The Public's Prioritization of Probability and Intensity in Tornado Risks

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ABSTRACT

Historically, the Storm Prediction Center (SPC) has utilized both categorical risk and probabilistic information in their convective outlooks. The categorical risk information is based almost exclusively on the probability of storms with little or no attention to their intensity. The SPC has considered adding more explicit intensity information to their outlooks but there is limited research on how people define a risk using probability and intensity information. Our goal is to help the SPC determine if the addition of intensity information would improve the effectiveness of the convective outlook. In this study, we use survey data derived from the 2017 and 2019 Severe Weather and Society Surveys (WX17 and WX19) to evaluate how members of the public weigh probability and intensity information during severe weather events. Results from this study indicate that most members of the public use both types of information equally, even collaboratively, to make decisions. Our findings suggest that adding more explicit intensity information to the convective outlook may improve public assessment of tornado risk.

1. Introduction

The convective outlook, created by the National Weather Service (NWS) Storm Prediction Center (SPC), has been a substantial product in the field of meteorology for many decades (Krocak et al. 2021). Starting in 1955, the outlook product has been issued daily by the SPC and has undergone several revisions since its launch (Ernst et al. 2021). Issued outlooks include an estimate of occurring severe weather events (e.g. tornadoes, hail, and convective wind) within 25 miles of an area (Krocak et al. 2022). Using categorical terms and colors, the convective outlook presents a combination of risk level, storm probability, and, to a lesser extent, intensity information (Thompson 2003). The product was designed to forecast the probability of severe weather threats for a 1-8 day period (Thompson 2003), however, the use of the outlook varies across all meteorological professions (Krocak et al. 2022).

Current convective outlooks produced by the SPC prioritize probabilistic information when defining categorical risks. This includes both numeric and estimative probabilities. In the early 2000s, numeric probabilities were incorporated with SPC categorical risk labels to provide more direct, comprehensible information to decision-makers (Kay and Brooks 1999). Traditional categorical convective outlooks solely conveyed risk information using risk phrases such as "Slight Risk", "Moderate Risk", and "High Risk" (Thompson 2003). However, probabilistic forecasts were shown to express more uncertainty compared to categorical forecasts which often used indefinite terms and phrases that can be easily misinterpreted (Kay and Brooks 1999). Evidence of their utility motivated more organizations to utilize probabilities in their weather forecasts to aid in communication, but research has revealed a stalemate in this progression (Krocak et al. 2022). Multiple studies have indicated that the current convec-

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tive outlook can be challenging to comprehend which hinders the public's understanding of issued weather forecasts. Probabilities can be hard to understand among less numerate users, and interpretations of the product's design tend to vary between individuals (Ernst et al. 2021). As one possible improvement, the SPC has considered including more information to describe the intensity of severe weather hazards. For instance, the SPC could use something like the Enhanced Fujita (EF) Scale to convey tornado intensity. This system assesses the strength and damage path of tornadoes to classify the intensity of tornado outbreaks. Intensity information similar to the EF scale could be added but more research on the public's reception, comprehension, and response to this information must be performed to support this decision.

Research on the general public's knowledge of the convective outlook has been rather limited, yet in recent years, researchers have sought to close this gap in knowledge (Ernst et al. 2021). The object of this project is to determine what information presented in the SPC convective outlook (e.g. probability and intensity) is prioritized more by public users to help improve risk management and communication. In this study, we want to evaluate how members of the public weigh the probability and intensity information presented in the current outlook when making weather-related decisions. Understanding what information is prioritized by the public will help the SPC determine if more information, such as intensity, would make a beneficial impact on people's risk perception and severe weather preparation habits.

2. Literature Review

The SPC convective outlook functions as a hazard warning system, therefore, adequately interpreting the product is critical for all users. Several social and behavioral studies have been conducted on the convective outlook focusing on how members of the public interpret the categorical words used to convey risks (Ripberger et al. 2020; Krocak et al. 2021; Bitterman et al. 2023).

a. Challenges of categorical words and colors

The current convective outlook is displayed as a five-tier category system that increases in risk magnitude. Each level of risk is accompanied by a specific categorical word (e.g. Marginal, Slight, Enhanced, Moderate, and High) and color (e.g. green, yellow, orange, red, and magenta) that helps users differentiate risk. Nevertheless, current studies have highlighted observable differences in interpretation between expert users and the general public. In 2014, the SPC introduced new changes to the Day 1 convective outlook to expand the details of lower-risk categories (Ernst et al. 2021). These changes included expanding the categorical risk scale by adding two new terms accompanied by the colors green and orange. In a public survey study conducted by Ernst et al. (2021), it was observed that most participants switched the order of the categorical terms from the original product order: "Marginal, Slight, Enhanced, Moderate, High," to the following order: "Slight, Marginal, Moderate, Enhanced, High" (Ernst et al. 2021). Participants in this study also frequently misordered the categorical colors, often placing the color red as the highest-ranking color instead of the actual High Risk color, magenta (Ernst et al. 2021). Ernst et al. (2021) concluded from their study that words used by the SPC may result in wider variations in risk interpretations which would pose a serious threat to public safety and create distrust in weather forecasts (Ernst et al. 2021). The following year, Williams et. al (2022) published a study examining if changes made to the convective outlook affected the understanding of expert users (e.g. emergency managers, forecasters, broadcast meteorologists, etc.) and non-expert users (e.g. the general public) in a three-part study. Their findings supported conclusions expressed in the previous study by Ernst et al. (2021). Overall, expert users such as emergency managers and broadcast meteorologists found the changes "effective for their use", but expressed concern about the publics' comprehension and use of the modified convective outlook (Williams et al. 2022). Through a small customer feedback survey, Williams et al. (2022) found that many non-expert users noted that both 'Marginal' and 'Enhanced' were "vague terms", and that 'Enhanced' was often confused with 'Moderate' causing more inadequate interpretations that could be risky to the public's safety (Williams et al. 2022).

b. Inquiries of outlook information

Although previous studies and evaluations have provided significant evidence of its forecast quality (Hitchens and Harold E. Brooks" 2012), researchers are motivated to observe how members of the public interpret the categorical, numerical, and probabilistic information presented in the current outlook (Krocak et al. 2021). In a study led by Krocak et al. (2022), another challenge of the convective outlook was brought to light. This new study analyzed results from the 2020 Severe Weather and Society Survey (WX20) where respondents were prompted to answer scenario-based questions that assessed the concern and likelihood of responding to severe weather warnings (Krocak et al. 2022). Krocak et al. (2022) highlighted in their discussion that there was a high concern and response rating of categorical labels that were misordered throughout the study, which aligns with findings in previous studies (Ernst et al. 2021; Williams et al. 2022). Most participants would switch the terms Marginal with Slight and Enhanced with Moderate (Krocak et al. 2022). This habit of reversing terms can lead people to underestimate high-risk storms or overestimate less severe storms which could incite distrust in weather forecasts while increasing the risk of harm. The researchers also indicated that the concern and response ratings for numeric and probabilistic information were fairly more consistent than label information, meaning level labels and probability labels were more likely to trigger protective actions in respondents (Krocak et al. 2022). When the categorical terms were combined with either percentages or level labels, participants were more likely to order them correctly and increase concern and response ratings (Krocak et al. 2022). However, probabilistic information alone did not perform as an aid to all participants such as non-white and low numerate respondents who relied more on categorical labels (Krocak et al. 2022). These findings raise some conflicting perspectives as recent research reveals numeric information in forecasts is most beneficial to participants and can increase survey respondents' forecast reliability (Krocak et al. 2022; Rosen et al. 2021). Nonetheless, the difference in interpretation of categorical and numerical information, even when combined, could suggest that this presentation of information in the current convective outlook is not impacting the risk response of the overall population as effectively as previously believed. It is encouraged to further investigate the general public's current understanding and how additional information (such as probabilistic or intensity information) can be more effectively communicated to the public (Krocak et al. 2022).

3. Data and Methods

Data for this study was derived from the Severe Weather and Society Survey (WX) – one out of three Extreme Weather and Society Surveys – which was developed and maintained by the University of Oklahoma's Institute for Public Policy Research and Analysis (IPPRA). The public surveys are administered annually to a sample of adults ages 18 and older who live in the continental United States. Surveys are received by respondents through email and respondents are dynamically sampled to demographically represent the U.S. population as estimated in the U.S. Census. We are using data from the 2017 (WX17) survey which collected data from 2,009 participants, and the 2019 (WX19) survey which collected responses from 3,006 participants.

The WX17 survey, fielded in June 2017, was designed to measure the extent of the public's reception, comprehension, and response to severe weather forecasts and warnings. Through several sets of multiple-choice questions and short-answers prompts, the survey evaluated the public's preferences of information presented in weather products, reliability of the National Weather Service (NWS), hazard risk literacy, importance of probability and intensity, and geographically specific severe weather warnings (Silva et al. 2020a). The WX19 survey, fielded June 24th through July 6th, 2019, further extends and refines the baseline measures established in WX17. This survey was developed to measure the public's reliance on the National Weather Service (NWS), extreme weather and climate risk perception, hazard risk literacy, comprehension of probabilistic language, and severe weather preparedness (Silva et al. 2020c). We are focusing on three questions from the mentioned surveys, two of which are from the WX17 survey and only one question from the WX19 survey.

The first question, chosen from WX17, is a multiple-choice question where participants are prompted to select their level of probability and intensity importance when thinking about the risk of tornadoes. The question asks, "When thinking about the risk of tornadoes, is probability (the likelihood that a tornado will occur) more important than intensity (the strength and size of the tornado)? Or, is intensity more important than probability?" Respondents are then allowed to choose one out of five answer choices: 1) "Probability is much more important than intensity," 2) "Probability is a little more important than intensity," 3) "Probability and intensity are equally important,"4) "Intensity is a little more important than probability," 5) "Intensity is much more important than probability." Results from this question help us garner a general idea of participants' preference of information (probability and/or intensity) during a certain severe weather risk such as a tornado risk.

The second survey question is an open-ended response found in the WX19 survey. The question states, "Forecasters use different phrases to describe the risk of tornadoes in an area. We want to know what these phrases mean to you. What does it mean if there is a [blank] of tornadoes in your area tomorrow evening?" A categorical risk word (Slight Risk, Moderate Risk, or High Risk) is randomly assigned to each participant's prompt to fill in the blank. Respondents are given a space to provide a sentence (or more) describing their personal interpretation of the given phrase. Responses received helped us determine if an individual's interpretation of a categorical risk is more influenced by probability information, intensity information, both, or neither.

The final survey question was taken from the WX17 survey. The question states, "Forecasters might consider the probability and intensity of extreme weather events when communicating information and risk. For example, a 1% chance of a severe (EF-3) tornado may be less risky than a 10% chance of a moderate (EF-2) tornado. Or, a 2% chance of a devastating (EF-4) tornado may be more risky than a 90% chance of a light (EF-0) tornado. We would like to know how YOU weigh the probability and intensity of extreme weather events. Please rate the risk of the following tornado scenarios:" This is then followed by a hypothetical situation stated as, "A [blank]% chance of a [blank] tornado." A randomized percent chance (5-100%) and word of intensity [Light (EF-0), Moderate (EF-

TABLE 1. Survey Response and Categorization Examples

Category	Assigned Risk Word	Participant Responses
Probability	Slight Risk	"Less than 20% chance"
	Moderate Risk	"Low possibility"
	High Risk	"That there is a potential for hail and damaging winds heavy rains along with lightning"
Intensity	Slight Risk	"Slight risk to me means that there is a risk but not as extreme as a warning"
	Moderate Risk	"Some hail damage, heavy winds"
	High Risk	"Cause severe damage"
Probability & Intensity	Slight Risk	"could be severe storms that could have tornadoes"
	Moderate Risk	"Storm or tornado outbreak is expected. ... The likelihood of tornadoes, often strong and/or long-lasting"
	High Risk	"Could lose it all"
Something Else	Slight Risk	"Just prepare"
	Moderate Risk	"Be ready to listen to info"
	High Risk	"Very risky"

1), Significant (EF-2), Severe (EF-3), Devastating (EF-4), Incredible (EF-5)] are filled into the blanks. Participants are then provided with five answer choices of risks: "1) no risk, 2) low risk, 3) moderate risk, 4) high risk, 5) extreme risk" and are prompted to choose one. With the received data, we want to observe how an increase in probability information and intensity information affected respondents' risk perception.

In this study, we analyzed the data received from the survey questions with a combination of quantitative and qualitative analysis. To investigate the public's use of probability information versus intensity information, we used a quantitative analysis approach to evaluate participant responses. We explored a distribution of survey responses between questions 1 and 3 using statistical measures and bar plot comparisons. Bar plots are used to explore the distribution of survey responses (grouped by parameters such as education and exposure to tornadoes) to question 1. Linear regression lines are used to explore the effect of probability and intensity information from question 3. Next, to collect our qualitative data we read through and analyzed each survey response from question 2 and categorized the responses into four groups: probability information, intensity information, both probability and intensity information, or other information (Table 1).

4. Results

a. Public's priority of probability and intensity information

When considering a tornado risk, the public relies on probability information and intensity information to aid in their interpretation and decision-making. Overall, survey rankings of probability and intensity information were similar among all respondents and followed an analogous trend across sub-groups such as the education levels of respondents and their general exposure to tornadoes. Most respondents (44%) considered probability and intensity information as equally important to assess when thinking about the risk of tornadoes. Following this, other respondents seemed to lean more towards the importance of intensity information over probability with 18% of surveyors choosing "intensity is a little more important than probability" and 14% of surveyors evaluated intensity as "much more important than probability" (Fig.1a). The same results were subdivided by education level ("less than bachelor's degree" and "bachelor's degree or more") in Fig. 1b and displayed a comparable relationship with slight variations. As shown in the following figure, 20% of respondents with a bachelor's degree or higher relied a little more on intensity information over probability information (Fig.1b). We then sorted the survey results by tornado exposure and grouped them into 3 categories: 1) infrequent tornadoes (resident area experiences tornado warnings and landings less frequently); 2) average tornadoes (resident area experiences an average number of tornado warnings and landings); and 3) frequent tornadoes (resident area experiences tornado warnings and landings frequently) (Fig.1c). These rankings generally followed a similar distribution as the previous overall and education analyses.

b. Public interpretation of tornado risk labels

The categorization of responses from the question 2 analysis differed significantly from previous results shown in Figure 1. When presented with a categorical risk word such as "Slight Risk," "Moderate Risk," or "High Risk," probability information is the most prioritized set of hazard information for a majority of participants, with 60% of respondents using numeric probabilities or estimative language in their interpretations (Fig.2a). From the portion of responses that only used probability information, more than half of the participants (64%) reported having a bachelor's degree or higher (Fig.2b). It is also true that a majority of participants with less than a bachelor's degree submitted responses that included probability (Fig.2b). Results remained similar for those who experience tornadoes less frequently, on average, or frequently with probability information being the most used hazard information (Fig.2c). Few participants used solely intensity information or a combination of probability and intensity to describe their understanding of a given risk category altogether (Fig.2a).

c. Public risk perception based on probability and intensity information

Furthermore, respondents' risk perception shared a direct relationship with the presentation of probability and

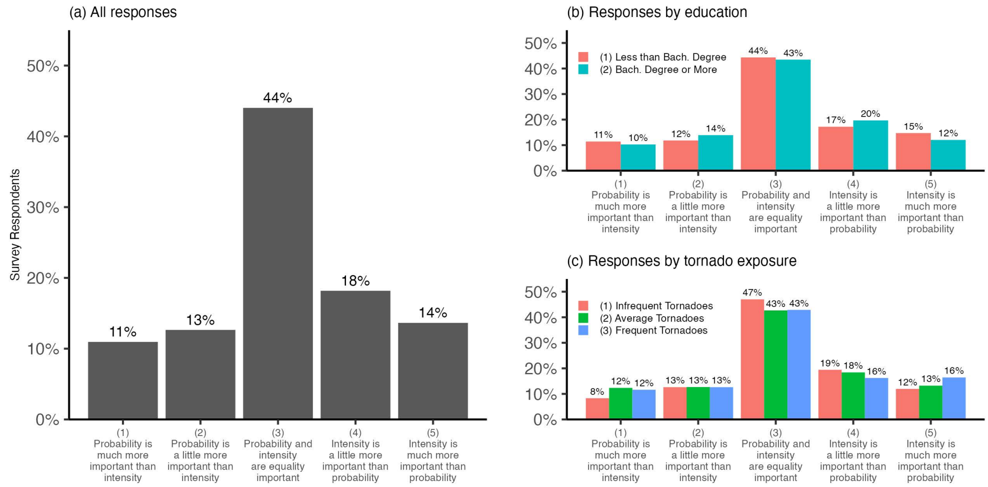

FIG. 1. Bar plots display the proportion of survey respondents who selected a response 1-5. All responses (a) are also analyzed by education level (b) and tornado exposure (c).

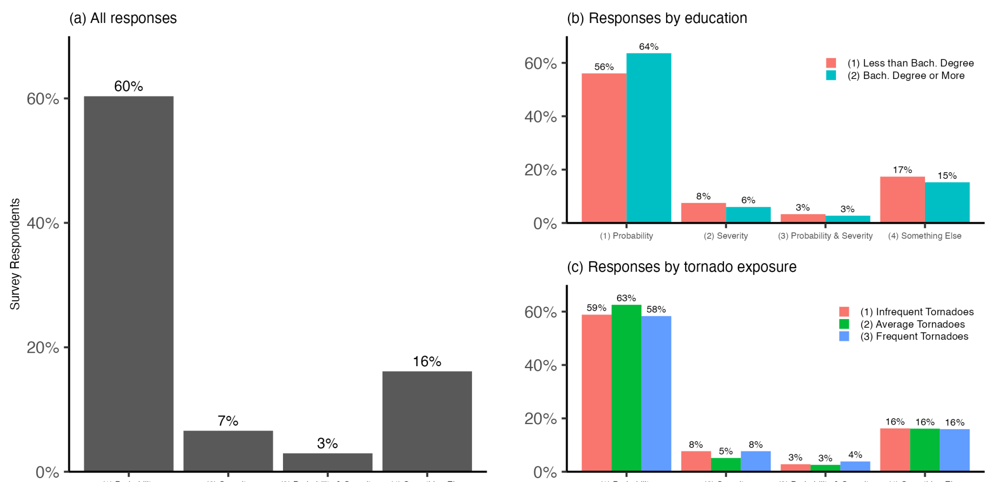

FIG. 2. Survey responses are categorized by which set of information (probability, intensity, both, or something else) influences one's risk phrase interpretation.

intensity information. Generally, a respondent's risk perception increased with an increase in probabilistic value or storm magnitude, however, the rate at which one's ranking of risk varied significantly between the information (probability or intensity) presented. As the percent chance of a given severe weather scenario increased, most respondents chose an incrementally higher risk category to classify the storm (Fig.3a). Similarly, respondents chose higher, more critical risk categories as the level of storm magnitude (using the EF scale) intensified (Fig.3a - Intensity). Although the relationship between risk perception versus probability and risk perception versus intensity were both positive, the magnitude (slope) of the relationship was greater between probability and risk. This pattern remained relatively consistent across additional sub-groups for both probability and intensity comparisons.

5. Discussion and Conclusion

In conclusion, this research paper has provided valuable insights into how members of the public weigh probability and intensity information when making decisions about possible tornadoes. Through quantitative and qualitative analyses of survey data, our primary conclusion is that members of the public consider both probability and intensity information when evaluating weather risks. While our quantitative analyses revealed weighing both probability and intensity significantly affects an individual's judgment, the qualitative analysis indicated that probability information comes to mind more frequently than intensity during a severe weather event.

The results obtained from our research have significant implications for the SPC's decision to include (or not include) more explicit intensity information in their convec-

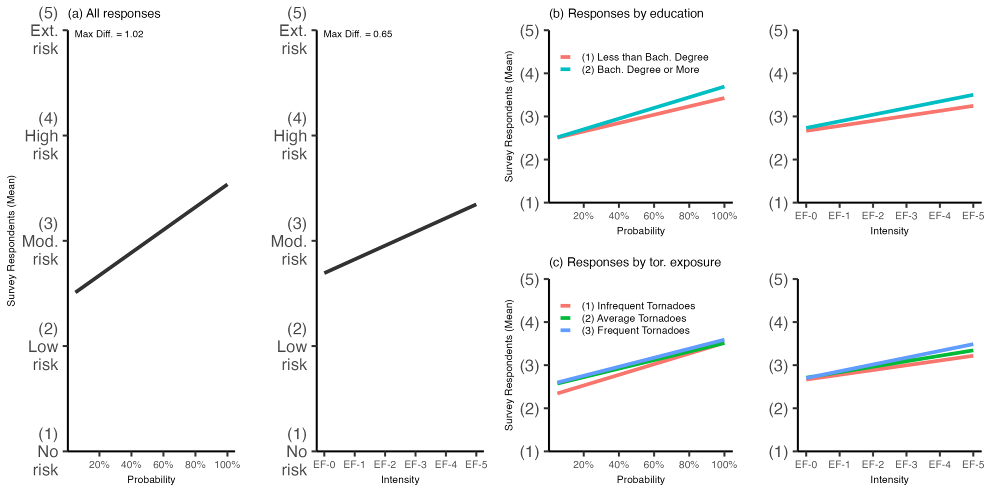

FIG. 3. The slope of the relationship between the level of presented information (probability or intensity) and the level of a respondent's risk perception. The line indicates the relationship between probability value vs. risk level chosen by respondents (left) and intensity level vs. risk level (right).

tive outlook. Our work suggests including additional intensity information would benefit the overall quality of the current outlook and enhance comprehension for all users. As highlighted in our results, most members of the public consider both probability and intensity as equally essential pieces of information during severe weather events (Fig. 1a). We believe neither set of information should be eliminated nor replace the other as probability and intensity details synergistically work together to improve the effectiveness of the convective outlook.

It is important to acknowledge the limitations of this research, as they offer opportunities for future investigations. To collect our data, we used several online surveys that were distributed via the Internet which introduces the issue of self-selection bias when gathering responses. Although the surveys are demographically representative of the population, a decision to participate in the study is entirely voluntary which makes self-selection bias difficult to avoid (Silva et al. 2020b). Moreover, online surveys only provide hypothetical severe weather scenarios which can indirectly influence responses. Respondents may respond differently to severe weather threats during actual occurrences which is not accounted for in this study. For our qualitative analysis, we faced multiple challenges when interpreting survey responses that made it difficult to categorize responses accurately. Several responses appeared incomplete in thought, vague, ineligible, or misconstrued, so if a response could not be interpreted clearly or directly it was categorized as "something else" in Figure 2. We also want to emphasize that adding more information to the outlook may present the issue of becoming overwhelming to users in the future. We encourage follow-up studies on the effectiveness of additions made to the convective outlook so we can further improve the balance of information and presentation.

Moving forward, we urge future research on this topic to investigate more subgroup analyses such as differences in tornado risk receptions between regional populations. For instance, responses from California residents can be compared to responses from Oklahoma residents regarding tornado risks and warnings. This type of study can be used to closely observe how location and exposure influence the usage of probability or intensity. On the other hand, more realistic studies can be conducted with tornado survivors and witnesses. This way researchers can analyze responses made during real-life severe weather events to observe what information members of the public initially search for or readily rely on.

Overall, this research article has made significant contributions to our understanding of how people evaluate probability and intensity information when judging the risk of a possible tornado. More work is necessary, but this is an essential first step towards developing new forecast products that better match the information people are looking for when deciding what to do about extreme weather events.

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