Effective education and risk communication in the weather enterprise require deep knowledge of the atmospheric and climate conditions in communities that enterprise members serve as well as knowledge about the residents of those communities. While abundant meteorological and climatological data are available, there is relatively little information about the populations our enterprise serves. As a result, it can be difficult to answer basic questions: What risks do the people in a community worry about or neglect? Do they generally receive, understand, and respond to forecasts and warnings? What sources of information do they rely on and trust? Reliable answers to these questions are needed to develop public education and risk communication strategies and track the response to—and effectiveness of—those strategies.

To help answer such questions, we are developing a database of community statistics with an interactive platform providing dynamic accessibility to some of it. The approach we use leverages population data from the Severe Weather and Society Survey (Wx Survey) and known subpopulation characteristics from the U.S. Census to explore differences in tornado warning, reception, comprehension, and response in counties and county warning areas (CWAs) across the United States. The nationally representative Wx Survey, run yearly by the University of Oklahoma Center for Risk and Crisis Management, includes baseline questions that measure core concepts such as risk perceptions; forecast and warning reception, comprehension, and response; knowledge about hazards; and trust in information sources. It also includes one-time questions and experiments that address topics such as the impact of uncertainty and probabilistic information on risk judgments and protective action decision-making.

Somewhat analogous to climate downscaling, survey researchers downscale data from large population surveys to subpopulations, such as states and counties. We use one of these techniques in combination with the Wx Survey to create a database of community statistics that members of the weather enterprise can use to increase knowledge about the populations they serve. The value of the database stems from an ability...
to track similarities and differences between and within communities over time, requiring ongoing collection and analysis of data.

**Database: Tornado warning reception, comprehension, and response**

The most recent Wx Surveys include multiple questions that measure tornado warning reception, comprehension, and response. A concurrent study indicates that responses to these questions provide statistically reliable scales that adequately discriminate between people with low, average, and high reception, comprehension, and response tendencies. The scales measure these concepts with percentile scores to facilitate interpretation. A participant’s percentile score on each scale varies as a function of their demographic profile (gender, age, a gender–age interaction, race, and ethnicity) and geographic area (CWA). CWA effects vary in relation to climatology (mean number of tornado event days per year).

Results suggest that men and women demonstrate roughly comparable levels of reception, objective comprehension, and response, but men have more confidence in subjective warning comprehension than women. More notably, there is variation across age and race groups, as well as across CWAs. The models further indicate relatively large differences in subjective and objective comprehension, moderate differences in reception, and small differences in tornado warning response across CWAs. Tornado climatology has a relatively strong effect on tornado warning reception and comprehension, but little effect on warning response. These findings suggest that geography, and the community differences that overlap with geographic boundaries, likely exert more direct influence on warning reception and comprehension than on response, but the models do not account for the effect of warning reception and comprehension on response. Therefore, they don’t allow for the possibility that geographic differences indirectly influence tornado warning response.

Poststratification is used to weight the demographic group predictions in each CWA by population frequency, which we calculate using data from the U.S. Census. This provides the multiplication term we use when averaging predictions across demographic groups to calculate aggregate estimates of reception, subjective comprehension, objective comprehension, and response in CWAs. Finally, we estimate an *average person percentile* (APP) score for each CWA in the contiguous United States (CONUS) on each measure. As an example, an APP estimate of 62 indicates adults who live in...
that CWA are above the national average, scoring higher than 62% of U.S. adults across the country. APP scores range from 38 to 61 on the reception scale, 32 to 69 on the subjective comprehension scale, and 37 to 60 on the objective comprehension scale. Response scores, by comparison, exhibit less variation across CWAs, with a minimum APP of 45 and maximum of 54. These findings suggest that warning reception and comprehension are more likely to vary across communities than warning response.

On average, the APP estimates indicate that reception, comprehension, and response are lowest in western CWAs, slightly below average in eastern CWAs, and above average in the central portion of the United States, similar to tornado climatology. On the whole, people in communities that experience the most tornadoes are the most likely to receive warnings, know what they mean, and take protective action in response.

In addition to patterns across regions, there are noteworthy differences within regions that are more difficult to explain with tornado climatology alone. In many cases, adjacent communities that have similar tornado climatologies respond differently, as with the Norman, Oklahoma, CWA (APP=66) and the Fort Worth, Texas, CWA (APP=58). Exploring the reasons for differences like this presents important opportunities for research and learning within the weather enterprise.

As with all forecast models, inherent uncertainty necessitates constant verification. We accomplish this by comparing predictions to observations. Our analysis shows a relatively strong correlation between the independent survey observations and the estimates. While the community estimates we produce have skill, they sometimes overshoot observations in some CWAs and undershoot them in others as the result of systematic bias or anomalous communities. There is something unique about the people in these communities that distinguishes them from communities with comparable demographic and geographic profiles. This is an area for future research.

Future: Research and development
As this project continues, we are working to develop and validate estimates for the database and modules for the platform. These estimates and modules will allow enterprise members to identify and explore significant changes over time that may relate to changing demographics or new education and communication strategies. We are also working to produce estimates

Average person percentile (APP) estimates of (top left) tornado warning reception, (top right) subjective comprehension, (bottom left) objective comprehension, and (bottom right) response (bottom right) by county warning area (CWA) in the CONUS. The inset plots indicate the frequency distribution of APP estimates across CWAs. Not surprisingly, all categories broadly reflect the higher frequency of tornadoes in middle and southeastern CWAs.
Table 1. Example survey questions we use to measure tornado warning reception, subjective comprehension, objective comprehension, and responses.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Example question(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reception</td>
<td>Sometimes people miss tornado WARNINGS because they are doing something that makes it difficult to pay attention to the weather. For example, people often miss tornado warnings when they are sleeping. How confident are you that you would receive tornado warnings in the following situations? If you are… sleeping, in a car, at work, etc.</td>
</tr>
<tr>
<td>Subjective comprehension</td>
<td>In general, do you understand the difference between watches and warnings? How would you rate your understanding of tornado watches and warnings?</td>
</tr>
<tr>
<td>Objective comprehension</td>
<td>If the National Weather Service issues a tornado warning for your area, how much time do you have before the tornado arrives? If the National Weather Service issues a tornado watch for your area, how much time do you have before the tornado arrives?</td>
</tr>
<tr>
<td>Response</td>
<td>For some people, the time of day influences tornado warning reception, understanding, and/or responsiveness. If a tornado WARNING were issued for your area tomorrow at [RANDOM TIME], how confident are you that you would take protective action in response to the warning?</td>
</tr>
</tbody>
</table>

**METADATA**

**BAMS:** What would you like readers to learn from this article?

**Joseph Ripberger (University of Oklahoma and National Institute for Risk and Resilience):** We hope readers will leave this article with two thoughts: (1) we know relatively little about how and why different communities get, understand, and respond to weather forecasts and warnings; and (2) this project begins to address this limitation in knowledge by creating a database of community estimates (and an interactive platform) that details geographic variation in core concepts like tornado warning comprehension.

**BAMS:** How did you become interested in the topic of this article?

**JR:** We began thinking about this topic many years ago. We knew (from experience) that people in different places think about and respond to the weather in different ways. For example, my neighbors in Norman, Oklahoma, (where I currently live) seem to think about and respond to tornado warnings in different ways than my former neighbors in Cincinnati, Ohio (where I grew up). We believe that it is important to measure these differences so that we can develop risk communication strategies that match the different experiences, expectations, and needs that different communities have, and systematically track the effectiveness of these strategies over time.

**BAMS:** What surprised you the most about the work you document in this article?

**JR:** Honestly, we went into this project with very few expectations, so there weren’t too many surprises. If anything, the amount of variation in tornado warning comprehension was a little surprising. We thought there might be a few modest differences from community to community, but there were more differences and the differences were more significant than we might have thought going into the project.

**BAMS:** What was the biggest challenge you encountered while doing this work?

**JR:** The biggest challenge in this project was (and continues to be) a lack of systematic data. We are fortunate to have a few years of survey data to work with, but the amount and quality of data we have on people pales in comparison to the amount and quality of data we have on the atmosphere. This makes it extremely difficult to estimate and verify models that inform our understanding of how people think about and respond to forecasts and warnings.