# Public Understanding of the Atmospheric River Scale

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## ABSTRACT

Atmospheric rivers (ARs) are long, narrow bands of moisture in the atmosphere that transport large amounts of water vapor, producing hazards ranging from heavy rain to high winds once they reach land. In 2019, researchers at the Center for Western Weather and Water Extremes, with partners including the National Weather Service and the California Department of Water Resources, developed the AR Scale, which ranges from one to five and categorizes the intensity and potential impacts of ARs to improve communication and public understanding of these events. This study presents the first nationwide, bilingual (English/Spanish) quantitative assessment of the AR Scale in the United States. Using a cross-sectional survey, we examine three key areas: (1) perceived benefits and risks of AR events at different levels, (2) thresholds for taking protective actions during an event based on the AR Scale, and (3) category comprehension of hazard potential. Results provide insight into current levels of public understanding and may help improve the design of forecast products and communication tools used during ARs, supporting better decision-making and response during these high-impact weather events.


## SIGNIFICANCE STATEMENT

Atmospheric rivers (ARs) can bring both beneficial rain and dangerous flooding, and as the AR Scale is being adopted globally, effective communication of AR intensity is increasingly important for public safety. This study provides the first nationwide, bilingual assessment of how the U.S. public interprets the AR Scale. Results show that many participants struggle to correctly order categories, understand impacts, and know when to take protective action, with greater uncertainty among Spanish speakers. By identifying where confusion occurs, this study offers practical ways to improve clarity of AR risk communication across language groups. Improving how ARs are communicated can support clearer decision-making and more equitable preparedness as these events become more frequent with a changing climate.

## CAPSULE

A nationwide bilingual survey shows that the public struggles to interpret the Atmospheric River Scale, highlighting key gaps in risk communication and potential opportunities to improve future messaging strategies.

## 1. Introduction

Atmospheric rivers (ARs) are long, narrow bands of concentrated moisture in the atmosphere that transport large amounts of water vapor, producing hazards such as flooding and high winds when interacting with terrain (Ralph et al. 2019). A global phenomenon most frequent in mid-latitudes, ARs commonly affect the Western U.S. and other regions across the country, including the Southeast, the central United States, and the Northeast (Mahoney et al. 2016; Moore et al. 2012; Debbage et al. 2017). From 1978 to 2017, ARs drove 84% of major river floods in the Western U.S., with estimated damages totaling $50.8 billion (Ralph et al. 2006; Neiman et al. 2013; Corringham et al. 2019). As the climate warms, ARs are projected to be wetter, stronger, and longer-lasting across the globe (Payne et al. 2020).

To communicate the risks, hazards, and benefits of ARs to the public, Ralph et al. (2019) developed the Atmospheric River Scale (AR Scale), which has since been used worldwide (Guan et al. 2023). Despite its widespread adoption and recent use by broadcast meteorologists in English and Spanish (Fig. 1), existing evaluations of the AR Scale have focused on its hydrological applications, leaving its effectiveness as a public risk communication tool an open empirical question.  With ARs projected to intensify under climate change, it is crucial to obtain needed input on whether the AR Scale is not only understood but also provides enough information to prompt protective action for the public.

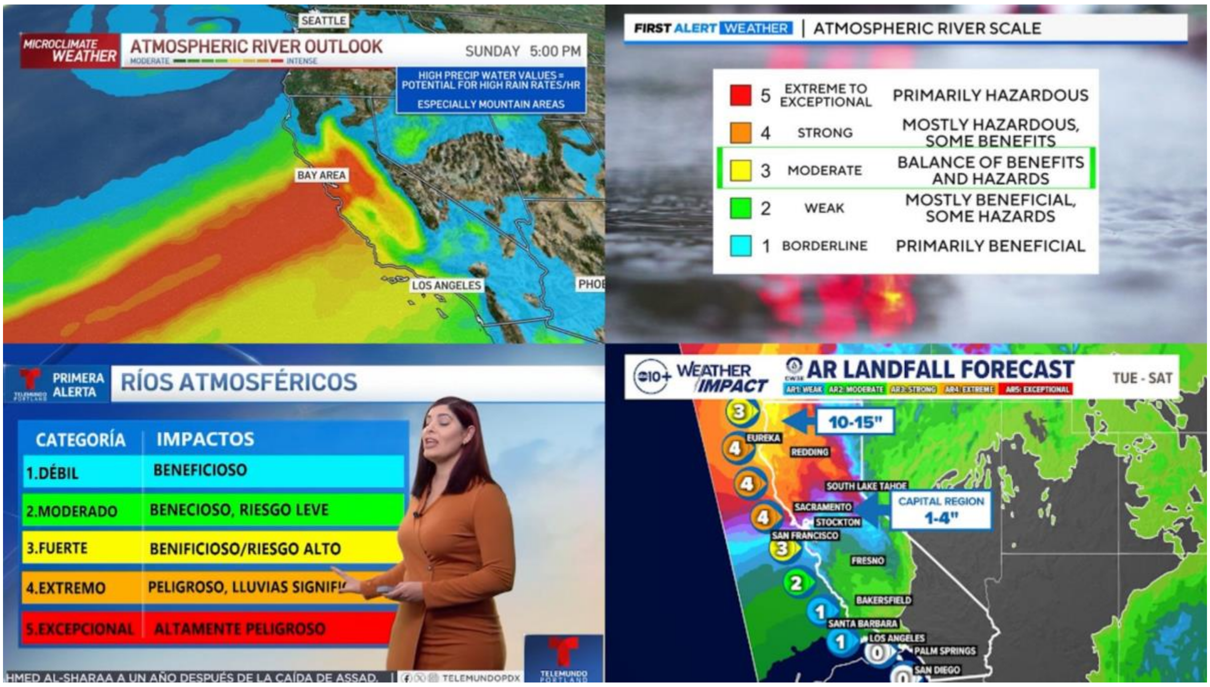


**Fig. 1.** Examples of AR Scale usage across English and Spanish broadcast media in the United States

The AR Scale distribution is calculated based on vertically integrated vapor transport (IVT) (see Ralph et al. 2019 for calculations), with intensity represented by the maximum IVT value at the location where ARs make landfall. The AR Scale follows a 1-5 ranking from weak to exceptional, represented as “AR 1” to “AR 5”, “Category 1 to Category 5”, or more recently, “Level 1 to 5.” Visually, this scale uses colors to express intensity with blue representing weak or Category 1 and red representing exceptional or Category 5 (Fig. 2). There are two main exceptions to the scale: the maximum category is “AR 5,” regardless of whether the event is longer than 48 hours, and some ARs can be classified as too “weak” to be recognized on the scale based on their duration and intensity.

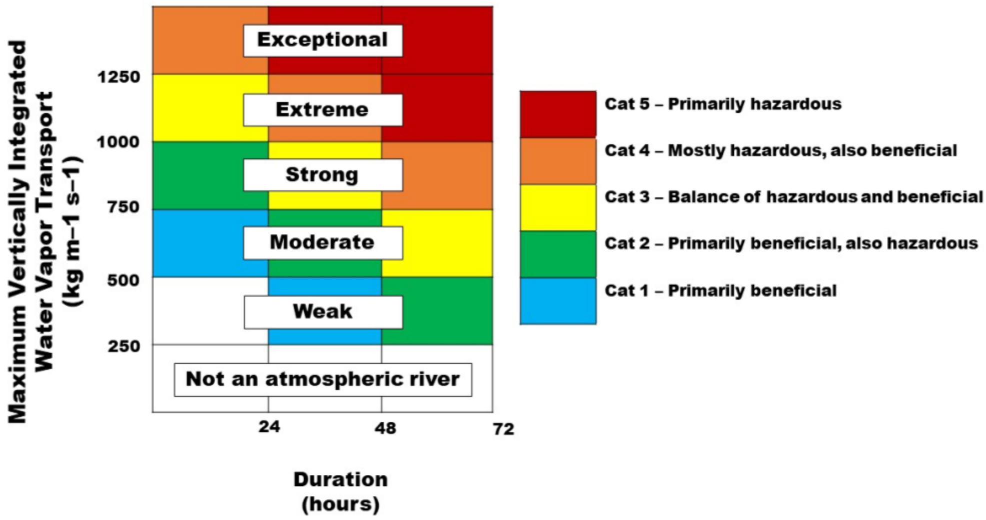


**Fig. 2.** The Atmospheric River Scale, as presented in USGS (2021)

By using the duration and intensity framework, this scale is unique in that its categories primarily distinguish between beneficial and hazardous events. As ARs have higher intensity and rank higher on the scale from “AR 1 to AR 5,” the potential impacts shift from being primarily beneficial to primarily hazardous (Fig. 1; Ralph et al. 2019). Primarily beneficial ARs can replenish water sources, whereas primarily hazardous ARs can cause severe flooding and wind damage (Guan et al. 2023). Broadcast meteorologists have also used this wording in their reports to distinguish between AR categories and communicate their associated impacts to the public in both English and Spanish (Fig. 1).

In risk communication, there has been a long-standing history of scales used to warn the public, whether issued in advance for interpretation or after an event to measure its severity. A few examples of these scales are the Excessive Rainfall Outlook (ERO) for flooding (Burke et al. 2023), the Saffir-Simpson Scale for hurricane wind speed (NHC 2025), the

Storm Prediction Center (SPC) categorical outlook, used to communicate the likelihood of severe thunderstorm hazards (Ernst et al. 2021), and the NorthEast Snowfall Impact Scale (NESIS) for winter weather (NCEI 2025). Most of these scales range from four to six levels and vary in their use of wording, numbering, and coloring, yet most were developed primarily as operational tools for scientists and forecasters rather than as products designed with public comprehension in mind (Ernst et al. 2026).

Like the AR Scale, many use a numerical system to convey hazard intensity. The Saffir-Simpson scale ranks hurricane maximum wind speed from Category 1 to Category 5, with Category 3 representing the threshold for storms considered major hurricanes (NHC 2025). NESIS similarly uses a Category 1 to Category 5 framework for snowfall impacts, pairing each level with words ranging from 'Notable' to 'Extreme' (NCEI 2025). One of the oldest scales combines numbers and words to communicate tornado intensity on a 0–5 scale based on wind speed and damage (Fujita 1971; WSEC 2006). Ripberger et al. (2015) were among the first to empirically test whether such impact words effectively communicate risk to the public alongside the numerical scale, a line of inquiry that has since expanded across multiple hazard types (e.g., Krocak et al. 2022; Ernst et al. 2021).

Recently, hazard scales have started to be evaluated in different languages. The SPC categorical outlook uses an English and Spanish version of the scale with increasing English risk terminology of “Marginal,” “Slight,” “Enhanced,” "Moderate,” and “High.” Bitterman et al. (2023) found that the direct translation of this scale from *Elevado* (Enhanced) and *Alto* (High) communicates similar values of risk to Spanish speakers. Trujillo-Falcón et al. (2021) developed an alternative Spanish SPC categorical outlook that was more intuitive for Spanish speakers using the words *Minimo*, *Bajo*, *Moderado*, *Alto*, and *Extremo*, with these changes implemented by the SPC and used in the Spanish versions of the categorical outlook (Bitterman et al. 2023).

Given the newness of the AR Scale and its application in English and Spanish, it is vital to assess whether the bilingual public can understand and use this scale to make protective decisions. As a key risk communication tool, the AR Scale conveys information about duration, intensity, and impacts, yet its effectiveness in shaping public comprehension and action remains understudied. Understanding how diverse and bilingual audiences interpret this scale is foundational to designing an AR Scale that people can follow and act on. To fill this gap, we address the following research questions:

*RQ1: How does the U.S. public interpret the risk communicated by the AR Scale?*

*RQ2: How does the U.S. public perceive the AR Scale categories in terms of risk and benefit?*

*RQ3: When does the U.S. public begin considering taking protective actions based on AR Scale categories?*

## 2. Methods

The study draws from questions from the 2025 Flooding and Society Survey (FL25; Bitterman et al. 2026a) and the 2025 Flooding and Society Spanish Survey (FLS25; Bitterman et al. 2026b), both led by the Institute for Public Policy Research and Analysis (IPPRA) at the University of Oklahoma. IPPRA fielded FL25 July 2–10, 2025, and FLS25 July 7–31, 2025, using self-administered online questionnaires. The University of Oklahoma's Institutional Review Board (IRB #91418) reviewed and approved both survey instruments and protocols. FL25 enrolled 1,223 U.S. adults, and FLS25 enrolled 375 Spanish-speaking U.S. adults, all aged 18 and older, residing in the contiguous United States. A national sample was selected, given that AR forecast products, including the AR Scale, are disseminated through national media channels (Fig. 2), and their impacts are increasingly encountered by publics beyond the Western U.S. (e.g., Debbage et al. 2017).[1] We also opted to center our study on both English and Spanish-speaking audiences, as they constitute the two biggest language groups in the United States (Trujillo-Falcón et al. 2021).

Verasight, a survey panel company, recruited participants through multiple methods, including address-based sampling, person-to-person text messaging, and dynamic online targeting. All panel members completed multistep identity verification, including SMS confirmation and Google reCAPTCHA v3, to ensure respondent validity and prevent automated responses. During data collection, Verasight applied a dynamic sampling procedure that adjusted invitation targets in real time to reduce over- or underrepresentation of key demographic groups. Participants completed FL25 in a median of 24.1 minutes and FLS25 in a median of 26.7 minutes.

Both surveys targeted the U.S. adult population using benchmarks derived from the 2024 American Community Survey (ACS) 1-year Public Use Microdata Sample accessed through

[1] The authors acknowledge that Western U.S. respondents may have greater direct exposure to AR events and familiarity with AR forecast products compared to the broader national sample. However, given the relatively small subsample size for Western U.S. respondents, these results are presented separately rather than alongside the main findings. Analyses of the subset of FL25 and FLS25 respondents residing in the Western U.S., identified through participant-reported ZIP codes, are therefore presented in Appendix A.

IPUMS USA (Ruggles et al. 2025). IPPRA constructed post-stratification weights using iterative proportional fitting (raking), which iteratively adjusts respondent weights until the marginal distributions of key demographic variables in the weighted sample converge to population benchmarks. For FL25, the weighting procedure incorporated age, gender, race, ethnicity, education, income, and NWS region. For FLS25, it incorporated age, gender, Hispanic heritage, English language proficiency, education, income, and NWS (n.d.) region, as previous work in bilingual risk communication has established these factors as important benchmarks (Trujillo-Falcón 2026). Table 1 presents the demographic composition of both survey samples alongside population benchmarks.

| | **FL25 (English, n = 1,223)** | | **FLS25 (Spanish, n = 375)** | |
|---|---|---|---|---|
| | **U.S. Adult Population (%)** | **Participants (%)** | **Spanish-Speaking U.S. Adult Population (%)** | **Participants (%)** |
| **Gender** | | | | |
| Female | 51.0 | 55.8 | 50.0 | 74.4 |
| Male | 49.0 | 44.2 | 50.0 | 25.6 |
| **Age** | | | | |
| 18–29 | 20.1 | 16.1 | 24.2 | 14.7 |
| 30–49 | 33.8 | 34.7 | 40.0 | 56.3 |
| 50–64 | 23.2 | 25.3 | 22.3 | 26.1 |
| 65 and up | 22.9 | 23.9 | 13.5 | 2.9 |
| **Education** | | | | |
| High School or Less | 37.3 | 30.7 | 56.9 | 34.9 |
| Some College/2-year Degree | 28.5 | 30.1 | 24.1 | 39.5 |
| 4-year/Post-Graduate Degree | 34.2 | 39.2 | 19.0 | 25.6 |
| **Race** | | | | |
| White | 59.2 | 60.7 | N/A | N/A |
| Black or African American | 11.6 | 11.9 | N/A | N/A |
| Other race | 11.0 | 9.7 | N/A | N/A |

| | | | | |
|---|---|---|---|---|
| **Ethnicity** | | | | |
| Hispanic | 18.2 | 17.7 | N/A | N/A |
| Non-Hispanic | 81.8 | 82.3 | N/A | N/A |
| **Hispanic Heritage** | | | | |
| Not Hispanic | N/A | N/A | 5.4 | 2.9 |
| Mexican | N/A | N/A | 52.6 | 17.9 |
| Other Hispanic | N/A | N/A | 42.0 | 79.2 |
| **English Language Proficiency** | | | | |
| Does not speak English | N/A | N/A | 10.3 | 12.3 |
| Yes, but not well | N/A | N/A | 16.4 | 44.3 |
| Yes, speaks well | N/A | N/A | 18.2 | 26.1 |
| Yes, speaks very well | N/A | N/A | 55.2 | 17.3 |
| **Income** | | | | |
| Less than $50,000 | 25.9 | 29.8 | 29.9 | 71.2 |
| $50,000 or more | 74.1 | 70.2 | 70.1 | 28.8 |
| **NWS Region** | | | | |
| Eastern | 31.4 | 30.8 | 21.1 | 25.3 |
| Southern | 27.8 | 28.8 | 36.7 | 53.1 |
| Central | 20.3 | 19.1 | 10.0 | 7.7 |
| Western | 20.5 | 21.3 | 32.2 | 13.9 |

**Table 1**. Demographic composition of FL25 (English) and FLS25 (Spanish) survey samples compared to U.S. adult population benchmarks.

Our study examined three sets of AR-specific items embedded in both surveys (for exact question wording, visit Bitterman et al. 2026 a,b). To assess perceived ordering of AR Scale intensity, participants ranked five AR Scale terms– “Weak,” “Moderate,” “Strong,” “Extreme,” and “Exceptional” (or *Débil*, *Moderado*, *Fuerte*, *Extremo*, and *Excepcional* in Spanish)– from 1 (lowest risk) to 5 (highest risk) based on how serious each term sounds, following previous work that has examined categorical risk terminology (Bitterman et al. 2023; Ernst et al. 2021). To assess perceived impact, participants characterized the expected impacts of each AR category (AR1–AR5) as primarily beneficial (*primordialmente beneficioso*), equally beneficial and hazardous (*igualmente beneficioso como peligroso*), primarily hazardous (*primordialmente peligroso*), or not sure, following the original definitions of the AR Scale (Ralph et al. 2019). To assess perceived protective action thresholds, participants were asked to indicate at which AR category they would begin to consider each of seven actions in a hypothetical AR event scenario: (1) seeking additional information, (2) preparing emergency supplies, (3) considering protective action, (4) securing outdoor items, (5) reconsidering travel plans, (6) preparing for power outages, and (7) evacuating. Each action also included a “would not take this action in any scenario option.”

We conducted all analyses in R version 2026.01.2+418 using the *srvyr* package (Freedman et al 2026) to incorporate post-stratification weights. For each survey item, we calculated weighted proportions and 95% confidence intervals. For the scale ordering task, we additionally calculated weighted mean perceived ranks for each AR intensity term and identified the most common response patterns across all five rankings. This analytical approach is consistent with prior weather risk communication studies that have used representative surveys to evaluate public interpretation of hazard scales and provided recommendations for NWS agencies (Bitterman et al. 2023; Ernst et al. 2021). Results from FL25 (English) and FL25 (Spanish) are presented in two-panel figures to facilitate direct comparison between language groups.

## 3. Results

Fig. 3 presents the weighted distributions of English and Spanish speakers’ rankings of each AR intensity term across Levels 1–5. Among English speakers, “Weak” accounted for the largest share of responses at Level 1 (43.0%) and “Strong” at Level 3 (47.3%). However, participants showed considerable variation at the upper end of the scale. At Level 4, “Moderate” received the highest proportion of responses (26.2%), followed closely by “Exceptional” (23.8%) and “Extreme” (22.9%). At Level 5, “Weak” received the largest share of responses (32.7%), with Extreme (28.0%) and Exceptional (23.4%) following. Spanish speakers showed a comparable pattern for *Débil* at Level 1 (35.8%), but considerably greater dispersion across the middle and upper categories. *Excepcional* received its highest proportion at Level 2 (42.2%) rather than Level 5, and at Level 5, *Extremo* was most frequently selected (38.5%) while *Excepcional* was assigned by only 12.7% of participants.

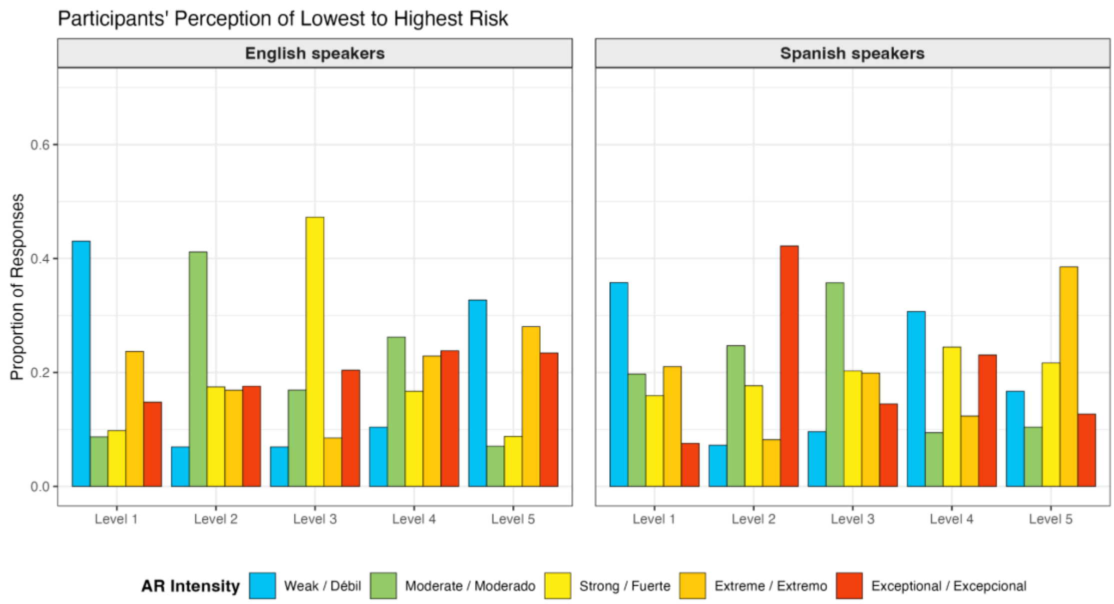


**Fig. 3.** Distributions of English and Spanish survey participants' rankings of the AR Scale categorical words.

The share of English speakers assigning "Weak" to Level 5 (32.7%) warranted additional investigation. To rule out data quality issues, we conducted three robustness checks: (1) rerunning the analysis with unweighted data, (2) removing respondents who spent fewer than 5 seconds on the ranking questions, and (3) removing respondents who spent fewer than 10 seconds on the ranking questions. All three approaches produced results substantively identical to those reported in Fig. 3, suggesting the pattern reflects genuine participant responses rather than inattentive or random answering.

Fig. 4 plots the weighted mean perceived rank for each intensity term. Among English speakers, all five terms fell between mean ranks of 2.82 ("Moderate") and 3.23 ("Exceptional"), a range of only 0.41 points on a 1–5 scale. The intended ordering was partially preserved, with "Moderate" (2.82) and "Weak" (2.83) receiving the lowest mean ranks and "Strong" (2.97), "Extreme" (3.15), and "Exceptional" (3.23) receiving progressively higher ranks. Among Spanish speakers, all five terms similarly clustered near the midpoint, ranging from 2.66 (*Moderado*) to 3.39 (*Extremo*), a range of 0.73 points. However, the intended ordering was not preserved: *Excepcional* (2.91) received a lower mean rank than both *Fuerte* (3.18) and *Extremo* (3.39), placing the highest intensity term third rather than fifth. *Débil* (2.85) received the second lowest mean rank, broadly consistent with its intended position, but *Moderado* (2.66) received the lowest mean rank overall.

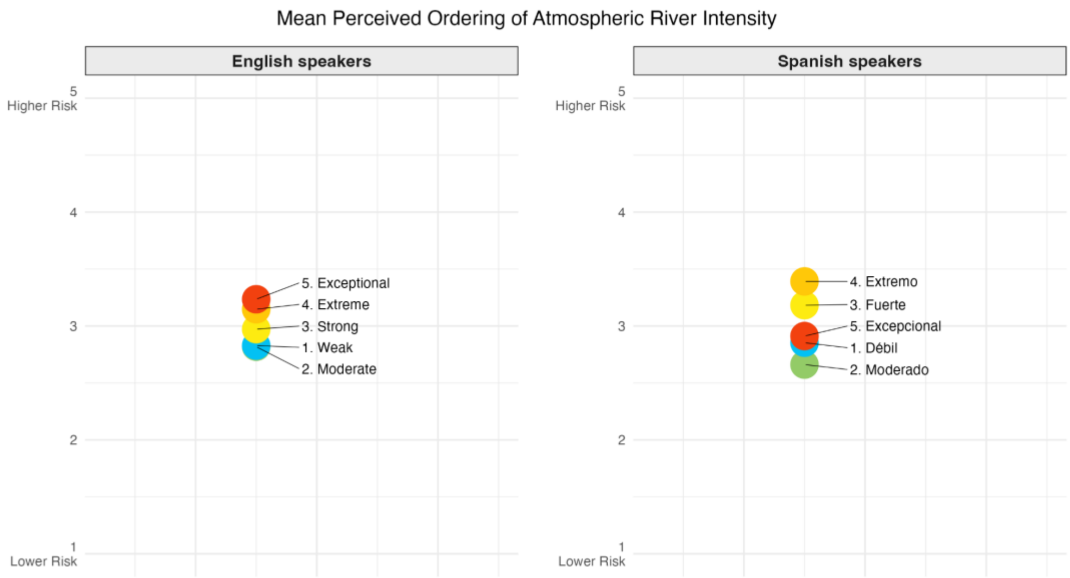


**Fig. 4.** Mean placement of each AR Scale term among English and Spanish participants

Table 2 presents the five most common ordering patterns among English and Spanish speakers. Among English speakers, the most common response was "Weak" → "Moderate" → "Strong" → "Exceptional" → "Extreme" (27.78%), which correctly places the lower three categories but inverts "Extreme" and "Exceptional" at the upper end. The official ordering (i.e., "Weak" → "Moderate" → "Strong" → "Extreme" → Exceptional) was the second most common response (26.51%), and the two most prevalent patterns differed only in the placement of the two highest-intensity terms. The third and fourth most common patterns (12.70% and 11.11%, respectively) represented complete reversals of the scale from highest to lowest risk.

| **Top Five Order of Common Responses (English)** | **n** | **%** |
|---|---|---|
| Weak → Moderate → Strong → Exceptional → Extreme | 175 | 27.78 |
| Weak → Moderate → Strong → Extreme → Exceptional | 167 | 26.51 |
| Extreme → Exceptional → Strong → Moderate → Weak | 80 | 12.70 |
| Exceptional → Extreme → Strong → Moderate → Weak | 70 | 11.11 |
| Extreme → Strong → Exceptional → Moderate → Weak | 69 | 10.95 |

**Table 2.** Top five most common ordering patterns of AR Scale intensity terms among English-speaking survey respondents (n = 1,223), with the official AR Scale ordering indicated in red font.

Among Spanish speakers (Table 3), the correct ordering (*Débil → Moderado → Fuerte → Extremo → Excepcional*) was most frequently selected (27.27%), with the second most common pattern transposing *Excepcional* and *Extremo* (26.36%). As with English speakers, the two most prevalent patterns were nearly equivalent in frequency and differed only in the placement of the two highest-intensity terms.

| **Top Five Order of Common Responses (Spanish)** | **n** | **%** |
|---|---|---|
| Débil → Moderado → Fuerte → Extremo → Excepcional | 30 | 27.27 |
| Débil → Moderado → Excepcional → Fuerte → Extremo | 29 | 26.36 |
| Débil → Moderado → Fuerte → Excepcional → Extremo | 13 | 11.82 |
| Débil → Excepcional → Moderado → Fuerte → Extremo | 10 | 9.09 |
| Débil → Extremo → Moderado → Fuerte → Excepcional | 7 | 6.36 |

**Table 3.** Top five most common ordering patterns of AR Scale intensity terms among English-speaking survey respondents (n = 375), with the official AR Scale ordering indicated in red font.

Fig. 5 presents the weighted distributions of English and Spanish speakers' characterizations of expected impacts for each AR category. Among English speakers, a majority identified AR1 ("Weak") as primarily beneficial (57.5%), and AR4 ("Extreme") and AR5 ("Exceptional") were most frequently characterized as primarily hazardous (66.5% and 65.0%, respectively). AR2 ("Moderate") was most commonly characterized as equally beneficial and hazardous (43.5%), and AR3 ("Strong") followed a similar pattern (46.5%).

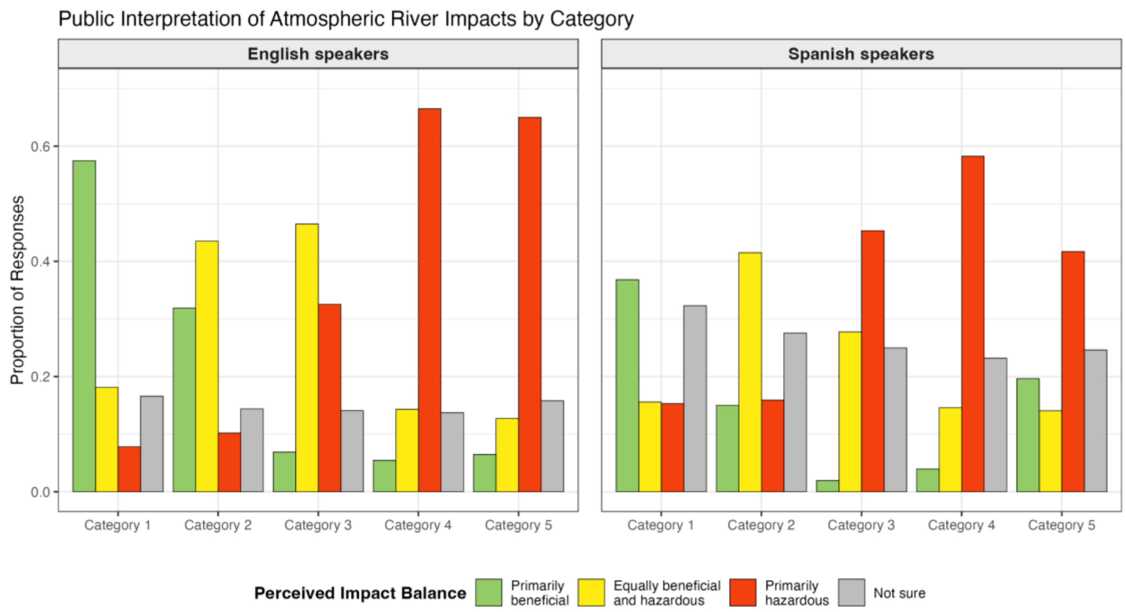


**Fig. 5.** Distributions of English and Spanish participants' characterizations of expected impacts by AR category.

Spanish speakers exhibited a similar pattern, with AR3 (*Fuerte*) through AR5 (*Excepcional*) most frequently characterized as primarily hazardous (45.3%, 58.2%, and 41.7%, respectively), but with three notable differences. First, "not sure" responses were substantially higher across all five categories among Spanish speakers, ranging from 23.2% to 32.3%, compared to 13.7% to 16.6% among English speakers. Second, Spanish speakers were less likely to characterize AR5 (*Excepcional*) as primarily hazardous (41.7%) compared to English speakers (65.0%), and 19.6% of Spanish speakers characterized AR5 as primarily beneficial, compared to 6.5% of English speakers. Third, AR1 (*Débil*) elicited a lower rate of "primarily beneficial" responses among Spanish speakers (36.8%) compared to English speakers (57.5%), accompanied by a higher "not sure" rate (32.3% vs. 16.6%).

Fig. 6 presents the AR category at which English and Spanish speakers reported they would begin to consider each of seven protective actions in a hypothetical AR event scenario. Among English speakers, the largest share of respondents indicated they would seek additional information beginning at AR3 (32.8%), followed by AR2 (25.1%). Stated thresholds for securing outdoor items (AR3: 39.1%), reconsidering travel plans (AR3: 37.9%), and preparing for power outages (AR3: 38.3%) followed comparable patterns, with AR3 as the modal threshold for each action. Stated thresholds for preparing emergency supplies were more evenly distributed across AR3 (29.8%) and AR4 (28.7%). Evacuation exhibited the highest stated threshold, with the largest shares of English speakers citing AR4 (33.5%) or AR5 (37.4%), and 8.3% reporting they would not evacuate under any scenario.

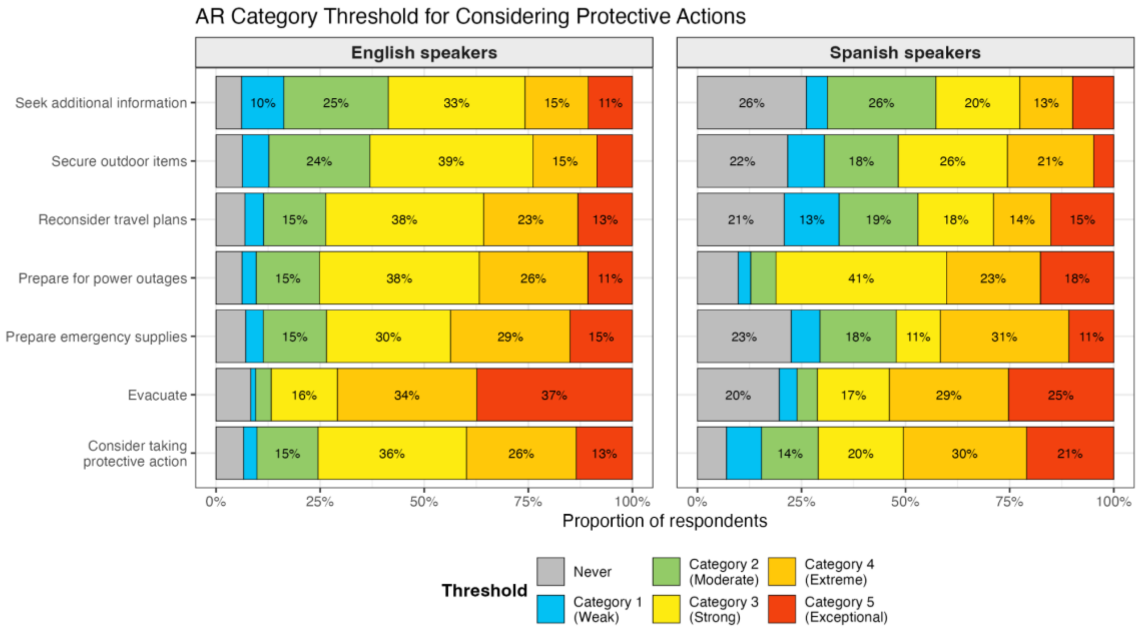


**Fig. 6.** Stated protective action thresholds by AR category among English and Spanish participants.

Spanish speakers exhibited broadly similar distributions but with two notable differences. First, "would not take this action in any scenario" responses were higher among Spanish speakers across several actions,  most notably for seeking additional information (26.1% vs. 6.1%), securing outdoor items (21.7% vs. 6.3%), and reconsidering travel plans (20.9% vs. 6.9%). Second, a higher percentage of Spanish speakers reported they would not evacuate under any scenario (19.7% vs. 8.3% among English speakers), though among those who indicated a threshold, responses were broadly comparable at the higher categories, with 28.6% citing AR4 and 25.3% citing AR5. Given the smaller Spanish sample (n = 375), confidence intervals for Spanish estimates are wider throughout, and these results should be interpreted accordingly.

## 4. Discussion

When Ralph et al. (2019) introduced the AR Scale, they provided forecasters and communicators with a reliable framework for conveying AR intensity and impact to the public. However, whether the public understands that framework it is meant to serve remains an open empirical question. This study presents the first nationwide bilingual assessment of public understanding of the AR Scale, finding that comprehension of the scale's intended intensity gradient is incomplete among both English and Spanish speakers, with notable differences between language groups across all three dimensions examined: intensity ordering, perceived benefits and hazards, and protective action thresholds.

***a. AR Scale Ordering.*** Categorical risk scales depend on language that intuitively conveys increasing levels of risk to the public, yet the words chosen to represent scale categories across various weather hazards have frequently proven difficult for the public to interpret accurately (Bitterman et al. 2023; Ernst et al. 2021; Krocak et al. 2022; Trujillo-Falcón et al. 2021; Williams et al. 2022). When applied to the AR Scale, both English and Spanish speakers showed difficulty ordering its intensity terms. The narrow spread of the weighted mean ranks–less than half a point across all five terms on a five-point scale (Fig. 2)–suggests that the current AR terms do not communicate a clearly differentiated gradient of risk, a finding with implications for how the scale is designed and presented.

At the upper end of the scale, two terms appear to be driving much of the observed difficulty. "Exceptional" and *Excepcional* can carry positive connotations in everyday usage in both languages, which may have led some participants to associate the term with lower risk rather than the scale's highest category. Among English speakers, a substantial share also placed "Weak" in the highest-risk position, a pattern confirmed in multiple robustness checks and in the Western U.S. subsample (Fig. A1). One possible explanation for this counterintuitive placement may relate to the recognition of compound AR sequences, where weaker events following stronger ones can still produce extreme impacts (Zhou et al. 2024). Future work should examine whether prior exposure to compound AR sequences shapes public risk perception of lower-category events through longitudinal designs, as has been done with hurricanes (Demuth et al. 2025).

Among Spanish speakers, the difficulty at the upper end of the scale is further consistent with Bitterman et al. (2023), who found that *Extremo* has been among the highest risk terms tested in Spanish-language hazard communication. The SPC categorical outlook may further reinforce this pattern: the first hazard scale to debut nationwide in Spanish uses *Extremo* as its highest category (Trujillo-Falcón et al. 2021). Future work should more deeply examine Spanish-speaking communities as a heterogeneous group, exploring how factors such as dialect group, English-language proficiency, and foreign-born status shape interpretation of the AR Scale, as previous work has documented differences in risk perceptions across these groups (Trujillo-Falcón et al. 2022).

***b. Perceived Benefits and Hazards.*** Public characterizations of AR impacts broadly aligned with the beneficial-to-hazardous gradient embedded in the AR Scale's design. English speakers correctly identified AR1 as primarily beneficial and AR4–AR5 as primarily hazardous at high rates, indicating that the scale's core risk communication logic (i.e., that higher categories signal greater hazard) is at least partially accessible to English-speaking audiences. AR3, designated as the balance point between beneficial and hazardous impacts in the scale's original framework (Ralph et al. 2019), was most commonly characterized as equally beneficial and hazardous, suggesting reasonable alignment at the midpoint. However, AR2, which the scale designates as mostly beneficial, was also frequently characterized as equally beneficial and hazardous, suggesting the distinction between the two lowest categories may not be clearly communicated by the scale's current design. Future work should examine whether supplementary impact language or visual design changes could better differentiate AR2 from AR3, particularly given the practical implications of mischaracterizing a mostly beneficial event as equally hazardous.

Spanish speakers exhibited a broadly similar beneficial-to-hazardous gradient, but with patterns that warrant closer attention. The substantially higher "not sure" rates across all five categories likely reflect lower familiarity with ARs specifically, consistent with previous work showing that while weather salience is generally high among Spanish-speaking communities, awareness of specific hazard types may be limited by differences in disaster subculture (Gaviria Pabón et al. 2025; Trujillo-Falcón et al. 2024a). Most notably, a substantial share of Spanish speakers characterized AR5 as primarily beneficial, a finding with direct safety implications given that AR5 represents the scale's most dangerous category and is associated with the greatest potential for flooding and loss of life. Future work should examine whether targeted AR education and Spanish-language outreach can improve comprehension of the upper categories, particularly for communities in high-risk regions.

***c. Protective Action Thresholds.***

Stated thresholds for most protective actions clustered around AR3 among English speakers, with evacuation concentrating at AR4 and AR5. The concentration of information-seeking and preparatory action thresholds at AR3 is noteworthy given that AR3 represents the threshold at which the AR Scale's own framework begins to characterize events as primarily hazardous (Ralph et al. 2019), suggesting some intuitive alignment between scale design and public stated thresholds among English speakers. Evacuation, the highest-stakes action examined, followed patterns consistent with prior work finding that publics report higher stated thresholds for more disruptive protective actions (Morss et al. 2016; Kang et al. 2007).

Spanish speakers showed broadly comparable threshold distributions among those who reported a threshold, but differed substantially in the proportion reporting they would not take a given action under any scenario. Elevated 'would not act' rates for information seeking, securing outdoor items, and reconsidering travel, as well as a substantially higher rate of reported non-evacuation, should not be interpreted solely as reduced AR Scale comprehension. Prior research has documented that non-action in Spanish-speaking and immigrant communities is often shaped by structural constraints, limited access to Spanish-language hazard information, and reduced institutional trust (Trujillo-Falcon et al. 2024b). Future work should examine whether these patterns reflect perceived inapplicability of the hypothetical scenario, distrust of official messaging, or material constraints on action.

***d. Limitations.*** Several limitations of this study warrant consideration. First, the AR Scale includes components beyond wording, such as colors, which could be tested in the future, as in Ernst et al. (2021). Second, the survey did not test public understanding of the *duration* component of the AR Scale, which Ralph et al. (2019) built in as a key parameter. Third, while a nationwide sample is appropriate given the AR Scale's increasing use beyond the Western U.S., regional samples in high-exposure areas would allow for more targeted recommendations for communities with direct AR experience, beyond the exploratory Western U.S. subsample presented in Appendix A. Fourth, the Spanish-speaking sample was smaller than the English-speaking sample, resulting in wider confidence intervals throughout, and should be interpreted accordingly. Finally, all protective action items were presented as hypothetical scenarios, and stated thresholds may not correspond to actions taken during actual AR events, a limitation shared by survey-based hazard communication research more broadly (Morss et al. 2016). Future work could examine protective action decisions longitudinally during actual AR events, pairing survey data with real-time hazard information to better understand how stated thresholds translate into behavior under realistic conditions

## 5. Advancing the AR Scale for the U.S. Public

The AR Scale represents an important advance in communicating atmospheric river intensity and potential impacts to the public (Ralph et al. 2019), and the findings presented here offer an empirical foundation for its continued development as a risk communication tool. Several priorities emerge for advancing the scale across diverse populations.

Based on the findings presented here, several practical recommendations are offered for NWS forecasters, broadcast meteorologists, and emergency managers in advance of more systematic testing of alternative scale terminology. First, current AR Scale products should consider supplementing intensity terms with explicit impact language across all five categories to enhance understanding. This approach is consistent with the NWS impact-based warning framework, where the addition of specific hazard and impact language has been shown to improve risk perception and promote protective action (Casteel 2016). Second, future scale design efforts should examine whether numerical labels alone communicate risk more clearly. Krocak et al. (2022) found that numeric level information reduced misordering of the SPC categorical scale relative to verbal labels alone, suggesting a similar approach may improve public interpretation of the AR categories. Third, Spanish-language AR Scale terminology should be reviewed for consistency with existing bilingual hazard scales, particularly given the SPC categorical outlook's established use of *Extremo* as its highest category (Bitterman et al. 2023). Finally, while media training efforts such as those led by the Scripps Institution of Oceanography (n.d.) have begun to equip broadcast meteorologists with AR Scale communication tools, future outreach should extend beyond media professionals toward broader public educational campaigns, particularly for Spanish-speaking communities, where structural barriers to protective action were most evident.

Addressing the terminology challenges identified in our study will require systematic testing of alternative intensity descriptions, particularly at the upper end of the scale where AR4 and AR5 were poorly differentiated by both language groups. Prior work in hazard communication has shown that small changes in terminology can alter perceived severity and stated protective action (Trujillo-Falcón et al. 2021; Bitterman et al. 2023). Importantly, the Spanish-language AR Scale should not be treated as a direct translation of the English version but rather evaluated as an independent system shaped by distinct linguistic and cultural interpretations of the terminology (Bitterman et al. 2023; Trujillo-Falcón et al. 2022). The elevated 'would not act' rates among Spanish speakers further highlight the need to distinguish between perceived understanding of risk and perceived ability to respond, which are fundamentally different dimensions of protective decision-making.

Beyond the AR Scale itself, situating it within the broader ecosystem of hazard communication products is an important next step. The Excessive Rainfall Outlook (Burke et al. 2023), SPC categorical outlooks, and WSSI may all operate simultaneously during high-impact AR events, yet their combined influence on public interpretation remains poorly understood. Comparative research may help determine whether consistency across scales improves comprehension or whether variation introduces uncertainty in how risk is perceived (Ernst et al. 2021).

Complementing these quantitative directions, qualitative work with both English and Spanish-speaking populations would offer insights that surveys alone cannot provide. Interviews and focus groups may help clarify how individuals interpret AR terminology in context, understand overlapping hazard products, and how these interpretations are shaped by lived experience and structural constraints. Integrating qualitative insights with survey-based findings may help provide a more complete foundation for refining the AR scale as both a meteorological and communicational tool. As the AR Scale continues to evolve as a communicative product, its success will ultimately depend on how well it supports a timely and equitable response across *all* communities.

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*Data Availability Statement.*

The datasets analyzed in this study are available in the Harvard Dataverse. English-language data are described in Bitterman et al. (2026a) or at https://doi.org/10.7910/DVN/5VYPUQ. Spanish-language data are described in Bitterman et al. (2026b) or at https://doi.org/10.7910/DVN/QGDEKA.

# APPENDIX

## Appendix A

### ***An Analysis of the Western U.S. Subsample***

To supplement the national findings, we present results from a subsample of participants residing in the Western NWS region (as defined by NWS n.d.), which experiences the most frequent and well-documented AR landfalls in the United States. Participants were assigned to NWS regions based on their self-reported ZIP code. The Western NWS region subsample includes 260 English speakers from FL25 and 52 Spanish speakers from FLS25. Given the substantially smaller sample sizes relative to the national sample, these results should be interpreted with caution and treated as exploratory. Confidence intervals are wider throughout, and some cells have limited data, particularly for the Spanish subsample. Nonetheless, these patterns may be of interest to practitioners and researchers focused specifically on AR-prone regions. We call on researchers to examine this region in deeper detail in the future so that more generalizable findings can be provided.

Fig. A1 presents the weighted distributions of NWS Western Region English and Spanish speakers' rankings of each AR intensity term across Levels 1–5, mirroring the structure of Fig. 3 in the main text. Fig. A2 plots the weighted mean perceived rank for each intensity term among NWS Western Region respondents, following the format of Fig. 4. Fig. A3 presents the weighted distributions of perceived impact (primarily beneficial, equally beneficial, and hazardous, primarily hazardous, and not sure) for each AR category among NWS Western Region participants, corresponding to Fig. 5 in the main text. Finally, Fig. A4 presents the AR category thresholds at which NWS Western Region English and Spanish speakers reported they would begin to consider each of the seven protective actions, paralleling Fig. 6.

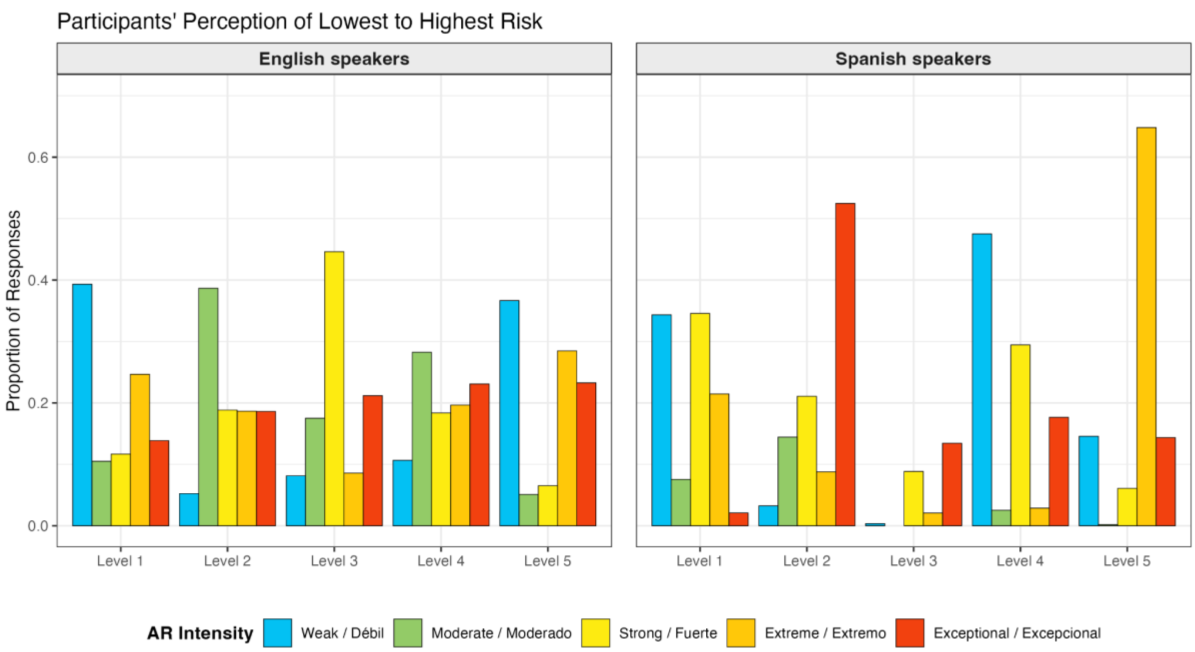

**Fig. A1.** Distributions of English and Spanish Western U.S. subsample participants' rankings of the AR Scale categorical words.

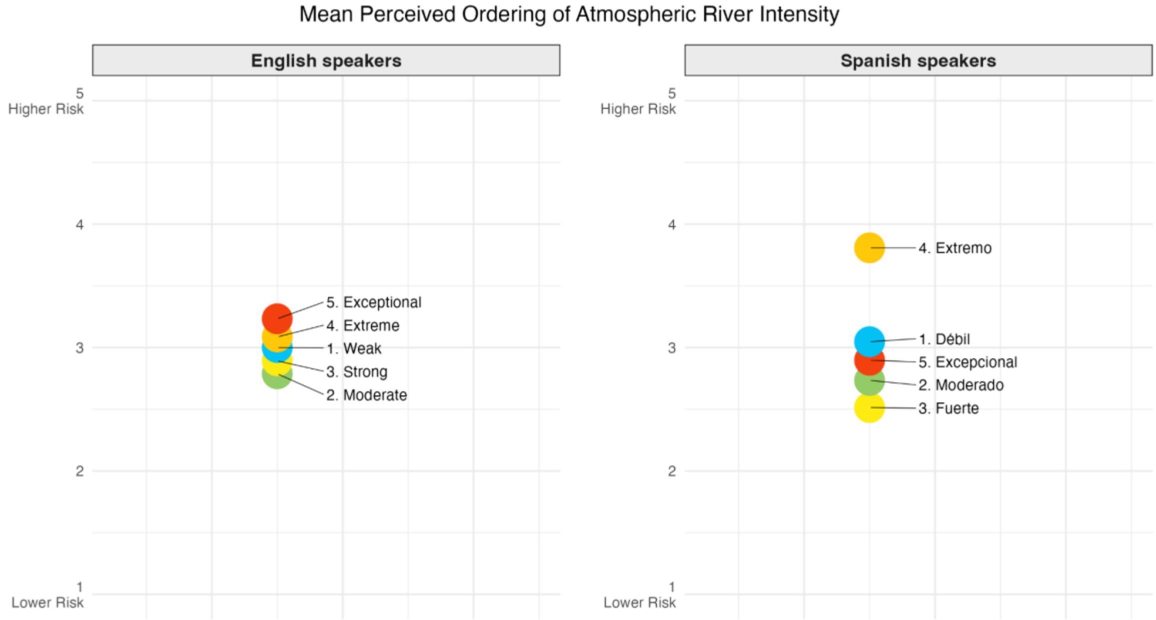


**Fig. A2.** Mean placement of each AR Scale intensity term among English and Spanish Western U.S. subsample participants.

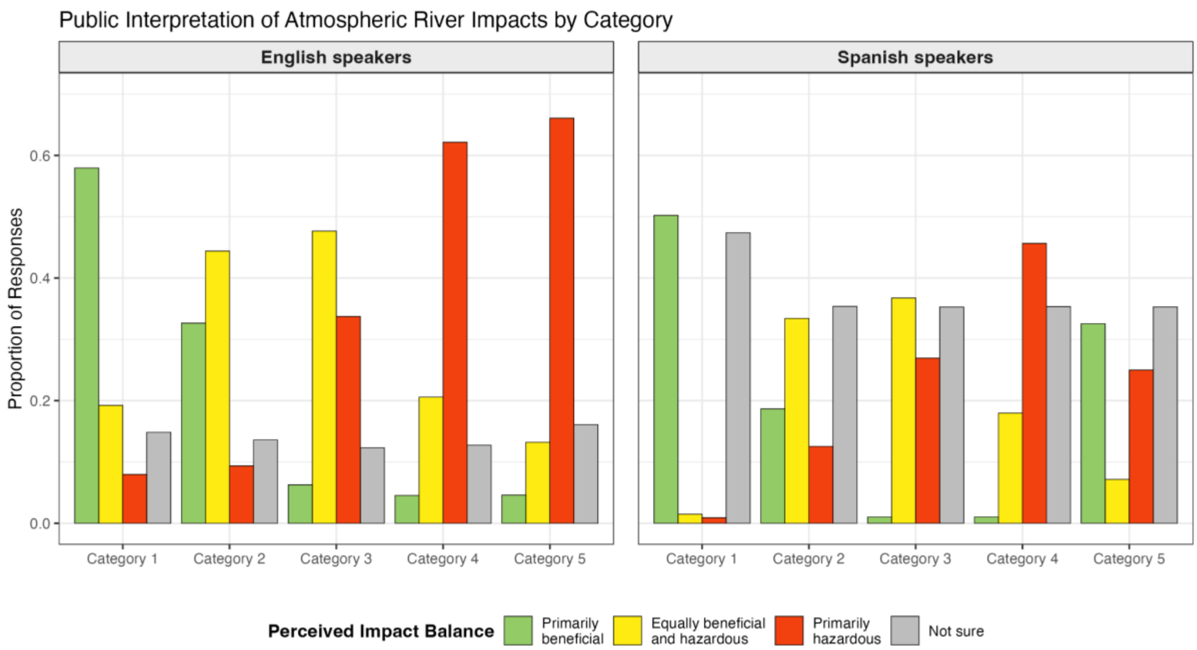


**Fig. A3.** Distributions of English and Spanish Western U.S. subsample participants' characterizations of expected impacts by AR category.

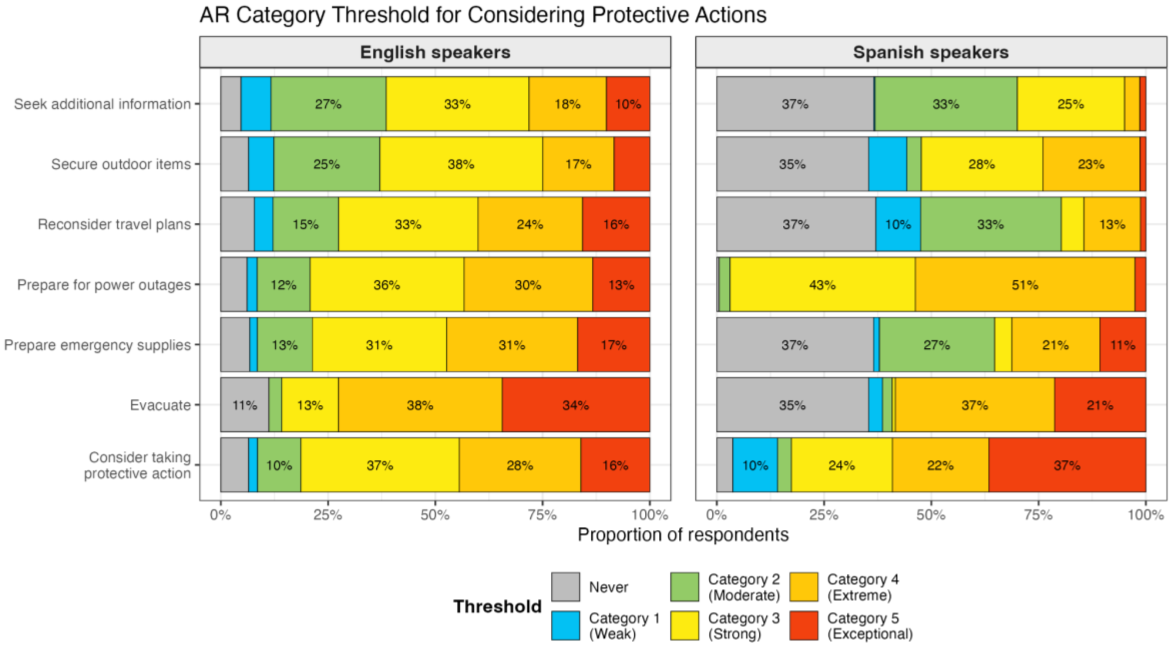


**Fig. A4.** Stated protective action thresholds by AR category among English and Spanish Western U.S. subsample participants.

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