personal information, including the respondent's IP address, was collected. This link was posted to my personal social media accounts and personal contacts also helped to distribute this survey to a wider audience through social media or personal emails. The survey was also shared by NWS State College on their social media platforms. Additionally, I talked about my overall research project on WeatherWorld, a 15-minute weather magazine show that airs across Pennsylvania weekdays, and asked viewers to fill out this survey. Responses were collected from March 10 through April 1, 2021, with 833 people completing the survey.

### 5.2 Results of General Questions of the Survey

Analyzing the demographics of those who completed this survey, a wide range of ages was reached, with a skew towards the older age ranges, and responses from 38 of the 50 United States were collected, plus few responses from Washington D.C. (Figures 9 and 10). Not surprisingly, 61% of the responses came from the state of Pennsylvania, where the most effort was focused on distributing the survey (Figure 10). 85% of respondents did not have a background in meteorology, which achieved the goal of this survey to reach as many non-meteorologists in the public as possible (Table 4). Out of the 85% of non-meteorologists who completed the survey, 53% considered themselves to be weather enthusiasts - defined as looking at the weather and forecasts rather closely each day (Table 4).

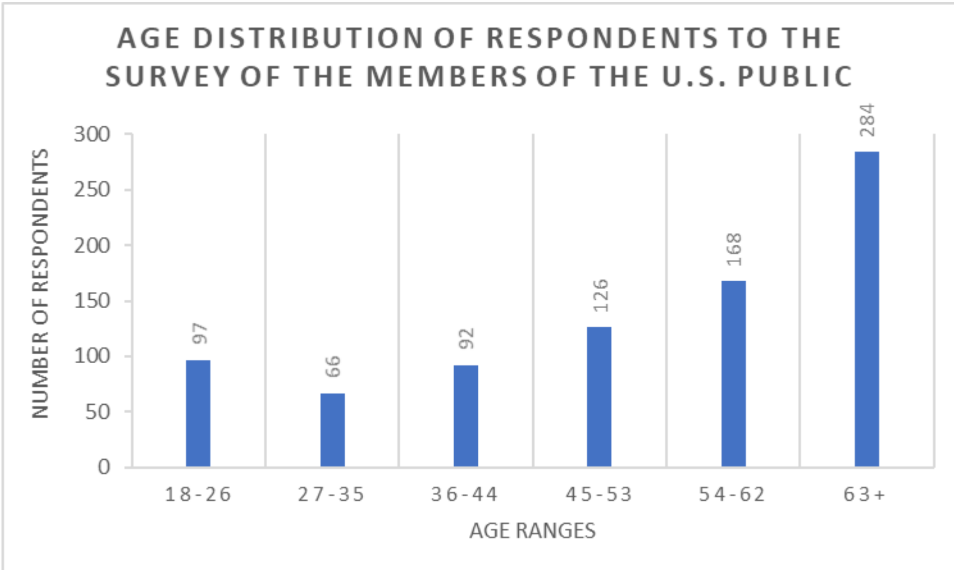



**Figure 9.** Age distribution of the 833 members of the public across the U.S. who completed the survey presented as a bar graph with the number of respondents for each age range shown.

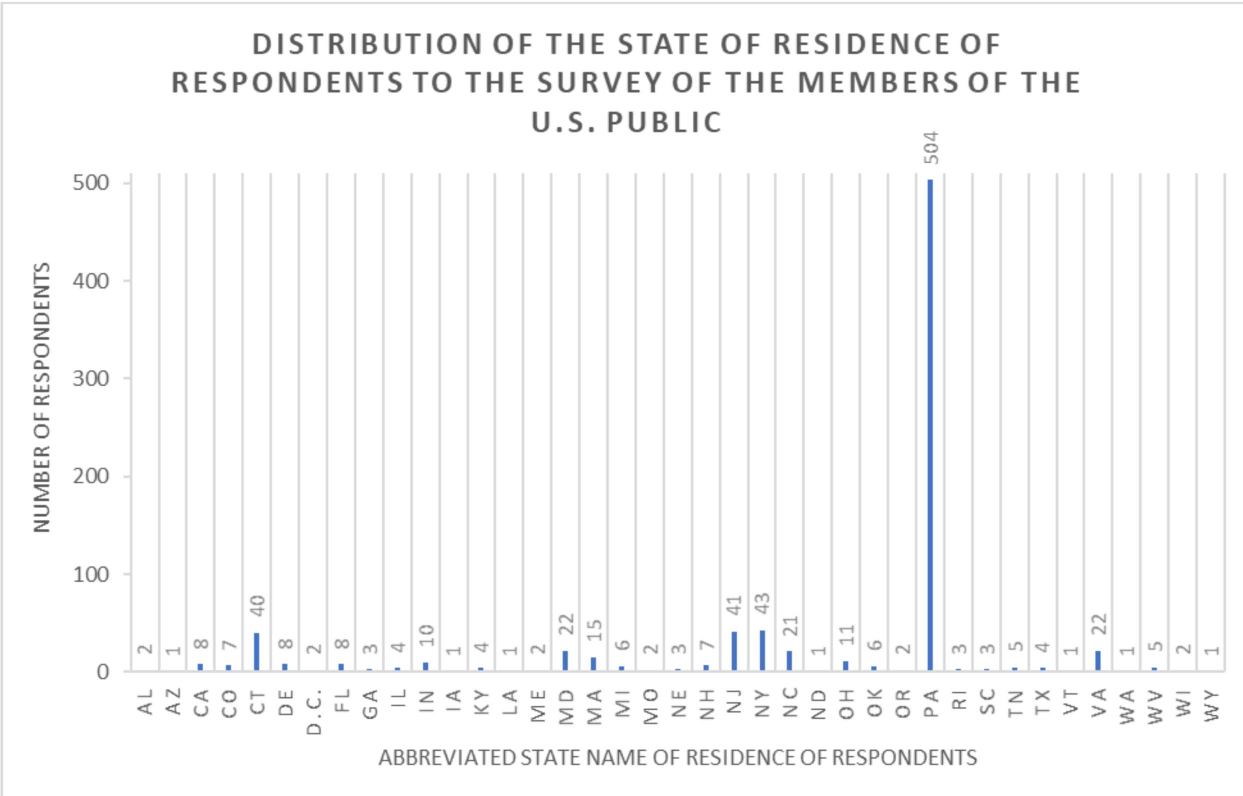



**Figure 10.** Distribution of the state of residence of respondents to the survey of the 833 members of the U.S. public presented as a bar graph with the number of respondents for each state shown.

Additionally, 87% of all respondents had experienced at least five winter storms within the past 10 years, which meant that most respondents knew how winter storms were usually communicated to the public and therefore could provide some useful feedback on the graphics that are used to do so throughout the rest of this survey (Table 4). There was a wide range in the source of weather information that respondents primarily rely on in the winter, with 29% of respondents saying that the NWS was their primary source of weather information (Table 4). Most likely, this meant that some respondents were familiar with some of the graphics presented throughout this survey that NWS offices used to communicate winter storms, while others who primarily rely on other sources of weather information besides the NWS might be familiar with a different way of communicating winter weather information. Hence, for some respondents, they were probably seeing some of the graphic styles presented in this survey for the first time, forcing them to interpret the graphics and some questions in this survey checked their understanding of the graphics.

**Table 4.** Results from some of the multiple-choice questions asked of the public (833 respondents total). Refer to Appendix C for full questions, option choices, and answers as they were shown on the survey. The questions are in the first column with the options and the number of respondents for each option in the other columns of this table.

| Question | Options for Each Question and Number of Respondents for Each Option | | | | | | |
|---|---|---|---|---|---|---|---|
| Q2 – Do You Have a Background in Meteorology | Yes | No | No, but I consider myself a weather enthusiast | | | | |
| | **122** | **333** | **378** | | | | |
| Q3 – Are You A Partner of the NWS? | No | Emergency Manager Partner | Department of Transportation Partner | School/ University Partner | Health-care Partner | Other NWS Partner | |
| | **791** | **10** | **1** | **9** | **1** | **21** | |
| Q4 – Prior Winter Storms Experienced | More Than 5 | A Few (2 to 5) | One or Less | | | | |
| | **722** | **101** | **10** | | | | |
| Q6 – Primary Weather Information Source During the Winter | NWS | Broadcast Meteor-ologists | Phone Weather Apps | Newspaper | Radio | Other Online Websites | Other Sources on Social Media |
| | **245** | **243** | **176** | **3** | **4** | **115** | **47** |
| Q52 – How Do You Interpret the Circled Area of Uncertainty on Snow Maps If You Live Within It (select all that apply) | Check the forecast again before the storm starts to see if anything has changed | Prepare for higher snowfall amounts in case the forecast changes | Actions do not change compared to if I lived in an area that was not circled | I do not understand what the circled area means | Other (type your own response) | | |
| | **627** | **381** | **45** | **11** | **32** | | |

42 responses were collected from people who are partners of the NWS, such as emergency managers and Department of Transportation members who receive forecast information from the NWS, and it was helpful to isolate their responses from the rest of the sample size (Table 4).

Respondents were also asked to rank six types of forecast information (precipitation onset time, timing of heaviest snowfall, wind speeds/power outage potential, snowfall totals, travel impacts, and amount of confidence/uncertainty in forecast) in terms of importance to them before a winter storm with rank 1 being the most important to them and rank 6 being least important. 38% of respondents ranked snowfall totals as the most important piece of forecast information to them before a winter storm, with another 21% of respondents saying that knowing the amount of confidence or uncertainty with the forecast was most important to them before a winter storm (Figure 11). Precipitation onset time was also a type of forecast information that respondents wanted to know about before a winter storm, receiving about 20-25% of the responses for ranks 1 through 3 (Figure 11). The timing of the heaviest snowfall seemed to be somewhat important to respondents, as about 24% of respondents placed this type of forecast information as either their third or fourth most important (Figure 11). Information about travel impacts, wind speeds, and the potential for power outages was deemed as highly important by many respondents, with these types of forecast information mostly being ranked as the 5$^{th}$ or 6$^{th}$ most important (Figure 11).

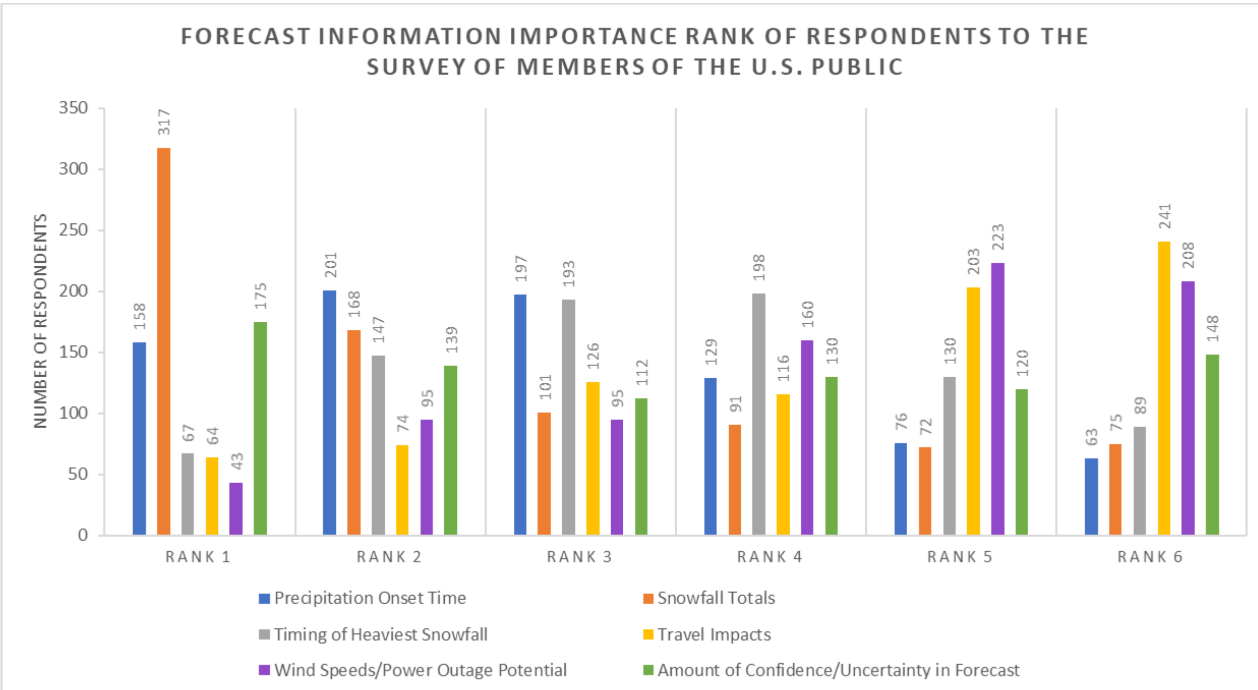


**Figure 11.** Results from question 8 of the survey of the U.S. public presented as a bar graph comparing how respondents ranked types of forecast information based on how important they deemed they are to them before a winter storm. 824 people answered this question.

When respondents were asked how they will interpret the circled area of uncertainty that they were theoretically located within for Question 52 of this survey (Figure 65), 75% said they will check back for forecast updates to see if anything has changed and 46% of respondents said they will prepare for higher snowfall amounts in case the forecast changes (Table 4). Only 5% of respondents said that their actions would not change compared to if they lived in an area that was not circled and only 1% of respondents did not understand what the circled area means (Table 4).

A question was included on this survey to determine respondents' preference towards the graphic styles used to communicate winter storms in the long-range, similar to how this question was asked of the meteorologist and non-meteorologists who work at NWS offices. Of the people who responded to this survey, 38% preferred the graphic style that used the track of the low-pressure system to communicate the timing of the storm and the impact area (Figure 12).

Additionally, 26% of respondents preferred the graphic style that circles one or more areas on a map for snowfall potential (Figure 12). Fewer respondents chose the more text-based graphic styles, including the timeline graphic where the potential for snow was highlighted and the graphic that lists out what is known as well as what is unknown about the forecast (Figure 12).

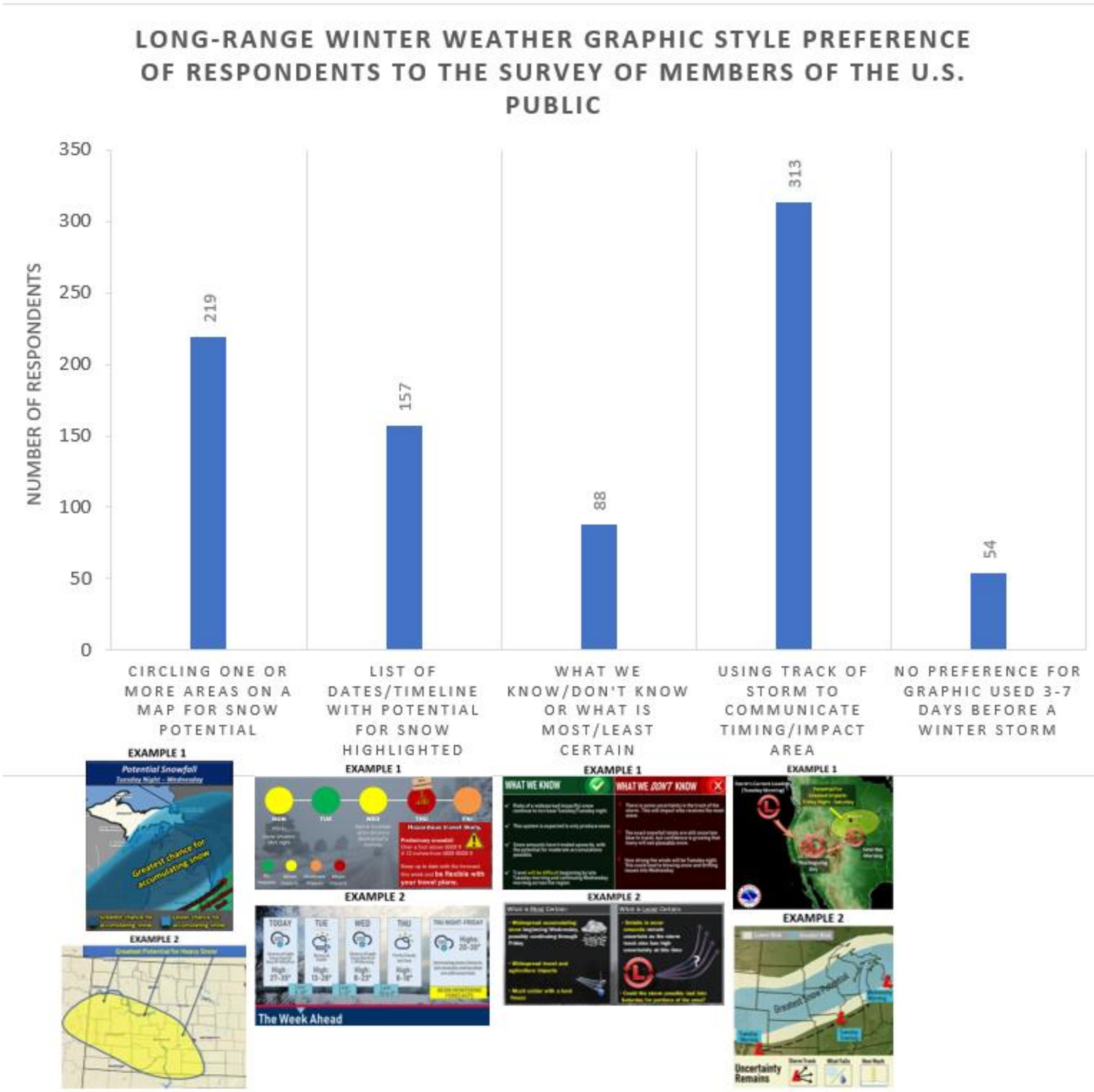



**Figure 12.** Results from question 50 of the survey of the U.S. public presented as a bar graph comparing respondents' preference towards the variety of graphic styles used to communicate winter storms at the long-range lead time. 831 people answered this multiple-choice question. The example graphics that were presented in the survey for each option are included in this figure for easy reference. See Appendix C for the full-size graphics.

Question 51 of this survey was included to determine if a certain color scheme was preferred among the public to be used on the risk probability graphics, otherwise known as probability of exceedance graphics. Respondents were presented with five of the most common color schemes used for this type of graphic by NWS offices and the WPC, including ones that had probability percentages plotted at each location on the map and ones that did not.

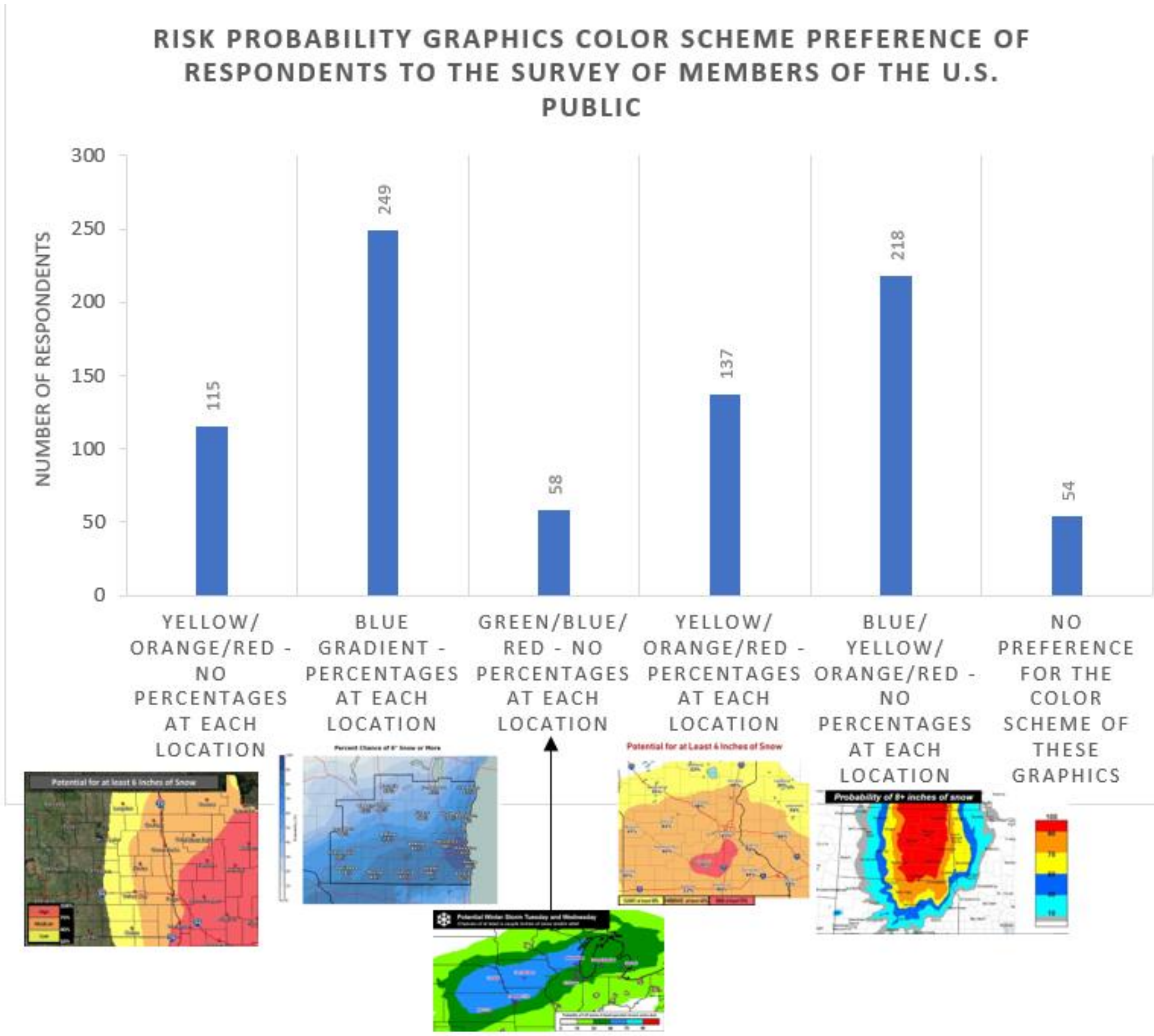



**Figure 13.** Results from question 51 of the survey of the U.S. public presented as a bar graph comparing respondents' preference towards the variety of color schemes used on risk probability graphics. 831 people answered this multiple-choice question. The example graphics that were presented in the survey for each option are included in this figure for easy reference. See Appendix C for the full-size graphics.

30% of respondents preferred the blue gradient color scheme that had probability percentages plotted at each location on the map (Figure 13). Additionally, 26% of respondents thought that the blue/yellow/orange/red color scheme was the best to be used for this type of graphic (Figure 13). Fewer people selected the yellow/orange/red color scheme, either with probability percentages on the map or not, and only 7% of respondents thought the green/blue/red color scheme was the best one to use for this type of graphic (Figure 13).

Meteorologists at NWS offices can use probabilistic snowfall ranges when creating snow maps, and one of their options is to use the $25^{th}$ to $75^{th}$ percentile range of snowfall amounts on the snow map. This involves taking a distribution of possible snowfall amounts for a point location and using the $25^{th}$ and $75^{th}$ percentile values of this distribution as the lower and upper bounds of the snowfall forecast that is displayed at each point location on the snow map. The shaded region in Figure 14 demonstrates this concept, as the snowfall prediction values that fall within this region would be included within the $25^{th}$ to $75^{th}$ percentile snowfall forecast range. This allows the range that is displayed on the snow map at each point location to be centered on the median of the distribution of possible snowfall amounts.

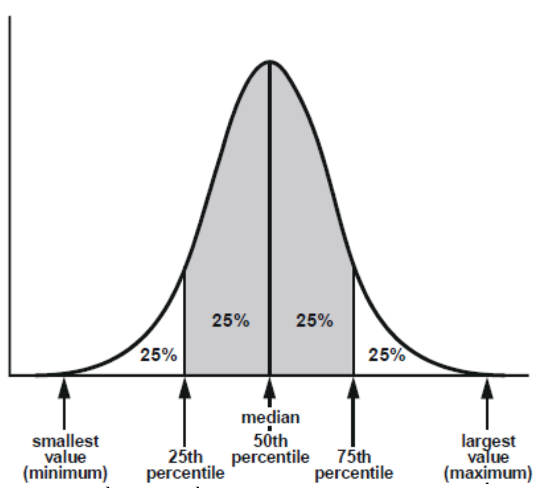



**Figure 14.** An illustration of the $25^{th}$ to $75^{th}$ percentile range of a normal distribution, highlighted by the shaded region under the curve.

Respondents were presented with two different snowfall forecast maps, one that utilized the 25$^{th}$ to 75$^{th}$ percentile ranges and one that used the standard NWS color table snowfall ranges (such as 3-4”, 4-6”, 8-12”, etc.). With the standard NWS ranges, if the forecast for a point location is 12.5” for example, it will automatically be entered into the 12-18” range. This differs from the probabilistic snowfall ranges that would center its range on the median of the distribution of possible snowfall amounts, using a 10-15” snowfall range, for example, depending on the spread of the distribution. The two snow maps that were selected for this question had a distribution of snowfall amounts that was very similar, allowing respondents to compare the two and decide which one they preferred. 60% of respondents preferred the NWS color table snowfall ranges map, that had the smaller ranges on it, when asked to decide which snowfall map they preferred based solely on the difference in snowfall ranges (Figure 15). The other 40% said that the probabilistic snowfall ranges, presented to respondents as the graphic with the larger snowfall ranges, were better (Figure 15). Respondents were then presented with additional information about these graphics, saying that the larger snowfall ranges, the probabilistic ones, verify 50% of the time, whereas the smaller snowfall ranges, the NWS color table ones, verify 30% of the time. These statistics were provided by Phil Schumacher from NWS Sioux Falls. When presented with this information, an additional 5% of respondents selected the probabilistic snowfall ranges graphic as their preferred option, raising the overall amount of respondents for this option to 45% (Figure 15).

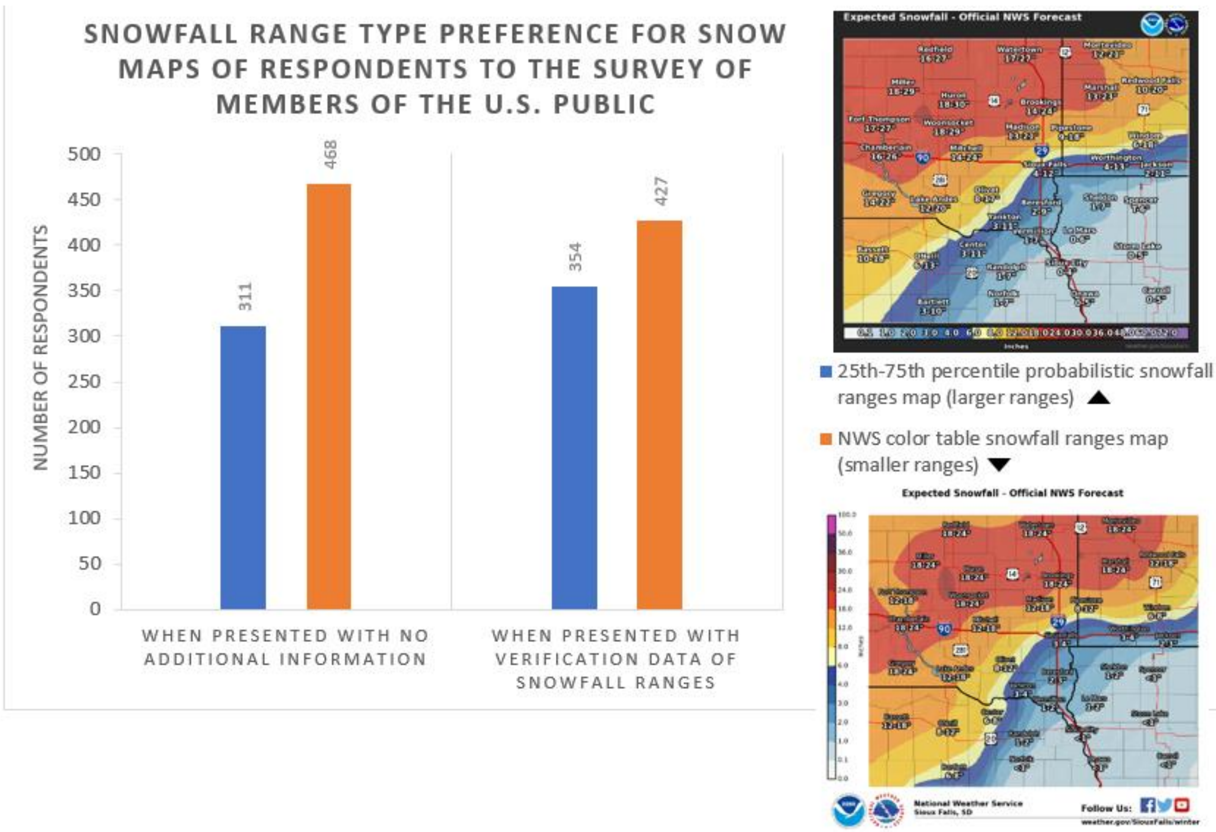



**Figure 15.** Results from questions 53 and 54 of the survey of the U.S. public presented as a bar graph comparing respondents' preference towards the type of snowfall ranges used on snowfall forecast maps (25$^{th}$ to 75$^{th}$ percentile probabilistic ranges or NWS color table ranges). 779 people answered question 53 and 781 people answered question 54. The graphics that were presented in the survey for each option are included in this figure for easy reference. See Appendix C for the full-size graphics.

### 5.3 Discussion of Results from the General Questions of the Survey

Overall, results from these selected questions of the survey that was distributed to the U.S. public indicate that many people value uncertainty-driven and probabilistic information given to them before a winter storm. When ranking the most important types of forecast information available to users before a winter storm, the second most respondents selected the amount of confidence or uncertainty in the forecast as their most important piece of forecast information that they want to know about. Snowfall totals were clearly the primary choice, indicating that most people want to see these forecasted snow amounts when they are available, but at longer lead times, before snowfall totals can be formulated and released, relying on uncertainty-driven and probabilistic information is important. Utilizing this information and releasing it to the public more frequently should be explored if people will interpret it correctly.

At longer lead times before a winter storm, 64% of respondents preferred either the graphic style that circles area(s) of snowfall potential on a map or the graphic style that uses the track of the storm to communicate the timing and impact area (Figure 12). The common thread between these top two choices is that they are both map-based, whereas the other two options to this question are more text-based graphics that communicate the threat of an upcoming winter storm. Map-based graphics might be preferred since they might be quicker to interpret for users as they are scrolling by them on their social media feed on their phone, whereas the text-based graphics will most likely take more time to read through and the text could be too small if people are viewing these graphics on their phones. As was noted in the other sections of this thesis, the graphic style used at longer lead times before a winter storm often depends on the specific storm setup and type, causing a variety of graphic styles to be used. Therefore, a variety of graphic styles should continue to be used based on the storm setup, however, based on the results from this survey, map-based options should be prioritized over fully text-based options.

When assessing the variety of color schemes that are used for risk probability graphics, the most respondents preferred the blue gradient color scheme with probability percentages plotted at each location on the map. This could indicate that people want to see and understand these percentages at each location on the map or it could signify that people just prefer the additional contours of the blue gradient color scheme, since the second most selected option from this question was the blue/yellow/orange/red color scheme with no percentages plotted at each location, an option that uses six color contours. A possible explanation for why these two color schemes were the most preferred is that it might be easier and quicker for users to figure out the probability of exceeding the snowfall amount listed on the graphic for their location when there are more color contours and/or the actual probability percentages plotted at each location. The other section of this survey will help gain some insight into if users understand these risk probability graphics.

When respondents were asked about their preference for the probabilistic snowfall ranges compared to the more commonly used NWS color table snowfall ranges, 40% selected the probabilistic snowfall ranges when given no explanation and then 45% selected this option when given the verification statistics of the snowfall range options. It should be noted that an extreme example of snowfall spreads was selected for the probabilistic snowfall map used in this question, with some snowfall ranges on the map spanning nine inches, such a 4-to-13-inch snowfall range for Worthington on the map (Figure 96). This means that the distribution of possible snowfall amounts was very spread out for this scenario with the 25$^{th}$ percentile and 75$^{th}$ percentile far apart from each other, indicating that the forecast was very uncertain. In many cases, the probabilistic snowfall ranges will be smaller with a forecast that has less uncertainty and could sometimes even be smaller than the NWS color table snowfall ranges. If a more average spread in snowfall ranges was selected for the probabilistic snowfall map, more people might have selected this option compared to the NWS color table snowfall ranges, especially when the verification statistics were explained to them. However, these survey results could be interpreted that even in an extreme case like this one, 45% of respondents preferred the larger, probabilistic ranges when given the verification statistics, possibly indicating that 25$^{th}$ to 75$^{th}$ percentile snowfall ranges should be used more often by NWS offices. Several respondents reached out with feedback based on this part of the survey, noting that in an extreme case like this one, very large snowfall ranges are not very helpful when trying to determine the impacts of the storm as a 4” snowstorm is going to have very different impacts compared to a 12” storm. Therefore, it might be best for NWS meteorologists to continue to use probability of exceedance graphics to discuss snowfall totals for an upcoming winter storm in this scenario where the forecast remains very uncertain instead of releasing a snowfall map with very large ranges. Once the distribution of possible snowfall amounts becomes less spread out, a snowfall map with probabilistic snow ranges can be used.

Additionally, when asked about their actions if respondents lived in a circled area of uncertainty on snowfall forecast maps, 75% of people said they would check the forecast again before the storm starts to see if anything has changed and almost half said they would prepare for higher snowfall amounts in case the forecast changes (Table 3). This indicates that this practice of circling regions of uncertainty on a snow map when there is a tight gradient or a great deal of uncertainty with forecast models is liked by the public since they will take actions if they live in the circled area and should be used by NWS offices when it is deemed necessary to do so.

Some filters were applied to the survey response data to determine if any possible biases occurred within this sample size based on a person’s demographics or background. When the meteorologists who filled out this survey were taken out from the pool of responses, all the distributions of responses remained practically the same for the questions that were just discussed. The same is true when Pennsylvania residents, those who primarily rely on the NWS for forecast information in the winter, and those who had not experienced more than five winter storms within the past ten years were each filtered out, allowing for the conclusions discussed throughout this section to hold true.

### 5.4 Results from the Four Scenarios of the Survey

The next section of this survey randomly placed respondents into one of four possible scenarios, with each scenario having a unique set of graphics that were actually used to communicate upcoming winter storms by four different NWS offices across the country.

#### 5.4.1 Long Range Graphics Used in the Survey

Five different types of long-range graphics were used in the scenarios. NWS Omaha used a graphic that had the track of the low-pressure system along with the timing of the storm and some additional text-based information on the graphic three days before an upcoming winter storm (Figure 67). NWS Bismarck used a "what is most certain" and "what is least certain" text-based graphic five days before a winter storm (Figure 77). NWS Green Bay using a map with a circled region of winter weather impacts and statements about "what we know" and "what we don't know" three days before a winter storm as well as a text-based graphic that includes confidence information two days before a winter storm (Figures 81 and 82). NWS State College used a probability of plowable snowfall graphic with a red/orange/yellow color scheme five days before an upcoming winter storm (Figure 72). This is an experimental graphic developed by NWS State College that just started to be used during the 2020-2021 winter season to communicate upcoming winter storms, four through seven days before the storm is expected to impact the area. It uses the WPC's probability of exceeding 0.25 inches of liquid equivalent of snow/sleet map and puts those probabilities into a three-tiered, red/orange/yellow color scheme similar to some of the risk probability graphics that were previously investigated with this research. Using a 10 to 1 snow to liquid ratio, this graphic would display the probability of exceeding 2.5 inches of snow, which NWS State College used the term “plowable” to define. Snow to liquid ratios can vary for each winter storm, which is one of the reasons why NWS State College chose to use a more generalized term instead of explicitly stating that this graphic provides the probability of exceeding 2.5 inches of snow throughout the forecast area. When all respondents were asked how many inches of snow they consider to be “plowable,” 61% said they interpreted it as 3 inches or 4 inches, while 14% interpreted it as meaning 2 inches of snow (Figure 16).

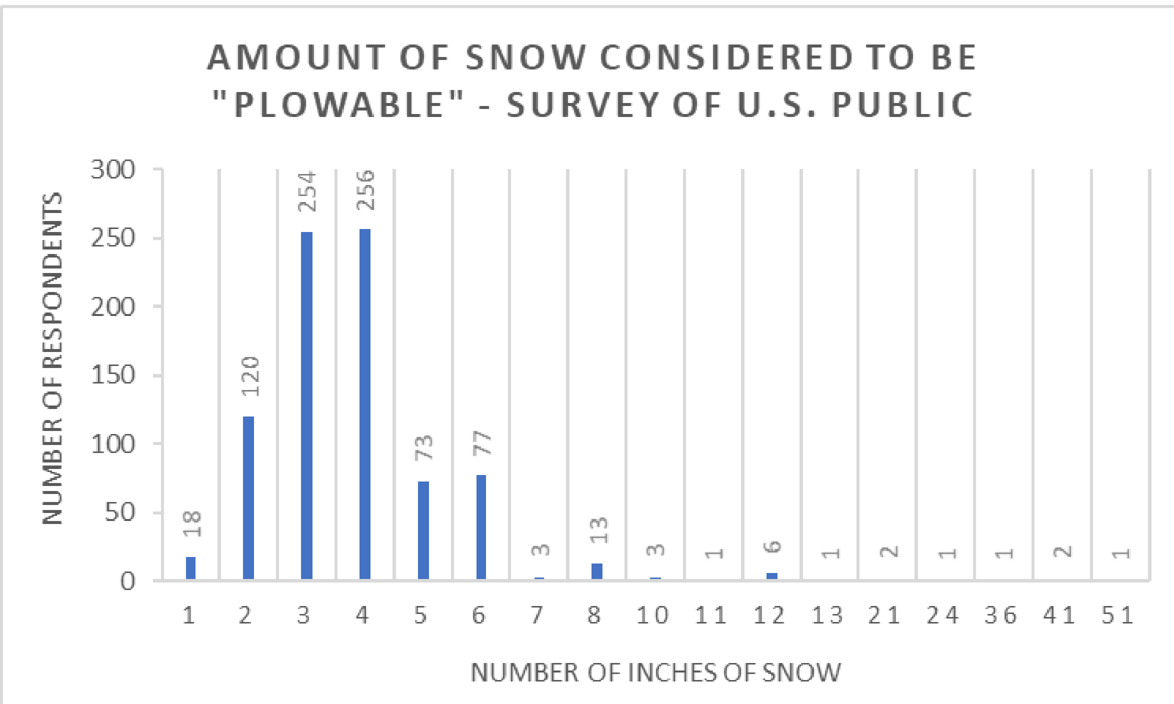



**Figure 16.** Results from question 7 of the survey of the U.S. public presented as a bar graph showing how many inches of snow people interpreted as meaning “plowable.” 832 people answered this question.

186 people answered questions in the NWS Omaha scenario, 214 people answered questions in the NWS State College scenario, 220 people answered questions in the NWS Bismarck scenario, and 213 people answered questions in the NWS Green Bay scenario.

For all five long-range graphics, respondents were asked "how easy is this graphic to interpret?" They were presented with numbers from zero through ten that they could choose from, with zero indicating that the graphic was not easy at all to interpret and ten indicating that the graphic was very easy to interpret. Respondents thought all five graphics were easy to interpret with all the mean scores at 6.8 or higher, but two of the map-based options, the probability of plowable snowfall graphic from NWS State College and the circled region of winter weather impacts graphic from NWS Green Bay had the highest scores, with a mean of eight or greater (Figure 17).

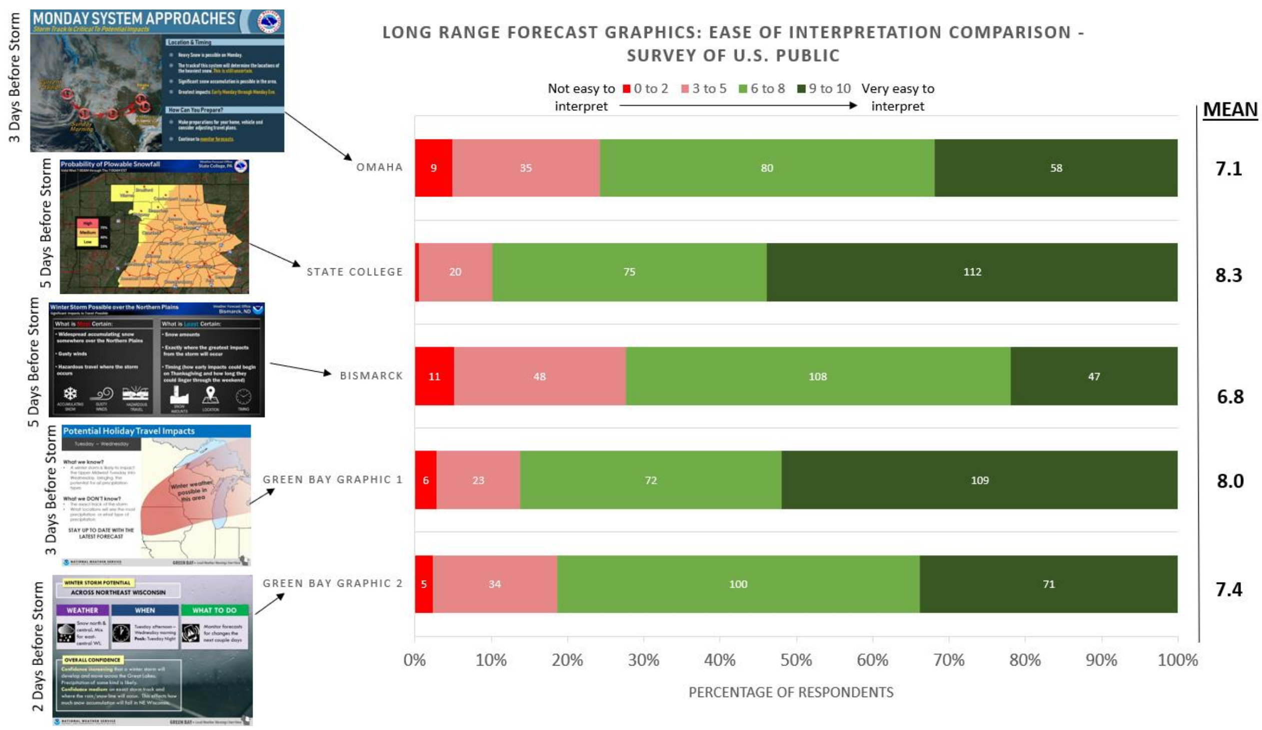



**Figure 17.** Results from the survey of the U.S. public comparing graphics used to communicate winter storms at longer lead times. Respondents ranked each graphic on a scale from zero to ten based on how easy it was to interpret, and results were grouped into four ranges – zero to two in dark red, three to five in light red, six to eight in light green, and nine to ten in dark green. The length of the bars corresponds to the percentage of the respondents that answered with a number within each range. The numbers on the bars corresponds to the amount of people that answered with a number within each range. The mean score for each graphic is also included. The graphics that were presented in the survey are included in this figure for easy reference. See Appendix C for the full-size graphics.

Additionally, for all five long-range graphics, respondents were asked "how well does this graphic communicate the uncertainty with the forecast?" They were again presented with numbers from zero through ten that they could choose from, with zero indicating that the graphic did not communicate the uncertainty well at all and ten indicating that the graphic communicated the uncertainty very well. Respondents thought that the NWS Green Bay text-based graphic that includes confidence information communicated the uncertainty with the forecast well, while the NWS State College probability of plowable snowfall graphic and the NWS Omaha graphic which uses the track of the low-pressure system to indicate the timing of the storm along with other text-based information did not do as good of a job communicating the uncertainty with the forecast at this lead time (Figure 18).

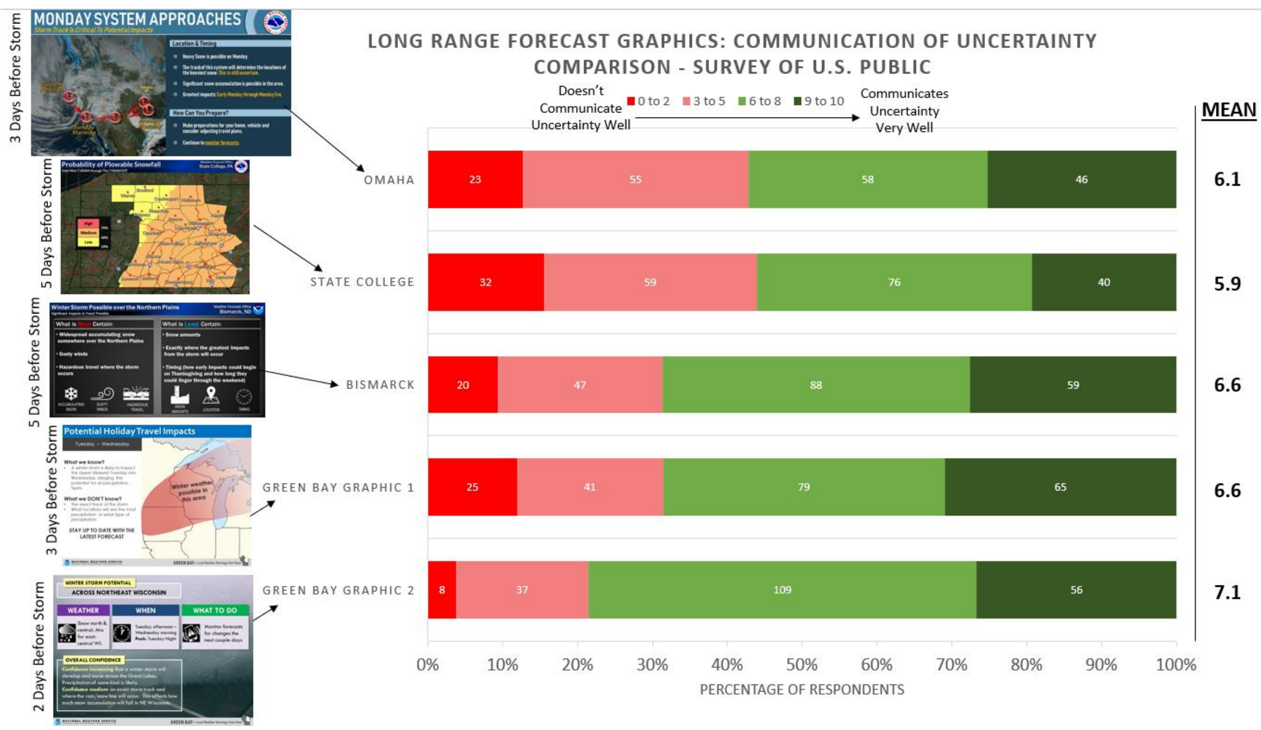



**Figure 18.** Results from the survey of the U.S. public comparing graphics used to communicate winter storms at longer lead times. Respondents ranked each graphic on a scale from zero to ten based on how well it communicated the uncertainty with the forecast, and results were grouped into four ranges – zero to two in dark red, three to five in light red, six to eight in light green, and nine to ten in dark green. The length of the bars corresponds to the percentage of the respondents

that answered with a number within each range. The numbers on the bars corresponds to the amount of people that answered with a number within each range. The mean score for each graphic is also included. The graphics that were presented in the survey are included in this figure for easy reference. See Appendix C for the full-size graphics.

Two of the long-range graphics were posted on social media five days before the upcoming winter storm by their respective offices, so a question was asked when presented with these graphics if the forecast information the graphics provided was useful to respondents at this lead time. Respondents were again presented with numbers from zero through ten that they could choose from, with zero indicating that the graphic was not useful at all at this lead time and ten indicating that the graphic was very useful at this lead time. Both graphics received a mean score of about six, indicating that each graphic was somewhat useful at this lead time (Figure 19).

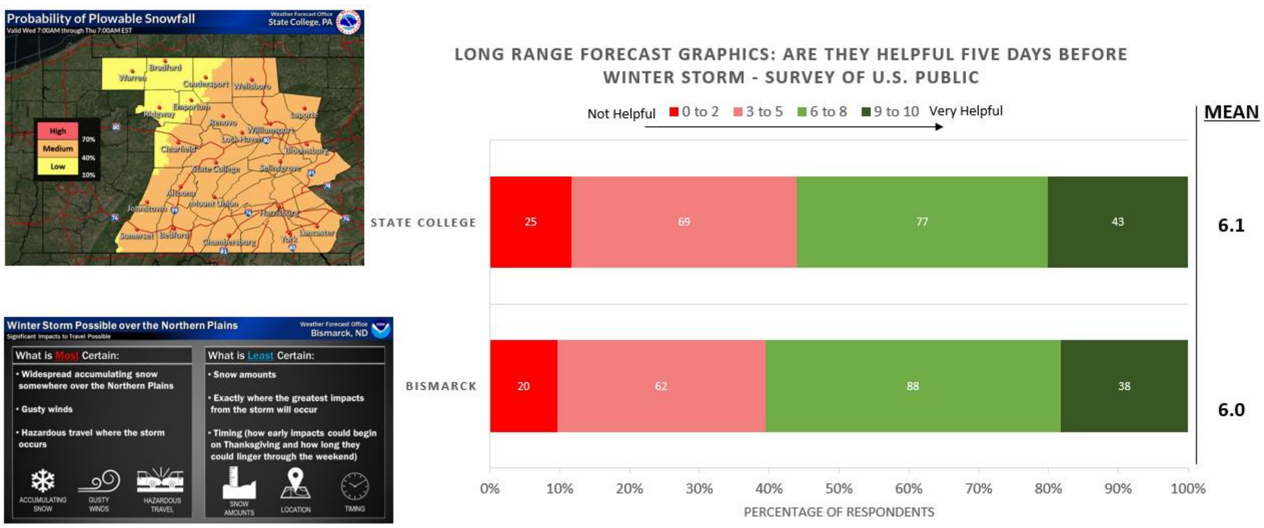



**Figure 19.** Results from the survey of the U.S. public comparing graphics used to communicate winter storms at longer lead times. Respondents ranked each graphic on a scale from zero to ten based on how helpful it was to them at this five-day lead time before the winter storm, and results were grouped into four ranges – zero to two in dark red, three to five in light red, six to eight in light green, and nine to ten in dark green. The length of the bars corresponds to the percentage of the respondents that answered with a number within each range. The numbers on the bars corresponds to the amount of people that answered with a number within each range. The mean score for each graphic is also included. The graphics that were presented in the survey are included in this figure for easy reference. See Appendix C for the full-size graphics.

Three of the long-range graphics were used as heat map questions, where respondents had to click on a part of the graphic that they thought provided them with the most important and helpful information. For the NWS Omaha graphic, many people thought the sentence talking about “how the track of the system will determine the locations of the heaviest snow which is still uncertain” was helpful and important (Figure 20a). Many other people thought that the statement of when the greatest impacts would be as well as the final position of the low-pressure system on the map were important and helpful (Figure 20a).  For the NWS Green Bay graphic, many people thought the statements about what type of weather is expected and when it will occur were the most important and helpful to them (Figure 20b). And for the NWS Bismarck graphic, there were a lot of different parts of the graphic that were selected, but many people thought that the statement and icon referring to widespread accumulating snow under the “what is certain” category was important and helpful (Figure 20c).

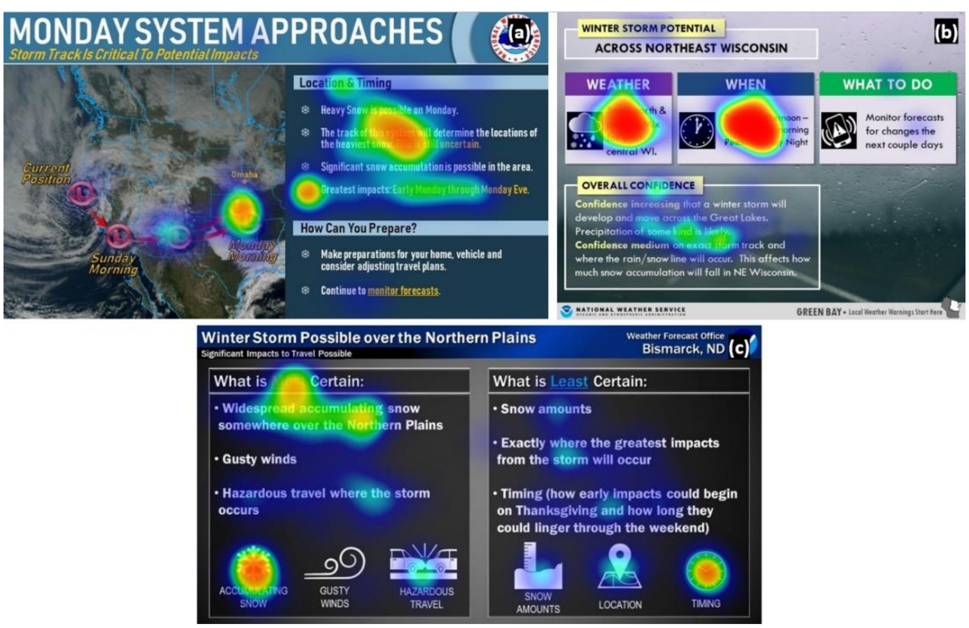



**Figure 20.** Results from the survey of the U.S. public comparing graphics used to communicate winter storms at longer lead times. Respondents chose what part of each graphic they thought provided them with the most important and helpful information, and results are displayed as a heat map with blue and green shadings indicating that not many people selected that part of the

graphic while red, orange, and yellow shadings indicate that many people selected that part of the graphic. (a) NWS Omaha graphic, (b) NWS Green Bay graphic #2, (c) NWS Bismarck graphic. See Appendix C for the full-size graphics

### 5.4.2 Risk Probability Graphics Used in Survey

For the risk probability graphics presented to respondents in each scenario, four different color schemes were used. NWS Omaha used a risk probability map with a red/orange/yellow color scheme and probability percentages plotted at each location, along with additional text-based information on the graphic (Figure 68). NWS State College used a green/yellow/orange/red/pink color scheme with no scale for the color scheme and additional text-based information on the graphic about what is known and what is still unclear (Figure 73). NWS Bismarck used a red/orange/yellow color scheme with no probability percentages plotted at each location with additional text-based timing information on the graphic (Figure 78). And NWS Green Bay used a blue gradient color scheme with probability percentages plotted at each location, along with additional text-based information on the graphic (Figure 83).

For all five long-range graphics, respondents were asked "how easy is this graphic to interpret?" They were presented with numbers from zero through ten that they could choose from, with zero indicating that the graphic was not easy at all to interpret and ten indicating that the graphic was very easy to interpret. Respondents thought that the NWS Bismarck red/orange/yellow color scheme risk probability map and the NWS Green Bay blue gradient color scheme risk probability map were the easiest to interpret, as both graphics received a mean answer of 8.2 (Figure 21). Respondents had a tough time interpreting the NWS State College risk probability map, as this graphic received a mean score of only 6.0 (Figure 21).

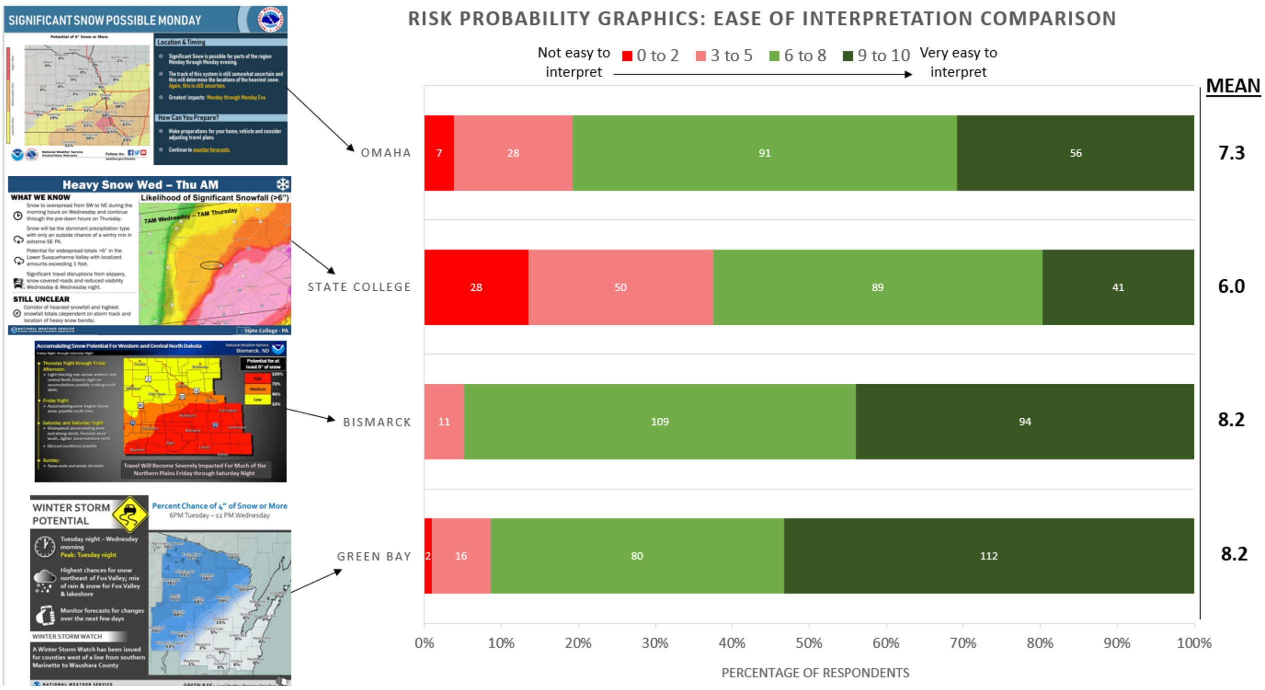


**Figure 21.** Results from the survey of the U.S. public comparing risk probability graphics (otherwise known as probability of exceedance graphics) used to communicate upcoming winter storms. Respondents ranked each graphic on a scale from zero to ten based on how easy it was to interpret, and results were grouped into four ranges – zero to two in dark red, three to five in light red, six to eight in light green, and nine to ten in dark green. The length of the bars corresponds to the percentage of the respondents that answered with a number within each range. The numbers on the bars corresponds to the amount of people that answered with a number within each range. The mean score for each graphic is also included. The graphics that were presented in the survey are included in this figure for easy reference. See Appendix C for the full-size graphics.

Additionally, for all four risk probability graphics, respondents were asked “how well does this graphic communicate the uncertainty with the forecast?” They were again presented with numbers from zero through ten that they could choose from, with zero indicating that the graphic did not communicate the uncertainty well at all and ten indicating that the graphic communicated the uncertainty very well. Respondents thought that the NWS Green Bay blue gradient risk probability map with probability percentages plotted at each location and the NWS Omaha red/orange/yellow risk probability map with probability percentages plotted at each location both communicated the uncertainty with the forecast the best, with mean scores of 7.3 and 6.7 respectively (Figure 22).

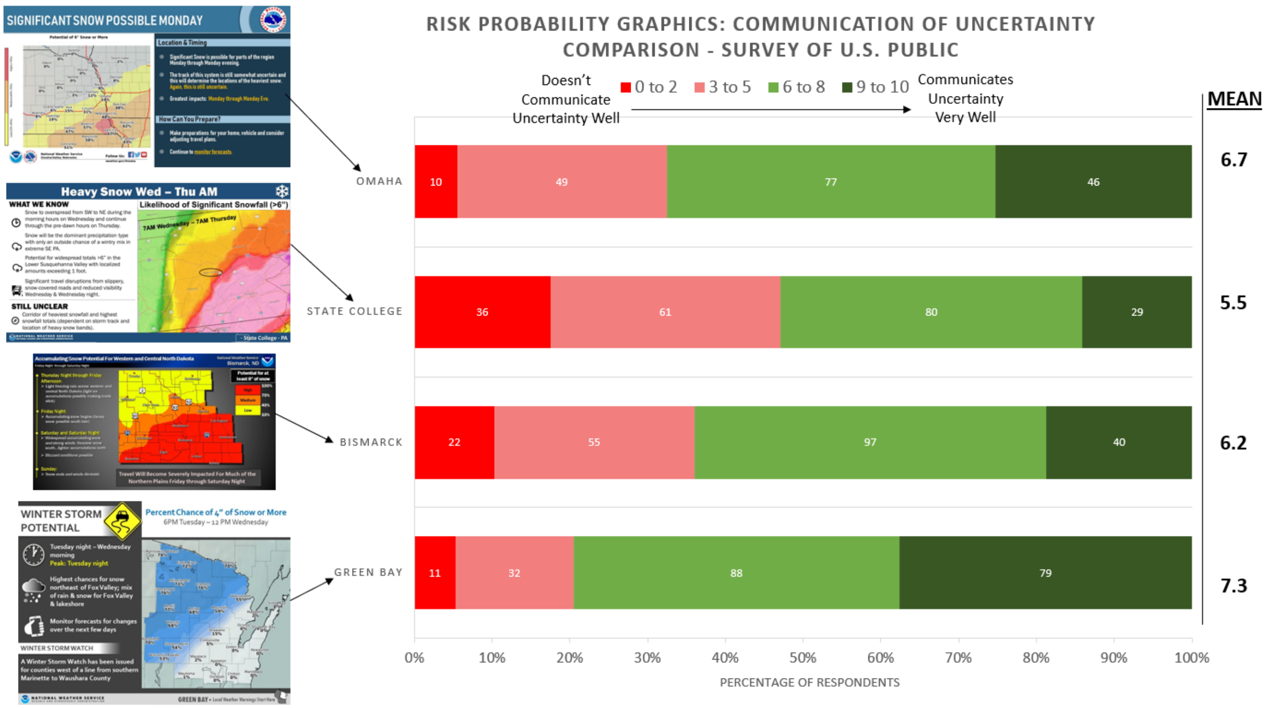



**Figure 22.** Results from the survey of the U.S. public comparing risk probability graphics (otherwise known as probability of exceedance graphics) used to communicate upcoming winter storms. Respondents ranked each graphic on a scale from zero to ten based on how well it communicated the uncertainty with the forecast, and results were grouped into four ranges – zero to two in dark red, three to five in light red, six to eight in light green, and nine to ten in dark green. The length of the bars corresponds to the percentage of the respondents that answered with a number within each range. The numbers on the bars corresponds to the amount of people that answered with a number within each range. The mean score for each graphic is also included. The graphics that were presented in the survey are included in this figure for easy reference. See Appendix C for the full-size graphics.

In each scenario, a city was circled on the risk probability graphic and respondents were asked to enter how much snow they thought the city would receive from the upcoming winter storm based on the information to them on the risk probability map. Cities were chosen to test respondents' understanding of the risk probability map, with some being selected with lower probabilities and others being selected with higher probabilities. For the NWS Omaha risk probability map, the city of Omaha was circled, which had a 19% probability of receiving six or more inches of snow at the time this graphic was released, which was two days before the winter storm. Omaha was also located within the yellow gradient of the three-tiered risk probability map, where probabilities range from 10% to 40%. 32% of respondents thought that Omaha would receive two inches of snow, with a mean answer of 3.3 inches (Figure 23).

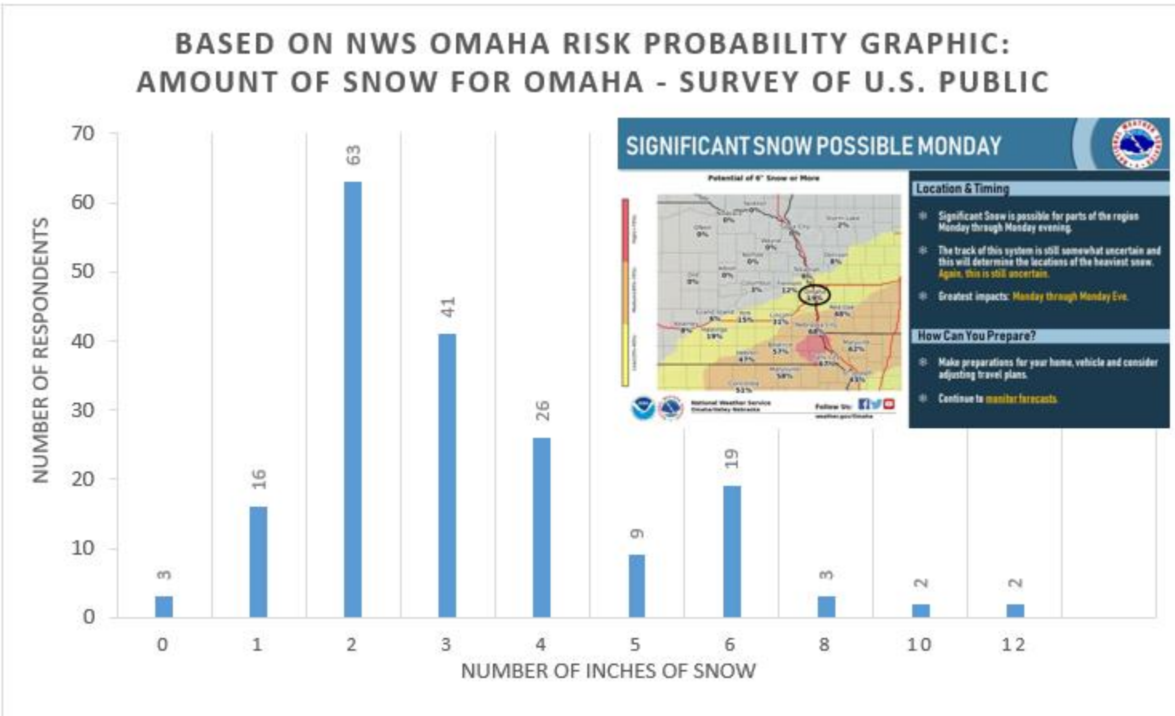



**Figure 23.** Distribution of the number of inches of snow that respondents thought Omaha would receive from this winter storm based on the risk probability graphic given to them which was released by NWS Omaha two days before the upcoming winter storm. The risk probability graphic is shown here for easy reference. See Figure 68 for the full-size graphic.

For the NWS State College risk probability map, the city of State College was circled and since no color scale was provided on this graphic it is hard to tell what probability percentage State College had at receiving six or more inches of snow. The location where the words “State College” are plotted on the map is on a region of a relatively tight gradient in colors, presumably meaning that there could be a sharp cutoff in snow amounts in this region. Based on other examples of color schemes where the red color usually indicates the higher amount or the greater risk, the green color most likely indicated the region where the probabilities of exceeding six inches of snow were lowest and the light red or pink color most likely indicated the region where the probabilities of exceeding six inches of snow were the greatest. The distribution of answers was much more spread out with the most respondents, at 31% indicating they thought State College would receive six inches of snow from this winter storm (Figure 24). The mean amount of snow that people thought State College would receive was 4.9 inches.

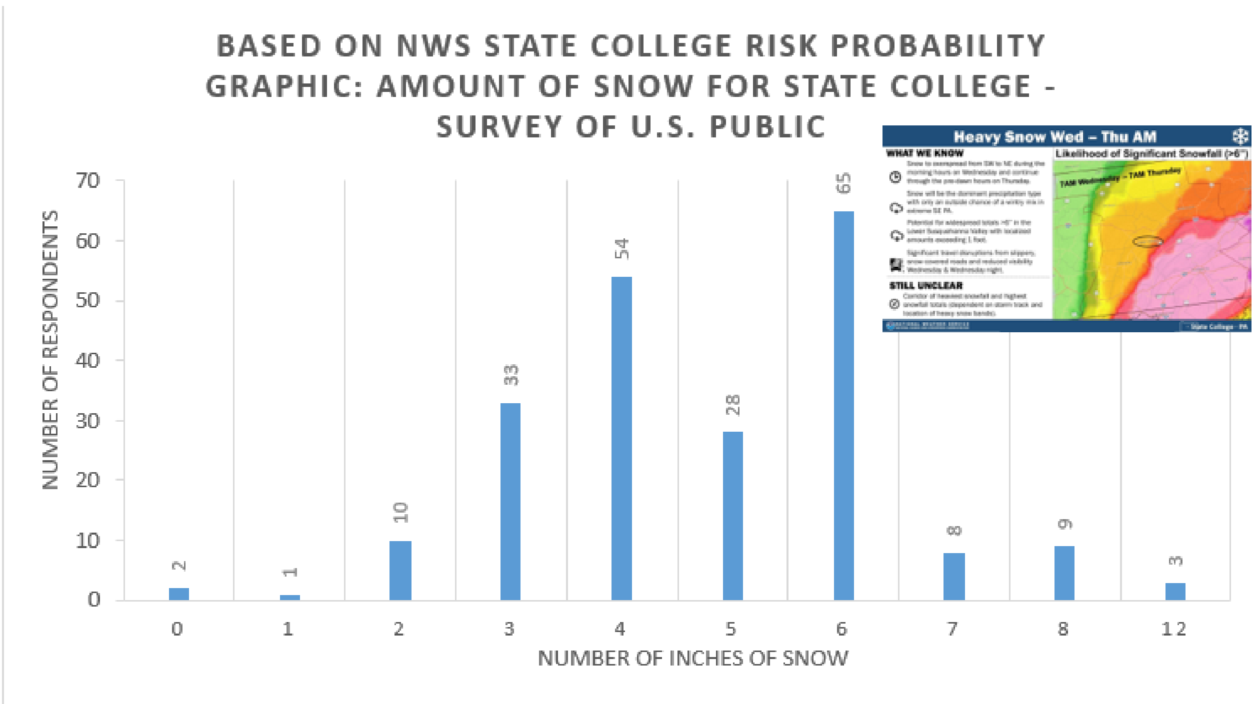



**Figure 24.** Distribution of the number of inches of snow that respondents thought State College would receive from this winter storm based on the risk probability graphic given to them which was released by NWS State College three days before the upcoming winter storm. The risk probability graphic is shown here for easy reference. See Figure 73 for the full-size graphic.

For the NWS Bismarck risk probability map, the city of Bismarck was circled, which was located within the 70% to 100% red contour of the risk probability map at the time this graphic was released two days before the winter storm. 68% of respondents thought that Bismarck would receive eight inches of snow, with a mean response of 8.6 inches (Figure 25).

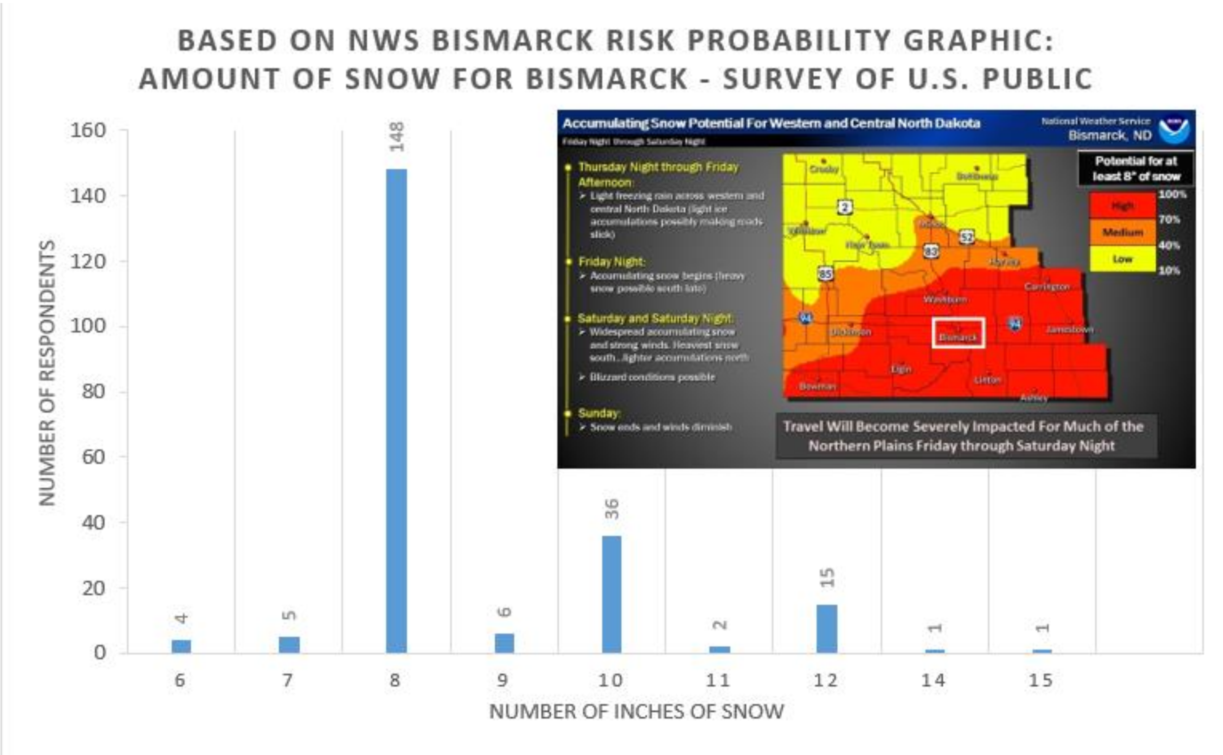



**Figure 25.** Distribution of the number of inches of snow that respondents thought Bismarck would receive from this winter storm based on the risk probability graphic given to them which was released by NWS Bismarck two days before the upcoming winter storm. The risk probability graphic is shown here for easy reference. See Figure 78 for the full-size graphic.

And for the NWS Green Bay risk probability map, the city of Wausaukee was circled which had a 55% probability of receiving six or more inches of snow at the time this graphic was released two days before the winter storm. Wausaukee was located along a tight gradient in the color scheme on this risk probability graphic, indicating that there could be a sharp cutoff in snowfall amounts with higher totals more likely to the west and lower totals more likely to the east. 32% of respondents thought that Omaha would receive two inches of snow, with a mean answer of 3.3 inches (Figure 26).

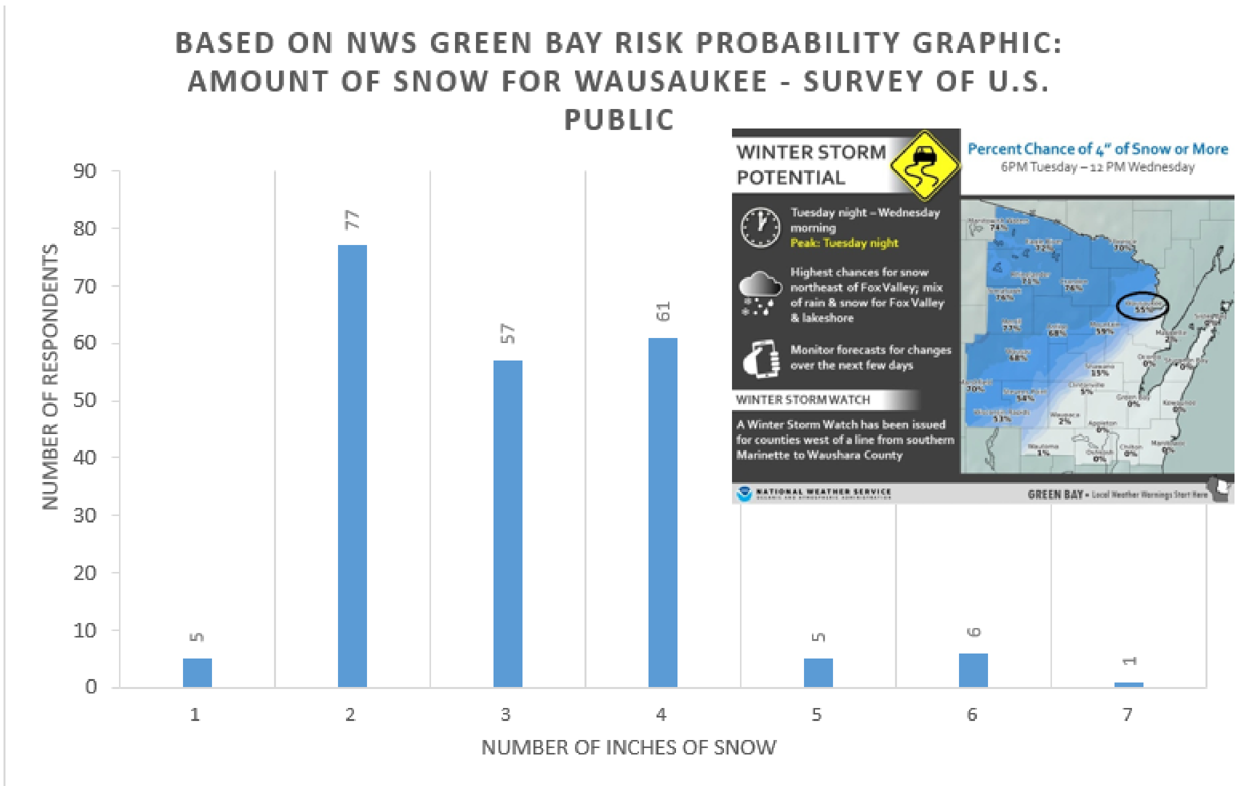



**Figure 26.** Distribution of the number of inches of snow that respondents thought Wausaukee would receive from this winter storm based on the risk probability graphic given to them which was released by NWS Green Bay two days before the upcoming winter storm. The risk probability graphic is shown here for easy reference. See Figure 83 for the full-size graphic.

Two of the risk probability graphics were used as heat map questions, where respondents had to click on a part of the graphic that they thought provided them with the most important and helpful information. For the NWS State College risk probability graphic, many people thought that the map itself along with much of the additional text-based forecast information, including timing and precipitation type information as well as a general statement about how much snow was expected throughout the region (Figure 27a). Text-based information about travel impacts and the thing that still remained unclear with the forecast were the items on this graphic that respondents did not think were the most important or helpful to them (Figure 27a). For the NWS Bismarck graphic, many people thought that the map itself along with the color scale, the travel impacts statement, and the timing information about when the snow would start and become the heaviest were all considered to be important and helpful parts of the graphic (Figure 27b).

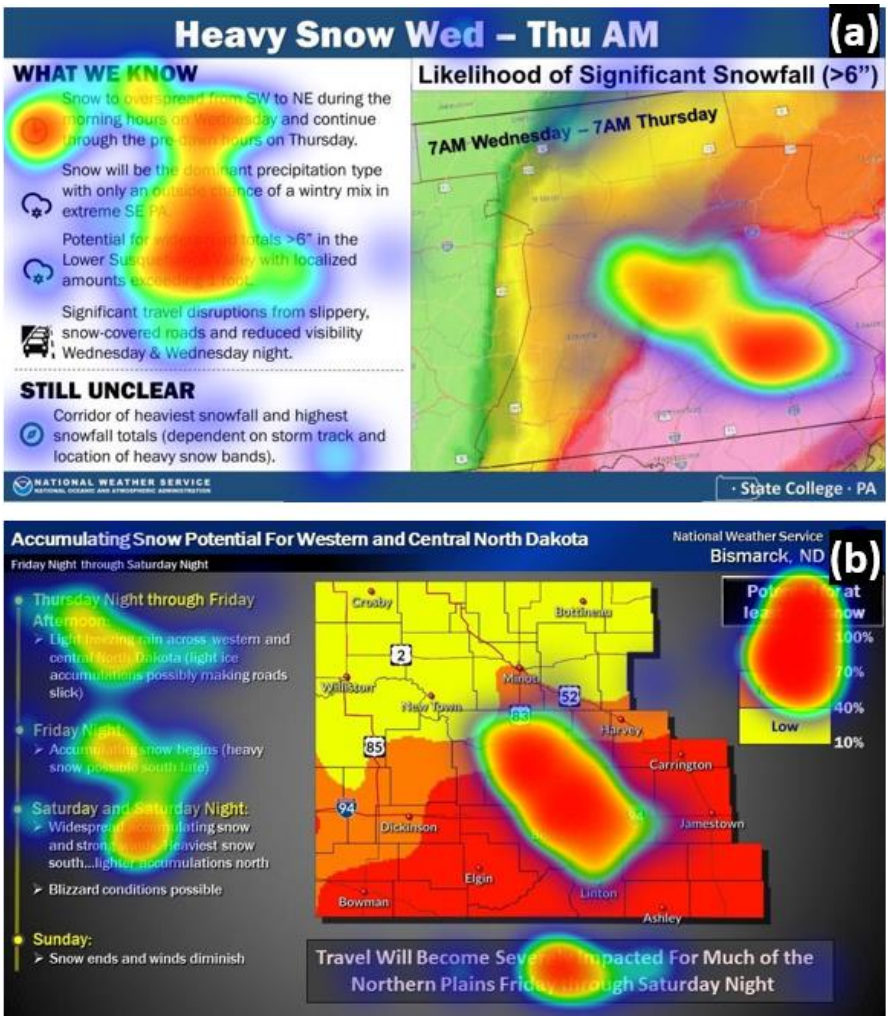



**Figure 27.** Results from the survey of the U.S. public comparing risk probability graphics (otherwise known as probability of exceedance graphics) used to communicate upcoming winter storms. Respondents chose what part of each graphic they thought provided them with the most important and helpful information, and results are displayed as a heat map with blue and green shadings indicating that not many people selected that part of the graphic while red, orange, and yellow shadings indicate that many people selected that part of the graphic. (a) NWS State College graphic, (b) NWS Bismarck graphic. See Appendix C for the full-size graphics

As mentioned before, the risk probability graphics serve as an important bridge for meteorologists to use between long-range forecast graphics, but before snowfall forecast maps can be released because there is likely still too much uncertainty with the forecast. Therefore, the risk probability graphics should prepare the end user for what the snow map might look like when it is eventually released by emphasizing the areas that have a high probability of receiving the amount of snow listed on the risk probability graphic and the areas that have a low probability of achieving this amount. This way once the snow map is released it would not come as too much of a surprise to the end user as to where the highest snow totals will be and generally how much snow is expected throughout the region. This would also keep the forecast messaging consistent, which is important for meteorologists when communicating forecast information.

In each scenario on this survey, respondents went to a new page after answering the questions that were previously discussed about the risk probability graphics that were used in each scenario. On this new page, respondents were presented with the snow map that each of the NWS offices posted for the upcoming winter storm, usually one day after the risk probability graphic had been posted. Respondents were asked if this snowfall forecast map matched their expectations based on the previous risk probability graphic they saw. A forecast that had more certainty when the risk probability graphic was released, such as the NWS Bismarck scenario, with about half of the area in the 70% to 100% contour of receiving over eight inches of snow, resulted in a higher average number that respondents answered with (Figure 28). This signals that many respondents' expectations were met by the snow map based on the previous risk probability graphic. On the other hand, the snow map the NWS State College office released received a lower mean answer, possibly because the risk probability graphic in this scenario was not understood well by respondents (Figure 28). It should be noted that the storm setup and situation were rather different for each of the four scenarios, making it hard to determine the real reasons why more respondents' expectations were met for some scenarios compared to others and if it had to do with the type of color scheme used for the risk probability graphic or not.

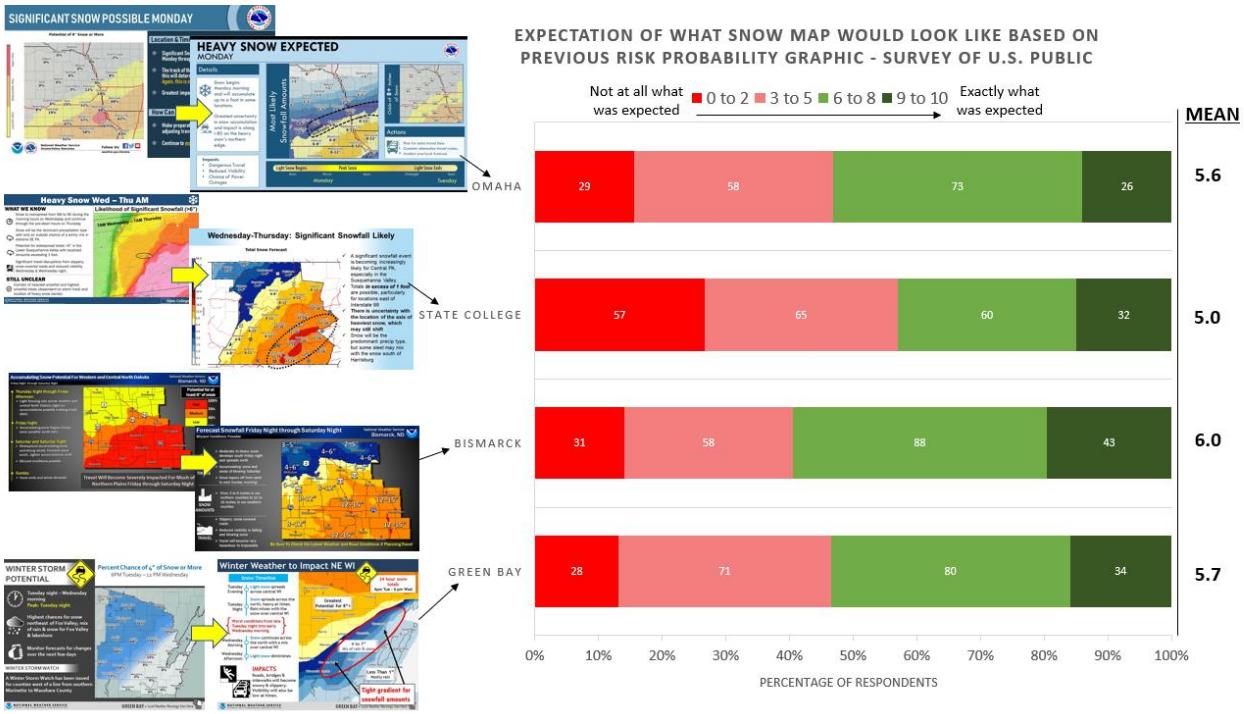



**Figure 28.** When presented with a snowfall forecast graphic in each scenario, respondents answered on a scale from zero to ten based on if the snowfall forecast map was what they expected to see based on the prior risk probability graphic – zero to two in dark red, three to five in light red, six to eight in light green, and nine to ten in dark green. The length of the bars corresponds to the percentage of the respondents that answered with a number within each range. The numbers on the bars corresponds to the amount of people that answered with a number within each range. The mean score for each scenario is also included. The graphics that were presented in the survey - the risk probability graphics and the snowfall forecast maps for each scenario - are included in this figure for easy reference. See Appendix C for the full-size graphics.

### 5.4.3 Snowfall Forecast Maps Used in Survey

Finally, communicating uncertainty information on snow maps was investigated in three of the four scenarios of this survey, specifically determining how helpful the public thinks circling areas of uncertainty on snow maps is. NWS Omaha used a dashed, black circle on their snow map with the words “greatest uncertainty” within the circled region (Figure 70). There was also timing information, a risk probability graphic, and text-based forecast details on this graphic

(Figure 70). NWS State College released a snow map two days before the upcoming winter storm, with a dashed, black circle on their snow map with a bolded description of the circled area on the graphic saying that “there is uncertainty with the location of the axis of heaviest snow, which may still shift” (Figure 75). Then, NWS State College released an updated snow map one day before the upcoming winter storm with a dashed, black circle on their snow map again, this time with two arrows pointing in the direction they thought the band of heaviest snow may shift (Figure 76). NWS Green Bay used a solid, red circle on their snow map with the words “tight gradient for snowfall amounts” to label this circled region (Figure 85).

Respondents were first asked if the circled area and associated description on the snow map that was displayed were helpful for them to understand the uncertainty with the forecast. They were presented with numbers from zero through ten that they could choose from, with zero indicating that the graphic was not helpful at all for understanding the uncertainty and ten indicating that the graphic was very helpful for understanding the uncertainty with the forecast. Respondents thought that the circled area on the snow map in all three scenarios was helpful for them to understand the uncertainty with the forecast, as the mean response was between 6.8 and 7.4 for each snow map (Figure 29). The two snowfall forecast maps from NWS State College that also included a short description about the circled area of uncertainty, for instance saying that the band of heaviest snow might shift within a certain region, had the highest response scores (Figure 29). The response score was lower for the NWS Green Bay snow map that used a different phrase to describe its circled area, indicating a region where there will be “tight gradient in snowfall amounts” (Figure 29).

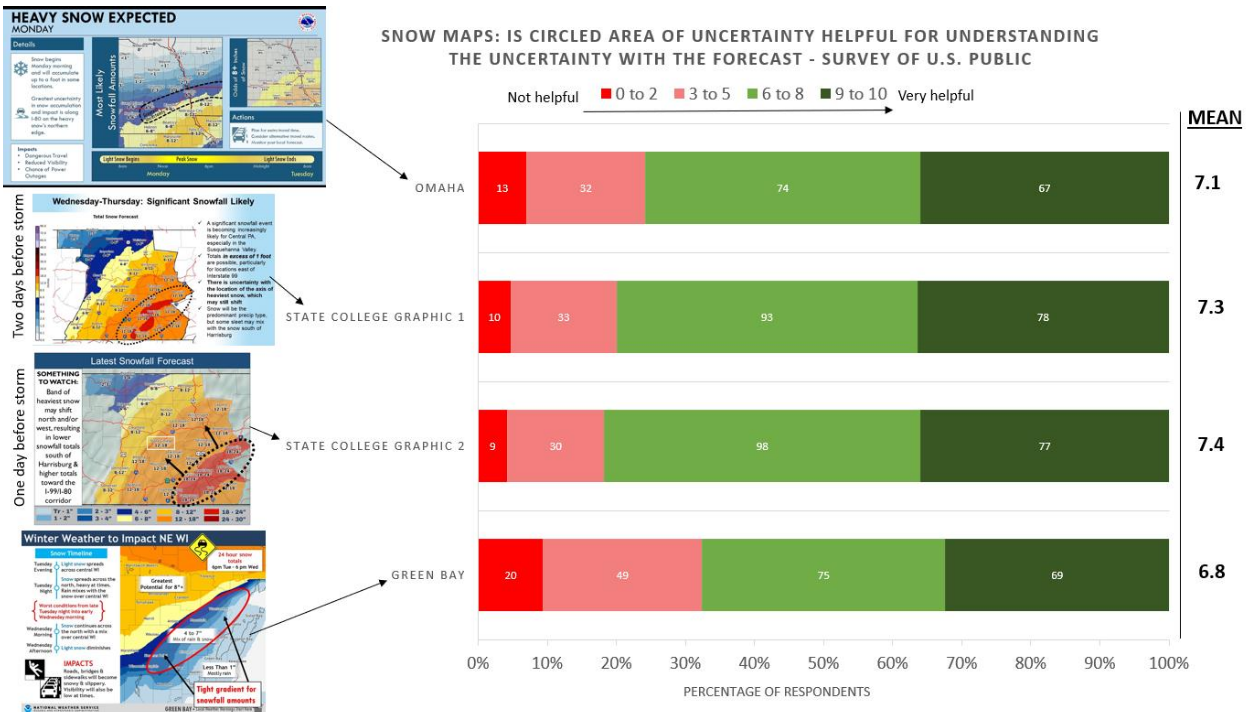



**Figure 29.** Results from questions of the survey of the U.S. public where a snowfall forecast map was presented to respondents with a circled area of uncertainty on the map. Respondents ranked each graphic on a scale from zero to ten based on how helpful the circled area was for them to understand the uncertainty with the forecast, and results were grouped into four ranges – zero to two in dark red, three to five in light red, six to eight in light green, and nine to ten in dark green. The length of the bars corresponds to the percentage of the respondents that answered with a number within each range. The numbers on the bars corresponds to the amount of people that answered with a number within each range. The mean score for each graphic is also included. The graphics that were presented in the survey are included in this figure for easy reference. See Appendix C for the full-size graphics.

NWS Omaha updated their snowfall forecast map the next day after their first snowfall forecast map was released, and this included a large increase in forecasted snow totals for the city of Omaha (Figure 71). On the first snowfall forecast map that was released two days before the upcoming winter storm, NWS Omaha was predicting that Omaha would receive four to six inches of snow, but the city was within the region of “greatest uncertainty.” On the next snowfall forecast map, released one day before the winter storm, NWS Omaha was now forecasting that Omaha would receive eight to twelve inches of snow. Respondents were asked if the circled region of “greatest uncertainty” on the first snowfall forecast map was help for them to anticipate the increase in predicted snowfall totals. They were presented with numbers from zero through ten that they could choose from, with zero indicating that the circled area on the previous snowfall forecast map was not helpful at all and ten indicating that the circled area on the previous snowfall forecast map was very helpful for them to anticipate the increase in snow totals for Omaha. 70% of respondents answered with a number of five or larger, and the mean was 5.8 indicating that most respondents found the circled area of uncertainty on the previous snowfall forecast map at least somewhat helpful (Figure 30).

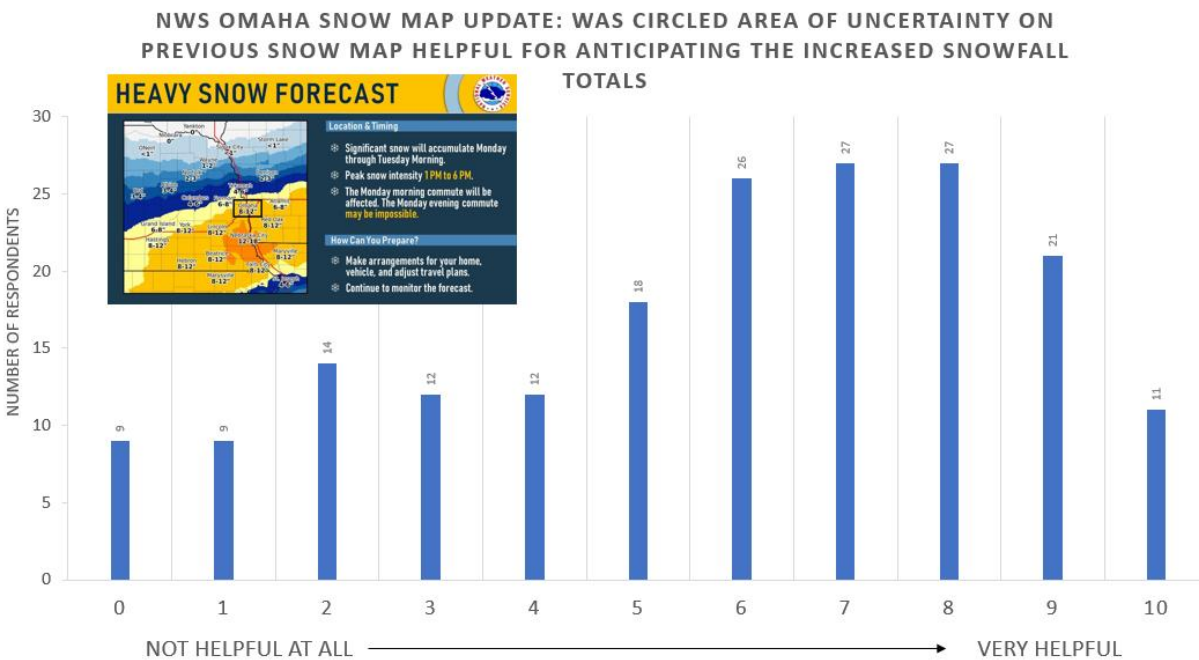



**Figure 30.** Distribution of responses when presented with question 18 on the survey of the U.S. public. Respondents chose a number from zero to ten based on how helpful the circled area of uncertainty was on the previous snow map to anticipate the increased snowfall totals on this snowfall forecast map. The snowfall forecast graphic that was presented in the survey is included in this figure for easy reference. See Appendix C for the full-size graphic.

Finally, three of the graphics with snowfall forecast maps on them were used as heat map questions, where respondents had to click on a part of the graphic that they thought provided them with the most important and helpful information. For all three graphics, the majority of people selected the snowfall forecast map itself as the most important and useful information to them (Figure 31). However, on the NWS Green Bay graphic, many people also selected the part of the storm timeline that indicates when the worst conditions will be during the storm (Figure 31b).

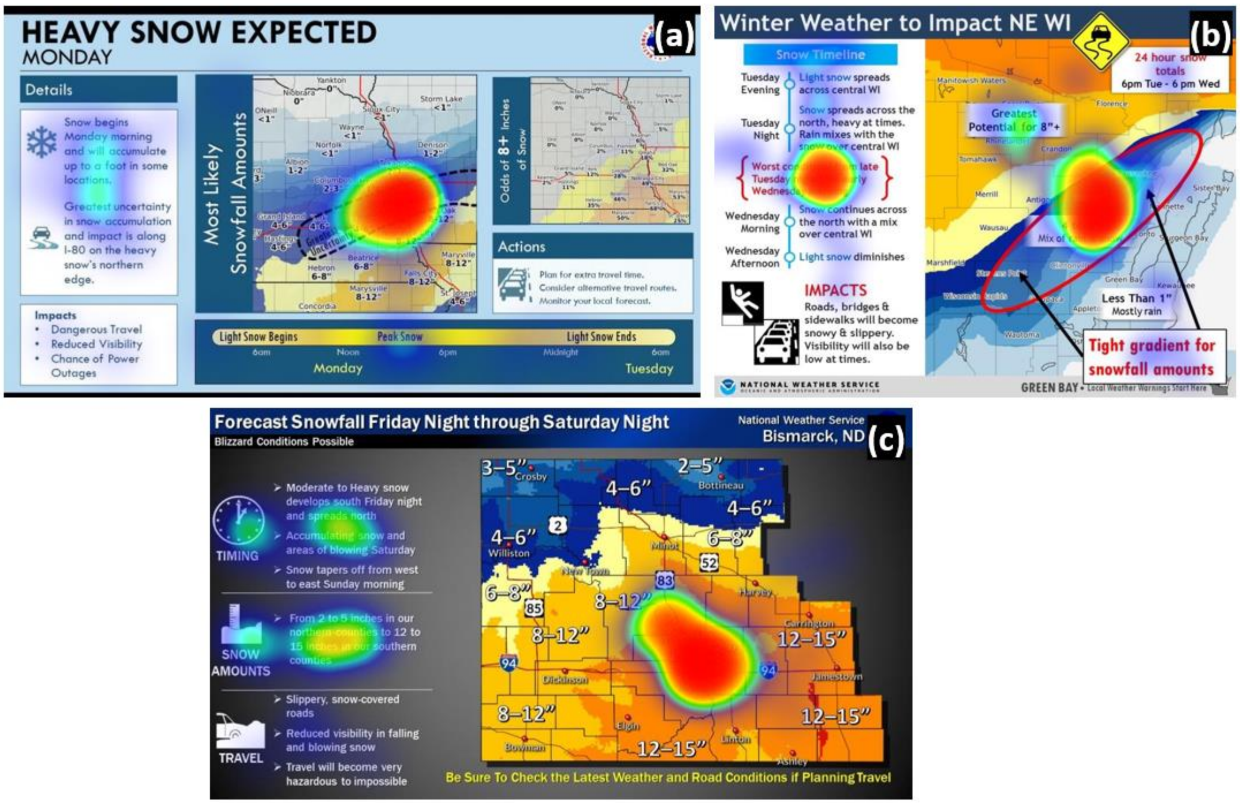



**Figure 31.** Results from the survey of the U.S. public comparing graphics that had snowfall forecast maps as a part of them. Respondents chose what part of each graphic they thought provided them with the most important and helpful information, and results are displayed as a heat map with blue and green shadings indicating that not many people selected that part of the graphic while red, orange, and yellow shadings indicate that many people selected that part of the graphic. (a) NWS State College graphic, (b) NWS Bismarck graphic. See Appendix C for the full-size graphics.

### 5.5 Discussion of Results from the Four Scenarios of the Survey

Many key conclusions can be drawn from this portion of the survey of the U.S. public about which graphics are easiest to interpret, communicate the uncertainty with the forecast the best, and provide the most important and helpful information to the public

With long-range winter weather graphics used in this survey, respondents preferred graphics that had a map on them with either the probability of plowable snowfall graphic developed by the NWS State College office or a circled region on a map that could see the impacts of a winter storm, as both graphic styles were the easiest to interpret among respondents. The word "plowable" in the title of NWS State College's probability of plowable snowfall graphics was interpreted slightly higher than intended, with 61% of respondents thinking that it meant three or four inches of snow would fall. Text-based information about what is most certain and what is least certain, as used in the NWS Bismarck graphic and the first NWS Green Bay graphic, and statements about the confidence level with different aspects of the forecast, as used in the second NWS Green Bay graphic, were determined to best communicate the uncertainty with the forecast. Additionally, the statement on the NWS Omaha graphic that said the track of the system is still uncertain was viewed as the most important and useful part of the graphic by many people when answering the heat map question. Several of the key elements that were discovered to be important to the public on long-range winter weather forecast graphics are summarized in Figure 32. Utilizing some of these aspects on a long-range forecast graphic, especially when combining a map along with a small amount of text on the graphic, while keeping it simple overall and easy to interpret will most likely lead to the end user understanding the graphic correctly and finding the information provided on the graphic useful to them.

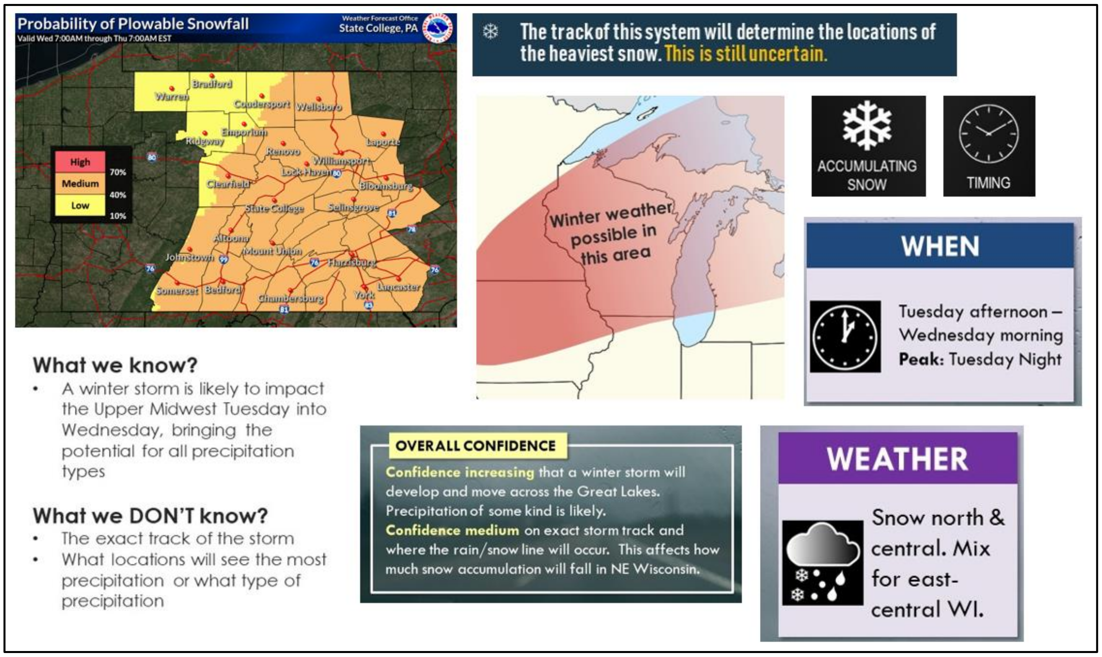



**Figure 32.** Elements of long-range winter weather graphics found to be helpful and important to respondents of the survey of the U.S. public. Full graphics can be found in Appendix C.

With risk probability graphics used in this survey, the blue gradient color scheme and the red/orange/yellow color scheme with no probability percentages at each location on the map were the easiest type of risk probability graphics to interpret. It is possible that the percentages at each location allowed users to see more quickly what the probability was of exceeding a certain amount of snow compared to having to use a color scale or legend to determine what gradient shading each location was within. The blue gradient color scheme was also determined to be the best communicator of uncertainty with the forecast, most likely because probability percentages were plotted at each location allowing respondents to see the probabilistic information clearly on the map. The color scheme the NWS State College office used on their risk probability graphic which included no color scale or legend, was found to be the hardest to interpret and the worst communicator of uncertainty among the four risk probability graphics used in this survey. Therefore, a color scale or legend is very important on risk probability graphics so that users can interpret them correctly. And based on the heat map of the Bismarck risk probability graphic, many respondents thought the color scale used on this red/orange/yellow risk probability graphic was the most important and helpful part of the graphic, indicating that people do actually look at the color scale or legend when interpreting these risk probability maps. Additionally, text-based information about the timing of the storm and short statements about "what is known" on the graphic was found to be useful to many people in addition to the risk probability map itself. These results suggest that the blue gradient color scheme should be used as the primary color scheme for risk probability graphics, and additional, brief text-based information should be included on the graphic to supplement the risk probability map.

Since cities were chosen in different parts of the risk probability graphics, with some in a region where there was a tight gradient in probabilities, one where probabilities were very high, and one where probabilities were very low, it is hard to determine which map style of the risk probability graphics users interpreted the best. However, for all four types of risk probability graphics, the majority of respondents did not enter a snowfall amount that was over the amount listed in the title of the graphic. In all four cases they entered snowfall amounts on the lower end of the possible outcomes. For example, for the NWS Bismarck three-tiered, red/orange/yellow risk probability graphic with no probability percentages plotted on the map, the city that the snow amount was being entered for, Bismarck, was located within the 70% to 100% contour of exceeding eight inches of snow. 68% of respondents entered a snowfall amount of eight inches, while only 28% of respondents entered a snowfall amount greater than eight inches. Even though eight inches of snow was verified at the Bismarck Airport for this particular situation, it's an interesting result that respondents were either erring on the side of caution and choosing lower snowfall amounts than the snow amount in the title of these graphics or latching on to the value listed in the title of these graphics. It is also possible that respondents are doing some quick math in their heads when presented with the two graphics that plotted probability percentages at each location. For example, the most respondents entered two inches of snow for the city of Wausaukee, which had a 55% chance of receiving four inches of snow or more according to the NWS Green Bay blue gradient risk probability graphic. 55% of four inches is about two inches, which could be a plausible reason why it was the most chosen snowfall amount. It is important to mention that users are not meant to predict snowfall totals with these risk probability graphics. However, these graphics are meant to be an important tool to use before snowfall forecast maps can be released, so users should be able to get a general sense of how much snow is expected to fall throughout the region, without having to pin down exact snowfall amounts.

Finally, with the snowfall forecast maps used in this survey, respondents found circling areas of uncertainty on the map helpful for them to understand the uncertainty with the forecast. This was especially true when the word “uncertainty” was used to describe the circled region and a brief statement or explanation about why the circled region was included on the graphic. It was also shown to be helpful if arrows or information about where the axis of heaviest snow could shift to in future forecast updates was provided. Additionally, it was shown that a circled area of uncertainty on one snowfall forecast map will help users anticipate a change in the forecasted snowfall amounts, as demonstrated by the updated snowfall forecast map in the Omaha scenario of this survey when forecasted snow totals increased from one snowfall forecast map to the next. In addition to including the snow map on a graphic, additional forecast information about the timing of the snowstorm, such as the predicted onset time and especially the predicted timing of the heaviest snowfall or when conditions will be the worst, was found to be valuable.

# Chapter 6

## Discussion of Results from Focus Groups and Social Media Research

Focus groups were an additional means of collecting feedback on the research topics of this thesis. Two focus group discussions were conducted. The first was with a group of 12 emergency managers from North Dakota; the second focus group was with four broadcast meteorologists from North Dakota. These focus groups were conducted on Google Meet during July 2020, with each focus group discussion lasting 30 minutes. Questions were prepared ahead of time to ask the broadcast meteorologists and emergency managers, and the format of the focus groups included an open discussion about the variety of topics of the research project. Many of the key takeaways from these focus groups reinforced the findings from other aspects of the research project.

For long-range winter weather graphics, all the broadcast meteorologists preferred the map-based graphics highlighting that maps stand out on social media and can communicate important information with few words, which is good for broadcasting. Several of the emergency managers also preferred the map-based long-range winter weather graphics, particularly the one that uses the storm to communicate the timing and impact area. A few other emergency managers emphasized that the type of graphic to be used for this lead time depends on each storm, so a variety of graphics should be implemented.

For risk probability graphics, the broadcast meteorologists said they would like to have the risk probability graphics available for them to download as KML or KMZ files from NWS offices and use in their graphics software on-air. The red/orange/yellow color scheme was preferred among both broadcast meteorologists and emergency managers, possibly because both groups are used to seeing this color scheme be used by the NWS Bismarck office for the past several years. A few emergency managers said that they did not like the blue gradient color scheme because it is hard to decipher between the contours. Many said that the three-tiered, red/orange/yellow color scheme is simplistic which is why they think the public would understand it. Including more specific information, such as including probability percentages on the risk probability maps, could be done for emergency managers to provide them with more detailed information. To maintain consistency, one emergency manager also suggested using the three-tiered, red/orange/yellow color scheme for other hazards outside of the winter season.

For communicating uncertainty on snowfall forecast maps, all the broadcast meteorologists and emergency managers lauded the idea of using circled areas of uncertainty on snowfall forecast maps when it is deemed necessary to do so. Two of the broadcast meteorologists started doing this during the winter of 2019-2020.

Some brief social media analytics research were also conducted investigating how many impressions graphics posted to Facebook and Twitter by NWS Bismarck got when communicating forecast information about two different winter storms that impacted the Bismarck region in October and November 2019. The number of impressions is defined by the number of times a post is displayed, no matter if it was clicked on or not. The primary finding from this work was that the first snowfall forecast map that is posted to Twitter or Facebook generates two times or more impressions than subsequent snowfall forecast maps that are posted (Figure 33). Only two winter storms were investigated from one NWS office, making this a very preliminary finding, as more social media analytics research would have to be done to further prove that this decline in engagements is commonly seen. However, if this finding is valid on a broader scale, this knowledge may help NWS offices because they might hold off posting their first snowfall forecast map a little while longer until they are more confident with their map because they know that the most people would see this snowfall map and not ones that are posted later which update and refine the forecast.

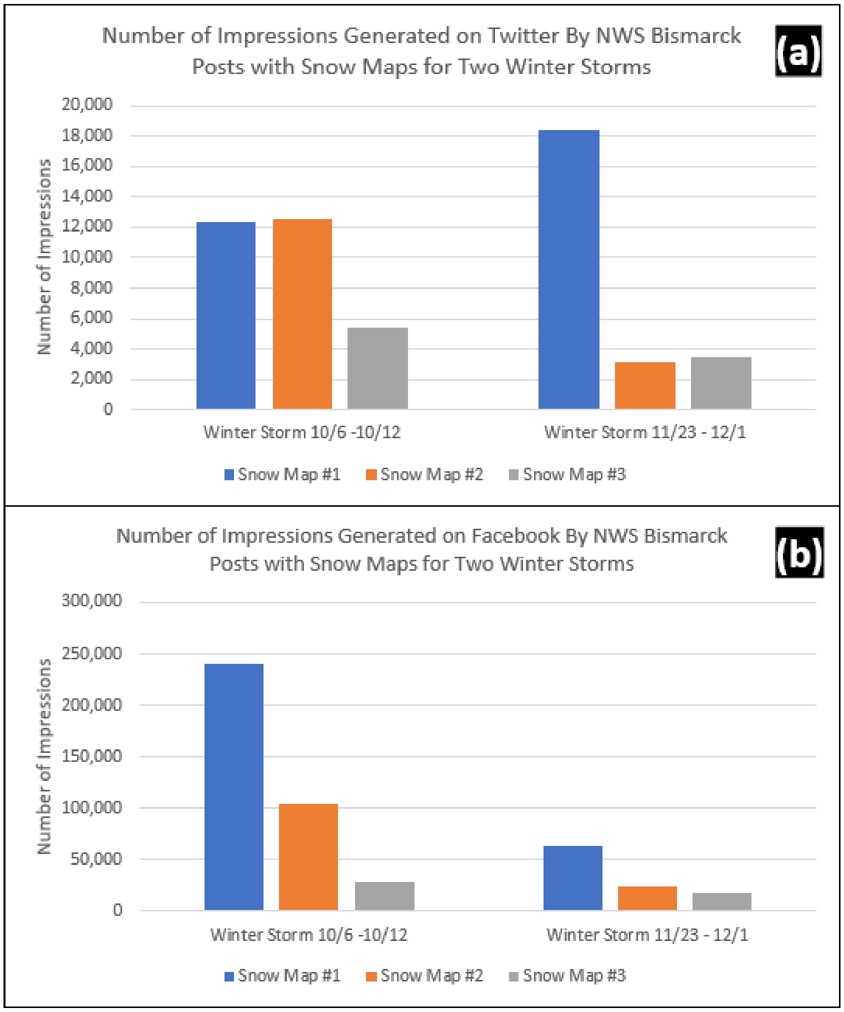



**Figure 33.** Social media analytics gathered from NWS Bismarck Facebook and Twitter pages from two winter storms that impacted North Dakota – storm #1 was messaged on social media from 10/6/19 through 10/12/19 and storm #2 was messaged on social media from 11/23/19 through 12/1/19. Snow map #1 indicates the first snow map that was posted by NWS office, snow map #2 was the second snow map posted, and snow map #3 was the third snow map that was posted in that order.

# Chapter 7

## Conclusion & Practical Recommendations for the Weather Enterprise

Several practical recommendations can be generated from this research project that can be directly applied to the ways that meteorologists at National Weather Service offices communicate winter storms to the public and their core partners. These recommendations also apply to others in the weather enterprise, such as broadcast meteorologists, who communicate important weather information to the public. Implementing these recommendations will help to achieve a more consistent way of communicating uncertainty-driven and probabilistic information in future winter storms that end users will find to be easily understandable and useful for their decision-making.

1. Map-based graphics are the preferred option for communicating predictions of winter storms in the longer-range, three to seven days before a winter storm. The two preferred map-based graphic styles were (1) circling one or more areas on a map for snow potential and (2) using the track of the storm to communicate the timing and impact area. These were the two most preferred options among the 831 respondents to this question from the survey of the U.S. public as well as among the 32 non-meteorologist who work at NWS offices in the Central Region that were surveyed. Additionally, the graphic style where one or more areas on a map is circled for snow potential was the most preferred among the 40 NWS meteorologists who work in the NWS Central Region that were surveyed.
2. Simplistic graphics were also preferred at longer lead times, with not too much text on the graphics making them easier to interpret. Some text-based information

communicating the uncertainty or confidence in the forecast was found to be useful to the public and should be added to these graphics alongside the maps.

3. NWS State College's probability of plowable snowfall graphic was identified as easy to interpret and useful to the public at long lead times, such as five days before a winter storm. This graphic can be easily used by NWS offices across the country, creating a more consistent message, and would allow WPC's probability of exceeding 0.25 inches of liquid equivalent of snow/sleet maps to be turned into helpful long-range weather information that is focused on the local area of the NWS office. Past studies have also suggested that people understand basic probability information about forecasts when presented with a map, which agrees with the results from this part of the research project (Wu et. al 2014). Careful word choice must be used for the title of these graphics, as the public infers "plowable" snowfall to mean three or four inches while "impactful" snowfall is usually interpreted as four to six inches of snowfall.
4. Risk probability graphics were understandable by non-meteorologists who work at NWS offices when using them to make decisions. However, the way the public interpreted the risk probability graphics when trying to determine how much snow a city on the risk probability map would receive might not have been the way these graphics are intended to be interpreted. People consistently thought that the city on the map would get the amount of snow listed in the title of the map or a range of values lower than that. Future work should be done investigating if the public can correctly interpret risk probability graphics and if any of the color scheme options make proper interpretation easier for the public. Additionally, investigating if adding

probability percentages at each location on the map helps or hurts people's interpretation of the graphics should be done.

5. The blue gradient color scheme with probability percentages plotted at each location was the most preferred risk probability color scheme based on the survey of the U.S. public. It was also the easiest to interpret and the best communicator of the uncertainty present in the forecast based on the survey of the U.S. public. This aligns with past research that suggests numerical expressions of uncertainty should be prioritized over purely categorical statements as numerical expressions of uncertainty are interpreted more consistently (Budescu et. al 1988, Jaffe-Katz et. al 1989). Some people found the probability percentages plotted at each location on this color scheme helpful for them to interpret the forecast. The second most preferred color scheme was blue/yellow/orange/red. If probability percentages are not included as plotted locations on the risk probability map, these percentages should at least be included on the legend of the graphic so that the risk probability graphic is not completely devoid of numerical expressions of uncertainty. A legend should be included on all risk probability graphics, as without one, as shown by the NWS State College risk probability graphic used in the survey of the U.S. public, the graphic is harder to interpret and more open to interpretation.
6. The red/orange/yellow color scheme for risk probability graphics was the preferred option for meteorologists that were surveyed in the Central Region along with broadcast meteorologists and emergency managers in North Dakota. This is most likely due to their familiarity with this color scheme for the risk probability graphics. It would be a transition for these people to prefer the blue gradient color scheme for

risk probability graphics, if this color scheme were to be adopted more universally across the NWS.

7. Risk probability graphics should overall be kept simple, but some brief, additional text should be added to the graphics such as timing information, potential impacts of the winter storm, or statements about "what is known" about the winter storm. Using risk probability graphics to communicate other hazards, such as for icing/freezing rain potential, was also shown to be something that NWS meteorologists in the Central Region would want to do.
8. Circling areas of uncertainty on snowfall forecast maps was liked by all and should be done by NWS offices and others in the weather enterprise when it is necessary. 68% of non-meteorologists who work in the NWS Central Region and 75% of the members of the public who were surveyed across the U.S. said that they would check back for forecast updates if they lived in the circled area of uncertainty to see if anything had changed. Additionally, 50% of non-meteorologists who work in the NWS Central Region and 46% of the members of the public that were surveyed said they would also prepare for higher snowfall amounts in case the forecast changes. Broadcast meteorologists and emergency managers in North Dakota also like the circled area of uncertainty, and the majority of meteorologists who work at NWS offices in the Central Region thought that users understand this circled area. The word "uncertainty" should be used when describing this circled area and adding a brief statement on the graphic as to why the uncertainty exists or where the band of heaviest snow might shift was shown to be preferred.

9. Probabilistic snowfall ranges are a viable alternative to the standard NWS color table snowfall ranges based on results from the survey of the U.S. public and the fact that they usually capture the spread of possible snowfall totals for a location better than the standard NWS color table snowfall ranges. However, snowfall ranges that are too large to be useable for the public and NWS core partners can be created by the 25$^{th}$ to 75$^{th}$ percentile probabilistic snowfall ranges, so NWS meteorologists should be careful when choosing what snowfall range option to use.
10. Members of the public want to see information about how confident or uncertain a forecast is during the winter, as the second most respondents in the survey of the U.S. public selected the amount of confidence or uncertainty in the forecast as their most important piece of forecast information that they want to know about. Snowfall totals were clearly the primary choice, indicating that most people want to see these forecasted snow amounts when they are available, but at longer lead times, before snowfall totals can be formulated and released, relying on uncertainty-driven and probabilistic information is important.

# Appendix A

## Survey Questions for NWS Meteorologists in NWS Central Region

Section 1 – Risk Probability Graphics

1. There are many different color schemes used in these risk probability graphics to communicate the probability of snow greater than a specified amount. Which color scheme do you think is the best? *(N = 40)*
   a. Three-tiered (red, orange, yellow)

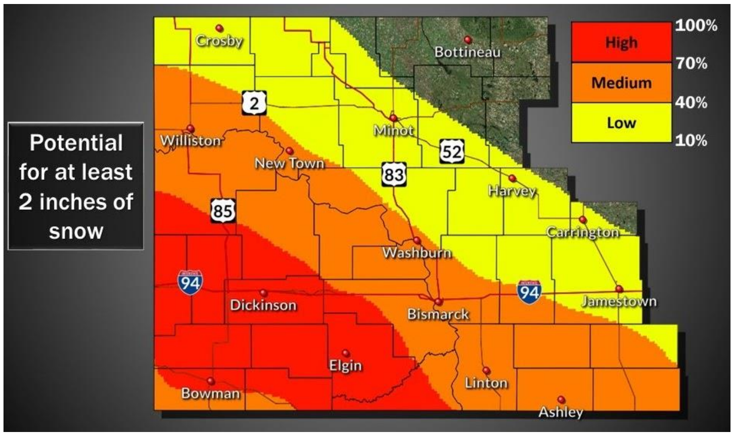



**Figure 34.** Red/orange/yellow color scheme risk probability graphic posted to social media by NWS Bismarck on 12/6/19

   b. Blue shadings (often with specific percentages at specific locations)

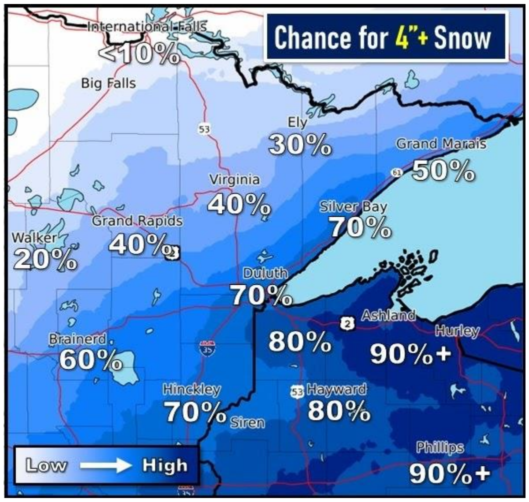



**Figure 35.** Blue shadings risk color scheme probability graphic posted to social media by NWS Duluth on 11/25/19

c. Brown → Yellow → Green → Blue → Red

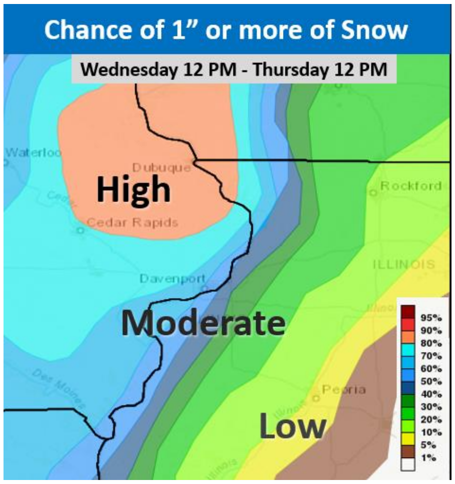



**Figure 36.** Red/blue/green/yellow/brown color scheme risk probability graphic posted to social media by NWS Quad Cities on 1/21/20

d. Grey → Blue → Yellow → Orange → Red (WPC scale)

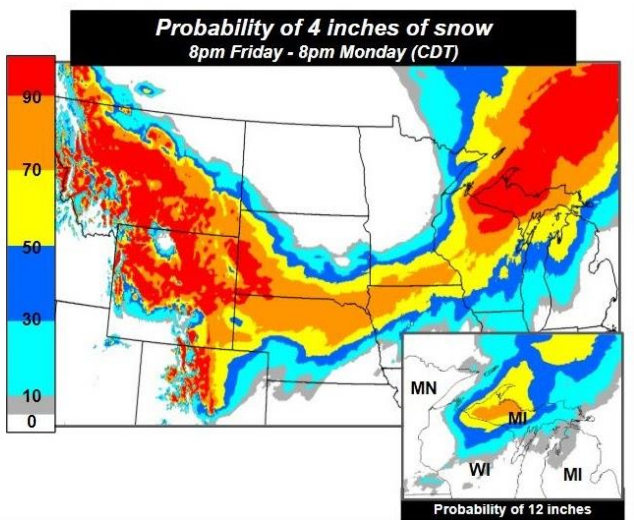



**Figure 37.** Red/orange/yellow/blue color scheme risk probability graphic posted to social media by Weather Prediction Center on 4/10/20

e. I don't have a preference for the color scale of these risk probability graphics

2. The graphic below is an example of the three-tiered (red, orange, yellow) risk probability graphic. What title do you think is best for describing these graphics? (the "x" in each option would be replaced by a specific snow amount like 4", 8", etc.) (*N = 40)*

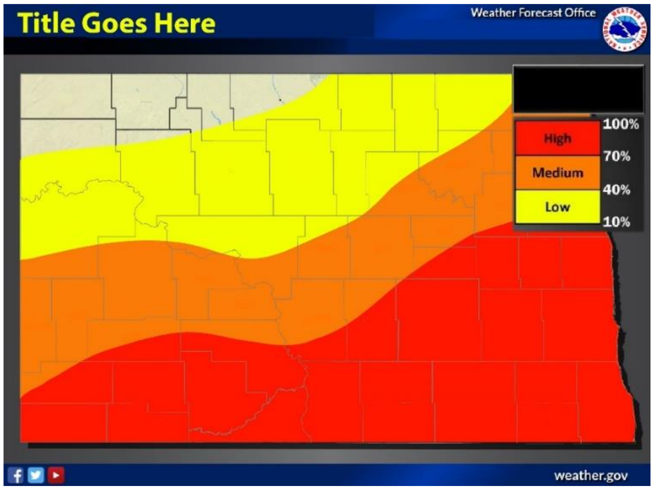



**Figure 38.** Generic graphic created to mimic the red/orange/yellow risk probability graphic style with the title of the graphic missing.

   a. Potential for at least "x" inches of snow
   b. Chance of at least "x" inches of snow
   c. Risk of greater than "x" inches of snow
   d. Probability of "x" Inches or greater snowfall
   e. I don't have a preference for the title of these graphics

3. There are various different color scales that have been used by National Weather Service offices for these three-tiered (red, orange, yellow) risk probability graphics. Please select the one that you think is best suited for these graphics. *(N = 40)*
   a. Option 1


**Figure 39.** Color scale for yellow/orange/red risk probability graphics with "greatest potential" (red) and "lowest potential" (yellow) descriptors

b. Option 2

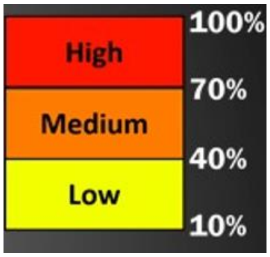



**Figure 40.** Color scale for yellow/orange/red risk probability graphics with percentages and "high/"medium"/"low" descriptors for each color

c. Option 3


**Figure 41.** Color scale for yellow/orange/red risk probability graphics with percentages and "slight"/"moderate"/"high" descriptors for each color

d. Option 4

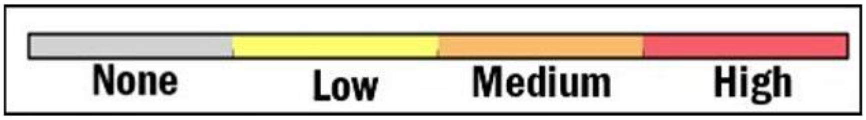



**Figure 42.** Color scale for yellow/orange/red risk probability graphics with "none," "low," "medium," and "high" descriptors for each color.

e. I don't have a preference for the color scales

4. Do you think adding probability percentages to the color scale at each color interval improves the risk probability graphic and helps users interpret it better? Yes OR No, then explain your decision briefly. *(N = 40)*

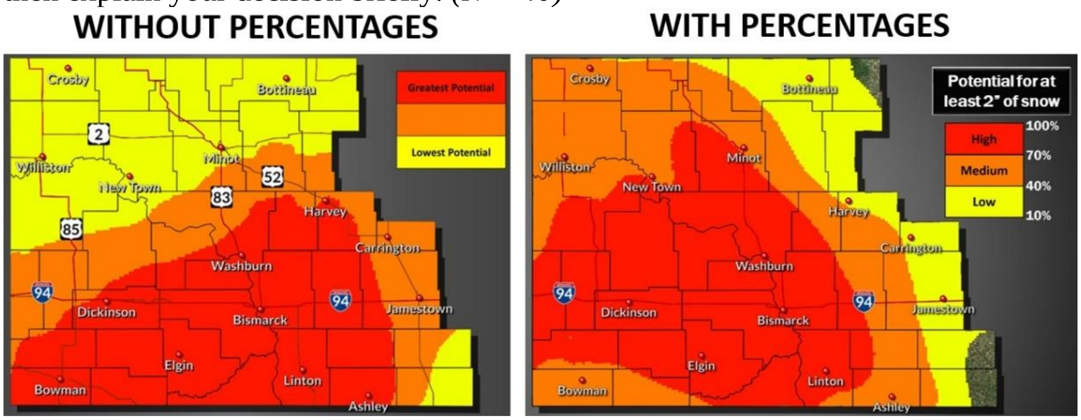



**Figure 43.** Two red/orange/yellow risk probability graphic styles displayed side by side - one with probability percentages in the color scale and one without

5. What are your thoughts on adding specific probability percentages to the three-tiered risk probability graphic at each location on the map? Select all that apply or type your own answer. *(N = 40)*

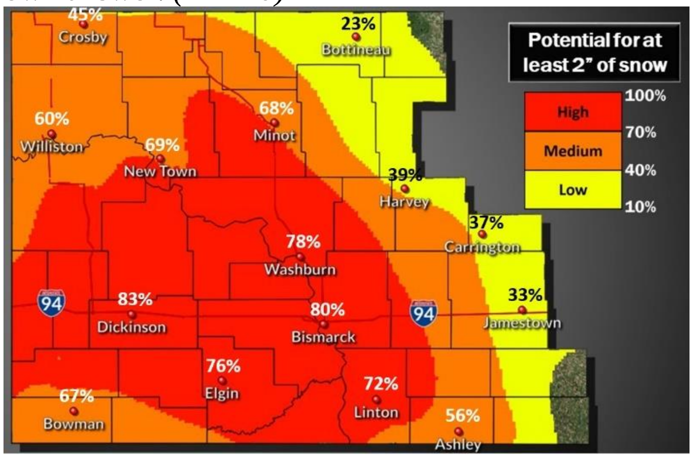



**Figure 44.** Red/orange/yellow risk probability graphic with hypothetical probability percentages included at each location

a. I think that the probability percentages would help users interpret and understand the graphic easier versus if they were not included
b. I think that users would be able to understand the discrete probability percentages at each location
c. I think the probability percentages at each location make the graphic more confusing
d. I do not think the probability percentages at each location are necessary (just having them on the color scale is enough)
e. I think the probability percentages at each location do not make a difference compared to if they were not included in the graphic
f. Other (please explain)

6. Do you think additional text (forecast information) on the risk probability graphics helps the user to interpret the message (A) or should the risk probability map take up the entire graphic (B)? Select all that apply or type your own answer. *(N = 40)*

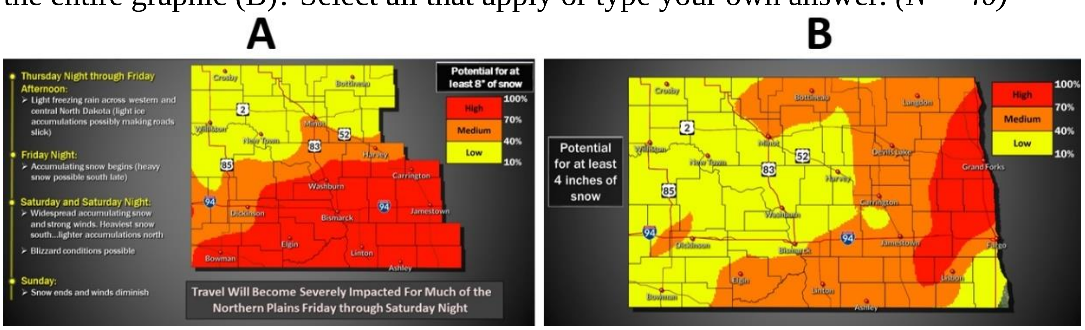



**Figure 45.** Two risk probability graphics compared side-by-side, one with additional timing information one without

a. "A" because the additional text helps users to interpret the risk probability graphic better
b. "A" because the additional text gives users important information about the storm that they might not have seen if they didn't look elsewhere
c. "B" because the additional text makes the graphic too busy and confusing
d. "B" because the additional text that would have been on the graphic should instead be a part of the post's text
e. Type your own response

7. Sometimes multiple risk probability maps have been included on the same graphic before, similar to the one below. What are your thoughts on doing this or should only one map be included in each graphic? Briefly explain your choice. *(N = 39)*

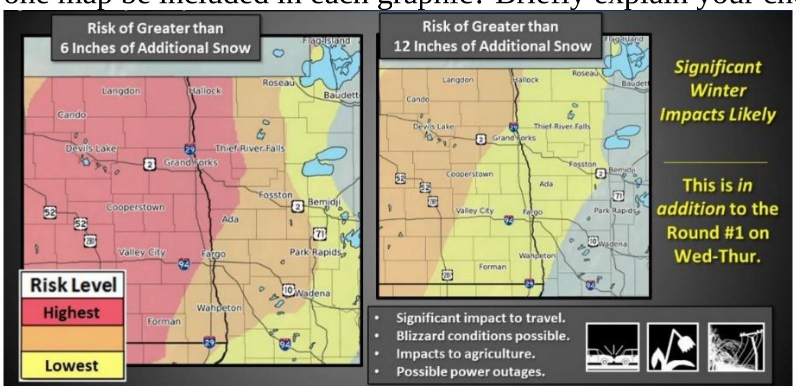


**Figure 46.** Graphic with two risk probability maps, one for the chance of seeing over 6" and one for the chance of seeing over 12" of snow

8. What actions should users take when they see the risk probability graphics? What value do you think they are adding to the messaging of a winter storm? *(N = 33)*

9. Three-tiered risk probability graphics have also been used for communicating the risk of other hazards besides snow. Below are several different examples of this. If you had the authority to choose which hazards the risk probability graphics were used for, select the ones that you would use it for. *(N = 40)*
    a. Blowing/Drifting Snow

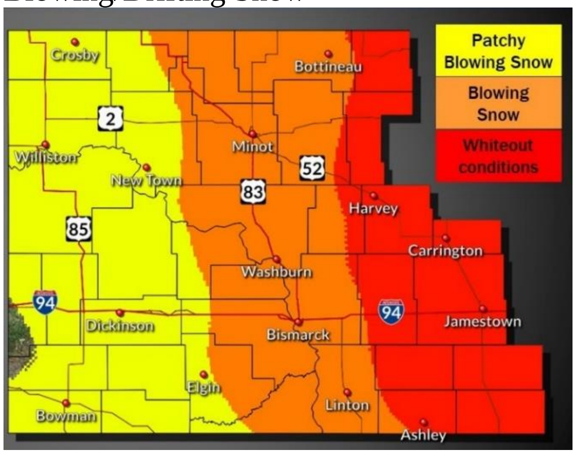



**Figure 47.** Risk probability graphic used to communicate blowing snow posted to social media by NWS Bismarck on 1/17/20

    b. Icing/Freezing Rain Potential

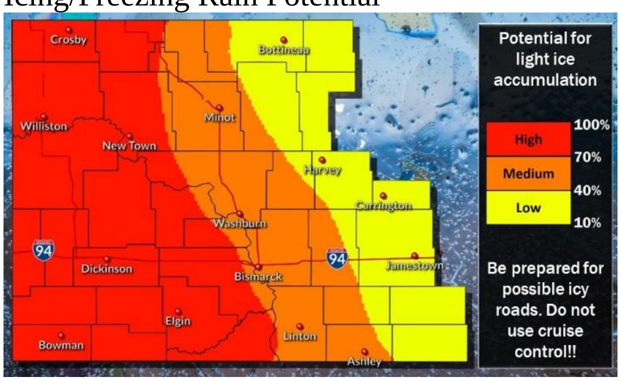



**Figure 48.** Risk probability graphic used to communicate freezing drizzle posted to social media by NWS Bismarck on 11/28/19

    c. Travel Impacts

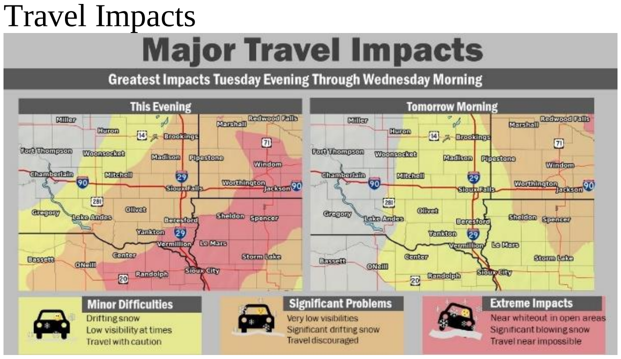



**Figure 49.** Risk probability graphic used to communicate travel impacts posted to social media by NWS Sioux Falls on 11/26/19

d. Wind Gusts

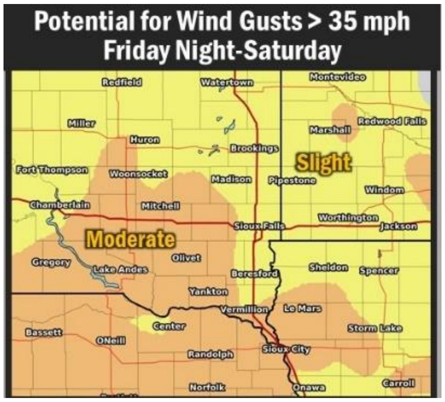



**Figure 50.** Risk probability graphic used to communicate wind gusts posted to social media by Sioux Falls on 1/15/20

e. Wind Chill


**Figure 51.** Risk probability graphic used to communicate wind chills posted to social media by Sioux Falls on 3/17/20

f. I would not use the risk probability graphics for any of these options

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<u>Section 2 – Long-Range Winter Storm Messaging and Communicating Uncertainty on Snow Maps</u>

10. Several days (4-7+) before a winter storm, National Weather Service offices will communicate the threat of this upcoming storm in a variety of ways. Please select the style of graphic that you think is MOST effective at communicating an upcoming storm threat. *(N = 40)*
    a. Circling one or more areas on a map for snow potential

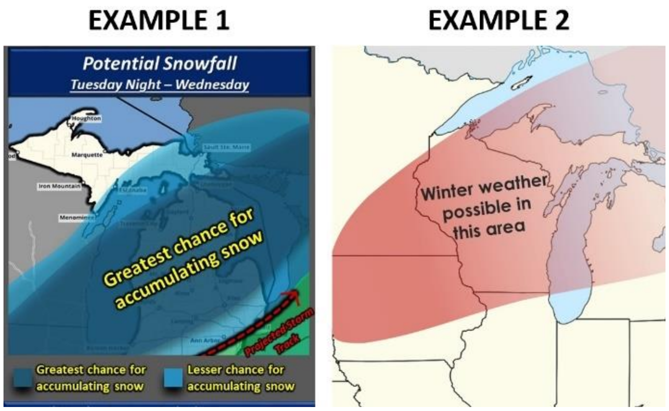


**Figure 52.** Two examples of circling regions on a map to communicate an upcoming winter storm. Example 1 posted by NWS Gaylord on 2/23/20. Example 2 posted by NWS Green Bay on 11/23/19.

    b. List of dates/timeline with the potential for snow highlighted

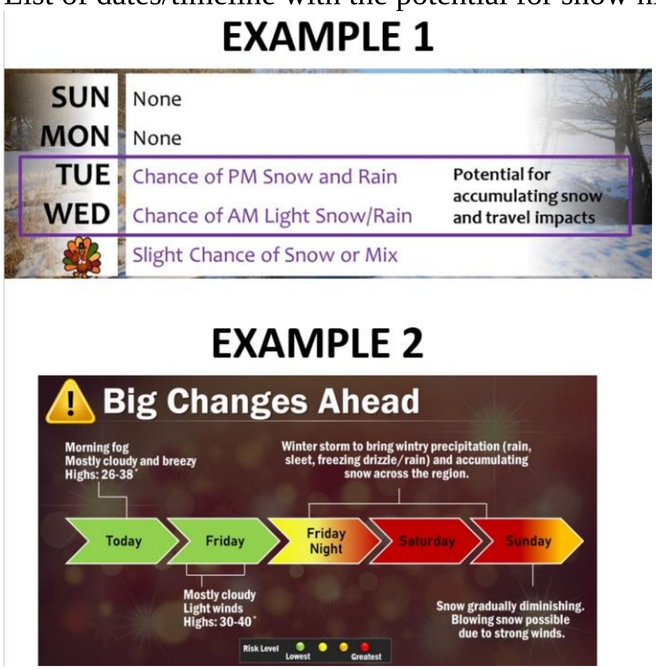


**Figure 53.** Two examples of a timeline used to communicate an upcoming winter storm. Example 1 posted by NWS Green Bay on 11/23/19. Example 2 posted by NWS Sioux Falls on 12/26/19.

c. “What we know,” “what is uncertain,” “what you should do”

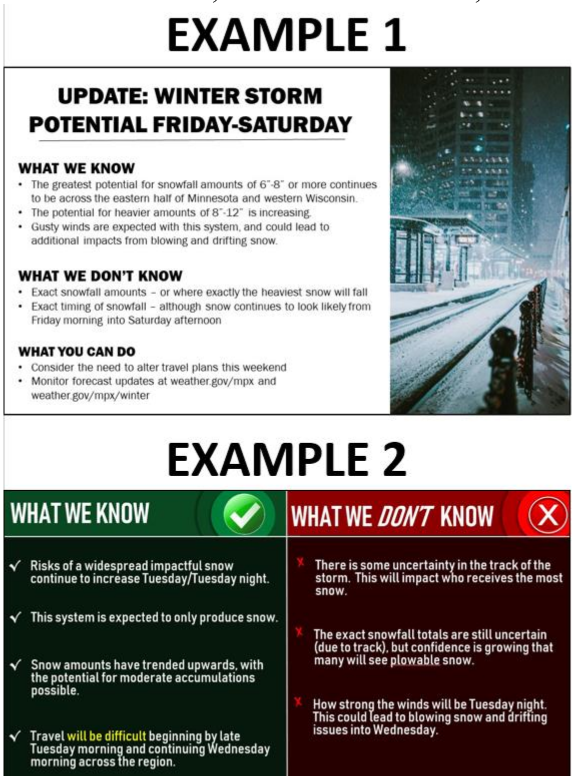


**Figure 54.** Two examples of a list of what is known and what is not known to communicate an upcoming winter storm. Example 1 posted by NWS Twin Cities on 12/26/19. Example 2 posted by NWS Sioux Falls on 11/14/19.

d. Using the track of the low-pressure system/storm to communicate the timing and the impact area

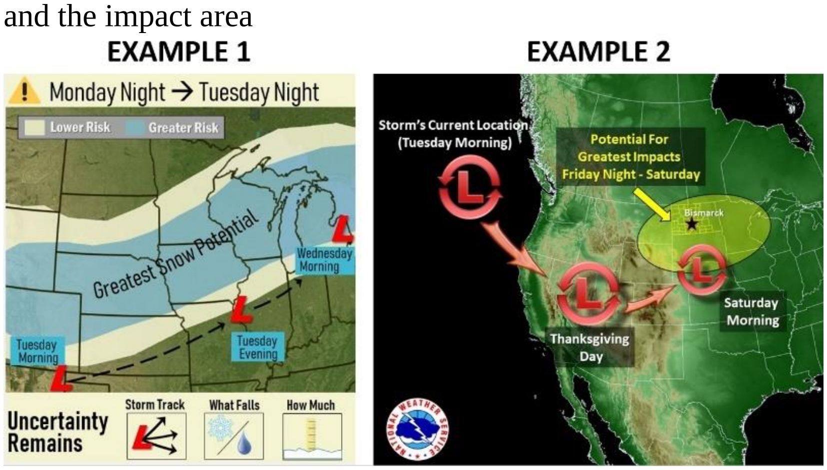


**Figure 55.** Two examples of using the track of the low-pressure system to communicate an upcoming winter storm. Example 1 posted by NWS Sioux Falls on 11/23/19. Example 2 posted by NWS Bismarck on 11/26/19.

e. I don't have a preference for the graphic used 4-7+ days before a winter storm

11. Below is an example of a long-range (days 4-7) storm risk graphic used by a few National Weather Service offices. Do you think this is an effective way of communicating the confidence and potential impact of a possible upcoming winter storm? *(N = 40)*


**Figure 56.** Long-range winter weather graphic, based on the threat matrix, created by NWS State College on 11/28/19 and shown on their website.

a. I think this is an effective way of communicating the storm risk and users will understand it
b. I think this is an effective way of communicating the storm risk, but some improvements need to be made to help the user understand it easier
c. I am unsure whether users will be able to interpret and understand it easily
d. I do not think this is a good way of communicating the long-range storm risk
a. Other (please explain)

12. Describe how you think long-range (4-7+ days) winter weather messaging can improve based on your past experiences. *(N = 24)*

13. When a tight gradient in snowfall amounts is present or lots of uncertainty remains a couple of days before the onset of a winter storm, sometimes National Weather Service offices circle these specific areas on a snow map, similar to the one below. Do you think that the user understands the circled area of uncertainty and will prepare for the storm differently if they live in the circled area? *(N = 40)*

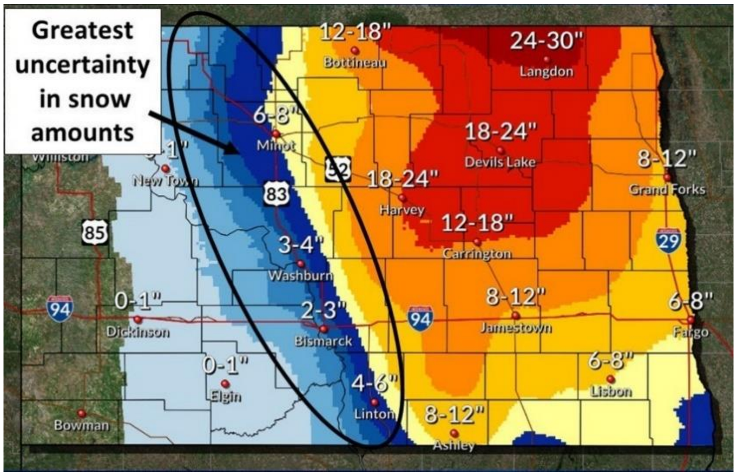


**Figure 57.** Snow map with greatest area of uncertainty circled posted to social media by NWS Bismarck on 10/10/19

a. I think the user understands the circled area of uncertainty and will prepare differently if they live in the circled area
b. I think the user understands the circled area of uncertainty, but will NOT prepare differently if they live in the circled area
c. I think the user does NOT understand the circled area of uncertainty, but will prepare differently if they live in the circled area
d. I think the user does NOT understand the circled area of uncertainty and will NOT prepare differently if they live in the circled area
e. I don't know what the user will think about the circled area of uncertainty or how they will prepare

14. From a forecaster standpoint, how do you decide when to add the circled area of uncertainty to a snow forecast map? What factors go into your decision to include or to not include it on the graphic? Please describe your reasoning briefly. *(N = 40)*

15. Sometimes the area of uncertainty on snow maps is circled, as shown in the examples below. However, National Weather Service offices sometimes talk about the uncertainty in text on the graphic next to the snow map, as shown in the examples below. Do you think one method is more effective and easier for the user to understand? *(N = 40)*

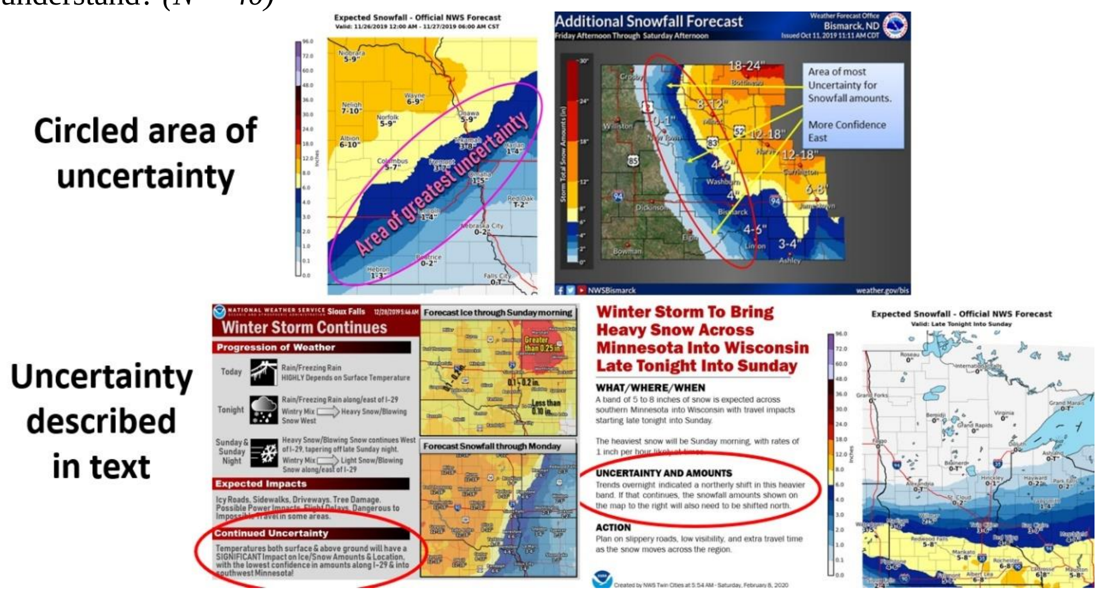


**Figure 58.** A collection of winter weather graphics created by NWS offices some of which present the uncertainty information as a circled area and others present it in the form of text on the graphic

a. I think the circling of the area of uncertainty is more effective and easier for the user to understand
b. I think the discussion of the uncertainty in text on the graphic is more effective and easier for the user to understand
c. I think that some combination of the two should be used with a circled area of uncertainty but also a text description on the graphic as well
d. I do not have an opinion on this

# Appendix B

## Survey Questions for Non-Meteorologists in NWS Central Region

<u>General Questions Section:</u>

1. Please select your age group (*N=32)*
    a. 18-26
    b. 27-35
    c. 36-44
    d. 45-53
    e. 54-62
    f. 63+

2. During the WINTER SEASON, what source of weather information do you look at most? *(N = 32)*
    a. National Weather Service (their website or on social media)
    b. Broadcast Meteorologists (TV, app, their website, or on social media)
    c. Radio
    d. Newspaper
    e. Phone Weather Apps
    f. Other Online Websites (not National Weather Service or TV stations)
    g. Other Sources on Social Media (not National Weather Service or broadcast meteorologists)
    h. Other (please explain)

3. How many days BEFORE the onset of a winter storm do you usually know that the threat of an upcoming storm exists? *(N = 32)*
    a. 1-2 days before
    b. 3-4 days before
    c. 5-6 days before
    d. 7+ days before

4. How many inches of snow would you consider to be "impactful"? (for instance, you might not be able to travel if more than this amount of snow accumulates) *(N = 32)* *(Type in a number)*

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Winter Weather Scenario #1 Section:

*Description Given at Start of Section:* Imagine that you are the leader of your local town's public works department and you need to make decisions about staffing before a winter storm could impact your town. If the snow accumulates more than 4 inches you need at least 10 people on staff to plow the roads. If the snow accumulates less than 4 inches you need less than 10 people on staff. Overstaffing will cause your department to lose money because too many people were called into work. Understaffing will cause the roads in your town to not be plowed in a timely manner and will cause delays for your residents who want to travel.

5. On Sunday evening, three days before the onset of a winter storm, your local National Weather Service office releases this graphic. Your town is located at the black X. If you had to make the staffing decision now, how many people would you have on staff on Wednesday? *(N = 32)*

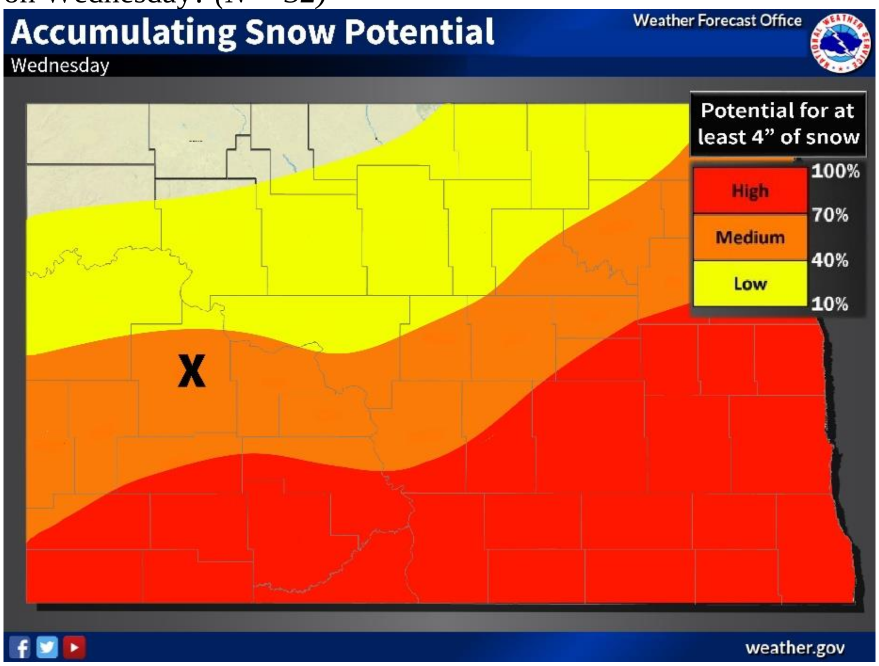


**Figure 59.** Generic red/orange/yellow color scheme risk probability graphic created with a black X located in the medium threat contour on the map.

   a. More than 10 people (expecting more than 4" of snow)
   b. Less than 10 people (not expecting more than 4" of snow)
   c. Too early to make the staffing decision due to uncertainty with the forecast

6. Explain why you chose that option and how you made your decision *(N = 24)*

7. What is your confidence level with your decision? Express as a percentage: 0% is not confident at all, 100% is totally confident. *(N = 32)*

8. Did you understand the above graphic as a way of communicating the forecast? *(N = 32)*
    a. I totally understood the graphic and thought it was valuable for making my decision
    b. I somewhat understood the graphic and used it for making my decision
    c. It took me a while to figure out how to interpret the graphic
    d. I did not understand the graphic and therefore did not use it for making my decision

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9. On Tuesday, one day before the onset of a winter storm, your local National Weather Service office releases this graphic. Your town is located at the white X (SAME LOCATION as the previous graphic that you just saw). How many people should you have on staff tomorrow (Wednesday)? *(N = 32)*


**Figure 60.** Generic snow map created for winter storm scenario #1 with multiple contours for different snow amounts and a white X placed in the 4-6" contour.

   a. More than 10 people (expecting more than 4" of snow)
   b. Less than 10 people (not expecting more than 4" of snow)
   c. Too early to make the staffing decision due to uncertainty with the forecast

10. Explain why you chose that option and how you made your decision *(N = 26)*

11. What is your confidence level with your decision? Express as a percentage: 0% is not confident at all, 100% is totally confident. *(N = 32)*

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Winter Weather Scenario #2 Section:

*Description Given at Start of Section:* You hold the same position as the leader of your local town's public works department, but now ANOTHER, DIFFERENT winter storm could impact your area. Again, you need to make decisions about staffing before this winter storm could impact your town. Reminder (same as before): If the snow accumulates more than 4 inches you need at least 10 people on staff to plow the roads. If the snow accumulates less than 4 inches you need less than 10 people on staff. Overstaffing will cause your department to lose money because too many people were called into work. Understaffing will cause the roads in your town to not be plowed in a timely manner and will cause delays for your residents who want to travel.

12. On Friday evening, three days before the onset of a winter storm, your local National Weather Service office releases this graphic. Your town is located at the black X. If you had to make the staffing decision now, how many people would you have on staff on Monday? *(N = 32)*

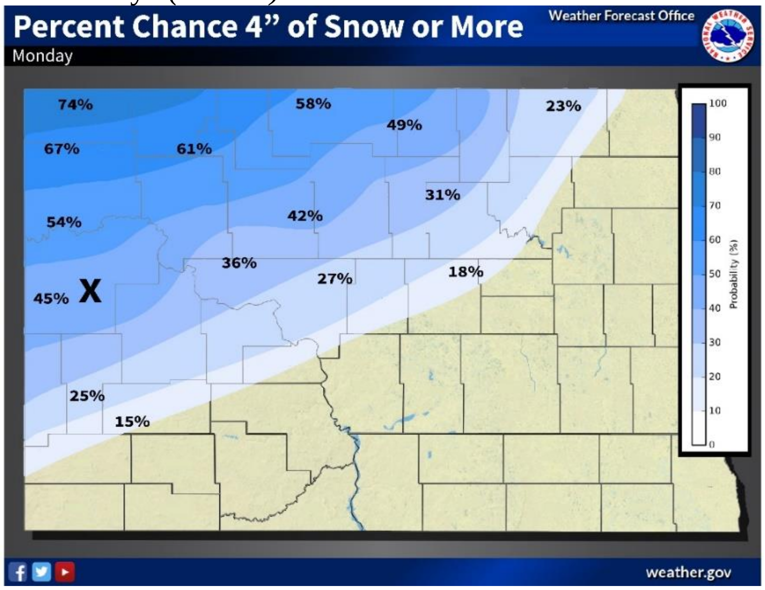


**Figure 61.** Generic blue shadings risk probability map created with a black X placed in the 40-50% contour.

a. More than 10 people (expecting more than 4" of snow)
b. Less than 10 people (not expecting more than 4" of snow)
c. Too early to make the staffing decision due to uncertainty with the forecast

13. Explain why you chose that option and how you made your decision. *(N = 23)*

14. What is your confidence level with your decision? Express as a percentage: 0% is not confident at all, 100% is totally confident. *(N = 32)*

15. Did you understand the above graphic as a way of communicating the forecast? *(N = 32)*
    a. I totally understood the graphic and thought it was valuable for making my decision
    b. I somewhat understood the graphic and used it for making my decision
    c. It took me a while to figure out how to interpret the graphic
    d. I did not understand the graphic and therefore did not use it for making my decision

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16. On Sunday, one day before the onset of a winter storm, your local National Weather Service office releases this graphic. Your town is located at the white X (SAME LOCATION as the previous graphic that you just saw). How many people should you have on staff tomorrow (Monday)? *(N = 32)*


**Figure 62.** Generic snow map created for winter storm scenario #2 with multiple contours for different snow amounts and a white X placed in the 4-6" contour.

    a. More than 10 people (expecting more than 4" of snow)
    b. Less than 10 people (not expecting more than 4" of snow)
    c. Too early to make the staffing decision due to uncertainty with the forecast

16. Explain why you chose that option and how you made your decision *(N = 21)*

17. What is your confidence level with your decision? Express as a percentage: 0% is not confident at all, 100% is totally confident. *(N = 32)*

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<u>Winter Weather Scenario #3 Section:</u>

*Description Given at Start of Section:* You hold the same position as the leader of your local town's public works department, but now one final winter storm could impact your area. Again, you need to make decisions about staffing before this winter storm could impact your town. Reminder (same as before): If the snow accumulates more than 4 inches you need at least 10 people on staff to plow the roads. If the snow accumulates less than 4 inches you need less than 10 people on staff. Overstaffing will cause your department to lose money because too many people were called into work. Understaffing will cause the roads in your town to not be plowed in a timely manner and will cause delays for your residents who want to travel.

18. On Tuesday evening, three days before the onset of a winter storm, your local National Weather Service office releases this graphic. Your town is located at the white X. If you had to make the staffing decision now, how many people would you have on staff on Friday? *(N = 32)*


**Figure 63.** Generic snow map created for winter storm scenario #3 three days before the onset of the storm with multiple contours for different snow amounts and a white X placed in the 2-4" contour.

a. More than 10 people (expecting more than 4" of snow)
b. Less than 10 people (not expecting more than 4" of snow)
c. Too early to make the staffing decision due to uncertainty with the forecast

19. Explain why you chose that option and how you made your decision *(N = 18)*

20. What is your confidence level with your decision? Express as a percentage: 0% is not confident at all, 100% is totally confident. *(N = 32)*

21. Did you understand the above graphic as a way of communicating the forecast? *(N = 32)*
    a. I totally understood the graphic and thought it was valuable for making my decision
    b. I somewhat understood the graphic and used it for making my decision
    c. It took me a while to figure out how to interpret the graphic
    d. I did not understand the graphic and therefore did not use it for making my decision

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22. On Thursday, one day before the onset of a winter storm, your local National Weather Service office releases this graphic. Your town is located at the white X (SAME LOCATION as the previous graphic that you just saw). How many people should you have on staff tomorrow (Friday)? *(N =32)*


**Figure 64.** Generic snow map created for winter storm scenario #3 one day before the onset of the storm with multiple contours that have been shifted slightly compared to the snow map three days before the storm to simulate an update to the forecast. The white X placed is now in the 4-6" contour.

    a. More than 10 people (expecting more than 4" of snow)
    b. Less than 10 people (not expecting more than 4" of snow)
    c. Too early to make the staffing decision due to uncertainty with the forecast

23. Explain why you chose that option and how you made your decision *(N = 15)*

24. What is your confidence level with your decision? Express as a percentage: 0% is not confident at all, 100% is totally confident. *(N = 32)*

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<u>Final Questions About Specific Graphic Types:</u>

25. Several days (4-7+) before a winter storm, National Weather Service offices will communicate the threat of this upcoming storm in a variety of ways. Please select the style of graphic that you think is MOST effective at communicating an upcoming storm threat. *(N = 32)*
    a. Circling one or more areas on a map for snow potential **- Figure 52 shown**
    b. List of dates/timeline with the potential for snow highlighted **- Figure 53 shown**
    c. “What we know,” “what is uncertain,” “what should you do” **- Figure 54 shown**
    d. Using the track of the low-pressure system/storm to communicate the timing and the impact area **- Figure 55 shown**
    e. I don't have a preference for the graphic used 4-7+ days before a winter storm

26. The graphic below is sometimes used by the National Weather Service to communicate the possibility of snowfall from a winter storm exceeding a certain amount (you used a similar one in a previous section of this survey). What title do you think is best for describing these graphics? (the "x" in each option would be replaced by a specific snow amount like 4", 8", etc.) **- Figure 38 shown** *(N = 32)*
    a. Potential for at least "x" inches of snow
    b. Chance of at least "x" inches of snow
    c. Risk of greater than "x" inches of snow
    d. Probability of "x" Inches or greater snowfall
    e. I don't have a preference for the title of these graphics

27. If you live at the white X on this snowfall forecast map for an incoming storm that will impact your area tomorrow, how do you interpret the circled area that you are located within? Select all that apply or type your own answer. *(N = 32)*

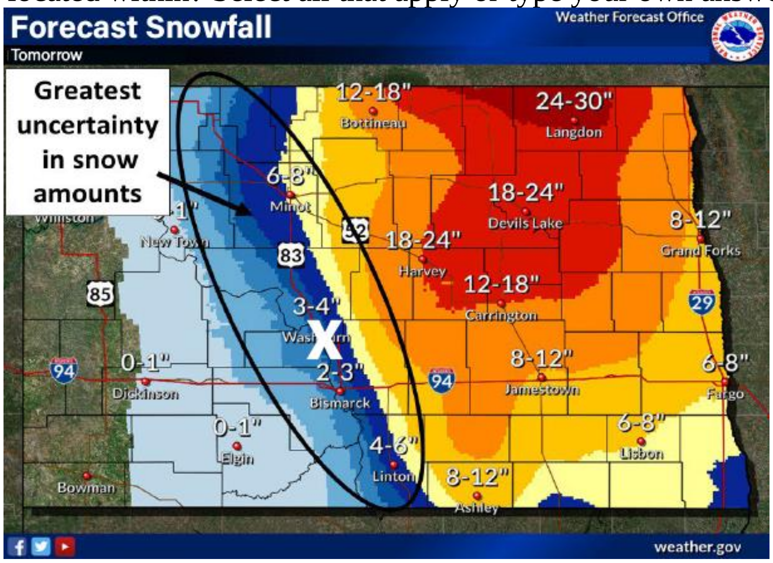


**Figure 65.** Graphic posted by NWS Bismarck on 10/10/19 with a circled area on the graphic that indicates a region of the forecasted snow amounts that has the greatest uncertainty. A white X is placed in this circled area and used as a part of the question.

a. Since I live in the circled area, I need to check the forecast again before the storm starts to see if anything has changed
b. Since I live in the circled area, I need to prepare for higher snowfall amounts in case the forecast changes
c. Since I live in the circled area, my actions do not change compared to if I lived in an area that was not circled
d. I do not understand what the circled area means
e. Other (please explain)

# Appendix C

## Survey Questions for the Public Across the U.S.

General Questions Section:

1. Please select your age group *(N=833)*
    a. 18-26
    b. 27-35
    c. 36-44
    d. 45-53
    e. 54-62
    f. 63+

2. Do you have a background in meteorology? (working towards a degree, have a degree, etc.) *(N=833)*
    a. Yes
    b. No
    c. No, but I consider myself a weather enthusiast (I look at the weather & forecasts rather closely each day)

3. Are you a partner of the National Weather Service? *(N=833)*
    a. No
    b. Yes – Emergency Manager Partner
    c. Yes – Department of Transportation Partner
    d. Yes – School/University Partner
    e. Yes – Healthcare Partner
    f. Yes – Other NWS Partner

4. How many winter storms have you experienced within the past 10 years? *(N=833)*
    a. Several (More than 5)
    b. A Few (2-5)
    c. One or Less

5. In which state do you currently reside? *(N=832)*
   *(drop down with all 50 states, Washington D.C., and Puerto Rico as options)*

6. During the WINTER SEASON, what source of weather information do you look at **most**? *(option choices presented in random order for each respondent) (N=833)*
    a. National Weather Service (their website or on social media)
    b. Broadcast Meteorologists (TV, app, their website, or on social media)
    c. Phone Weather Apps

d. Newspaper
e. Radio
f. Other Online Websites (not National Weather Service or TV stations)
g. Other Sources on Social Media (not National Weather Service or broadcast meteorologists)

7. In your opinion, at least how many inches of snow would need to fall for it to be considered "plowable"? (only numbers accepted) *(N=833)*

8. Rank the following types of forecast information in terms of importance to you before a winter storm? (most important on top) (drag and drop the options) *(option choices presented in random order for each respondent) (N=824)*
   a. Precipitation Onset Time
   b. Snowfall Totals
   c. Timing of Heaviest Snowfall
   d. Travel Impacts
   e. Wind Speeds/Power Outage Potential
   f. Amount of Confidence/Uncertainty in Forecast

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**<u>Each respondent was randomly presented with ONE of the following four scenarios.</u>** These are actual graphics that the following National Weather Service offices posted to social media at the specific lead times before a winter storm that are mentioned. These scenarios and graphics were chosen to offer the best opportunity for comparing the variety of different graphic types that are used to communicate an upcoming winter storm. The only alterations that were made to the graphics was to remove the information about when the graphic was created or posted.

For the questions on this survey where a number from 0 through 10 had to be selected, the way this was presented is shown below in Figure 66

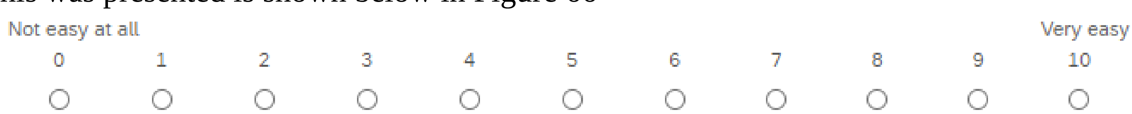


**Figure 66.** Screenshot of what the answer choices looked like for respondents when presented with questions where they had to select a number from 0 through 10. The descriptors on top of 0 and 10 varied based on the question.

<u>**Scenario #1** – Graphics posted from the National Weather Service in Omaha, Nebraska from 1/22/21 to 1/24/21 (10 questions asked in this section)</u>

9. Imagine you live in the Omaha, Nebraska area. The Omaha, NE National Weather Service releases this graphic on Friday, **three** days before a winter storm is expected to impact the region on Monday. Click on the part of the graphic below that provides you with the MOST important and helpful information, in your opinion. *(N=186)*

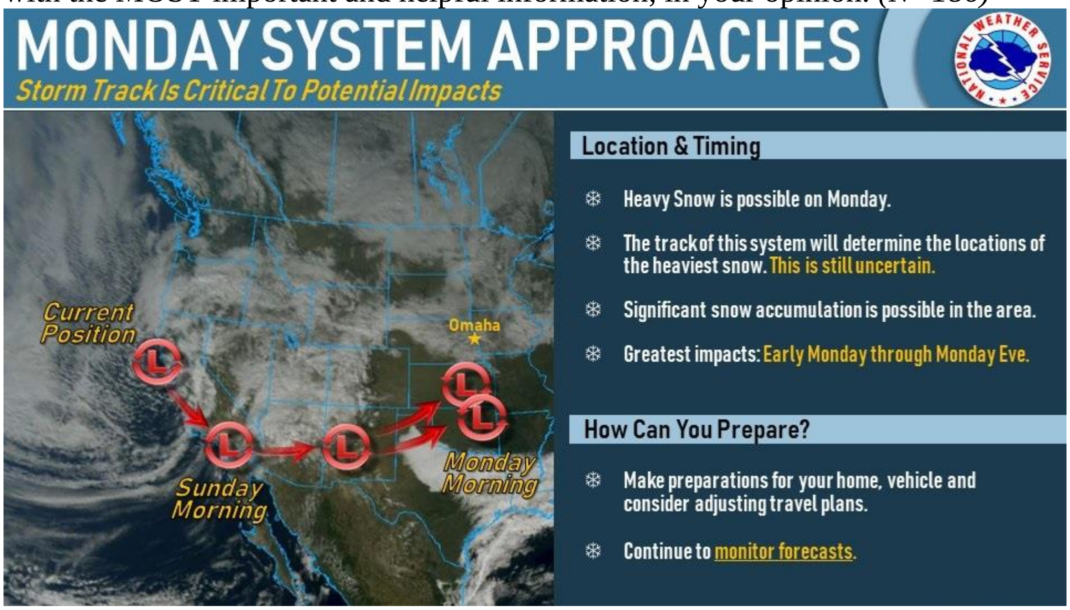


**Figure 67.** Graphic posted by NWS Omaha on 1/22/21 using a map with the track of the low-pressure system and timing information along with additional text on the graphic.

10. How easy is this graphic to interpret? *(N=186)*
    *Select a number from 0 (not easy at all) through 10 (very easy)*

11. How well does this graphic communicate the uncertainty with the forecast? *(N=186)*
    *Select a number from 0 (not well at all) through 10 (very well)*

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On Saturday, **two** days before the winter storm is expected to impact the Omaha area, the NWS Omaha office releases this graphic.

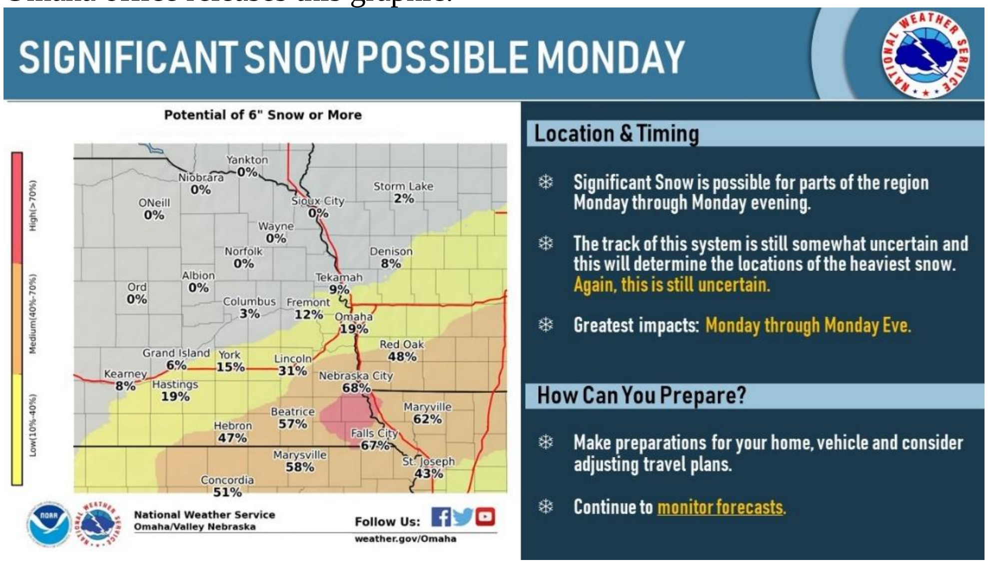


**Figure 68.** Graphic posted by NWS Omaha on 1/23/21 using a three-tiered red, orange, yellow risk probability map for the potential of 6” or more of snow with probability percentages at each location on the map and additional text on the graphic.

12. How easy is this graphic to interpret? *(N=186)*
    *Select a number from 0 (not easy at all) through 10 (very easy)*

13. How well does this graphic communicate the uncertainty with the forecast? *(N=186)*
    *Select a number from 0 (not well at all) through 10 (very well)*

Suppose you live in Omaha (circled on this graphic – same graphic as above)

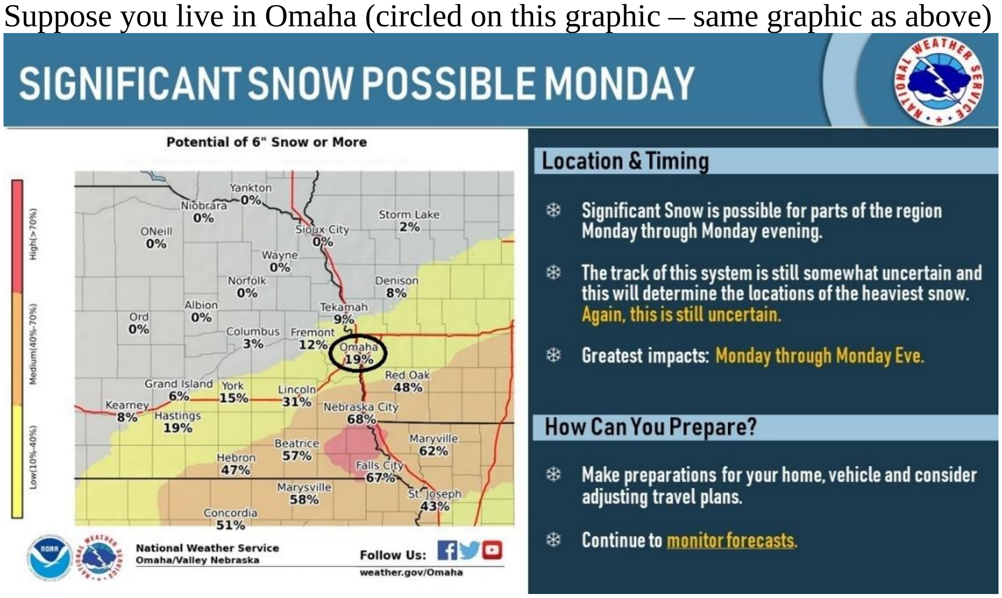


**Figure 69.** Graphic posted by NWS Omaha on 1/23/21. The same as Figure 68 but with Omaha and its probability percentage of receiving 6” of snow or more circled in a black oval.

14. How much snow do you think you, in Omaha, will receive from this storm? (in inches - only numbers accepted) *(N=185)*

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15. Later in the day on Saturday, again **two** days before the winter storm, the NWS Omaha office releases this graphic. Click on the part of the graphic below that provides you with the MOST important and helpful information, in your opinion.

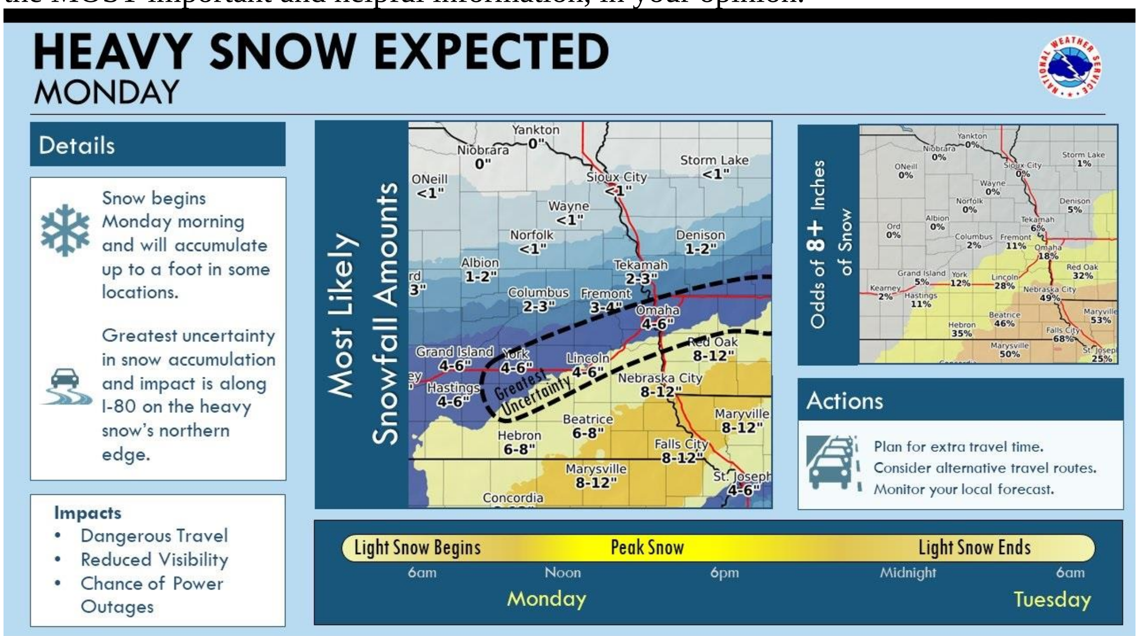


**Figure 70.** Graphic posted by NWS Omaha on 1/23/21 with a snow map, risk probability map with the odds of 8" or more of snow, action items, a timeline of the storm, impacts, and additional details all on the graphic.

16. Is this what you expected the snowfall forecast map to look like based on the previous "Potential of 6" of Snow or More" graphic that you saw? *(N=186)*
*Select a number from 0 (not at all what I expected) through 10 (exactly what I expected)*

17. Is the circled area of "greatest uncertainty" on the snowfall forecast map helpful for you to understand the uncertainty with the forecast? *(N=186)*
*Select a number from 0 (not helpful at all) through 10 (very helpful)*

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Finally, on Sunday, one day before the onset of the winter storm, the NWS Omaha office releases this graphic with an updated snowfall forecast map.


**Figure 71.** Graphic posted by NWS Omaha on 1/24/21 with an updated snow map and additional text-based information on the graphic.

18. Suppose you live in Omaha (in the black box on the graphic above). Did the circled area of uncertainty on the previous graphic help you anticipate the increased snow totals predicted for Omaha on this updated map? *(N=186)*
*Select a number from 0 (not helpful at all) through 10 (it was very helpful)*

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<u>**Scenario #2** – Graphics posted from the National Weather Service in State College, Pennsylvania from 12/11/20 to 12/15/20 (10 questions asked in this section)</u>

Imagine you live in Central Pennsylvania. The State College, PA National Weather Service releases this graphic on Friday, **five** days before a winter storm is expected to impact Central Pennsylvania on Wednesday.

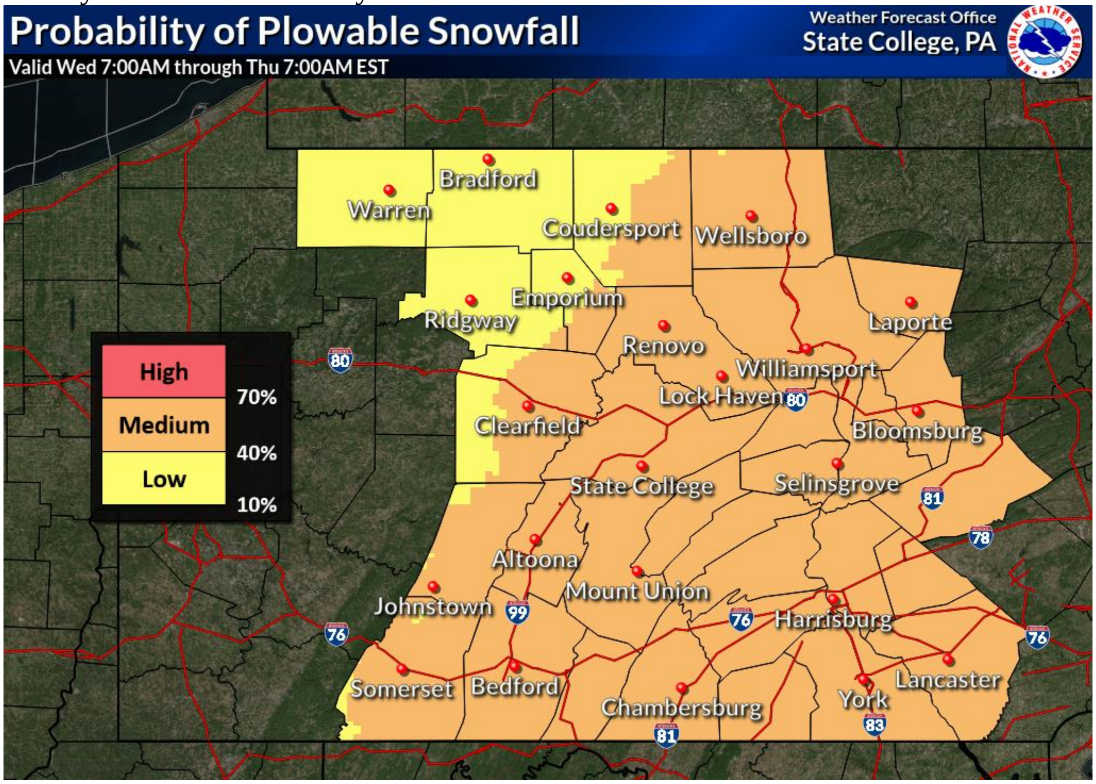


**Figure 72.** Graphic posted by NWS State College on 12/11/20 with a probability of plowable snowfall map for the forecast area. This is based on the Weather Prediction Center's probability of exceeding 0.25 inches of snow/sleet liquid equivalent in the 24-hour period listed.

19. How easy is this graphic to interpret? *(N=214)*
    *Select a number from 0 (not easy at all) through 10 (very easy)*

20. How well does this graphic communicate the uncertainty with the forecast? *(N=213)*
    *Select a number from 0 (not well at all) through 10 (very well)*

21. How useful is it that this forecast information is given to you five days before the winter storm? *(N=214)*
    *Select a number from 0 (not useful at all) through 10 (very useful)*

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22. On Sunday, **three** days before the winter storm is expected to impact Central PA, the NWS State College office releases this graphic. Click on the part of the graphic below that provides you with the MOST important and helpful information, in your opinion. *(N=214)*

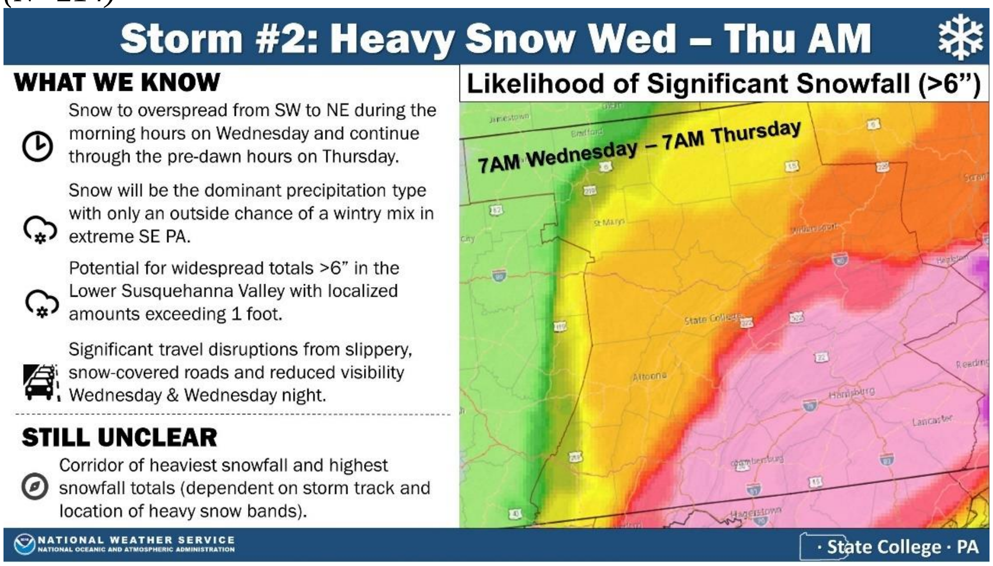


**Figure 73.** Graphic posted by NWS State College on 12/13/20 with a probability of exceedance map using a green, yellow, orange, red/pink color scheme and additional text-based information on the graphic as well.

23. How easy is this graphic to interpret? *(N=214)*
*Select a number from 0 (not easy at all) through 10 (very easy)*

24. How well does this graphic communicate the uncertainty with the forecast? *(N=212)*
*Select a number from 0 (not well at all) through 10 (very well)*

Suppose you live in State College (circled on this graphic – same graphic as above)

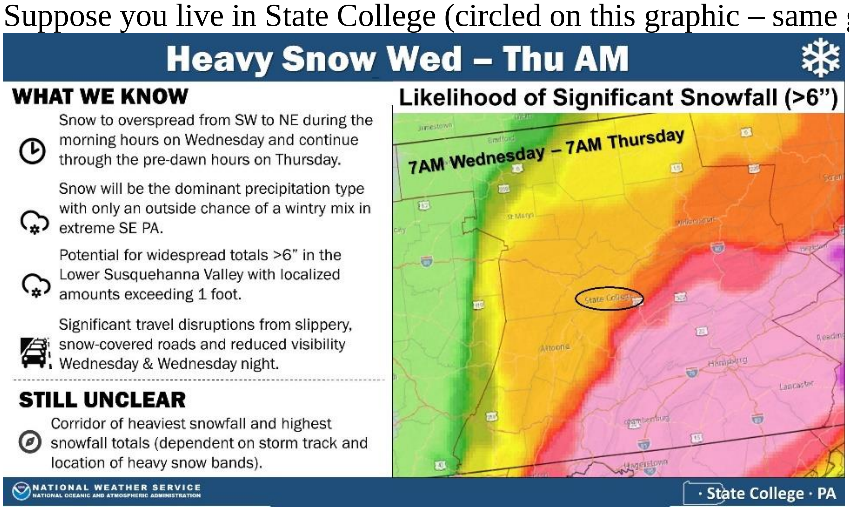


**Figure 74.** Graphic posted by NWS State College on 12/13/20. The same as Figure 73 but with State College circled in a black oval on the map for easier identification in Question 25.

25. How much snow do you think you, in State College, will receive from this storm? (in inches - only numbers accepted) *(N=213)*

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On Monday, **two** days before the onset of the winter storm, the NWS State College office releases this graphic.

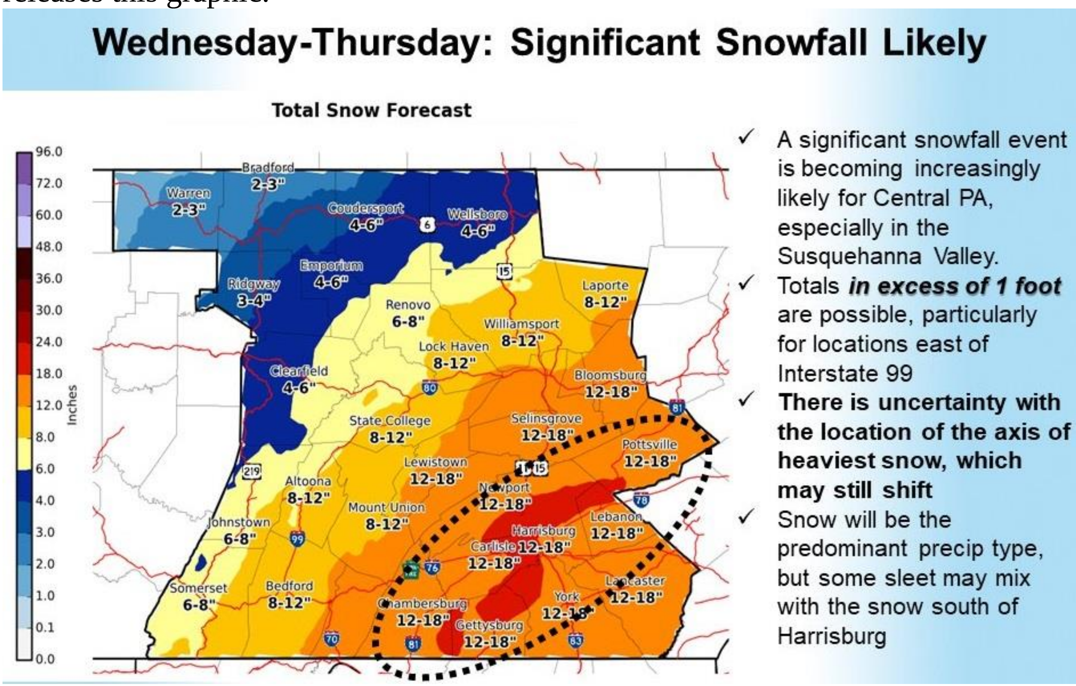


**Figure 75.** Graphic posted by NWS State College on 12/14/20 with a snow map and a dashed-circle region used to emphasize the enhanced uncertainty in the forecast in that region.

26. Is this what you expected the snowfall forecast map to look like based on the previous "Likelihood of Significant Snowfall (>6")" graphic that you saw? *(N=214)*
*Select a number from 0 (not at all what I expected) through 10 (exactly what I expected)*

27. Is the circled area of uncertainty (dashed black circle), and associated description (in bold), helpful for you to understand the uncertainty with the forecast? *(N=214)*
*Select a number from 0 (not helpful at all) through 10 (very helpful)*

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Finally, on Tuesday, **one** day before the onset of the winter storm, the NWS State College office releases this graphic with an updated snowfall forecast map.

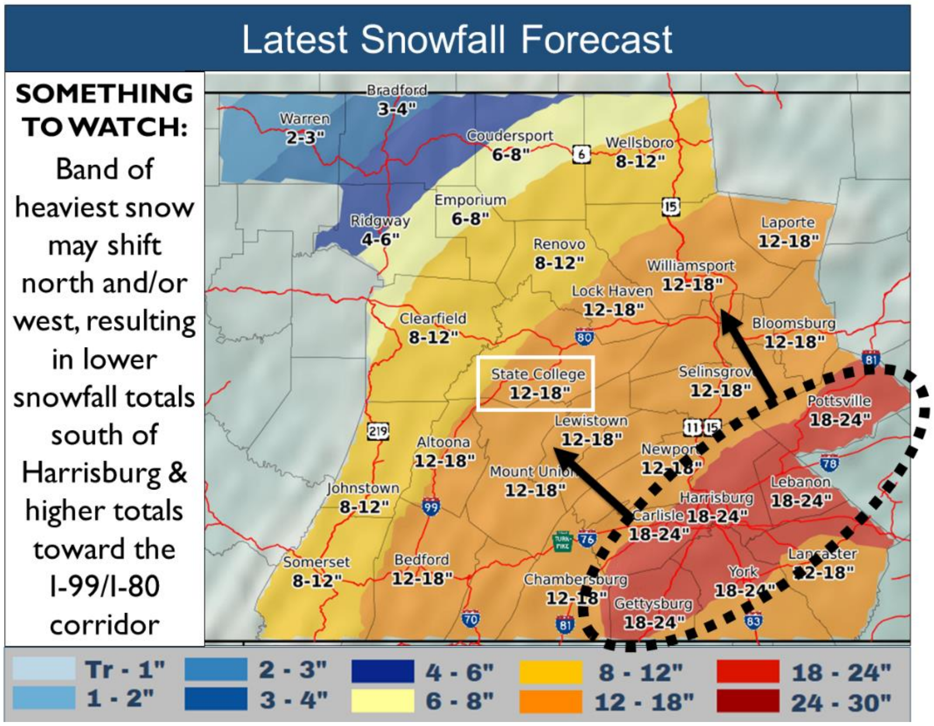


**Figure 76.** Graphic posted by NWS State College on 12/15/20 with an updated snow map and a circled area of heavy snow with arrows showing that the axis of heaviest snow might shift. A description of this is also included on the graphic.

28. Suppose you live in State College (in the white box on the graphic above). Is the circled area (dashed black circle), arrows, and associated description (on the left of the graphic), helpful for you to understand the uncertainty with the forecast and how the currently forecasted snow totals could change? *(N=214)*
*Select a number from 0 (not helpful at all) through 10 (very helpful)*

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<u>**Scenario #3** – Graphics posted from the National Weather Service in Bismarck, North Dakota from 11/24/19 to 11/28/19 (10 questions asked in this section)</u>

29. Imagine you live in North Dakota. The Bismarck, ND National Weather Service releases this graphic on Sunday, **five** days before a winter storm is expected to impact North Dakota on Friday. Click on the part of the graphic below that provides you with the MOST important and helpful information, in your opinion. *(N=220)*

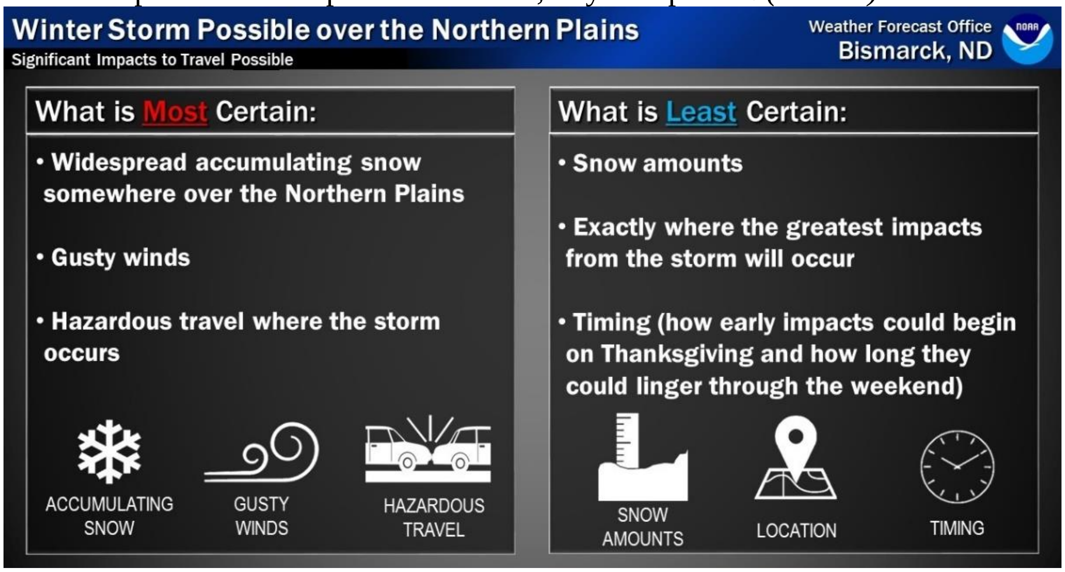


**Figure 77.** Graphic posted on 11/24/19 by NWS Bismarck which lists the things that are most certain and least certain about the forecast for the upcoming winter storm.

30. How easy is this graphic to interpret? *(N=220)*
*Select a number from 0 (not easy at all) through 10 (very easy)*

31. How well does this graphic communicate the uncertainty with the forecast? *(N=220)*
*Select a number from 0 (not well at all) through 10 (very well)*

32. How useful is it that this forecast information is given to you five days before the winter storm? *(N=220)*
*Select a number from 0 (not useful at all) through 10 (very useful)*

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33. On Wednesday, **two** days before the winter storm is expected to impact North Dakota, the NWS Bismarck office releases this graphic. Click on the part of the graphic below that provides you with the MOST important and helpful information, in your opinion. *(N=220)*

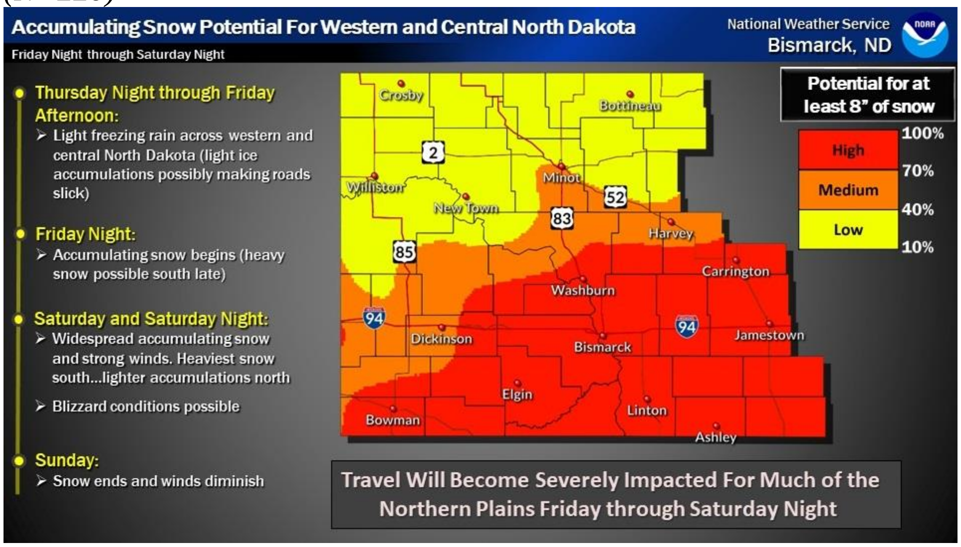


**Figure 78.** Graphic posted on 11/27/19 by NWS Bismarck with a three-tiered red, orange, yellow risk probability map for the potential of at least 8" of snow. Probability percentages are included in the color scale. Timing information and a statement about travel impacts is also included.

34. How easy is this graphic to interpret? *(N=220)*
*Select a number from 0 (not easy at all) through 10 (very easy)*

35. How well does this graphic communicate the uncertainty with the forecast? *(N=220)*
*Select a number from 0 (not well at all) through 10 (very well)*

Suppose you live in Bismarck (in the white box on this graphic – same graphic as above)

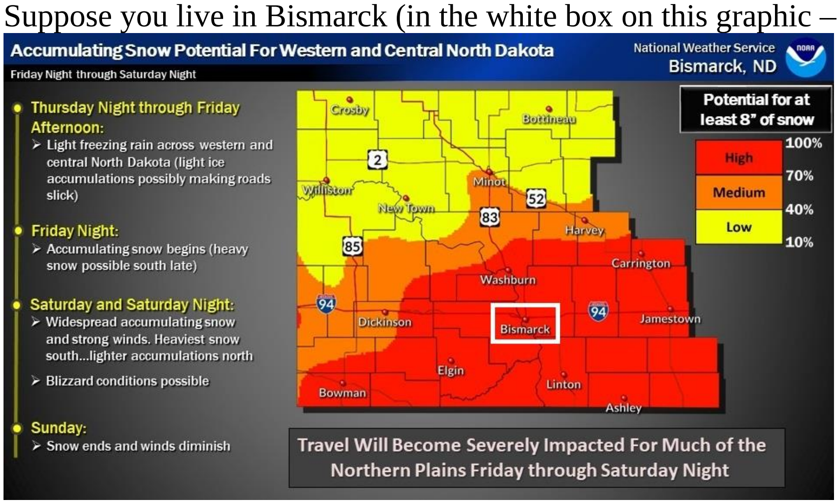


**Figure 79.** Graphic posted by NWS Bismarck on 11/27/19. The same as Figure 78 but with Bismarck now in the white box on the map for easier identification in Question 36.

36. How much snow do you think you, in Bismarck, will receive from this storm? (in inches - only numbers accepted) *(N=219)*

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37. Finally, on Thursday, **one** day before the onset of the winter storm, the NWS Bismarck office releases this graphic. Click on the part of the graphic below that provides you with the MOST important and helpful information, in your opinion. *(N=220)*

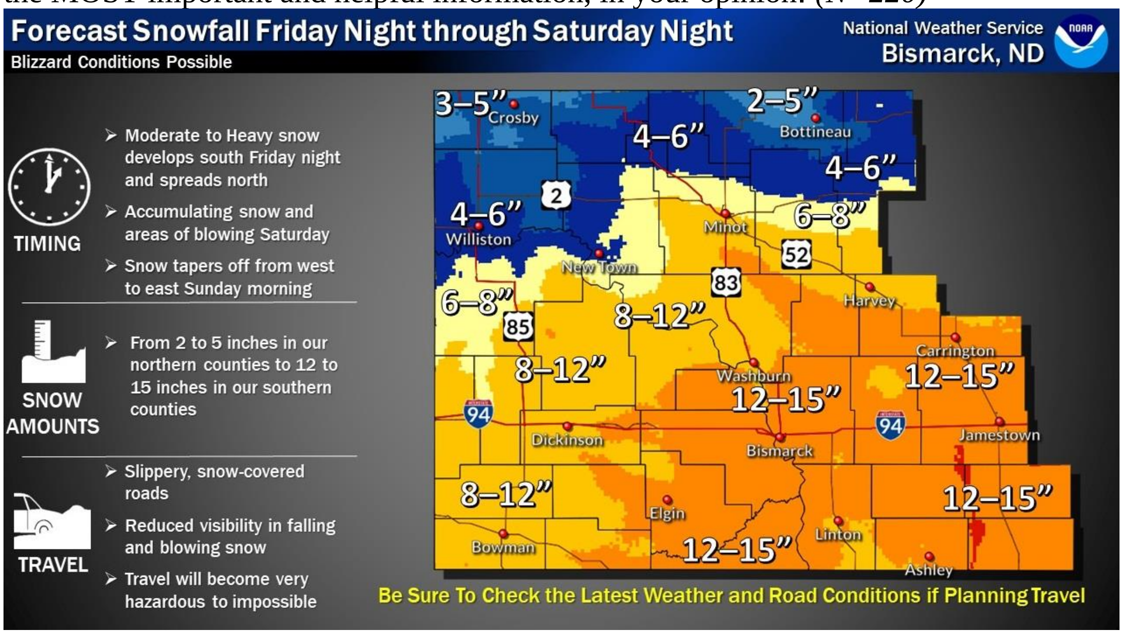


**Figure 80.** Graphic posted by NWS Bismarck on 11/28/19 with a snow map and additional text-based information on the graphic as well.

38. Is this what you expected the snowfall forecast map to look like based on the previous “Potential for At Least 8" of Snow” graphic that you saw? *(N=220)*
*Select a number from 0 (not at all what I expected) through 10 (exactly what I expected)*

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<u>**Scenario #4** – Graphics posted from the National Weather Service in Green Bay, Wisconsin from 11/23/19 to 11/25/19 (11 questions asked in this section)</u>

Imagine you live in Wisconsin. The Green Bay, WI National Weather Service releases this graphic on Saturday, **three** days before a winter storm is expected to impact Wisconsin on Tuesday.

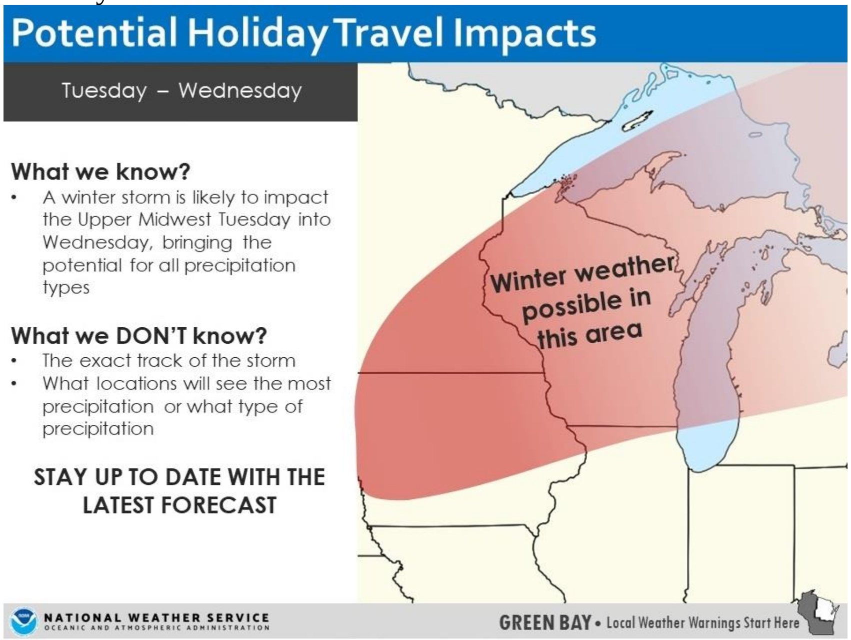


**Figure 81.** Graphic posted by NWS Green Bay on 11/23/19 circling and highlighting a region in the Midwest that could receive some winter weather. Things that are known and things that are not known about the forecast are stated on the graphic as well.

39. How easy is this graphic to interpret? *(N=213)*
    *Select a number from 0 (not easy at all) through 10 (very easy)*

40. How well does this graphic communicate the uncertainty with the forecast? *(N=213)*
    *Select a number from 0 (not well at all) through 10 (very well)*

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41. On Sunday, **two** days before the winter storm is expected to impact Wisconsin, the NWS Green Bay office releases this graphic. Click on the part of the graphic below that provides you with the MOST important and helpful information, in your opinion. *(N=213)*

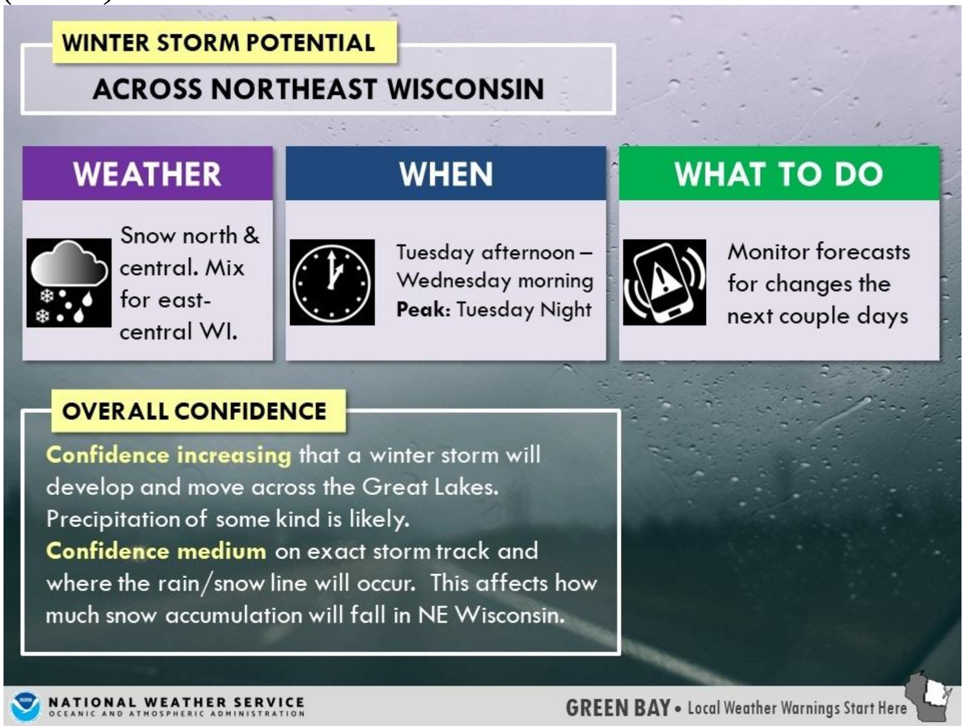


**Figure 82.** Graphic posted by NWS Green Bay on 11/24/19 stating what will happen, when it will happen, and things that people can do before the upcoming winter storm. The amount of confidence in certain aspects of the forecast are also stated on the graphic.

42. How easy is this graphic to interpret? *(N=213)*
*Select a number from 0 (not easy at all) through 10 (very easy)*

43. How well does this graphic communicate the uncertainty with the forecast? *(N=213)*
*Select a number from 0 (not well at all) through 10 (very well)*

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Later in the day on Sunday, **two** days before the winter storm is expected to impact Wisconsin, the NWS Green Bay office releases this graphic. *(N=213)*

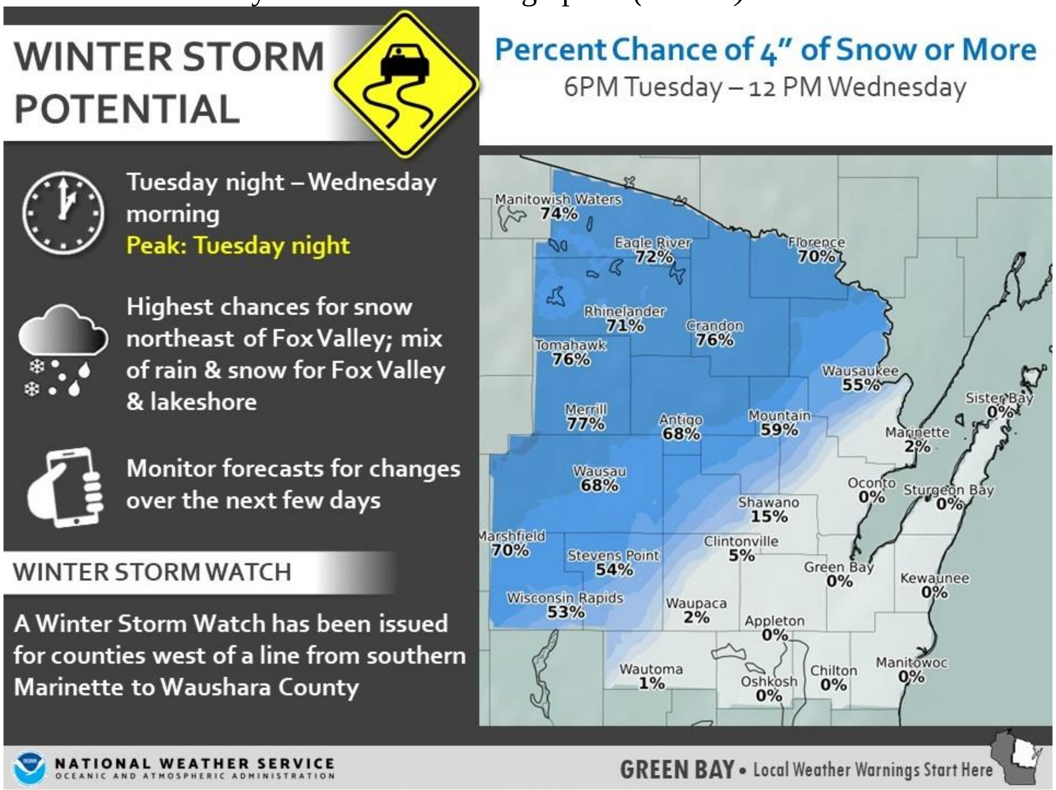


**Figure 83.** Graphic posted by NWS Green Bay on 11/24/19 with a risk probability map that uses the blue shadings color scheme and has probability percentages plotted at each location. Additional information about the winter storm is listed on the graphic as well.

44. How easy is this graphic to interpret? *(N=213)*
    *Select a number from 0 (not easy at all) through 10 (very easy)*

45. How well does this graphic communicate the uncertainty with the forecast? *(N=213)*
    *Select a number from 0 (not well at all) through 10 (very well)*

Suppose you live in Wausaukee (circled on this graphic – same graphic as above)

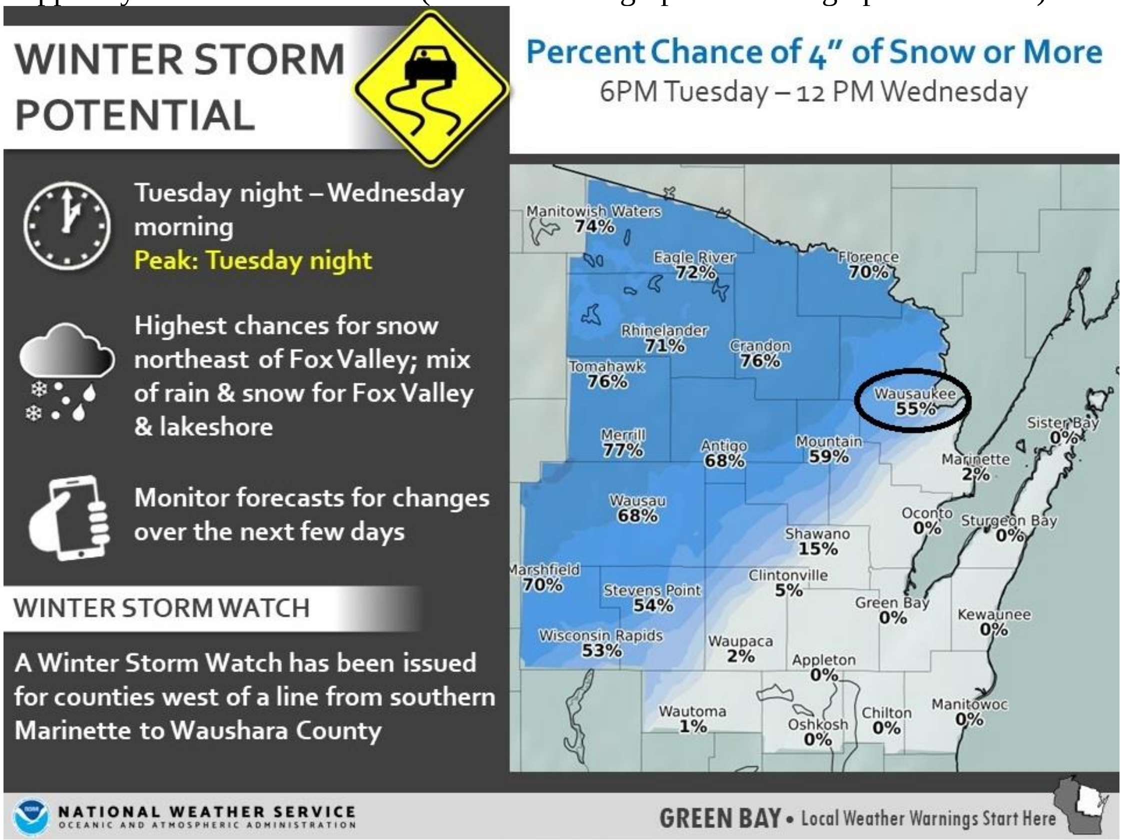


**Figure 84.** Graphic posted by NWS Green Bay on 11/24/19. The same as Figure 83 but with Wausaukee now circled in a black oval on the map for easier identification in Question 46.

46. How much snow do you think you, in Wausaukee, will receive from this storm? (in inches - only numbers accepted) *(N=212)*

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47. Finally, on Monday, **one** day before the onset of the winter storm, the NWS Green Bay office releases this graphic. Click on the part of the graphic below that provides you with the MOST important and helpful information, in your opinion.

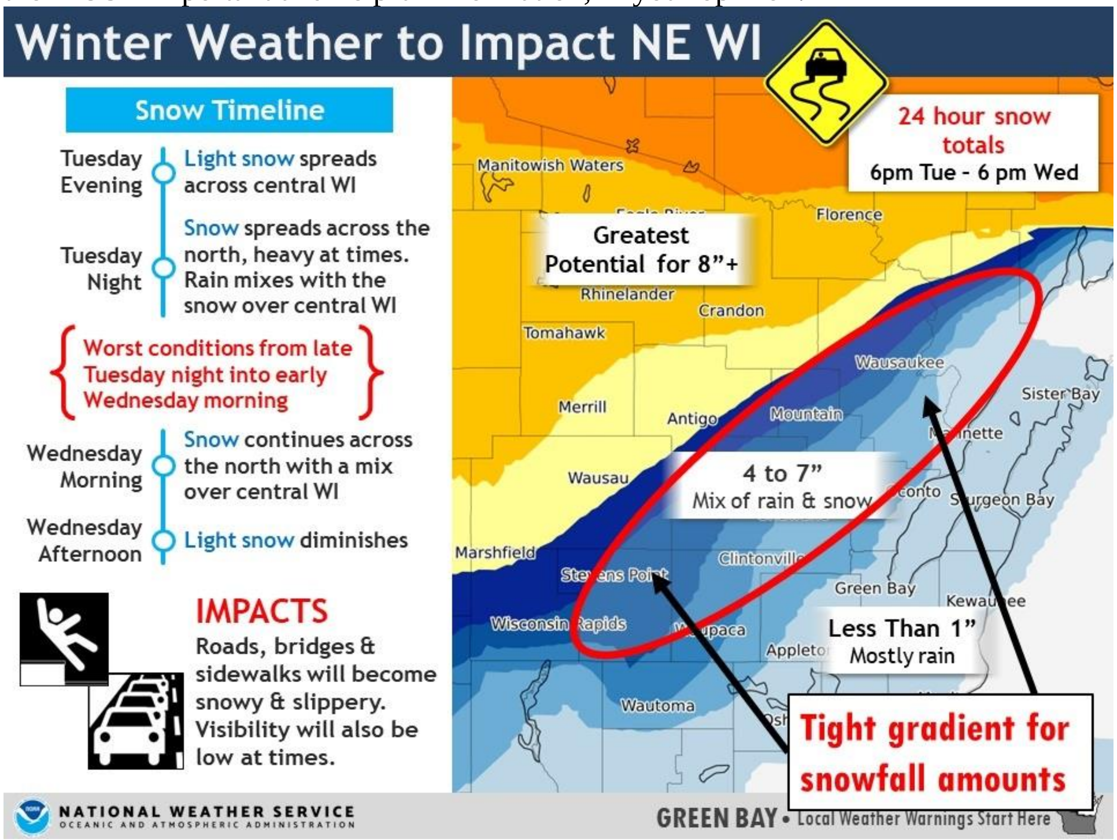


**Figure 85.** Graphic posted by NWS Green Bay on 11/25/19 with a snow map that has a red circled area titled "tight gradient for snowfall amounts." The timeline of the winter storm is also included on this graphic along with the major impacts.

48. Is this what you expected the snowfall forecast map to look like based on the previous "Percent Chance of 4" of Snow or More" graphic that you saw? *(N=213)*
*Select a number from 0 (not at all what I expected) through 10 (exactly what I expected)*

49. Is the circled area of "tight gradient for snowfall amounts" on the snowfall forecast map helpful for you to understand the uncertainty with the forecast? *(N=213)*
*Select a number from 0 (not helpful at all) through 10 (very helpful)*

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<u>Final Questions</u>

50. Several days (about 3-7 days) before a winter storm, National Weather Service offices will communicate the threat of an upcoming winter storm in a variety of ways. Please select the style of graphic that you think is MOST effective at communicating an upcoming winter storm. *(option choices presented in random order for each respondent) (N=831)*

a. Circling one or more areas on a map for snow potential

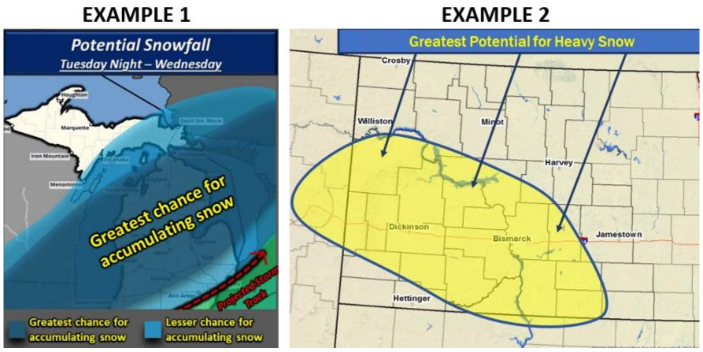


**Figure 86.** Two examples of circling regions on a map to communicate an upcoming winter storm. Example 1 posted by NWS Gaylord on 2/23/20. Example 2 posted by NWS Bismarck on 4/12/20.

b. List of dates/timeline with the potential for snow highlighted


**Figure 87.** Two examples of using a timeline or list of dates to highlight the potential for an upcoming snowstorm. Example 1 posted by NWS Flagstaff on 11/24/19. Example 2 posted by NWS Sioux Falls on 1/13/20.

c. What we know/don't know or what is most/least certain

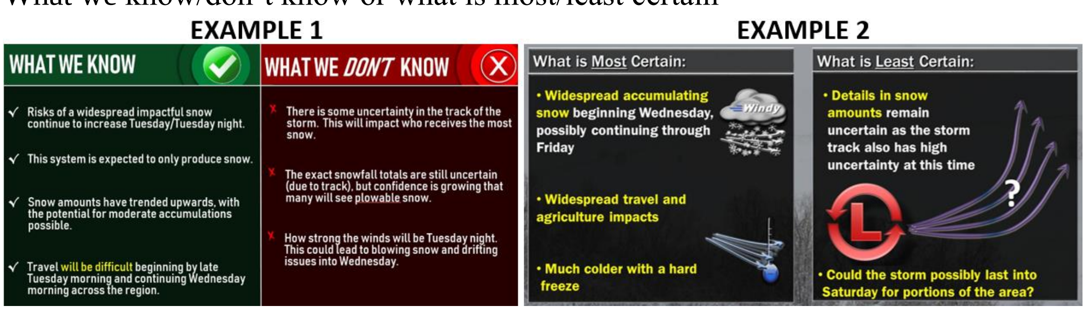


**Figure 88.** Two examples of listing what is known/certain and what is unknown/uncertain for an upcoming snowstorm. Example 1 posted by NWS Sioux Falls on 11/14/19. Example 2 posted by NWS Bismarck on 10/7/19.

d. Using the track of the low-pressure system/storm to communicate the timing and impact area

**EXAMPLE 1** **EXAMPLE 2**

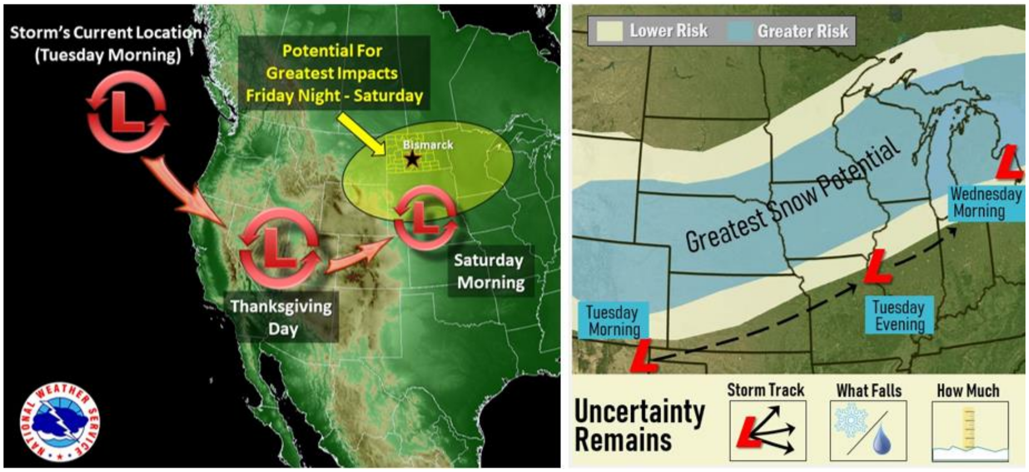


**Figure 89.** Two examples of using the storm track to show the timing and impact area of an upcoming winter storm. Example 1 posted by NWS Bismarck on 11/26/19. Example 2 posted by NWS Sioux Falls on 11/23/19.

e. I don't have a preference for the graphic used ~3-7 days before a winter storm

51. There are many different color schemes used in graphics to communicate the **probability of snowfall from a winter storm exceeding a specified amount** (in other words, the probability of at least a certain amount of snow).
Which **color scheme** do you think is the BEST? (Note: each graphic is from a different snow event - do not judge based on the situation or the extent of the map) *(option choices presented in random order for each respondent) (N=831)*

a. Yellow/orange/red – no probability percentages at each location

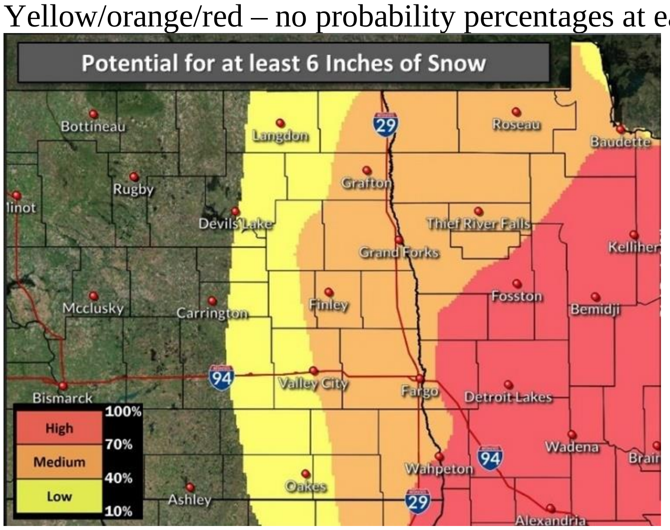


**Figure 90.** Graphic posted by NWS Grand Forks on 1/15/20 and used as an example of the yellow/orange/red color scheme with no probability percentages at each location for the risk probability graphics.

b. Yellow/orange/red – probability percentages at each location

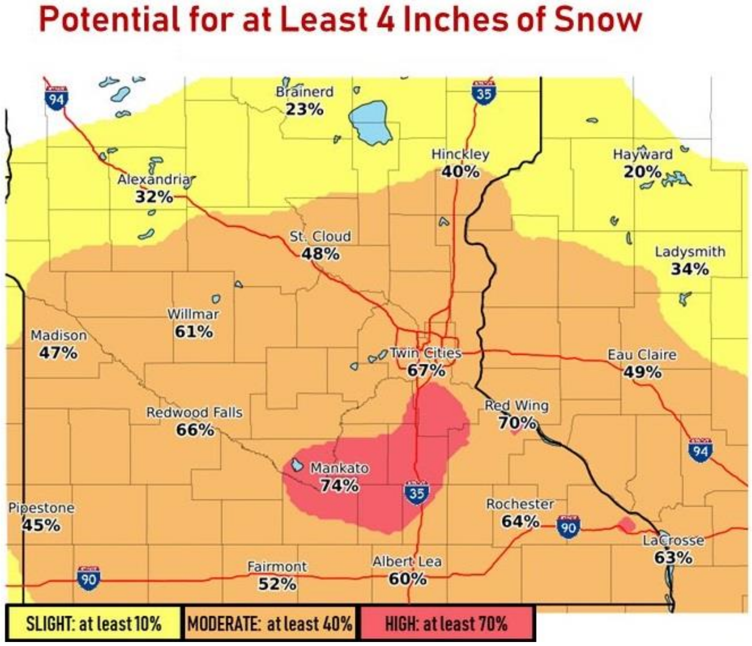


**Figure 91.** Graphic posted by NWS Twin Cities and used as an example of the yellow/orange/red color scheme with probability percentages at each location for risk probability graphics.

c. Blue shadings – probability percentages at each location

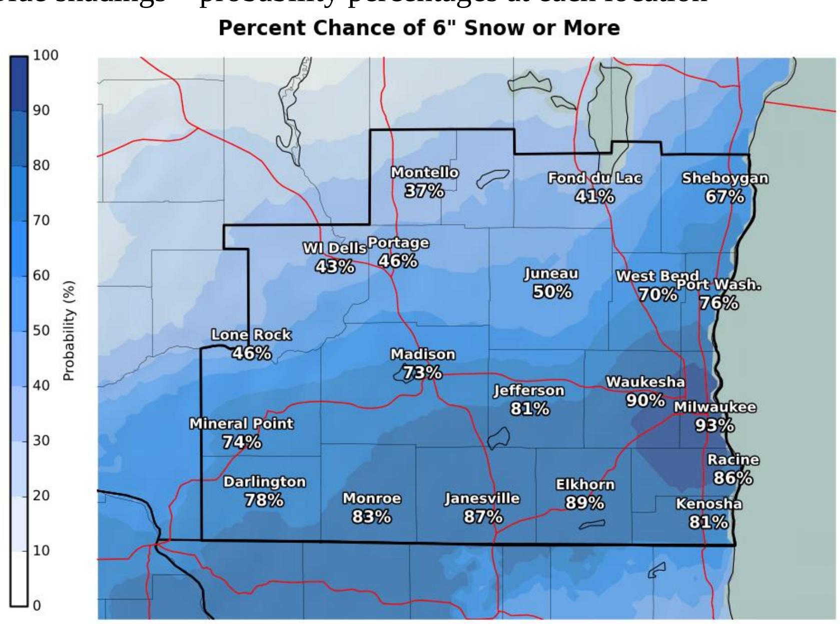


**Figure 92.** Graphic posted by NWS Milwaukee on 2/23/20 and used as an example of the blue shadings/gradient color scheme with probability percentages at each location for the risk probability graphics.

d. Green/blue/red – no probability percentages at each location

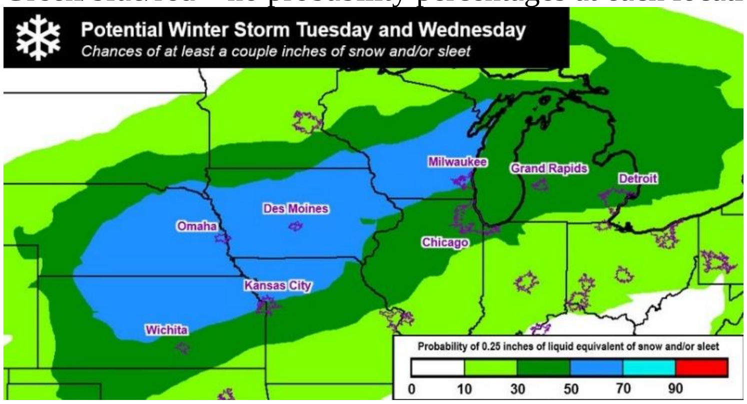


**Figure 93.** Graphic posted by the NWS Weather Prediction Center and used as an example of the green/blue/red color scheme with no probability percentages at each location for the risk probability graphics.

e. Blue/yellow/orange/red – no probability percentages at each location

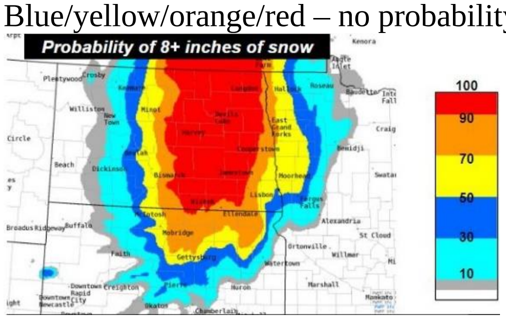


**Figure 94.** Graphic posted by the NWS Weather Prediction Center on 10/10/19 and used as an example of the blue/yellow/orange/red color scheme with no probability percentages at each location.

f. I don’t have a preference for the color scheme of these graphics

52. If you live at the white X on the snowfall forecast map below for an incoming storm that will impact your area tomorrow, how do you interpret the circled area that you are located within? **Select all that apply** or type your own answer. *(option choices presented in random order for each respondent)* **- Figure 65 shown** *(N=831)*
    a. Since I live in the circled area, I need to check the forecast again before the storm starts to see if anything has changed
    b. Since I live in the circled area, I need to prepare for higher snowfall amounts in case the forecast changes
    c. Since I live in the circled area, my actions do not change compared to if I lived in an area that was not circled
    d. I do not understand what the circled area means
    e. Other *(type your own response)*

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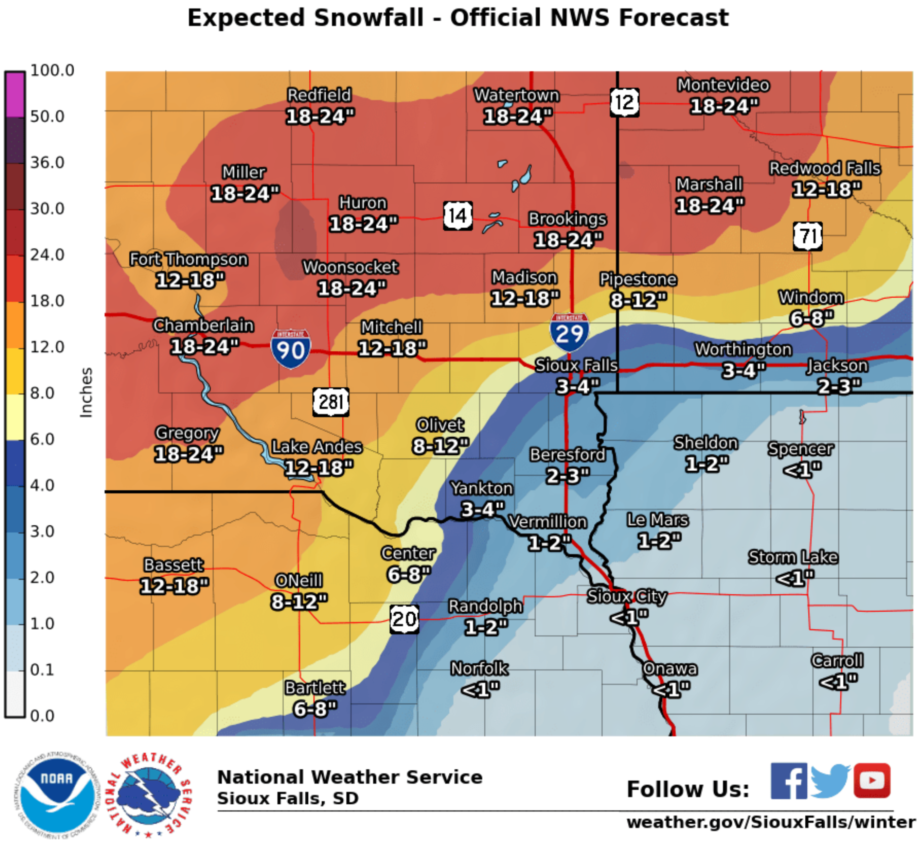
Optional Final Questions About Probabilistic Snowfall Ranges

53. Suppose you live in the Sioux Falls, SD area and a winter storm will impact your area tomorrow. The National Weather Service could release one of the two snowfall forecast maps shown below. Both display virtually the same forecast, however, **the way that the snowfall forecast ranges are shown is different between the two**. Which snowfall forecast map do you prefer **based on this difference**? *(option choices presented in random order for each respondent) (N=779)*




a.
**Figure 95.** Snowfall forecast map created by NWS Sioux Falls utilizing the normal NWS color table ranges for the ranges plotted at each location (for example, 6-8", 12-18", etc.).

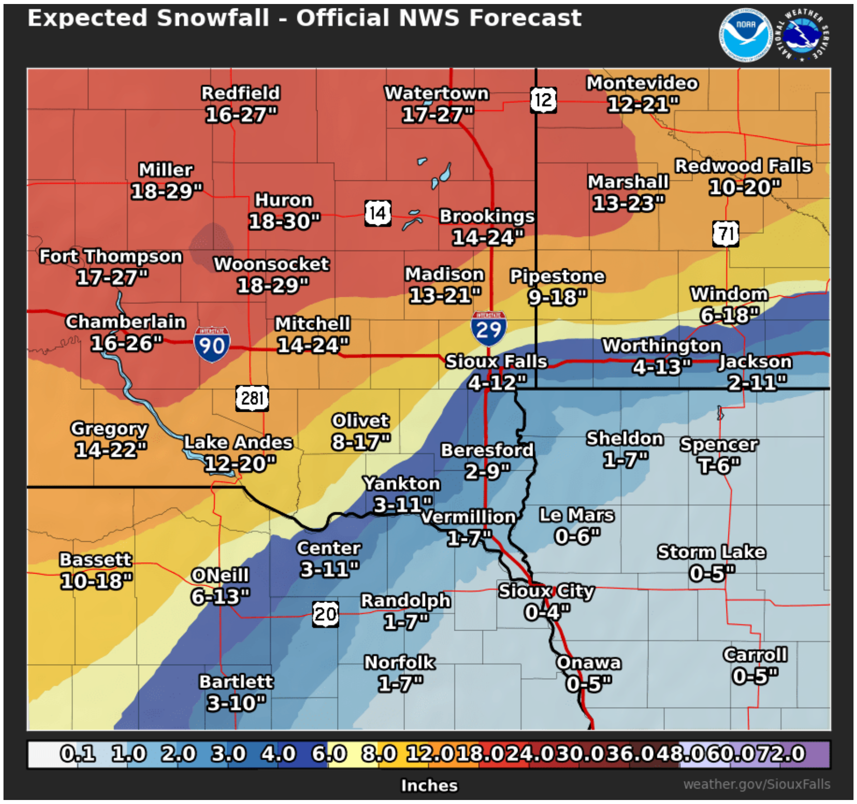
b. 


**Figure 96.** Snowfall forecast map created by NWS Sioux Falls utilizing probabilistic snowfall ranges by utilizing the 25th percentile of the distribution of possible snowfall ranges from an ensemble forecast and using that as the lower end of the range at each location. The 75th percentile of the distribution is used as the upper end of the range at each location. Most of the time this results in larger snowfall ranges.

--- Advance to Next Page of Survey ---

54. Studies have shown that using the **larger snowfall ranges** results in the actual snowfall amount verifying within that range **50% of the time** (for example, if the forecasted range for Yankton is 3-11" and the actual amount of snow that falls in Yankton is 7", this forecast verifies). The **smaller snowfall ranges** result in the actual snowfall amount verifying within that range **30% of the time**. Given this information, which snowfall forecast map do you prefer? Note: snowfall forecast map graphics are the same as those from the previous question *(option choices presented in random order for each respondent) (N=781)*
    a. Snowfall forecast map with the larger snowfall ranges **- Figure 95 shown**
    b. Snowfall forecast map with the smaller snowfall ranges - **Figure 96 shown**

# Appendix D
# Penn State Institutional Review Board Approval of Survey for the Public

PennState

**Office for Research Protections**
Vice President for Research
The Pennsylvania State University
205 The 330 Building
University Park, PA 16802

814-865-1775
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orp@psu.edu
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**EXEMPTION DETERMINATION**

**Date:** March 10, 2021

**From:** Brigitt Leitzell,

**To:** Jacob Morse

| | |
|---|---|
| Type of Submission: | Initial Study |
| Title of Study: | Evaluating the Usefulness and Response to Uncertainty-Driven and Probabilistic Hazardous Winter Weather Messaging |
| Principal Investigator: | Jacob Morse |
| Study ID: | STUDY00017285 |
| Submission ID: | STUDY00017285 |
| Funding: | Not Applicable |
| Documents Approved: | • HRP 591 Jacob Morse (2), Category: IRB Protocol<br>• Survey Questions and Survey Flow/Design (2), Category: Other |

The Office for Research Protections determined that the proposed activity, as described in the above-referenced submission, does not require formal IRB review because the research met the criteria for exempt research according to the policies of this institution and the provisions of applicable federal regulations.

Continuing Progress Reports are **not** required for exempt research. Record of this research determined to be exempt will be maintained for five years from the date of this notification. If your research will continue beyond five years, please contact the Office for Research Protections closer to the determination end date.

Changes to exempt research only need to be submitted to the Office for Research Protections in limited circumstances described in the below-referenced Investigator Manual. If changes are being considered and there are questions about whether IRB review is needed, please contact the Office for Research Protections.

Penn State researchers are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within CATS IRB (http://irb.psu.edu).

This correspondence should be maintained with your records.

We would like to know how the IRB Program can better serve you.
Please fill out our survey; it should take about a minute: https://www.research.psu.edu/irb/feedback.
ID27

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## ACADEMIC VITA

# Jacob Morse

jmorse879@gmail.com | jacobmorsewx.com

## EDUCATION

**The Pennsylvania State University | The Schreyer Honors College** — **University Park, PA**
**Bachelor of Science in Meteorology and Atmospheric Science** — *Graduation: May 2021*
*Geographic Information Science Minor*

## PROFESSIONAL EXPERIENCE

**National Weather Service Bismarck** — **Bismarck, ND**
*NOAA Hollings Scholarship Research Intern* — *May 2020 – July 2020*

- Evaluated how winter storms are messaged by the NWS by receiving feedback through focus groups and surveys to improve winter weather graphics and achieve more consistency across the weather enterprise
- Collaborated with NWS forecasters from many different NWS offices in the Central Region
- Presented research to NWS Bismarck office and at NWS Hollings Virtual Symposium

**Weather World/WPSU** — **University Park, PA**
*On-Air Forecaster, Host, Director, & Feature Creator* — *August 2019 – Present*

- Part-time on-air forecaster and host discussing weather across Pennsylvania
- Film, script, and edit 6-minute features that air on the show about weather and climate topics
- Make graphics for the show using WSI MAX and use NewTek's Tricaster to direct the show
- Create original WSI MAX graphics for the award-winning weekly WxYz segment
- Weather World is a 15-minute weather magazine show that airs across PA weeknights

**NBC Connecticut, WVIT** — **West Hartford, CT**
*Weather Intern* — *May 2019 – August 2019*

- Created original graphics using the WSI MAX system for use in newscasts and on social media
- Analyzed various meteorological guidance products to assist in creating state-wide forecasts
- Wrote and published website articles and updated forecasts on all platforms
- Assisted meteorologists in the studio and in the field during and after severe weather events

**Centre County Report LIVE** — **University Park, PA**
*On-Air Meteorologist* — *Sept. – Dec. 2020*

- Build original graphics in WSI MAX to tell the day's weather story
- Execute a 2-3-minute weather hit during the live news program
- Conduct live shots outside of the studio talking about a variety of weather topics

**PSU Department of Meteorology & Atmospheric Science** — **University Park, PA**
*Weather Observer/Forecaster* — *August 2019 – Present*

- Take official weather observations in cooperation with the National Weather Service
- Create short and long-range weather forecasts for pool companies for the entire United States by drawing maps in Adobe Illustrator and writing forecast discussions focused on pool use

**Penn State Undergraduate Speaking Center** — **University Park, PA**
*Mentor* — *January 2019 – Present*

- Mentor students one-on-one during each step of the speech writing and preparation process
- Took a training course to examine the theory and proper techniques of public speaking

**Weather or Not, CNET-TV Weekly Weather Show** — **University Park, PA**
*Forecaster, Host, and Producer* — *August 2018 – May 2019*

- Worked with a team of meteorology students to produce the 15-minute show each week
- Created features and wrote weather and climate related stories that were used in the show

## CAMPUS INVOLVEMENT

**Penn State Campus Weather Service (CWS)** *Member: Aug. 2017 – Present*

***Head of Communications (Jan. – Dec. 2020)***

- Oversee all communication branch operations including communicating with various clients
- Adapted to COVID-19 restrictions by providing members with opportunities to record forecasts from home
- Lead weekly WSI MAX training sessions and participate in the WSI MAX University Challenge
- Lead weekly Facebook Live forecast discussions with other students discussing PA weather
- Record daily video and radio forecasts for CWS clients that are broadcast on-air in parts of PA
- Forecaster for the Live Broadcast Team, covering major weather events on Facebook Live
- Create forecasts for specific regions of PA and write forecast discussions for the entire state
- Organize summer break coverage of radio forecasts and in charge of posts on social media

**Penn State Branch of the American Meteorological Society & National Weather Association**

***Vice President (Aug. 2019 – Present)*** *Member: Aug. 2017 – Present*

- Plan events, such as tours and gatherings, with AccuWeather & NWS State College
- Created and led a workshop to help students with their Hollings Scholarship applications
- Manage all social media accounts throughout the year

**Penn State Habitat for Humanity Campus Chapter** *Member: Aug. 2017 – Present*

***Public Relations Chair (Aug. 2020 – Present)***

- Maintain all social media accounts for the organization
- Record and create videos for the club about volunteer events throughout the year
- Volunteer building houses in Central PA and helping the local Habitat ReStore on weekends
- Traveled to Denver over spring break in 2018 to help build houses

**Chi Epsilon Pi: National Meteorology Honors Society** *Member: April 2019 – Present*

- Part of a tutoring service that helps students with specific meteorology classes

**College of Earth and Mineral Sciences Student Council/THON** *Member: Aug. 2017 – Present*

- Participate in an annual 46-hour dance marathon to help those impacted by childhood cancer
- Mentor for the TOTEMS program, which welcomes new students into the college in August

**The Navigators at Penn State** *Member: August 2018 – Present*

- Traveled to North Carolina over spring break 2020 to help those impacted by Hurricane Florence

## SKILLS

WSI MAX Graphics, Adobe Premiere Pro, Adobe Illustrator, iNews, GR2 Analyst Radar, SkyWarn Official Weather Spotter, Bufkit, NewTek's Tricaster, Social Media Platforms, Facebook Live, OBS Studio, Website Development, Field Camera Operation, Photography, ArcGIS Pro, MATLAB, Python

## ACHIEVEMENTS

- NOAA Hollings Scholar (recognizes outstanding students studying in NOAA mission fields)
- EMSAGE Laureate (for notable achievement in scholarship, experiential learning and global literacy, and service)
- 2019 PNC Leadership Development Center Selected Participant

## CONFERENCES

- 45th National Weather Association Annual Meeting (Virtual) – *Oral presentation of my NOAA Hollings Scholarship research at the conference*
- 101st American Meteorological Society Annual Meeting (Virtual) – *Presented poster of my NOAA Hollings Scholarship research at the conference*
- 44th National Weather Association Annual Meeting – Huntsville, AL
- 100th American Meteorological Society Annual Meeting – Boston, MA
- 99th American Meteorological Society Annual Meeting – Phoenix, AZ