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Communicating weather warnings to the Swiss population – Insights of a representative online study

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Abstract

Weather warnings serve the purpose of informing the public about potentially dangerous weather events so they can take precautionary measures to avoid harm and damages. Even the best weather warning in meteorological terms is only effective if it reaches the affected individuals and organizations, if the receivers take the information into account, if they understand the risk at hand and take the necessary measures.

In order to get a better understanding on where MeteoSwiss, the Swiss Federal Office of Meteorology and Climatology, can improve with respect to that “last mile” of weather warnings, we conducted within the program OWARNA2@MCH an online-study with a representative sample of the Swiss population. By applying a factorial survey experiment with an implicit association test, we were able to estimate the effect of different elements of a warning message on people’s spontaneous reaction to the warning and their intention to take action.

Among others but most importantly, our results have shown that behavioral recommendations and statements about potential impacts should be presented more prominently in a warning than meteorological parameters such as wind speed to serve as a “wake-up call” and to promote action. We have also seen that when designing a warning message, care should be taken to ensure that it is perceived as personally relevant. For this purpose simple labels such as "high danger" are not effective. Rather, what is needed are indications of what this danger means in the sense of what can happen and what should be done.

In the survey we also asked questions about how well people have been reached so far by weather warnings and via which distribution channels, about people’s preferences for warning distribution channels in the future, about preferred timing of the warning and interest in uncertainty information. We found that MeteoSwiss with its app and website is and will be the most important distributor of weather warnings in Switzerland. Still a non-negligible fraction of the Swiss population is not reached by weather warnings, which highlights, among others, the relevance of redistributors, of the discussion on cell broadcast as well as of information campaigns on weather risks.

With respect to uncertainty and lead time we found that a clear majority is interested in uncertainty information and wants to receive warnings one to two days in advance with some people also interested in information about more uncertain severe weather forecast more in advance.

We discuss these findings in the context of the scientific literature and the Swiss warning landscape.

Contents

1 Introduction

One of the main tasks of a national weather service such as the Swiss Federal Office of Meteorology and Climatology MeteoSwiss is to issue warnings about severe weather events to authorities and the public. With the emerging climate crisis and the increasing frequency of extreme weather events (Seneviratne et al., 2021), this task becomes even more important. The ultimate goal of severe weather warnings is to enable the affected individuals and organizations to understand the specific threat and take appropriate protective measures. To reach this goal it is not enough to accurately forecast a severe weather event. The weather service also needs to make sure that the warning reaches the affected population, that the receivers consider the information, understand the communicated risk and know about the actions needed to protect themselves and their property.

In this study, which was conducted within the program OWARNA2@MCH, we look at these different aspects of a successful weather warning in the Swiss context and ask the following questions: How well has the Swiss population been reached so far by our warnings and what are preferred distribution channels in the future? Which information should we include in a warning so that people perceive it as a wake-up call and take action? How should we deal with the uncertainty inherent in the warning, i.e. at what time point should we issue a warning and does the Swiss public want information about the underlying uncertainty? To answer these questions, we have conducted an online-study with a representative sample (N = 2000) of the Swiss population. In the following, we describe in more detail the background for each question and what is known so far from the literature. After describing then the method and results, we discuss our findings in the end and put them into context.

1.1 Warning content

The MeteoSwiss warnings currently contain information on the following elements (see Figure 1 for an example of a warning via the app): Type of event (e.g., "thunderstorm"), warning level (1, 2,3,4, or 5), description of the warning level (*no or minor danger”, "moderate danger", "considerable danger", "high danger" or "very high danger"), name of the affected area, time period in which the warned event is predicted to occur, meteorological parameters (e.g., wind speed in km/h or 24 h sum of precipitation), potential amplifying factors if applicable, a web-link to general recommendations for action as well as the name of the sender of the message (“© MeteoSchweiz”).

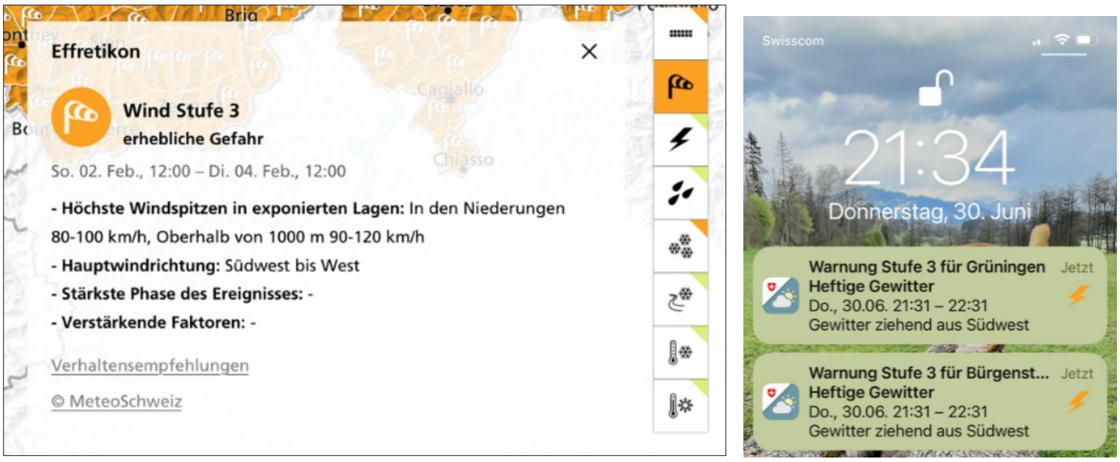


Figure 1: Example of a warning message in the MeteoSwiss App (left) and of push notifications as they appear on the mobile screen (right).

Hence, the MeteoSwiss warnings already contain information on the five elements that a warning message should contain according to Mileti and Sorensen (1990): "hazard, location, guidance, time, and source". However, information on guidance is only available through clicking on a link, and information on the hazard is only expressed in meteorological terms which is often difficult to understand for lay persons (Fleischhut, Herzog, & Hertwig, 2020). That is why the World Meteorological Organization (WMO) recommends to provide impact-based warnings, meaning, to communicate "what the weather might do" and not only "what the weather will be" (WMO, 2015). Such impact-based warnings have been found to increase understanding and raise risk perceptions (Weyrich, Scolobig, Bresch, & Patt, 2018; Potter, et al., 2018).

But what does that mean for the content of a warning message? Warning messages can only contain a certain amount of information and - depending on the channel and the type of transmission (e.g. push) - sometimes only a few sentences or even words. One way how to deal with that issue is to provide information through the principle of progressive disclosure, for example by showing only a small part of the information initially and conveying more information on request or by scrolling down. Still, the question remains, which pieces of information should be present on a first layer and which information can be displayed on a deeper layer. Weather services hence need to ask the question what are the most relevant pieces of information the population needs for a first evaluation of the situation. Should general information about the potential impacts be more prominently presented in the warning message than meteorological parameters? What about other pieces of information such as recommendations for action or the description of the warning level?

To answer this question, we need to understand which pieces of information of a warning message are particularly important to trigger a first spontaneous reaction to the warning. People usually receive warnings during daily activities, for example as push-notifications on the smartphone. That means that a warning competes with several other pieces of information that try to catch our attention. The decision of whether to respond to the information is taken within only a few seconds as the result of an uncontrolled and intuitive process. Accordingly, Lindell & Perry (2011) describe in their protective action decision model that a warning first enters a pre-decisional process before it is further considered for protective action decision making.

We investigated the effect of different warning contents through a factorial survey experiment that we describe in more detail below in chapter 2.2. On the one hand, we asked for people’s explicit evaluation of the warning message. On the other hand, we measured people's implicit associations with different warnings to investigate unconscious, pre-decisional processes. Originally a tool to measure unconscious stereotypes (Greenwald, Nosek, & Banaji, 2003), implicit measurements have already been successfully applied to gain a deeper understanding of risk perceptions of technological hazards (Siegrist, Keller, & Cousin, 2006). To the best of our knowledge, we are the first to use an implicit association task in the domain of natural hazards. Measuring implicit as well as explicit responses to a warning message also provides us with a further insight into the cognitive processes underlying the decision to take a protective action as response to a warning.
In addition to the goals described above we were interested in the following questions: Are recommendations for action only useful if shown together with impact information (as found in Weyrich et al., 2018)? Do the warning elements have different effects based on the type of severe weather event? And are there individual differences in the effects of different warning elements (e.g. do meteorological parameters have a stronger effect on warning response for people with high compared to low interest in weather)?

1.2 Distribution channels

MeteoSwiss currently distributes its warnings to the public via its mobile app (MeteoSwiss app), its website (www.meteoswiss.ch) and the Natural Hazard Portal (www.natural-hazards.ch). Additionally, information about the event and the warning is shared on Twitter. In the French- and Italian-speaking regions of Switzerland, MeteSwiss also informs public service radio and television (TV) about the warning. Online and print media also often report about MeteoSwiss warnings in their articles in case of impending severe weather. For very extreme events, MeteoSwiss can initiate a so called Single Official Voice process (SOV), according to which the main public media are obliged to publish the warning. MeteoSwiss has launched this process only once so far. Additionally, MeteoSwiss sends its warnings to Meteoalarm (www.meteoalarm.org), a website of European states' national meteorological services providing weather warnings, where they can be retrieved and redistributed by other actors such as Microsoft.

MeteoSwiss distributes its warning to the authorities (the Cantons) through secured channels who themselves also have means to warn the affected population. In addition, the warnings are also sent to other federal offices as a basis for issuing other natural hazard warnings (e.g. floods, avalanches, forest fires) and for the Common Information Platform for Natural Hazards (GIN), which is used by the relevant authorities in Switzerland.

In the past, there already have been conducted surveys that involved questions on the usage of different distribution channels in the context of natural hazards in Switzerland. Some of them have been published (Dallo, Stauffacher, & Marti, 2020; Maidl, Wiederkehr, & Buchecker, 2016; Maduz, Prior, Roth, & Wolf, 2018), others were commissioned by MeteoSwiss in 2014 and the Steering Committee on Intervention in Natural Hazards (LAINAT) in 2018 but have only been used for internal purposes so far. All these studies have mainly focused on distribution channels, which the public uses to *inform* themselves about a natural hazard, and not on channels, through which the public usually *receives warnings*. This is why we wanted to address this question in our survey. Moreover, we were also interested in how many people have ever received a weather warning in their lifetime and through which distribution channels they would like to receive weather warnings in the future. The exact questions that we asked are described in chapter 2.3.

1.3 Uncertainty information and lead time

In the current warning system of MeteoSwiss, severe weather warnings are issued at a lead-time between 0-36h if the probability of occurrence exceeds 70%. This occurrence probability has not been communicated in warnings so far. For warnings with longer lead times and higher uncertainties, MeteoSwiss has been issuing so called “warning outlooks”. To get an insight into whether we should stay with this warning strategy, we wanted to know how much in advance the majority of the population wants to receive a warning knowing about the trade-off between lead-time and uncertainty (the more in the future an event, the higher usually the uncertainty of the warning).

Moreover, we aimed to get a first insight into the Swiss public’s interest in uncertainty information in the warning. There exist several reasons to communicate uncertainty information such as a probability of occurrence in a weather warning: First, it allows individuals to assess the danger themselves and thus promotes informed decision-making (Fundel et al., 2019). If information on the uncertainty of the event is not included in the warning, laypersons have to guess how likely an event really is to be expected and over- or underestimate the probability (Fleischhut et al., 2020; Joslyn & Savelli, 2010). And secondly, experimental studies have shown that uncertainty information can increase trust in the forecast and even improve decision making (Joslyn & LeClerc, 2013; LeClerc & Joslyn, 2015). At the same time, it is often argued that the general public cannot deal with and hence, is not interested in uncertainty information of a forecast or warning. From a representative population survey in the U.S. we know, however, that the U.S. population find probability information in weather forecasts useful and prefer it over deterministic information (Morss, Demuth, & Lazo, 2008). In our survey, we included one question to see whether we find a similar interest by the Swiss population for warnings.

2 Method

2.1 Overview

We collected data with the professional Swiss panel provider LINK[1]. The sample consists of 2000 randomly selected participants of the online panel from German-speaking, French-speaking and Italian-speaking Switzerland. Data was collected in February and March 2021. Respondents were

1 The LINK panel has access to a pool of participants who signed up voluntarily to conduct surveys with LINK. Depending on the duration of their membership in the pool, they often conduct surveys and therefore are familiar with questionnaires. For

primed to imagine that there are no restrictions due to COVID-19 (e.g. lockdown or shutdown). Sample characteristics are presented in Table 1. Our sample was quota by gender, age and region based on statistics of the Federal Statistical Office and thus these variables corresponds to the distribution within the Swiss population.

The study took 15 minutes and mainly consisted of two parts: 1) a factorial survey experiment to measure the effects of different warning contents on people's perception, and 2) descriptive questions on people's behavior and preferences with respect to distribution channels, uncertainty and lead time as well as control questions.

Table 1: Sociodemographic characteristics of the representative Swiss sample from the LINK online panel.

Variable	Levels	Percentage
Gender	Male	50.6 %
	Female	49.4 %
Age	15-29	19.2 %
	30-44	29.0%
	45-59	31.4%
	60-79	20.3%
Region	German-speaking	50.0%
	French-speaking	30.0%
	Italian-Speaking	20.0%
Education	Low	4.9%
	Middle	47.1%
	High	48.0%
Income	Under 6k	25.4%
	6-10k	32.2%
	Over 10k	24.3%
	Don't know	18.1%
Residence: Mountainous area	Yes	37.2%
	No	62.8%
Residence: Countryside	City	61.0%
	Agglomeration	21.6%
	Countryside	17.4%

2.2 Warning content: Factorial Survey Experiment

The goal of our experimental part was to better understand the effects of different attributes or contents of a warning message (e.g. the presence of behavioral recommendations) on people's unconscious perception of the warning and their intended response behavior.

To investigate these effects we applied a factorial survey experiment. The goal of a factorial survey experiment (or "vignette analysis") is to find out what causal effect different attributes of a description of a person, object, or situation (a so called "vignette") exert on a target variable by systematically varying these attributes in the vignette (Auspurg & Hinz, 2014). This design addresses the dilemma

conducting the survey (e.g. at the computer, smartphone, or tablet), the respondents receive credits, for which they can either receive a cash value or coupons.

of conducting true experiments that maximize internal validity but are threatened by external validity concerns versus non-experimental research that provides higher levels of external validity but is weak in explaining causal relationships (Aguinis & Bradley, 2014).

The flow chart of the experimental procedure in our online-study is displayed in Figure 2. After an instruction of the task, participants saw one of several different warning messages (how we systematically varied and assigned warning messages is explained in detail below). This warning message was followed first by an attention check, to make sure that participants really pay attention to the content of the warning. After then seeing the warning message again, participants conducted a so called implicit test to measure their spontaneous, unconscious perception of the warning. At the end of each round, participants explicitly evaluated their intention to take action in response to the warning. This procedure was repeated for four different warning messages per person.

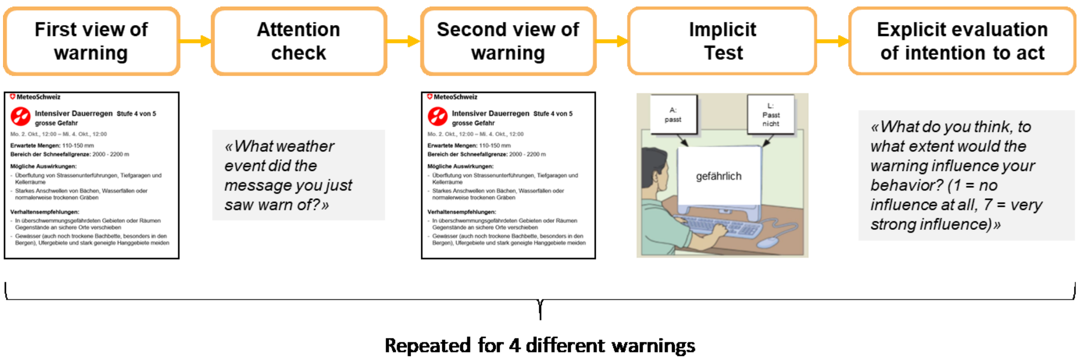


Figure 2: Flow chart of the experimental procedure in the factorial survey experiment. The procedure was repeated four times per participant for different warning messages.

2.2.1 Our vignettes: different warning messages

For our warning messages, we varied a total of six dimensions, each with two levels (see Table 2 for an overview of the dimensions and their levels). This resulted in 64 different warning messages tested in the experiment ($2^6 = 64$). Most of the dimensions in the warning messages are part of the current MeteoSwiss warnings (weather event, warning level label such as “high danger”, and meteorological parameters such as 80 km/h wind speed). The dimensions “potential impact” and “recommendations for action”, however, had to be newly created for this experiment. To this end, two sentences were chosen per dimension and weather event based on existing sentences on recommendation for action and potential impact from the Natural Hazards Portal (www.natural-hazards.ch). We based the selection of the sentences on results from a small pre-study, in which a convenience sample of 36 participants rated each sentence on their perceived usefulness. Figure 3 shows two examples of the 64 different warning messages.

In the factorial survey experiment, each respondent saw four different warning messages, following recommendations for conducting vignette studies (Atzmüller, Su, & Steiner, 2017; Aguinis & Bradley, 2014). To this goal, we grouped the 64 warning messages randomly into sixteen sets of four warnings each. The participants were randomly assigned to one of the 16 warning sets and saw all warning messages within their set in randomized order. This complies with a mixed research design of *Experimental Vignette Methodology*, where “different groups of participants receive different sets of vignettes; however, within each group, participants see the same vignettes” (Aguinis & Bradley, 2014).

With a total sample of n=2000 participants, a total of 8000 vignettes were assessed (2000 * 4 = 8000). Each individual vignette was thus rated 125 times (8000 / 64 = 125). On the one hand, this procedure guaranteed that no fatigue effects occurred for the respondent because too many vignettes have to be evaluated (depending on the length of the vignettes, it is recommended not to show more than 10 vignettes of such length). On the other hand, this procedure guaranteed that one single vignette was evaluated often enough (at least it should be evaluated 20 times, here it is evaluated 125 times).

Table 2: Overview of the different dimensions of our warning messages and their corresponding levels that were systematically varied.

	Dimension	Level 1	Level 2
1	Weather event	Storm	Intense rain
2	Warning level	displayed	Not displayed
3	Label for warning level («High danger»)	displayed	Not displayed
4	Meteorological parameters	displayed	Not displayed
5	Potential impact	displayed	Not displayed
6	Recommendations for action	displayed	Not displayed

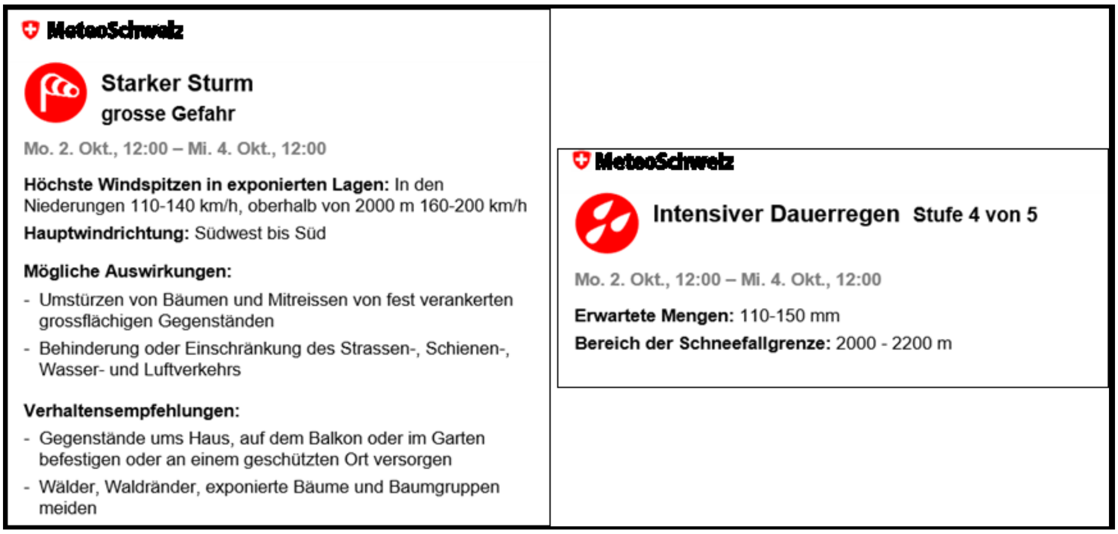


Figure 3: Two examples of the 64 different warning messages (vignettes).

2.2.2 Implicit Test

Implicit tests aim to overcome deliberate adjustment through self-report because they capture processes that operate to some extent at subconscious levels and thus beyond full introspective access. According to Siegrist et al. (2006), implicit tests are “a promising technique to provide a fuller understanding of people’s perceptions of risk”. In our study, the goal of the implicit test was to find out which perceptions of the respondents are addressed by the different elements of the warning message and how these perceptions affect the individual intention to act.

To measure implicit perceptions with the respective warning messages (vignettes), we applied the Single Association Test (SAT). The SAT is reaction time-based and measures the associations between the stimulus (the warning message) and dynamic elements (words) in the millisecond range. Participants saw the warning followed by words on a screen and had to categorize each of these words into "match" and "no match" under speeded conditions. Due to this time pressure, evaluations are more spontaneously and less controllably activated than by survey instruments, and therefore more likely to reflect intuitive and associative attitudes towards the object of evaluation. In our application of the test, the eight words that appeared successively on the screen are listed in Table 3. We chose the words based on the warning response model by Mileti & Sorensen (1990). According to this model, people's response to a warning depends on whether they have understood the warning, believe the warning and perceive the warned event as a personally relevant risk. That is why we chose to test for association with words describing perceived comprehensibility ("comprehensible", "clear"), trust ("trustworthy", "will occur"), risk perception ("dangerous", "risky") and personal relevance ("affects me", important").

The instruction was to respond quickly and without much reflection by pressing the corresponding button ("A" for 'match' or "L" for 'no match'). The attributes were presented in randomized order and remained visible until the participants pressed either of the specified keys.

We considered responses within a time span of 300 to 10,000 milliseconds for further evaluation (Greenwald et al., 2003). By following this convention, we ensured that the observations complied with what is widely acknowledged in the literature as quasi-automatic and largely implicit reactions to stimuli. Furthermore, we regarded response times that exceeded the mean plus two standard deviations as outliers and deleted them (Greenwald et al., 2003). In total, 124 outliers were excluded, which resulted in a final sample containing 7876 responses from 2000 participants (every participant evaluated four vignettes).

Table 3: Words we presented in the Single Association Test (SAT). For each concept (category), two words (attributes) were shown.

Category	Attribute 1	Attribute 2
Comprehensibility	comprehensible	clear
Trust	trustworthy	will occur
Risk	dangerous	risky
Relevance	affects me	important

2.2.3 Explicit Evaluation of the intention to act

Intention to act was measured after the implicit test by asking people to rate the following question on a scale from 1 (="no influence at all") to 7 ("very strong influence"): "What do you think, to what extent would the warning influence your behavior?". In research on risk perception in the medical domain, such question on intended behavior have been proven a good predictor for actual future behavior (e.g. Renner & Reuter 2012)

2.2.4 Analysis

In our analysis, we investigated which elements of the warning message had the strongest effect on intention to act and on implicit evaluation in the SAT. We also estimated the effects of implicit attributes on the intention to act, to get a further insight into the cognitive processes underlying warning response behavior.

We applied multilevel mixed-regression as it accounts for our nested data structure, which results from the fact that each respondent saw four vignettes and thus completed the speeded categorization task four times. The intercept-only model showed an intraclass correlation coefficient (ICC) of 57.6% which means that 57.6% percent of the variance in the dependent variable resides on level 2 (i.e. the level of respondents). Hence, we have reason to assume that multilevel analysis is an adequate estimation approach.

We calculated different models for the different independent variables *intention to act* (values between 1 and 7, fitted with a linear regression model) and *implicit perceptions* of relevance, risk, confidence, and comprehensibility in the SAT. As these implicit perceptions are each count variables with the values 0 (no association with the two attributes of a category, e.g. implicit perception of risk = 0 if no association with “dangerous” and “risky”), 1 (association with one attribute of the category) or 2 (associations with both attributes of a category), a Poisson regression model was adapted for which report the incidence rate ratio (IRR).

The dimensions of the warning message acted as dependent variables and were each coded either 0 or 1 with the expressions described in Table 2 above. We additionally added the following control variables to our models: *weather attitudes* (vulnerability, interest and disengagement, measured on a scale from 1-7)[2], *gender* (male, female), *age group* (15-29, 30-44, 45-59, 60-79), *region* (German- , French-, and Italian-speaking Switzerland), *education* (low, middle, high) and *mountain area* (yes, no).

The overall findings of these models are described in chapter 3.1. The models themselves are reported in the appendix. For all models, we report the standardized regression coefficient beta (β), the unstandardized regression coefficients b can also be found in the models in the appendix. The standardized regression coefficient allows the comparison of the different coefficients and indicates which variable has the largest and thus the strongest effect on the dependent variable.

2.3 Descriptive Part

In the descriptive part of the online survey, we were mainly interested in how well people have been reached so far by weather warnings and via which distribution channels as well as people’s preferences for warning distribution channels in the future. We also asked questions about people’s preferred timing of the warning and about their preference for uncertainty information in the warning. An overview of these questions can be found in Table 4.

Additionally, we asked several control questions such as people’s attitudes towards weather (based on Taylor, Kause, Summers, & Harrowsmith; 2019).

[2] Weather attitudes were measured according to Taylor & Kause (2019): The construct consists of three scales with two to three questions each, namely interest in weather (r (e.g., ‘‘I am interested in weather forecasts’’), perceived vulnerability (e.g. ‘‘Bad weather makes it difficult for me to get around’’), and disengagement (e.g. ‘‘I hardly ever think about the weather’’).

Table 4: Questions in the descriptive part of the survey.

<table>
<tr><th>Topic</th><th>Question</th><th>Method</th></tr>
<tr><td>Reachability</td><td>Have you ever seen, heard or read a severe weather warning?
a) Yes
b) No
c) I do not remember</td><td>Single-select</td></tr>
<tr><td>Used distribution channels</td><td>Through which channel do you usually find out about a severe weather?
Please tick all that apply.
a) Television
b) Radio
c) In the newspaper (online or print)
d) On websites
e) Weather app or warning app
f) Social media
g) Family or acquaintances
h) SMS
i) Email
j) Other

If d), e), or f) was selected, participants were additionally asked to specify the channel from a list of options. The list of apps and websites that we provided as options in the different language regions is shown in Tables A1 and A2 in the appendix.</td><td>Multi-select, randomized order</td></tr>
<tr><td>Preferred distribution channels for the future</td><td>Which channels are the most important and which channels are the least important for you personally to be warned of a severe weather in the future?
a) MeteoSwiss App (from the Federal Office of Meteorology and Climatology MeteoSwiss)
b) Meteoschweiz.ch (the website of the Federal Office of Meteorology and Climatology MeteoSwiss)
c) Naturgefahren.ch (natural hazards portal of the federal government)
d) Radio
e) TV
f) Twitter
g) Facebook
h) Instagram
i) Newspaper (online or print)
j) Alertswiss App
k) Map app (Google Maps, Swisstopo, ...)
l) Messenger app (WhatsApp, Telegram, Signal, Threema ...)
m) Video-based channel (YouTube, Vimeo, TikTok, …)
n) SMS
o) Email</td><td>Maximum Difference Scaling: The channels are juxtaposed in various combinations and the respondents select several times the channel that is most and least important to them in each case. See a screenshot of this task in Figure A1 in the appendix.</td></tr>
<tr><td>Uncertainty information</td><td>How strongly do you agree with the following statement? “I am also interested in information about the uncertainty of the forecast in a severe weather warning, such as the probability of occurrence (e.g., "The probability that a level 4 storm will actually occur is 80% (very likely)”)."</td><td>Rating scale from 1 (=”do not agree at all”) to 7 (”fully agree”)</td></tr>
<tr><td>Timing</td><td>A weather warning can be issued several days in advance. But the further in advance the forecast is made, the less accurate it is and the lower the probability that the severe weather event will actually occur.</td><td>Multi-select</td></tr>
</table>

	At what time would you like to be warned about severe weather? You can also select multiple options if you would like to receive a warning or an update of the warning at multiple times. a) 4-5 days before the severe weather occurs (usually low probability of occurrence) b) 3 days before the severe weather occurs (usually rather low probability of occurrence) c) 2 days before the severe weather occurs (usually rather high probability) d) 1 day before the severe weather occurs (usually high probability) e) On the same day the severe weather occurs (usually very high probability) f) I do not want to be warned about severe weather at all [Exclusive Answer].	
Attitudes towards weather, which was divided for analysis into the following subscales: interest in weather (items a and b), perceived vulnerability (items c and d), and disengagement (items f, g and g) similar to Taylor et al. (2019)	*The following is a general statement about your attitudes toward the weather. To what extent do you agree with the following statements?* a) I pay a lot of attention to weather forecasts b) I am interested in weather forecasts c) Weather has a great influence on my daily life d) Bad weather makes it difficult for me to get around e) I worry a lot about the weather f) Weather forecasts are not relevant for me g) I almost never think about the weather h) The weather does not have a big influence on my daily activities	Rating scale from 1 (=”do not agree at all”) to 7 (”fully agree”)

2.3.1 Analysis

We report results of the descriptive survey part mainly in descriptive terms, e.g. the percentage of respondents who have chosen a specific answer. We also checked for group differences, for example between age groups, language regions and people with low, middle or high interest in weather information.

For the maximum difference scaling question, probability scores were calculated for each channel. The probability score represent the relative preference for an item (here: distribution channel) within the evaluated item set. The scores add up to 100% to represent preference shares. Scores are based on how often an item is chosen as worst and best, and are calculated using a hierarchical Bayes estimation procedure.

3 Results

3.1 Warning content: Factorial survey experiment

3.1.1 Which elements of the warning have the strongest effect on intention to act?

As can be seen in model 1 in Table A3 the appendix, the dimensions impact and behavioral recommendation have the greatest effects on participant's reported intention to act (behavioral recommendations: $\beta = 0.10$, $p < .001$, impact: $\beta = 0.10$, $p < .001$). Then comes the warning level ($\beta = 0.04$, $p < .001$), and only then the meteorological parameters ($\beta = 0.02$, $p = .004$). The intention to adjust one's behavior due to the warning decreases for a rain warning compared to a wind warning ($\beta = -0.19$, $p < .001$). The description of the warning level has a negative effect on the intention to act, i.e. if there is no description of the warning level ("high danger"), there is a greater tendency to act. However, one should not over-interpret this effect, as the effect is close to zero ($\beta = -0.02$, $p = 0.008$).

3.1.2 Which elements of the warning have the strongest effect on implicit evaluation?

To answer this question, a Poisson model was estimated (see model 2, Table A4 in the appendix). This takes into account that the dependent variable is a count variable of either 0, 1 or 2. The Poisson model clearly shows that that behavioral recommendations and impacts have the greatest effect on the implicit perception of risk ($IRR_{recommendations} = 1.09$, $p < .001$; $IRR_{impact} = 1.09$, $p < .001$), relevance ($IRR_{recommendations} = 1.05$, $p = .004$; $IRR_{impact} = 1.05$, $p = .009$) and comprehensibility ($IRR_{recommendations} = 1.06$, $p = .001$; $IRR_{impact} = 1.04$, $p = .015$). Presenting the warning level also positively affects the implicit perception with risk, but to a smaller degree than behavioral recommendations and impacts ($IRR_{warning\_level} = 1.04$, $p = .015$). The meteorological parameters positively influence implicit perceptions with comprehensibility ($IRR_{meteo\_parameters} = 1.04$, $p = .011$). The description of the warning level, again, does not have an effect on associations with any of the implicit categories. Concerning the weather event, intense rain is perceived as less risky ($IRR_{weather\_event} = 0.85$, $p < .001$) and relevant ($IRR_{weather\_event} = 0.91$, $p < .001$) than storm, which fits well to the results on intention to act.

3.1.3 Which implicit associations trigger a behavioral response?

To test which of the implicit categories (risk, relevance, comprehensibility and trust) have the strongest influence on people's intention to act, we included the count variable of implicit perception for each of these categories to our mixed effects linear regression (model 3, Table A5 in the appendix). It shows that the implicit category relevance ("affects me", "important") has the greatest influence on the intention to act ($\beta = 0.30$, $p < .001$). Implicit associations with risk ("dangerous", "risky") also have a clear influence on the intention to act ($\beta = 0.21$, $p < .001$). Comprehensibility ("understandable", "clear") plays a smaller role ($\beta = 0.04$, $p < .001$), whereas trust ("I trust", "applies") has no influence on the intention to act ($\beta = 0.02$, $p = .087$).

3.1.3.a) Do recommendations for action need to be combined with impact information?

We did not find an interaction between impact and behavioral recommendation (model 4, Table A6 in the appendix; interaction recommendations*impact: β = -0.01, p = .209). Both dimensions have a positive effect on the intention to act independently from each other.

3.1.3.b) Is the effect of the warning content dependent on the type of weather event?

In a population survey conducted by the Dutch weather service KNMI, the majority of respondents preferred to receive an indication of impact in the case of rain rather than an indication of physical values (rainfall in mm/h); in the case of a wind warning, this was exactly the opposite (Royal Netherlands Meteorological Institute, 2020). That is why we tested for an interaction between the weather event (intense rain vs. storm) and impact as well as between the weather event and meteorological parameters. We find that although impact information has its effect independently of the weather event (model 5, Table A7 in the appendix; interaction impact*weather_event: β = -0.01, p = .523), this is not the case for meteorological parameters: for intense rain, the meteorological description has a negative effect on intention to act, for storm this effect is positive (model 6, Table A8 in the appendix; interaction meteo_parameters*weather_event: β = -0.04, p = .002).

3.1.3.c) Does the effect of the warning elements depend on individual characteristics?

The effect of meteorological parameters on intention to act is independent of people's interest in weather (model 7, table A9 in the appendix) and their education (model 10, Table A12 in the appendix). That means that for people with higher education or higher interest in weather providing meteorological parameters in a warning does not increase intention to act to a stronger degree than for people with lower education (interaction meteo_parameters*education: β = 0.03, p = .307) or lower interest in weather (interaction meteo_parameters*interest: β = -0.00, p = .878). Similarly, the effect of behavioral recommendations and impact information are independent of people's disengagement with weather information (model 8, Table A10 and model 9, Table A11; interaction recommendation*disengagement: β = 0.03, p = .128; interaction impact*disengagement: β = -0.02, p = .414).

3.1.3.d) The role of individual differences for the intention to act

When looking at the effects of our individual-specific control variables on intention to act (coefficients reported for model 1, but similar effects across all models), we see that weather attitudes are important predictors for the intention to act, especially weather interest: intention to act increases with increasing weather interest (β = 0.18, p < .001) and vulnerability (β = 0.13, p < .001) and decreases with increasing disengagement (β = -0.05, p = .004). Moreover, women tend to report higher intentions to act compared to man (β = 0.07, p < .001) and older age groups tend to be more willing to react than younger ones (β = 0.13, p < .001). Interestingly, our data also suggest that participants from the French-Speaking Switzerland report higher intentions to act compared to people from the German-speaking part (β = 0.17, p < .001).

Looking at the standardized coefficients, we see that overall the best predictor for intention to act is people's interest in weather information. It's even a more important predictor on intention to act than the presence of recommendations for actions and information about impacts.

Although our models overall explain a relatively high proportion of the variance in intention to act as measured by the conditional R^2 (e.g. 64.2 % in Model 1), most of this explained variance is attributed to the random effects and only a smaller proportion the fixed effects, as measured by the marginal R^2 (17% in Model 1). Similarly, our ICC of 0.576 (model 1) suggests that 57.6% of the variance is explained by the grouping random factor, so in our case the level of the individual. All this suggest that an intention to act is caused to a stronger degree by individual differences than differences in the weather warning.

3.2 Descriptive Part

3.2.1 Distribution

3.2.1.a) Reachability

Nearly 91% of respondent have already seen or heard a weather warning. At the same time, 9% have never seen a weather warning or do not remember (see Figure 4). This proportion is particularly high among people with a low interest in weather (18.8%) and younger age groups (12.6 %) (see Figure A2 in the appendix). It is likely that this proportion is even higher in the population, as people with language barriers and offliners were not reached by our study.

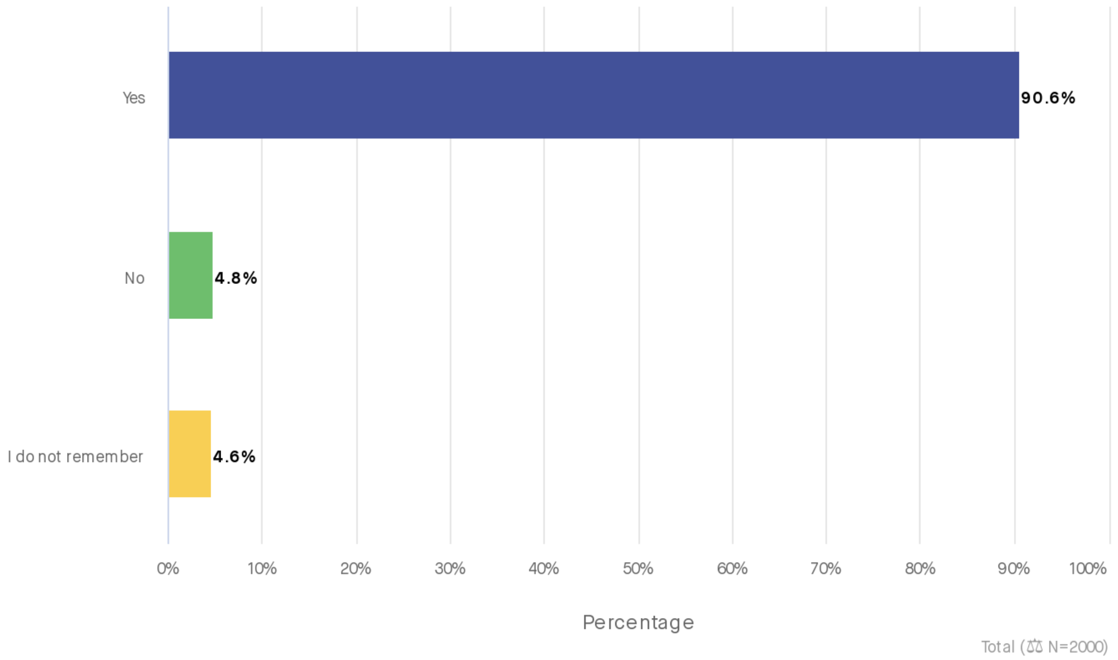


Figure 4: Answers to the question "Have you ever seen, heard or read a severe weather warning?"

3.2.1.b) Used distribution channels

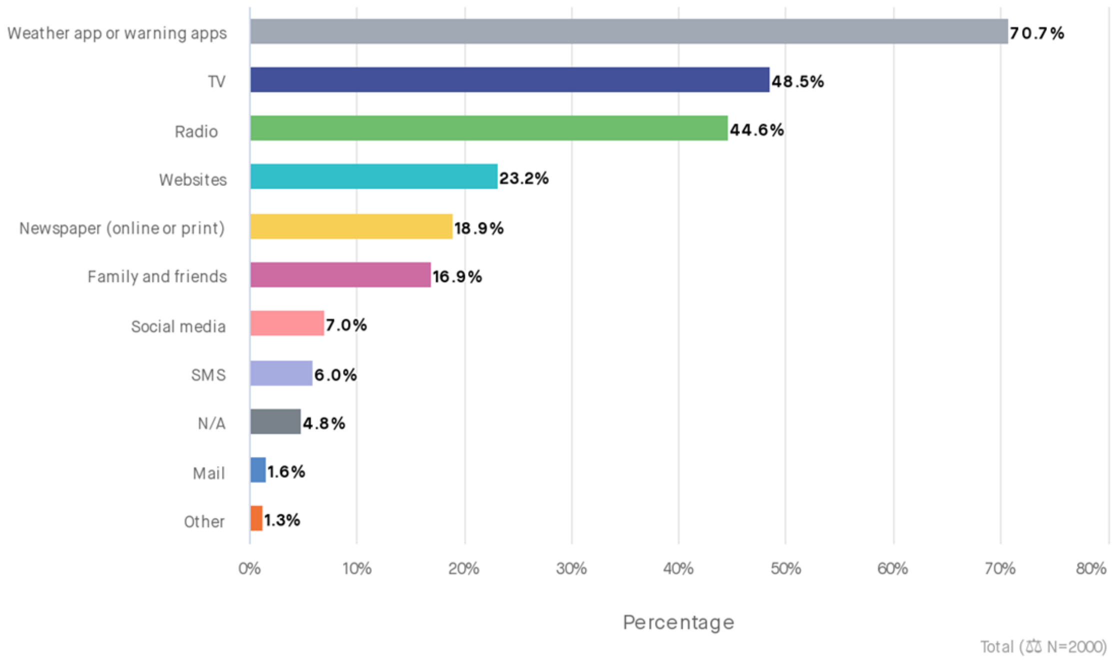
Of those, who have already seen or heard a severe weather warning, the majority usually receives the warning via a weather or warning app (70.7 %, Figure 5a). By far the most mentioned app to receive a warning is the MeteoSwiss App (71.1%), followed by the app of SRF Meteo (weather service of the public Swiss Radio and Television) (22.9%) and the Alertswiss app (warning app by the Federal Office for Civil Protection (FOCP)) (18.7%) (Figure 5 b).

The second and third most mentioned channels through which people learn about a warning are television (48.5%) and radio (44.6%), although this order is mainly influenced by age: younger people are more likely to receive the warning via family and friends than via radio, older people more often via TV than via app (see Figure A3 in the appendix). The region also plays a role in the order: in the German-speaking part of Switzerland, more people learn about a weather warning via radio than via TV, in the French- and Italian-speaking part it is the other way around (see Figure A3 in the appendix).

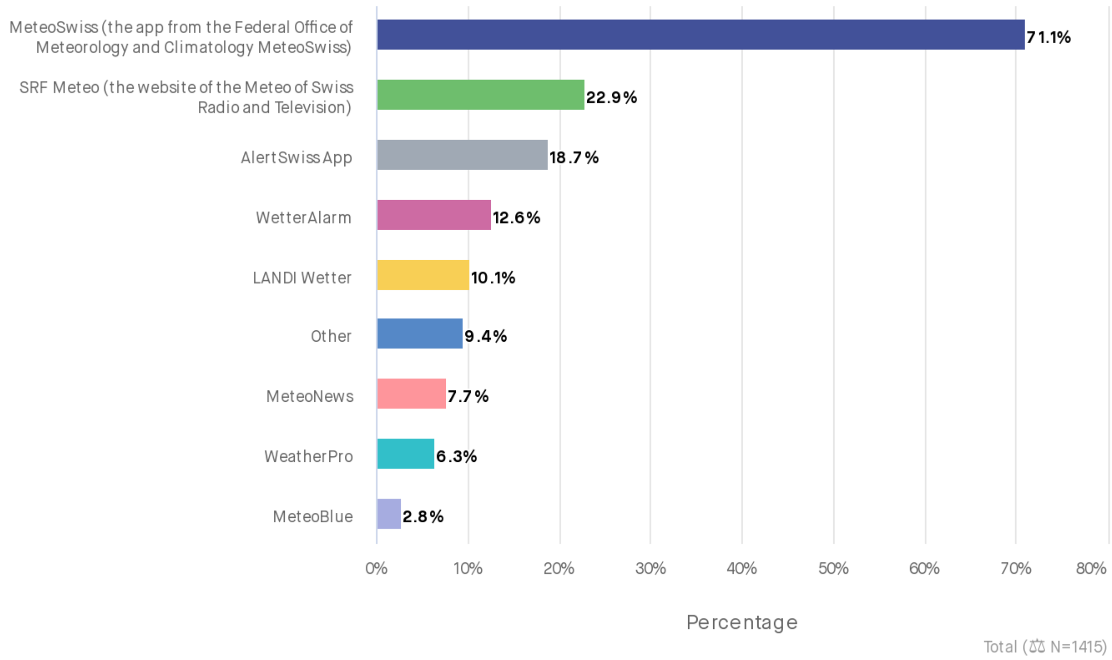
Nearly one quarter of participants (23.2 %) stated that they usually receive a warning via a website. Here, the MeteoSwiss Website is again by far the most mentioned website (72.4%, Figure 5 c). www.natural-hazards.ch, the natural hazard portal of the Swiss federal agencies with responsibility for natural hazards, is mentioned by 5.6% of respondents who usually receive a warning through a website.

So far, hardly any people receive severe weather warnings via social media (7%, Figure 5 a). This percentage is higher for younger age groups (11%) and people with a low interest in weather (9%) (See Figure A3 in the appendix). Of those who say they learn about severe weather via social media, 58.2% cite Facebook and only 5.1% cite Twitter (see Figure A4 in the appendix).

a) “Through which channel do you usually learn about a severe weather event?”



b) Distribution Channel: App



c) Distribution Channel: Website

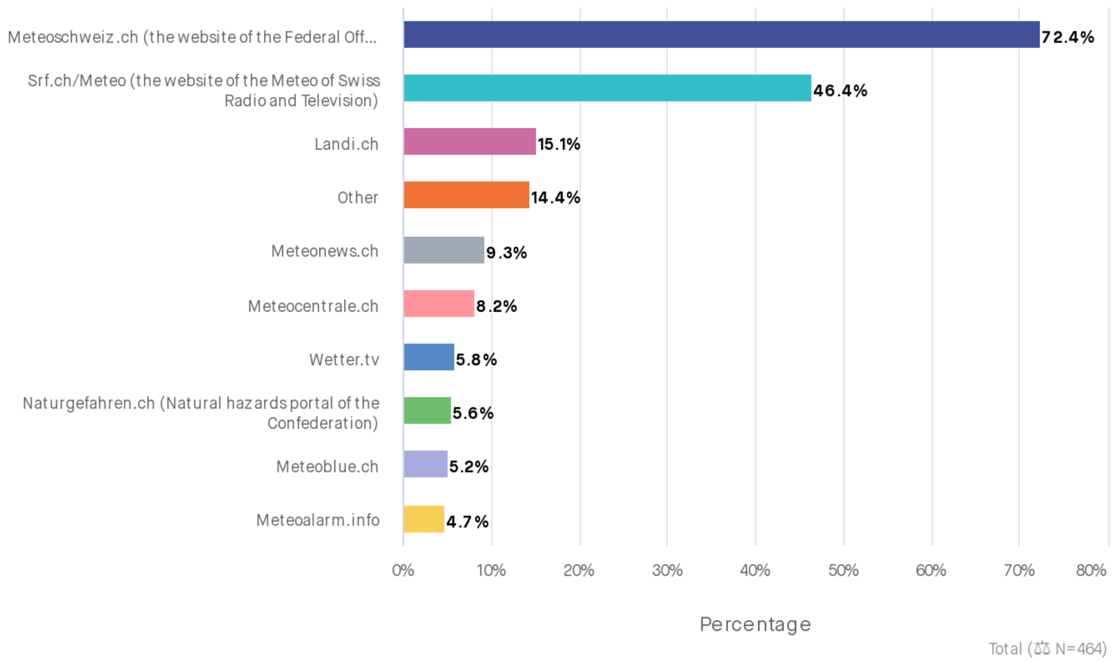


Figure 5 a) – c): Distribution channels through which respondents usually receive a weather warning ("Through which channel do you usually learn about severe weather event?" – multiple choice). Questions in graphic b) and c) were only answered by participants who have reported to usually receive a warning via an app or website, respectively.

3.2.1.c) Preferred channels for the future

When asking people about their preferred distribution channels for severe weather warnings in the future, the picture looks relatively similar than the results on current distribution channels. Of those channels that we provided in the choice set (see Table 4 in chapter 2.3), the MeteoSwiss app is considered the first (probability score = 16.6 %) and the MeteoSwiss website the second most important channel (probability score = 15.3 %) for being warned of severe weather in the future (see Figure 6) - regardless of age, region and interest in weather information (for group differences, see figures A5 in the appendix).

The Alertswiss app is also perceived as an important channel for severe weather warnings (probability score = 11.4 %), especially in the French- and Italian-speaking part.

Radio (11.6 %) and TV (9.9 %) are also considered one of the five most important channels in the future, although there is again an age effect: radio and TV become less important with decreasing age, but they are still among the five most important channels even among younger people.

SMS (7.4 %) is considered more important by respondents than social media (e.g. Facebook: 0.8%) and newspaper (5.3 %) for being warned of a storm in the future - regardless of age.

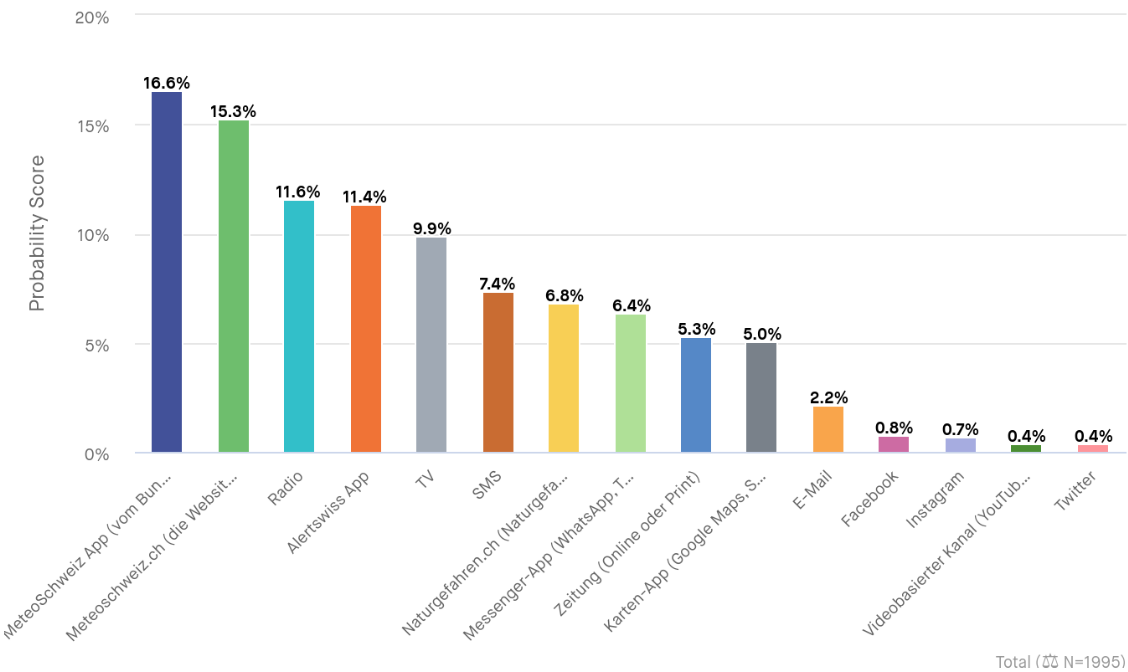


Figure 6: Results of the maximum difference scaling question about preferred warning channels for the future. The Probability Score represents the relative preference for an item within the evaluated item set. The scores add up to 100% to represent preference shares. Scores are based on how often an item is chosen as worst and best, and are calculated using a hierarchical Bayes estimation procedure.

3.2.2 Uncertainty and lead time

3.2.2.a) Preference for uncertainty information

In our survey, 83.9% of respondent agreed to the statement that they are interested in uncertainty information such as the probability of occurrence in a warning (rating 5-7, see Figure 7). Although interest in uncertainty information decreases with decreasing education level und decreasing weather interest, it is still at 75.5% for the lowest education group and at 76% for the lowest weather interest group (see Figure A6 in the appendix).

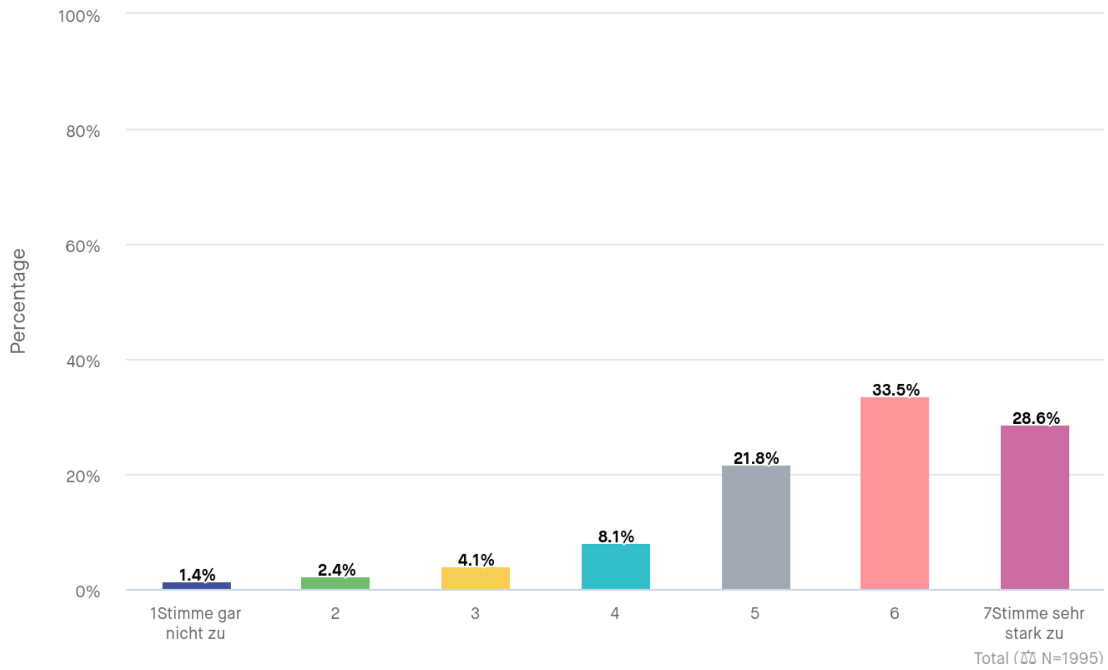


Figure 7: Answers to the question "How strongly do you agree with the following statement? "I am also interested in information about the uncertainty of the forecast in a severe weather warning, such as the probability of occurrence (e.g., "The probability that a level 4 storm will actually occur is 80% (very likely)")."

3.2.2.b) Preferred timing

The majority (56.3%) wants to be warned 1-2 days before the event at the earliest, while smaller proportions want to be warned 3-5 days in advance (23.6%) (Figure 8). A third of participants (30.6%) chose "on the same day that the severe weather occurs". However, these are mainly people who have chosen more than one time point (66.6%). For those who have only chosen one time point (56% of respondents have only chosen one time point for this question), only 4% want to be warned on the same day, the majority wants to be warned again 1-2 days before the event (80%). So people who want to receive a warning on the same day as the event are mainly people who would like to receive an update.

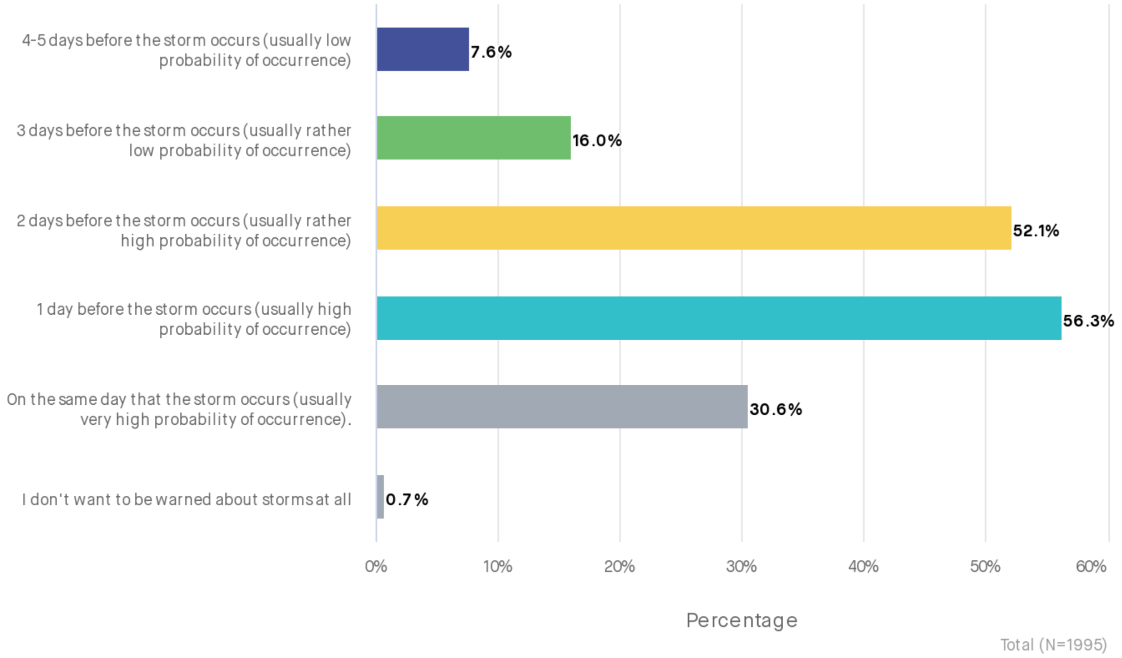


Figure 8: Answers to the question "A weather warning can be issued several days in advance. But the further in advance the forecast is made, the less accurate it is and the lower the probability that the severe weather event will actually occur. At what time would you like to be warned about severe weather?"

4 Discussion

4.1 Warning content

4.1.1 Which elements of the warning have the strongest effect on implicit evaluation and intention to act?

Our results from the factorial survey experiment have shown that including general recommendations for action and information about potential impacts into a warning can successfully trigger people's implicit perception of risk and relevance and, hence, foster the warnings character of a "wake-up call". These two information elements also increase people's intention to take protective action. The effect of behavioral recommendations and impact is stronger than the one of meteorological parameters which suggests that information about behavioral advice and impacts should be placed more prominently in a warning message than meteorological parameters such as wind speed in km/h.

Our findings are supported by other social science studies. In a representative study in Germany (Schulze & Voss, 2022), for example, participants were asked to rank different text modules of a warning in a preferred order. General recommendations for action and information on possible impacts were placed on the third and forth position in most cases, only after the location and time period of the storm and well ahead of meteorological values such as wind speed. Similarly, in a study by Weyrich et al. (2018), behavioral recommendations and impact information both increase warning perception and intended behavior. Our results also contribute to the ongoing discussion on whether impact-based warnings increase behavioral response (Golding, 2022): First, our results provide a further piece of evidence that impact messaging can increase intention to act. And second, they have shown that impact messaging can positively influence whether a warning is spontaneously perceived as relevant – a prerequisite to act on a warning. All of this does not mean that meteorological parameters should be discarded in warnings to the public. They have still shown to slightly increase implicit perceptions of comprehensability and people's intention to act and are important pieces of information in weather warnings.

Other warning elements that we tested for in our study were the warning level ("warning level 4") and the description of the warning level ("high danger"). Presenting the warning level in the warning had a slight positive effect on implicit perception and action intention. Even if this effect was not very big, providing a warning level is very important to help people in making a judgement about the risk. Research from risk communication in the medical domain, for example, shows that evaluative categories can result in better judgements and recall of information (Peters, et al., 2009). Providing a reference class to the warning level, such as "level 4 of 5", might further increase understanding of the warning. Specifying the description of the warning level ("high danger"), however, seems to have no effect and if so, a slightly negative effect on the intention to act and implicit association. In our study, we only tested for one warning level (level 4, "high danger"). It is possibel that the usefulness of a general verbal label such as "high danger" increases in contexts of varying warning levels, but this is due to further testing. Promising alternatives to labels such as "moderate danger" or "high danger" could be actionable statement such as "stay informed" or "act now".

4.1.2 Which implicit associations trigger a behavioral response?

In the SAT, we tested for people's implicit associations with the categories of risk, relevance, comprehensibility and trust. We also estimated to what extend implicit associations with these categories influence people's intention to take action. The results have shown that especially associations with risk and relevance increase action intention, whereas relevance had the strongest effect. For the designing of warning messages that means that particular attention should be paid to the fact that the warning should be associated with perceptions of risk and personal relevance in order to lead people to respond to it. Mileti & Sorensen (1990) describe this aspect quite well: *«People think of warnings in personal terms - that is, in terms of the implications of the risk for themselves, their families, or their group. If people do not feel that they are the targets of the warning (even though it may be understood and believed), they may well ignore it"*. One way to increase perceived personal relevance could be to explicitly state in the warning who might be especially affected by the severe weather event (e.g. "people traveling on Friday evening"). Another way, at least for weather app users, could be to expand options for personalizing push-notifications for warnings. To what extend these ideas would be feasible and effective is open to further investigations.

4.1.3 Do recommendations for action need to be combined with impact information?

In their survey experiment on impact-based warnings and behavioral recommendations for severe weather, Weyrich et al. (2018) indicate that the positive effects of behavioral recommendations and impact information on warning response depend on each other and that these two information elements need hence be presented together in a warning. We explicitly tested for an interaction between behavioral recommendations and intention to act in our analysis, but did not find a significant effect. Both elements had a similar positive effect on implicit perception and warning response, independent of each other. Our results therefore suggest that it would still be effective to only include either behavioral advice or impact statements in case a warning had to be very short. Still, we recommend that both pieces of information should be present in a warning, together with meteorological parameters on the magnitude of the hazard (which had a smaller but also a positive effect on warning response in our study). This will help people to get a fuller understanding of the risk at hand.

4.1.4 Is the effect of the warning content dependent on the type of weather event?

How a warning is perceived seems to strongly depend on the type of the severe weather event. In our survey experiment, warnings about intense rain were spontaneously perceived less risky and led to a decreased intention to act than storm warnings. The type of the weather event had an even stronger effect on intention to act than behavioral recommendations or impact information. Also, the effect of the meteorological parameters depended on the severe weather event: In the case of storm, presenting the wind speed in km/h increased intention to act. In the case of continuous rainfall, presenting the amount of rain in mm reduced the intention to act. A potential explanation could be that people might have a better understanding and mental representation of wind speed in km/h than of amount of rain in mm. General recommendations for action and impacts, however, seem to increase warning response independent of the weather event according to our data. This highlights again the relevance of including advice and impacts more prominently in the warning than meteorological parameters.

4.1.5 The role of individual characteristics

In our analysis we also tested whether the effect of different warning elements depends on individual differences such as attitudes towards weather or education. We hypothesized, for example, that for people with higher interest in weather information and for people with higher education meteorological parameters would have a stronger effect on intention to act than for people low in weather interest or education. However, our results indicate that effect of meteorological parameters on intention to act is independent of people’s interest in weather and their education. Similarly, the effect of general recommendations for action and impact information was independent of people’s disengagement with weather information. This suggests that for most people, no matter whether engaged and interested in weather or not, it makes sense to communicate recommendation for action and potential impacts more prominently in a warning than meteorological parameters.

We still found individual differences in people’s reported intention to act: Weather attitudes have shown to be very important individual factors predicting the intention to act, especially people’s interest in weather information. Similarly, Taylor et al. (2019) have found in their post-event survey with the U.K. public that those with a greater general interest in weather were more likely to report having undertaken a protective response.

Moreover, women and older age groups have reported to be more willing to react than their comparison groups. This is in line with findings on response behavior to heat and hurricane warnings (Lazo et al., 2015; Kalkstein & Sheridan, 2007; Morss, et al., 2016). We also found that participants from the French-Speaking Switzerland reported higher intentions to act compared to people from the German-speaking part – an effect for which we currently have no conclusive explanation.

In addition to these effect of our control variables, our models have shown that a relatively big part of the explained variance can be attributed to variation between individuals. All this underlines the fact that weather service can only influence protective behavior to a certain degree with their warnings. Much of what determines whether people protect themselves against severe weather depends on individual factors. These factors can be, for example, environmental attributes (e.g. social cues), social attributes (e.g. activity), psychological attributes (e.g. stress), or physiological attributes (e.g. disabilities) (Mileti & Sorensen, 1990). Large-scale information campaigns about high-risk weather events and about the most effective protective measures might be a promising complementary approach to foster people's severe weather competencies, in addition to improving warning content, timing and distribution.

4.2 Distribution

The results from the survey questions indicate that MeteoSwiss is and will be the most important distributor for weather warnings in Switzerland. The MeteoSwiss app was the most stated channel through which people usually receive warnings and the MeteoSwiss app and website were chosen most often as important distribution channels to receive warnings in the future.

At the same time, many people still receive weather warning via TV and radio and perceive them as important channels for warnings in the future. One reason why radio is still considered one of the most important distribution channels to distribute warnings in the future might be that it is explicitly mentioned as one of the information channels for emergency cases as for example by the Swiss Federal Office for Civil Protection (FOCP) (https://www.alert.swiss/en/precaution/respond-correctly-when-in-danger.html). MeteoSwiss is currently only present with its warnings in TV and radio in the Italian- and French-speaking part of Switzerland but not in the German-speaking part. Here, SRF Meteo provides the weather information on television and radio – a weather service that is often confused by the general public with MeteoSwiss. For very extreme weather warnings (only for warning levels 4 or 5), however, MeteoSwiss currently still has the option to distribute its warnings according to a "single official voice" (SOV) process. In that case, the main media, including TV and radio, are subject to the duty to publish the warning. It has been observed within the recent years, however, that media pick up information about the warning very quickly through social media. This possibility did not yet exist when SOV was introduced. SOV activation is therefore moving further into the background and would probably only be used in rare cases (very short-term and very extreme events). In which way this SOV process will still be pursued in the future, is an open question within the Swiss Steering Committee on Intervention in Natural Hazards (LAINAT).

Although social media has shown to not be a primary channel for the population to receive warnings, it is an additional possibility to spread information about warnings and to reach people with little interest in weather, low education and younger people. It is also a very important channel for multipliers (e.g. media representatives take over information about warnings from Twitter).

Interestingly, SMS has been valued partly as an important channel to distribute warnings, although most people rarely use SMS anymore as a means of communication. This is in line with increasing discussions and application of cell broadcast in the international warning context. With Cell Broadcast, warnings are sent to all cell phones within a radio cell as text messages and the messages appear automatically on all phones. In Switzerland, the usage of cell broadcast is currently discussed by the FOCP (https://www.admin.ch/gov/de/start/dokumentation/medienmitteilungen.msg-id-85847.html).

According to our data, around a tenth of the population has never received a warning or doesn't remember. Especially younger age groups and people with low interest in weather have shown to be difficult to reach. When we also consider offliners, people with language barriers and tourists – groups that were not included in our study - the proportion of people not reached by a warning might even be higher. One promising way to increase reach of warnings might be to make it very easy for people to share the information in the warning, e.g. by including sharing buttons into distribution channels and by creating appealing information formats, e.g. short videos or visually attractive infographics. Especially for younger age groups and people low in weather interest our data suggests that the social network is an important channel to receive warnings. Another important factor is the role of multipliers and redistributors who further distribute our warnings such as media, Google Public Alerts or Microsoft. Here, the usage of the Common Alerting Protocol (CAP) plays an important role, an internationally widely used xml-based standardized format for exchanging public warnings (OASIS, 2010). For Switzerland there is currently the attempt by the LAINAT to create a CAP Standard for Switzerland ("CAP Suisse") and for a provision to an API (pull) interface for further processing for third parties, which would facilitate the exchange of warnings and their presentation in different contexts. Moreover, it is important to make the warning information accessible for all, also for people with language barriers. MeteoSwiss warnings are already available in five languages (German, French, Italian, English and Romansh). Considerations have been started as to how relevant warning information can also be available in easy language and sign language. Finally, information campaigns especially tailored for high-risk groups might increase awareness about weather risks.

4.3 Uncertainty and lead time

4.3.1 Preferred lead time

According to results from our question on preferred lead time, the majority wants to be warned 1-2 days before the event at the earliest, while smaller proportions want to be warned 3-5 days before and receive an update on the day of the event.

However, when asked about desired lead time, it is difficult to separate preferred lead time from preferred uncertainty level. That is, based on our results, it is not possible to answer unequivocally whether the majority would want to be warned earlier than 2 days in advance in the case of good predictability.

It is also not clear what the respondents understood by "receiving a warning": Being actively "pushed" with a warning or having the warning available on demand. For example, one could imagine to issue warnings and push them only after a specific probability level has been reached while at the same time providing information about potentially dangerous events with lower probabilities at a longer lead time but without actively pushing this information. With this method, people who want to be informed about what could come more in advanced even if it is still uncertain can actively retrieve this information. Whereas people only interested in being warned when the event gets closer and more certain will only receive a warning when a specific probability threshold has been reached.

4.3.2 Interest in uncertainty information

Our study has shown that a clear majority of respondents is interested in uncertainty information such as the probability of occurrence in a weather warning - even people with lower education levels and low interest in weather information. A representative sample of the German population provided very a very similar result. In their study, Schulze & Voss (2022) asked nearly the same question on uncertainty information as we did, with the only difference, that the probability provided in the question was 60% instead of 80%. Here, 76% agreed with the statement, so slightly less than the 84% in our study. The authors also found in their study that the assessment of uncertainty information varies depending on the level of uncertainty: Whereas a 60% likelihood of occurrence of a violent storm was perceived as threatening, useful, and motivating protective behavior, a probability of 20% resulted in significant lower threat perception, perceived usefulness and decreased intention to act. Whether people perceive uncertainty information as useful therefore seems to be influenced by the height of the uncertainty. Of course, this does not implicate that only relatively high probabilities and not low probabilities should be communicated. It rather stresses the importance of communicating probabilities in a comprehensible way and providing this information together with further explanation.

One way to communicate small probabilities in a comprehensive way might be to state the probability not only as an absolute risk, but also as a relative probability to the baseline risk, e.g. "Wind speeds above > 140km/h are 5 times more likely in this period than usual for this time of year (probability for a "normal" day at this time of year: 1%, probability for tomorrow: 5%)" (Fundel et al., 2019). Other recommendations for communicating uncertainty information include, besides others, reporting verbal uncertainty labels together with numbers (e.g. "80% (very likely")) (Budescu, Por, & Broomell, 2011; Budescu, Por, Broomell, & Smithson, 2014) providing clear reference classes for probabilities (e.g. "80% (very likely), which means that in 80 out of 100 forecasts like this there will be wind speeds above 140km/h in given time period and region") (Gigerenzer, Hertwig, van den Broek, Fasolo, & Katsikopoulos, 2005) and providing graphical support wherever possible (Spiegelhalter, Pearson, & Short, 2011).

Challenges in providing uncertainty information in form of probabilities in a warning lie, however, not only on the communication side but also within the production of the warning. A concrete probability should only be communicated if the probability of the severe weather event occurring in the forecasted area and time can be reliably estimated and clearly defined. Alternatives to providing a probability of occurrence in a warning would be to verbally describe the underlying uncertainties with respect to the strength of the event, its timing and location.

Abbreviations

CAP	Common Alerting Protocol, internationally widely used xml-based standardized format for exchanging public warnings.
FOCP	Federal Office for Civil Protection.
ICC	Inter Class Correlation.
IRR	Incidence Rate Ratio.
LAINAT	Swiss Steering Committee on Intervention in Natural Hazards which consists of the Federal Office for the Environment (FOEN), the Federal Office of Meteorology and Climatology MeteoSwiss, the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) with the Institute for Snow and Avalanche Research (SLF), the Swiss Seismological Service (SED) and the Federal Office of Topography swisstopo.
SAT	Single Association Test. Implicit measure that was applied in the study.
SOV	Single Official Voice, warning distribution process according to which all public media are obliged to publish the warning.
SRF Meteo	Weather service of the Swiss Radio and Television.
TV	Television.
WMO	World Meteorological Organization.

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Appendix

Method

Selection options for distribution channels app and website

Table A2: Options that were shown after the question «Through which app do you usually receive weather warnings?”. Answered partly differed between the different Swiss language regions as different apps are present or popular in these regions.

	Apps German-Speaking Switzerland	Apps French-Speaking Switzerland	Apps Italian-Speaking Switzerland
a)	MeteoSwiss (die App vom Bundesamt für Meteorologie und Klimatologie MeteoSchweiz)	MeteoSwiss (l'application de l'office fédéral de météorologie et de climatologie MétéoSuisse)	MeteoSwiss (App dell'ufficio federale di meteorologia e climatologia MeteoSvizzera)
b)	SRF Meteo (die App vom Meteo des Schweizer Radio und Fernsehens)		IlMeteo
c)	LANDI Wetter	LANDI Météo	3B Meteo
d)	WeatherPro	WeatherPro	WeatherPro
e)	Alertswiss	Alertswiss	Alertswiss
f)	MeteoNews	MeteoNews	MeteoNews
g)	WetterAlarm	WetterAlarm (Alarme-Météo)	WetterAlarm (Allarme Meteo)
h)	Wetter für die Schweiz	Météo pour la Suisse	Meteo per la Svizzera
i)	Andere :	Autres:	Altri:

Table A2: Options that were shown after the question «Through which website do you usually receive weather warnings?”. Answered partly differed between the different Swiss language regions as different apps are present or popular in these regions.

	Websites German-Speaking Switzerland	Websites French-Speaking Switzerland	Websites Italian-Speaking Switzerland
a)	Meteoschweiz.ch (die Website vom Bundesamt für Meteorologie und Klimatologie MeteoSchweiz)	Meteosuisse.ch (le site web de l'office fédéral de météorologie et de climatologie MétéoSuisse)	Meteosvizzera.ch (sito web dell'ufficio federale di meteorologia e climatologia MeteoSvizzera)
b)	Naturgefahren.ch (Naturgefahrenportal des Bundes)	Dangers-naturels.ch (portail des dangers naturels de la Confédération)	Pericoli-naturali.ch (portale sui pericoli naturali della Confederazione)
c)	Meteoalarm.info	Meteoalarm.info	Meteoalarm.info
d)	Srf.ch/Meteo (die Website vom Meteo des Schweizer Radio und Fernsehens)	Rts.ch/meteo (le site web du Météo de la Radio Télévision Suisse)	Rsi.ch/meteo (sito web del Meteo della Radiotelevisione svizzera)
e)	Meteonews.ch	Meteonews.ch	Meteonews.ch
f)	Meteocentrale.ch	Meteocentrale.ch	Meteocentrale.ch
g)	Landi.ch	Landi.ch	Meteoblue.ch
h)	Meteoblue.ch	Meteoblue.ch	3bmeteo.com
i)	Wetter.tv	Meteo.fr	Meteo.it
j)	Andere:	Autres :	Altri:

Maximum Difference Scaling

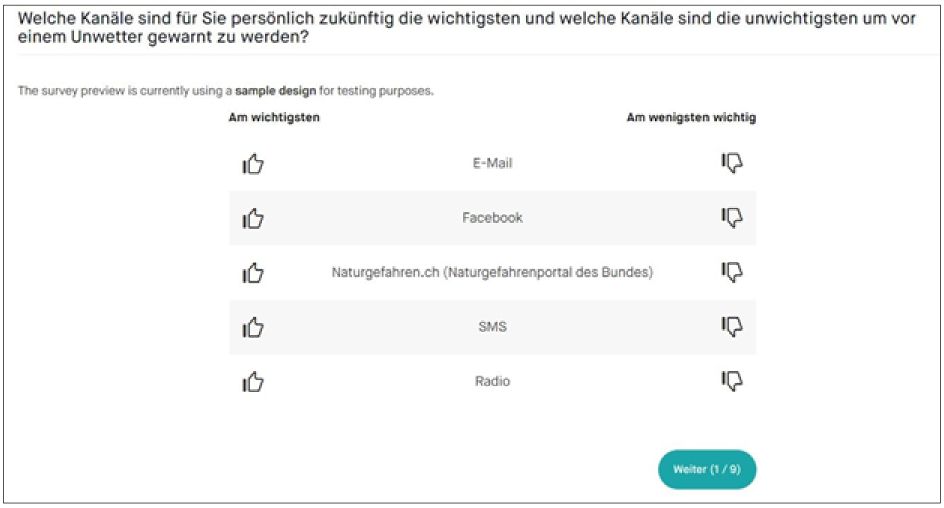


Figure A2: Screenshot of the Maximum Difference Scaling question: The channels are juxtaposed in various combinations and the respondents select the most and least important channel for them several times.

Results

Regression models

Table A3: Model 1: Mixed effects regression analysis on the effect of warning content on intention to act. * p<0.05 ** p<0.01 *** p<0.001

	Model 1 Dependent variable: intention to act		
	Coefficient (standard error)	***Standardized Coefficient***	***p***
Intercept	2.79 *** (0.18)	-0.07 (0.03)	<0.001
Warning content (dimensions)			
Weather event (0 = storm, 1 = intense rain)	-0.60 *** (0.02)	-0.19 (0.01)	<0.001
Warning level	0.14 *** (0.03)	0.04 (0.01)	<0.001
Description of warning level	-0.06 ** (0.02)	-0.02 (0.01)	0.008
Meteorological parameters	0.07 ** (0.02)	0.02 (0.01)	0.004
Impact	0.32 *** (0.02)	0.10 (0.01)	<0.001
Behavioral recommendations	0.31 *** (0.02)	0.10 (0.01)	<0.001
Control variables			
Vulnerability	0.33 *** (0.05)	0.13 (0.02)	<0.001
Interest	0.35 *** (0.04)	0.18 (0.02)	<0.001
Disengagement	-0.14 ** (0.05)	-0.05 (0.02)	0.004
Gender (0 = male, 1 = female)	0.22 *** (0.05)	0.07 (0.02)	<0.001
Age groups (Reference: 15-29)	0.21 *** (0.03)	0.13 (0.02)	<0.001
Region: French (Reference: German-)	0.27 *** (0.06)	0.17 (0.04)	<0.001
Region: Italian (Reference: German)	0.16 (0.09)	0.10 (0.06)	0.074
Education (Reference: low education)	-0.01 (0.04)	-0.00 (0.02)	0.885
Mountainous area (0 = no, 1 = yes)	-0.11 (0.07)	-0.03 (0.02)	0.106
Random Effects			
σ^2	0.93		
$\tau_{00\ \text{Participant}}$	1.22		
ICC	0.57		
$N_{\text{Participant}}$	1996		
Observations	7984		
Marginal R^2 / Conditional R^2	0.170 / 0.642		

Table A4: Model 2: Poisson regression analysis on the effect of warning content on implicit perceptions of the different categories. * p<0.05 ** p<0.01 *** p<0.001

	Model 2 Dependent variable: implicit perception							
	Risk		***Relevance***		***Trust***		***Comprehensibility***	
	Incidence Rate Ratios	*std. Beta*	*Incidence Rate Ratios*	*std. Beta*	*Incidence Rate Ratios*	*std. Beta*	*Incidence Rate Ratios*	*std. Beta*
Intercept	1.50 *** (0.04)	1.53 (0.01)	1.59 *** (0.04)	1.61 (0.01)	1.65 *** (0.04)	1.72 (0.01)	1.58 *** (0.04)	1.71 (0.01)
Warning content (dimensions)								
Weather event (0 = storm, 1 = intense rain)	0.85 *** (0.02)	0.92 (0.01)	0.91 *** (0.02)	0.95 (0.01)	0.99 (0.02)	0.99 (0.01)	0.99 (0.02)	0.99 (0.01)
Warning level	1.04 * (0.02)	1.02 (0.01)	1.03 (0.02)	1.02 (0.01)	1.02 (0.02)	1.01 (0.01)	1.02 (0.02)	1.01 (0.01)
Description of warning level	0.97 (0.02)	0.99 (0.01)	0.99 (0.02)	0.99 (0.01)	1.00 (0.02)	1.00 (0.01)	1.01 (0.02)	1.01 (0.01)
Meteorological parameters	1.01 (0.02)	1.00 (0.01)	1.00 (0.02)	1.00 (0.01)	1.03 (0.02)	1.01 (0.01)	1.04 * (0.02)	1.02 (0.01)
Impact	1.09 *** (0.02)	1.04 (0.01)	1.05 ** (0.02)	1.02 (0.01)	1.02 (0.02)	1.01 (0.01)	1.04 * (0.02)	1.02 (0.01)
Behavioral recommendations	1.09 *** (0.02)	1.04 (0.01)	1.05 ** (0.02)	1.03 (0.01)	1.04 * (0.02)	1.02 (0.01)	1.06 *** (0.02)	1.03 (0.01)
Observations	7984		7984		7984		7984	
R2 Nagelkerke	0.035		0.018		0.005		0.011	

Table A5: Model 3: Mixed effects regression analysis on the effect of implicit perceptions of on intention to act.

	Model 3 Dependent variable: intention to act		
	Coefficient (standard error)	***Standardized Coefficient***	***p***
Intercept	0.91 *** (0.18)	-0.04 (0.02)	<0.001
Implicit perceptions			
Trust	0.05 (0.03)	0.02 (0.01)	0.087
Risk	0.44 *** (0.02)	0.21 (0.01)	<0.001
Relevance	0.74 *** (0.03)	0.30 (0.01)	<0.001
Comprehensibility	0.09 *** (0.03)	0.04 (0.01)	<0.001
Control variables			
Vulnerability	0.26 *** (0.04)	0.10 (0.02)	<0.001
Interest	0.27 *** (0.03)	0.14 (0.02)	<0.001
Disengagement	-0.05 (0.04)	-0.02 (0.02)	0.243
Gender (0 = male, 1 = female)	0.22 *** (0.05)	0.07 (0.02)	<0.001
Age groups (Reference: 15-29)	0.21 *** (0.03)	0.14 (0.02)	<0.001
Region: French-speaking (Reference: German-speaking)	0.15 * (0.06)	0.09 (0.04)	0.012
Region: Italian-speaking (Reference: German-speaking)	0.11 (0.08)	0.07 (0.05)	0.200
Education (Reference: low education)	0.00 (0.04)	0.00 (0.02)	0.964
Mountainous area (0 = no, 1 = yes)	-0.07 (0.06)	-0.02 (0.02)	0.272
Random Effects			
σ^2	0.78		
$\tau_{00\ Participant}$	1.04		
ICC	0.57		
$N_{Participant}$	1996		
Observations	7984		
Marginal R^2 / Conditional R^2	0.318 / 0.707		

Table A6: Model 4: Mixed effects regression analysis testing for the interaction effect between impact and behavioral recommendations on intention to act. * p<0.05 ** p<0.01 *** p<0.001

	Model 4 Dependent variable: intention to act		
	Coefficient (standard error)	***Standardized Coefficient***	***p***
Intercept	2.79 *** (0.18)	-0.07 (0.03)	<0.001
Warning content (dimensions)			
Weather event (0 = storm, 1 = intense rain)	1.04 *** (0.18)	-0.05 (0.02)	<0.001
Warning level	-0.38 *** (0.02)	-0.12 (0.01)	<0.001
Description of warning level	0.07 ** (0.02)	0.02 (0.01)	0.083
Meteorological parameters	-0.04 (0.02)	-0.01 (0.01)	0.042
Impact	0.04 * (0.02)	0.01 (0.01)	<0.001
Behavioral recommendations	0.23 *** (0.03)	0.07 (0.01)	<0.001
Impact* Behavioral recommendations	-0.05 (0.04)	-0.01 (0.01)	0.209
Implicit perceptions			
Trust	0.06 * (0.03)	0.02 (0.01)	0.025
Risk	0.35 *** (0.02)	0.16 (0.01)	<0.001
Relevance	0.68 *** (0.02)	0.27 (0.01)	<0.001
Comprehensibility	0.09 ** (0.03)	0.03 (0.01)	0.001
Control variables			
Vulnerability	0.27 *** (0.04)	0.11 (0.02)	<0.001
Interest	0.28 *** (0.03)	0.15 (0.02)	<0.001
Disengagement	-0.06 (0.04)	-0.02 (0.02)	0.196
Gender (0 = male, 1 = female)	0.22 *** (0.05)	0.07 (0.02)	<0.001
Age groups (Reference: 15-29)	0.21 *** (0.03)	0.14 (0.02)	<0.001
Region: French (Reference: German)	0.16 ** (0.06)	0.10 (0.04)	0.006
Region: Italian (Reference: German)	0.12 (0.08)	0.08 (0.05)	0.133
Education (Reference: low education)	-0.00 (0.04)	-0.00 (0.02)	0.982
Mountainous area (0 = no, 1 = yes)	-0.08 (0.06)	-0.02 (0.02)	0.200
Random Effects			
σ^2	0.73		
$\tau_{00\ Participant}$	1.04		
ICC	0.59		
$N_{Participant}$	1996		
Observations	7984		
Marginal R^2 / Conditional R^2	0.323 / 0.722		

Table A7: Model 5: Mixed effects regression analysis testing for the interaction effect between impact and weather event on intention to act. * p<0.05 ** p<0.01 *** p<0.001

	Model 5 Dependent variable: intention to act		
	Coefficient (standard error)	***Standardized Coefficient***	***p***
Intercept	1.04 *** (0.18)	-0.05 (0.02)	<0.001
Warning content (dimensions)			
Weather event (0 = storm, 1 = intense rain)	-0.37 *** (0.03)	-0.12 (0.01)	<0.001
Warning level	0.07 ** (0.02)	0.02 (0.01)	<0.001
Description of warning level	-0.03 (0.02)	-0.01 (0.01)	0.135
Meteorological parameters	0.05 * (0.02)	0.01 (0.01)	0.038
Impact	0.22 *** (0.03)	0.07 (0.01)	<0.001
Behavioral recommendations	0.18 *** (0.02)	0.06 (0.01)	<0.001
Impact* weather event	-0.03 (0.04)	-0.01 (0.01)	0.523
Implicit perceptions			
Trust	0.06 * (0.03)	0.02 (0.01)	0.026
Risk	0.35 *** (0.02)	0.17 (0.01)	<0.001
Relevance	0.68 *** (0.02)	0.27 (0.01)	<0.001
Comprehensibility	0.09 *** (0.03)	0.03 (0.01)	0.001
Control variables			
Vulnerability	0.27 *** (0.04)	0.11 (0.02)	<0.001
Interest	0.28 *** (0.03)	0.15 (0.02)	<0.001
Disengagement	-0.06 (0.04)	-0.02 (0.02)	0.196
Gender (0 = male, 1 = female)	0.22 *** (0.05)	0.07 (0.02)	<0.001
Age groups (Reference: 15-29)	0.21 *** (0.03)	0.14 (0.02)	<0.001
Region: French (Reference: German)	0.16 ** (0.06)	0.10 (0.04)	0.006
Region: Italian (Reference: German)	0.12 (0.08)	0.08 (0.05)	0.132
Education (Reference: low education)	-0.00 (0.04)	-0.00 (0.02)	0.984
Mountainous area (0 = no, 1 = yes)	-0.08 (0.06)	-0.02 (0.02)	0.200
Random Effects			
σ^2	0.73		
$\tau_{00\ \text{Participant}}$	1.04		
ICC	0.59		
$N_{\text{Participant}}$	1996		
Observations	7984		
Marginal R^2 / Conditional R^2	0.323 / 0.722		

Table A8: Model 6: Mixed effects regression analysis testing for the interaction effect between meteorological parameters and weather event on intention to act. * p<0.05 ** p<0.01 *** p<0.001

	Model 6 **Dependent variable: intention to act**		
	Coefficient (standard error)	***Standardized Coefficient***	***p***
Intercept	1.02 *** (0.18)	-0.05 (0.02)	<0.001
Warning content (dimensions)			
Weather event (0 = storm, 1 = intense rain)	-0.30 *** (0.03)	-0.09 (0.01)	<0.001
Warning level	0.06 ** (0.02)	0.02 (0.01)	0.004
Description of warning level	-0.03 (0.02)	-0.01 (0.01)	0.151
Meteorological parameters	0.11 *** (0.03)	0.03 (0.01)	<0.001
Impact	0.21 *** (0.02)	0.06 (0.01)	<0.001
Behavioral recommendations	0.18 *** (0.02)	0.06 (0.01)	<0.001
Meteorological parameters* weather event	-0.14 ** (0.05)	-0.04 (0.01)	0.002
Implicit perceptions			
Trust	0.06 * (0.03)	0.02 (0.01)	0.025
Risk	0.35 *** (0.02)	0.16 (0.01)	<0.001
Relevance	0.68 *** (0.02)	0.27 (0.01)	<0.001
Comprehensibility	0.09 *** (0.03)	0.03 (0.01)	0.001
Control variables			
Vulnerability	0.27 *** (0.04)	0.11 (0.02)	<0.001
Interest	0.28 *** (0.03)	0.14 (0.02)	<0.001
Disengagement	-0.06 (0.04)	-0.02 (0.02)	0.195
Gender (0 = male, 1 = female)	0.22 *** (0.05)	0.07 (0.02)	<0.001
Age groups (Reference: 15-29)	0.21 *** (0.03)	0.14 (0.02)	<0.001
Region: French (Reference: German)	0.16 ** (0.06)	0.10 (0.04)	0.007
Region: Italian (Reference: German)	0.12 (0.08)	0.08 (0.05)	0.139
Education (Reference: low education)	-0.00 (0.04)	-0.00 (0.02)	0.977
Mountainous area (0 = no, 1 = yes)	-0.08 (0.06)	-0.02 (0.02)	0.212
Random Effects			
σ^2	0.73		
$\tau_{00\ \text{Participant}}$	1.04		
ICC	0.59		
$N_{\text{Participant}}$	1996		
Observations	7984		
Marginal R^2 / Conditional R^2	0.323 / 0.722		

Table A9: Model 7: Mixed effects regression analysis testing for the interaction effect between meteorological parameters and weather interest on intention to act. * $p<0.05$ ** $p<0.01$ *** $p<0.001$

	Model 7 Dependent variable: intention to act		
	Coefficient (standard error)	***Standardized Coefficient***	***p***
Intercept	1.04 *** (0.18)	-0.05 (0.02)	<0.001
Warning content (dimensions)			
Weather event (0 = storm, 1 = intense rain)	-0.38 *** (0.02)	-0.12 (0.01)	<0.001
Warning level	0.07 ** (0.02)	0.02 (0.01)	<0.001
Description of warning level	-0.03 (0.02)	-0.01 (0.01)	0.133
Meteorological parameters	0.05 (0.06)	0.02 (0.02)	0.400
Impact	0.21 *** (0.02)	0.06 (0.01)	<0.001
Behavioral recommendations	0.18 *** (0.02)	0.06 (0.01)	<0.001
Meteorological parameters* weather interest	-0.00 (0.03)	-0.00 (0.02)	0.878
Implicit perceptions			
Trust	0.06 * (0.03)	0.02 (0.01)	0.025
Risk	0.35 *** (0.02)	0.17 (0.01)	<0.001
Relevance	0.68 *** (0.02)	0.27 (0.01)	<0.001
Comprehensibility	0.09 *** (0.03)	0.03 (0.01)	0.001
Control variables			
Vulnerability	0.27 *** (0.04)	0.11 (0.02)	<0.001
Interest	0.28 *** (0.04)	0.15 (0.02)	<0.001
Disengagement	-0.06 (0.04)	-0.02 (0.02)	0.197
Gender (0 = male, 1 = female)	0.22 *** (0.05)	0.07 (0.02)	<0.001
Age groups (Reference: 15-29)	0.21 *** (0.03)	0.14 (0.02)	<0.001
Region: French (Reference: German)	0.16 ** (0.06)	0.10 (0.04)	0.006
Region: Italian (Reference: German)	0.12 (0.08)	0.08 (0.05)	0.132
Education (Reference: low education)	-0.00 (0.04)	-0.00 (0.02)	0.982
Mountainous area (0 = no, 1 = yes)	-0.08 (0.06)	-0.02 (0.02)	0.199
Random Effects			
σ^2		0.73	
$\tau_{00\ \text{Participant}}$		1.04	
ICC		0.59	
$N_{\text{Participant}}$		1996	
Observations		7984	
Marginal R^2 / Conditional R^2		0.323 / 0.722	

Table A10: Model 8: Mixed effects regression analysis testing for the interaction effect between behavioral recommendations and weather disengagement on intention to act. * p<0.05 ** p<0.01 *** p<0.001

	Model 8 Dependent variable: intention to act		
	Coefficient (standard error)	***Standardized Coefficient***	***p***
Intercept	1.09 *** (0.18)	-0.05 (0.02)	<0.001
Warning content (dimensions)			
Weather event (0 = storm, 1 = intense rain)	-0.38 *** (0.02)	-0.12 (0.01)	<0.001
Warning level	0.07 ** (0.02)	0.02 (0.01)	0.001
Description of warning level	-0.03 (0.02)	-0.01 (0.01)	0.135
Meteorological parameters	0.04* (0.02)	0.01 (0.01)	0.042
Impact	0.21 *** (0.02)	0.06 (0.01)	<0.001
Behavioral recommendations	0.09 (0.06)	0.03 (0.02)	0.134
Behavioral recommendations * disengagement	0.06 (0.04)	0.03 (0.02)	0.128
Implicit perceptions			
Trust	0.06 * (0.03)	0.02 (0.01)	0.024
Risk	0.35 *** (0.02)	0.17 (0.01)	<0.001
Relevance	0.68 *** (0.02)	0.27 (0.01)	<0.001
Comprehensibility	0.09 *** (0.03)	0.03 (0.01)	0.001
Control variables			
Vulnerability	0.27 *** (0.04)	0.11 (0.02)	<0.001
Interest	0.28 *** (0.03)	0.15 (0.02)	<0.001
Disengagement	-0.08 (0.05)	-0.03 (0.02)	0.077
Gender (0 = male, 1 = female)	0.22 *** (0.05)	0.07 (0.02)	<0.001
Age groups (Reference: 15-29)	0.21 *** (0.03)	0.14 (0.02)	<0.001
Region: French (Reference: German)	0.16 ** (0.06)	0.10 (0.04)	0.006
Region: Italian (Reference: German)	0.12 (0.08)	0.08 (0.05)	0.134
Education (Reference: low education)	-0.00 (0.04)	-0.00 (0.02)	0.986
Mountainous area (0 = no, 1 = yes)	-0.08 (0.06)	-0.02 (0.02)	0.203
Random Effects			
σ^2	0.73		
$\tau_{00\ \text{Participant}}$	1.04		
ICC	0.59		
$N_{\text{Participant}}$	1996		
Observations	7984		
Marginal R^2 / Conditional R^2	0.323 / 0.722		

Table A11: Model 9: Mixed effects regression analysis testing for the interaction effect between impact and weather disengagement on intention to act. * p<0.05 ** p<0.01 *** p<0.001

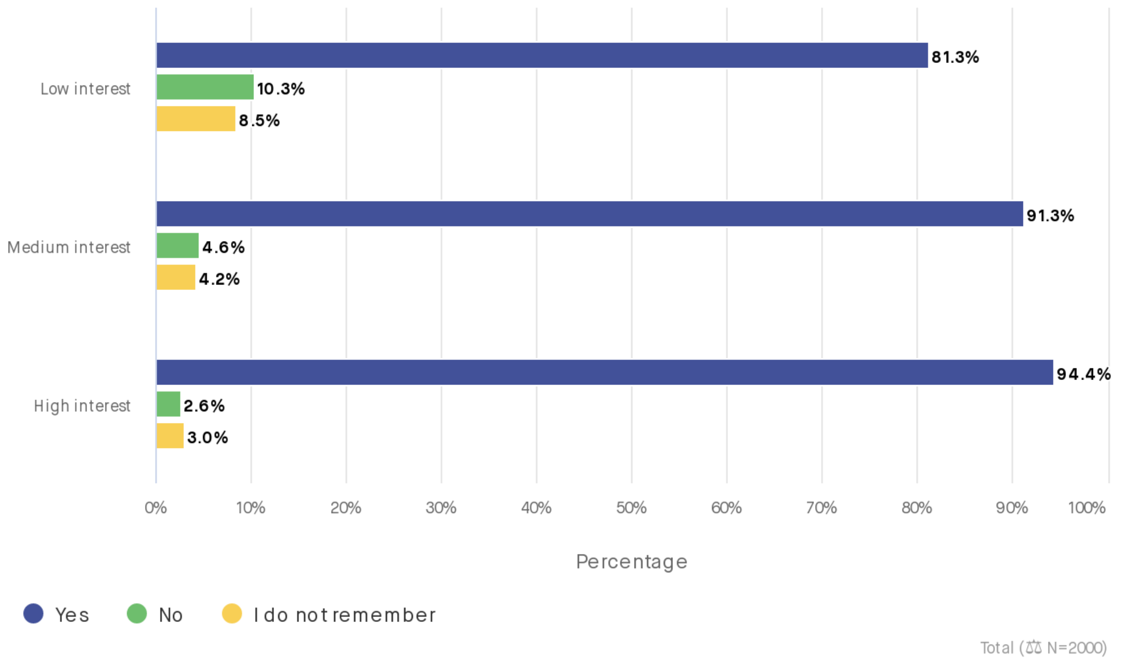
	Model 9 Dependent variable: intention to act		
	Coefficient (standard error)	***Standardized Coefficient***	***p***
Intercept	1.02 *** (0.18)	-0.05 (0.02)	<0.001
Warning content (dimensions)			
Weather event (0 = storm, 1 = intense rain)	-0.38 *** (0.02)	-0.12 (0.01)	<0.001
Warning level	0.07 ** (0.02)	0.02 (0.01)	0.001
Description of warning level	-0.03 (0.02)	-0.01 (0.01)	0.131
Meteorological parameters	0.04* (0.02)	0.01 (0.01)	0.042
Impact	0.25 *** (0.06)	0.08 (0.02)	<0.001
Behavioral recommendations	0.18*** (0.02)	0.06 (0.01)	<0.001
Impact * disengagement	-0.03 (0.04)	-0.02 (0.02)	0.414
Implicit perceptions			
Trust	0.06 * (0.03)	0.02 (0.01)	0.024
Risk	0.35 *** (0.02)	0.17 (0.01)	<0.001
Relevance	0.68 *** (0.02)	0.27 (0.01)	<0.001
Comprehensibility	0.09 *** (0.03)	0.03 (0.01)	0.001
Control variables			
Vulnerability	0.27 *** (0.04)	0.11 (0.02)	<0.001
Interest	0.28 *** (0.03)	0.15 (0.02)	<0.001
Disengagement	-0.04 (0.05)	-0.02 (0.02)	0.372
Gender (0 = male, 1 = female)	0.22 *** (0.05)	0.07 (0.02)	<0.001
Age groups (Reference: 15-29)	0.21 *** (0.03)	0.14 (0.02)	<0.001
Region: French (Reference: German)	0.16 ** (0.06)	0.10 (0.04)	0.006
Region: Italian (Reference: German)	0.12 (0.08)	0.08 (0.05)	0.132
Education (Reference: low education)	-0.00 (0.04)	-0.00 (0.02)	0.982
Mountainous area (0 = no, 1 = yes)	-0.08 (0.06)	-0.02 (0.02)	0.199
Random Effects			
σ^2	0.73		
$\tau_{00\ Participant}$	1.04		
ICC	0.59		
$N_{Participant}$	1996		
Observations	7984		
Marginal R^2 / Conditional R^2	0.323 / 0.722		

Table A12: Model 10: Mixed effects regression analysis testing for the interaction effect between meteorological parameters and education on intention to act. * p<0.05 ** p<0.01 *** p<0.001

	Model 10 Dependent variable: intention to act		
	Coefficient (standard error)	***Standardized Coefficient***	***p***
Intercept	1.09 *** (0.18)	-0.05 (0.02)	<0.001
Warning content (dimensions)			
Weather event (0 = storm, 1 = intense rain)	-0.38 *** (0.02)	-0.12 (0.01)	<0.001
Warning level	0.07 ** (0.02)	0.02 (0.01)	0.001
Description of warning level	-0.03 (0.02)	-0.01 (0.01)	0.131
Meteorological parameters	-0.04 (0.09)	-0.01 (0.03)	0.625
Impact	0.21 *** (0.02)	0.06 (0.01)	<0.001
Behavioral recommendations	0.18*** (0.02)	0.06 (0.01)	<0.001
Meteorological parameters * education	0.04 (0.04)	0.03 (0.03)	0.307
Implicit perceptions			
Trust	0.06 * (0.03)	0.02 (0.01)	0.025
Risk	0.35 *** (0.02)	0.17 (0.01)	<0.001
Relevance	0.68 *** (0.02)	0.27 (0.01)	<0.001
Comprehensibility	0.09 *** (0.03)	0.03 (0.01)	0.001
Control variables			
Vulnerability	0.27 *** (0.04)	0.11 (0.02)	<0.001
Interest	0.28 *** (0.03)	0.15 (0.02)	<0.001
Disengagement	-0.06 (0.04)	-0.02 (0.02)	0.195
Gender (0 = male, 1 = female)	0.22 *** (0.05)	0.07 (0.02)	<0.001
Age groups (Reference: 15-29)	0.21 *** (0.03)	0.14 (0.02)	<0.001
Region: French (Reference: German)	0.16 ** (0.06)	0.10 (0.04)	0.006
Region: Italian (Reference: German)	0.12 (0.08)	0.08 (0.05)	0.133
Education (Reference: low education)	-0.02 (0.04)	-0.01 (0.02)	0.668
Mountainous area (0 = no, 1 = yes)	-0.08 (0.06)	-0.02 (0.02)	0.200
Random Effects			
σ^2		0.73	
$\tau_{00\ Participant}$		1.04	
ICC		0.59	
$N_{Participant}$		1996	
Observations		7984	
Marginal R^2 / Conditional R^2		0.323 / 0.722	

Reachability

a) Reachability by weather interest



b) Reachability by age

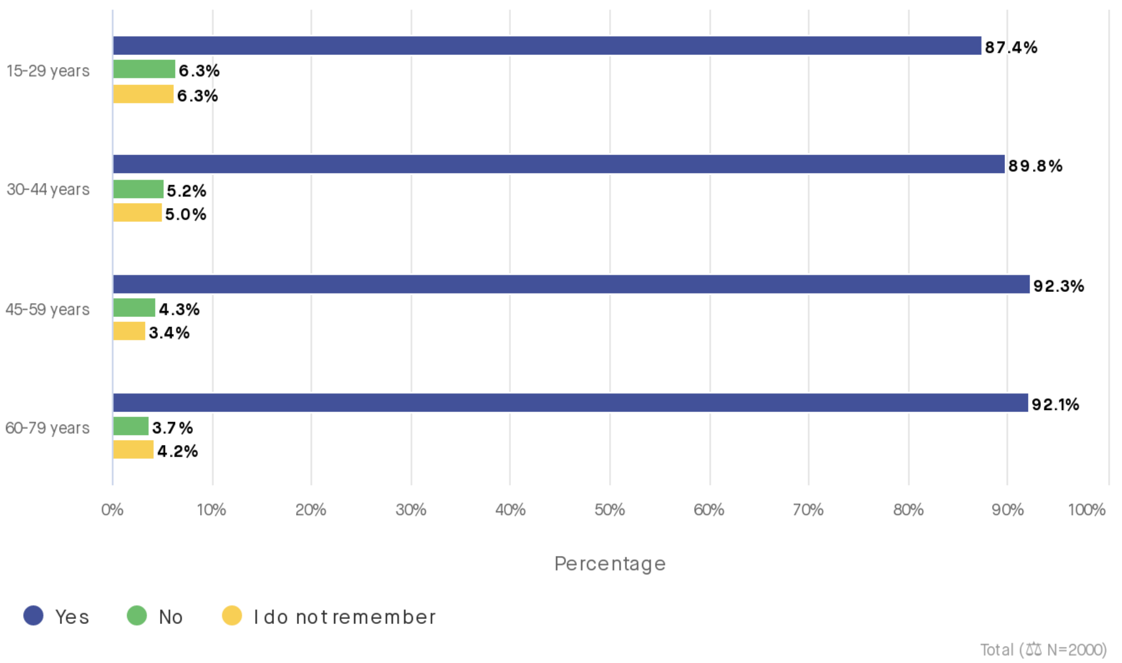
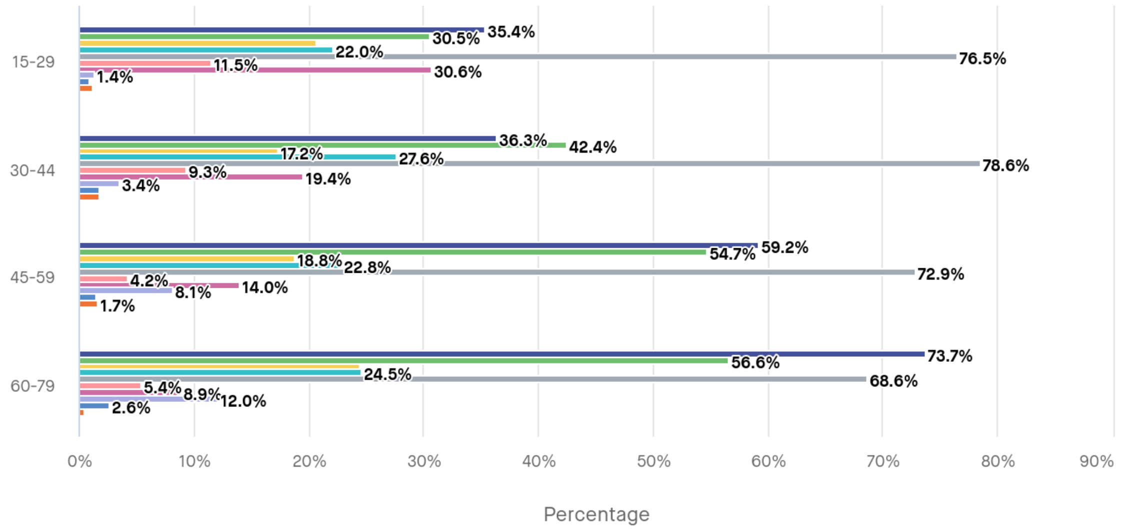


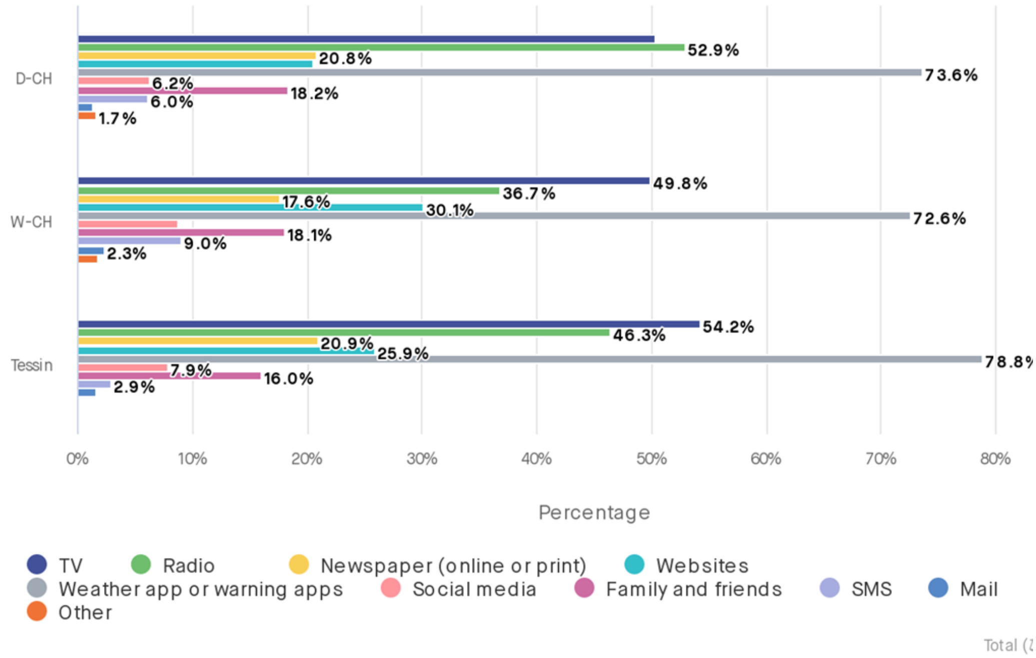
Figure A2: Answers to the question "Have you ever seen, heard or read a severe weather warning?" divided by weather interest and age groups.

Used distribution channels

a) Used distribution channels by age



b) Used distribution channels by region



c) Used distribution channels by weather interest

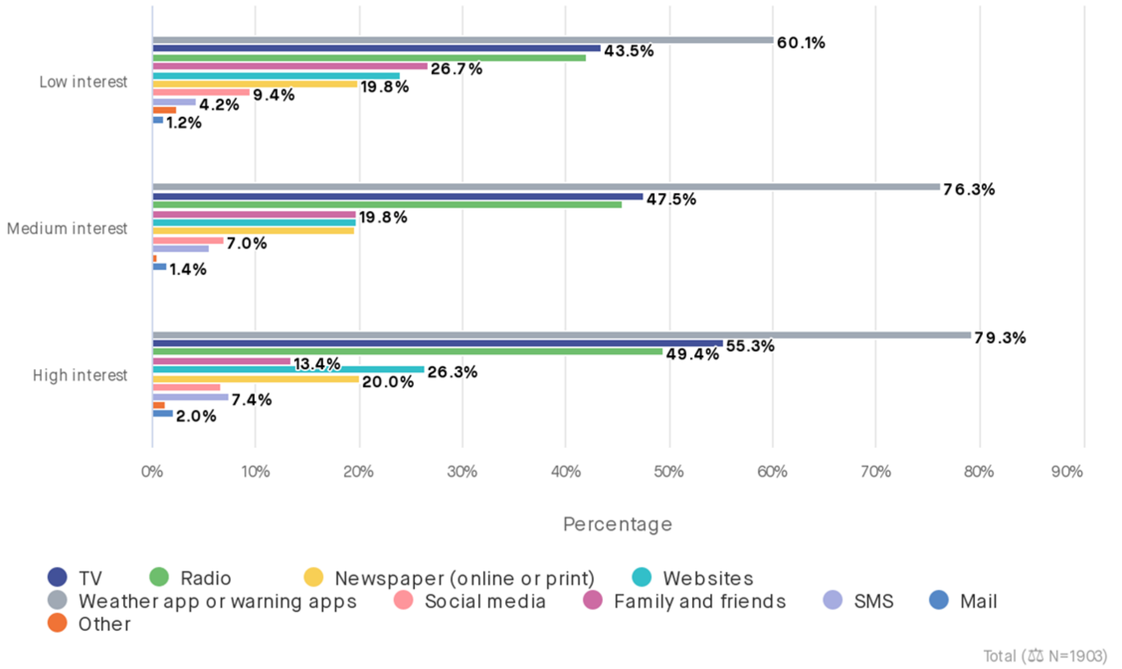


Figure A3: Distribution channels through which respondents usually receive a weather warning ("Through which channel do you usually learn about severe weather event?" – multiple choice) – divided by age groups (a), language region (b) and weather interest (c).

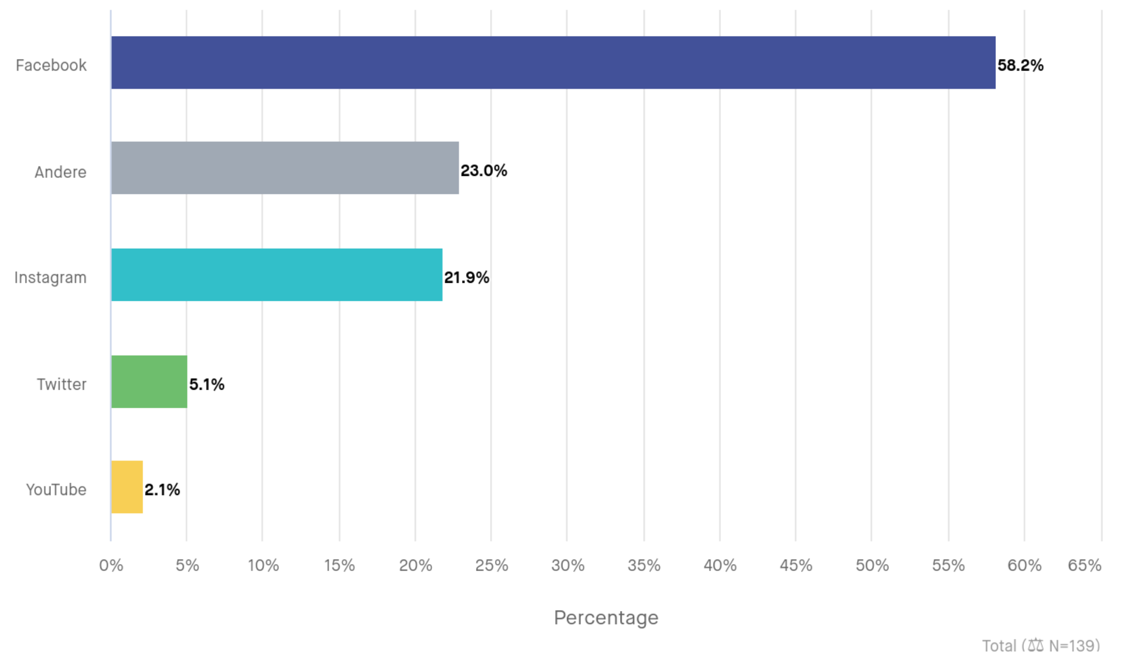
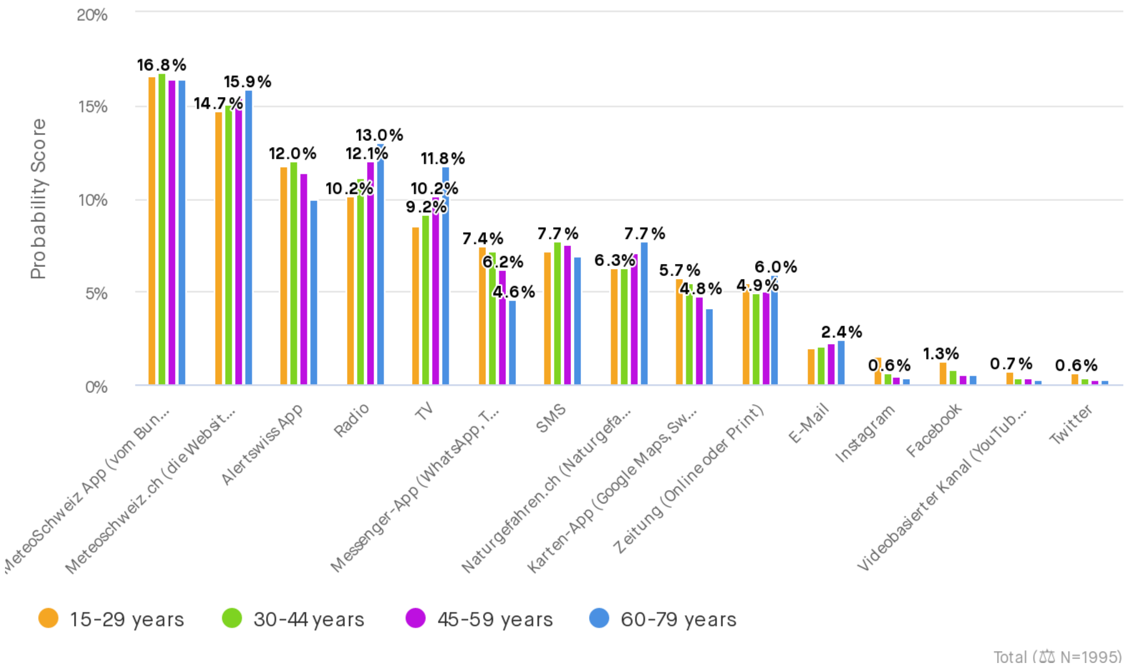


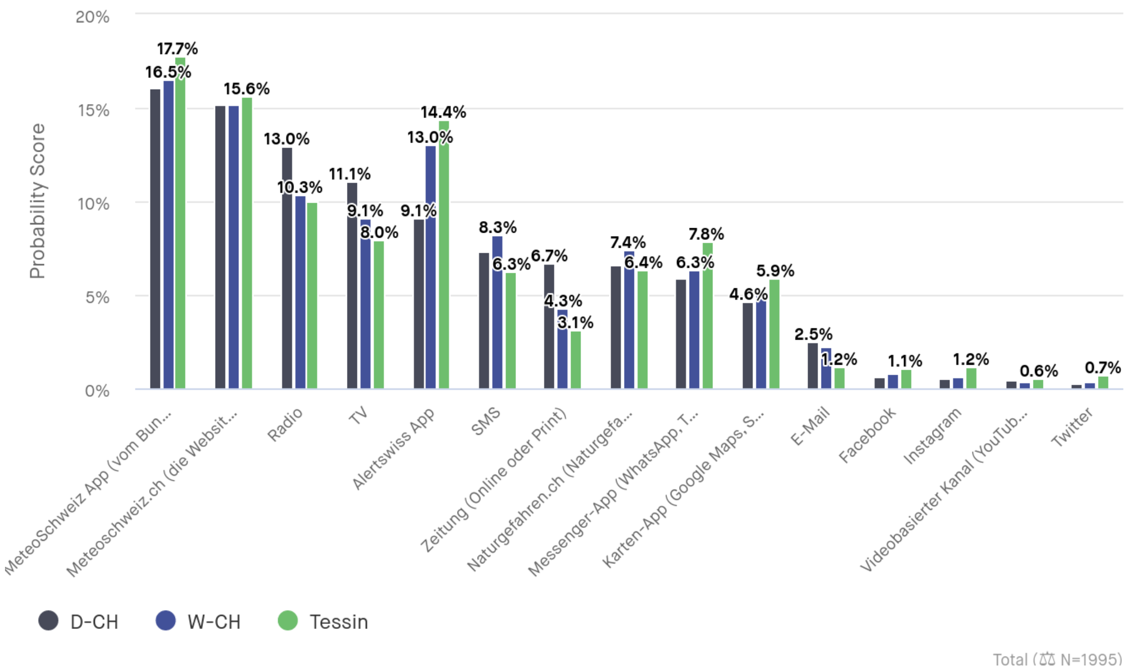
Figure A4: Social media channels through which respondents usually receive a weather warning ("Through which social media channel do you usually learn about severe weather event?" – multiple choice). This question was only answered by participants who have reported to usually receive a warning via a social media channel (7.0% of the total sample).

Future distribution channels

a) Future distribution channels by age



b) Future distribution channels by region



c) Future distribution channels by weather interest

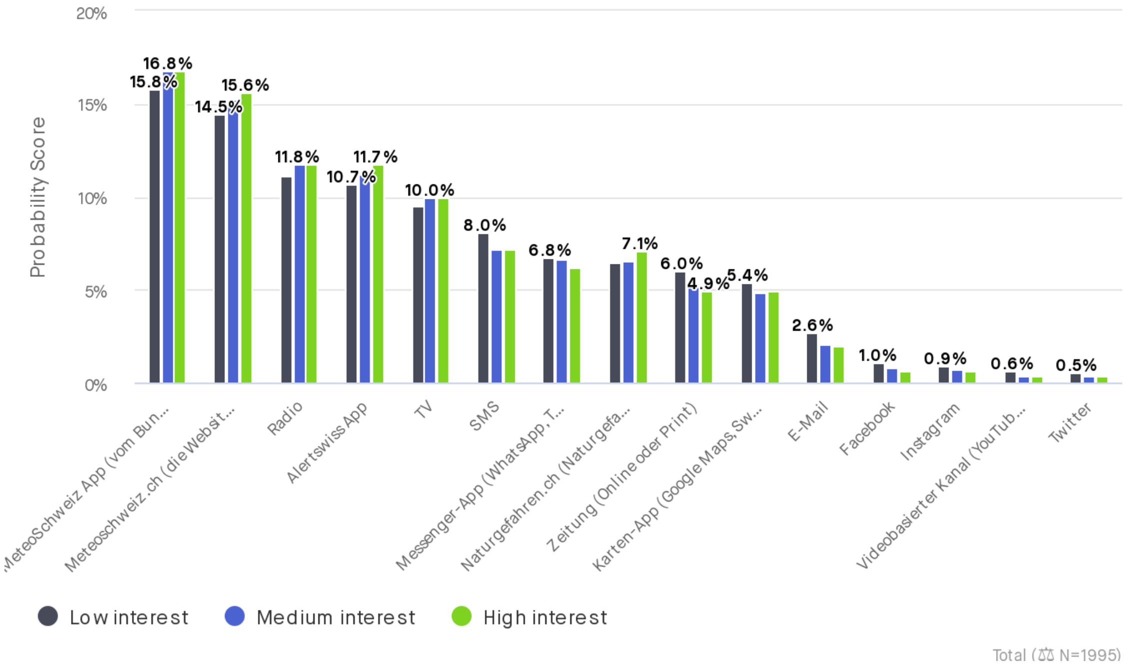
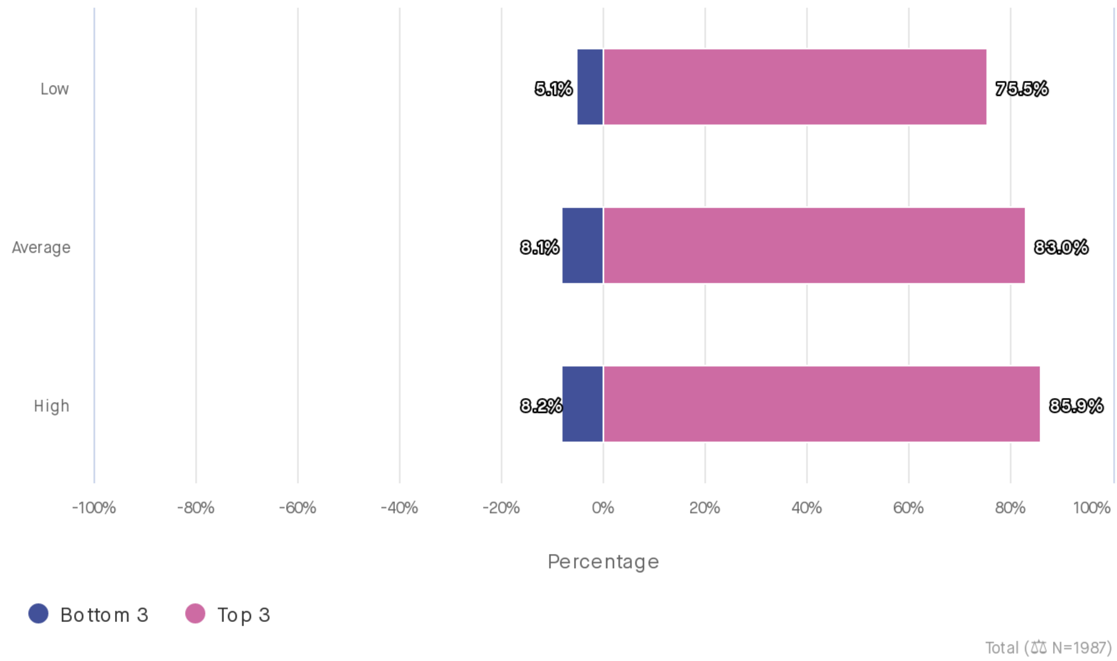


Figure A5: Results of the maximum difference scaling question about preferred warning channels for the future – divided by age (a), region (b) and weather interest (c). The Probability Score represents the relative preference for an item within the evaluated item set. The scores add up to 100% to represent preference shares. Scores are based on how often an item is chosen as worst and best, and are calculated using a hierarchical Bayes estimation procedure.

Interest in uncertainty information

a) Interest in uncertainty information by education level



b) Interest in uncertainty information by weather interest

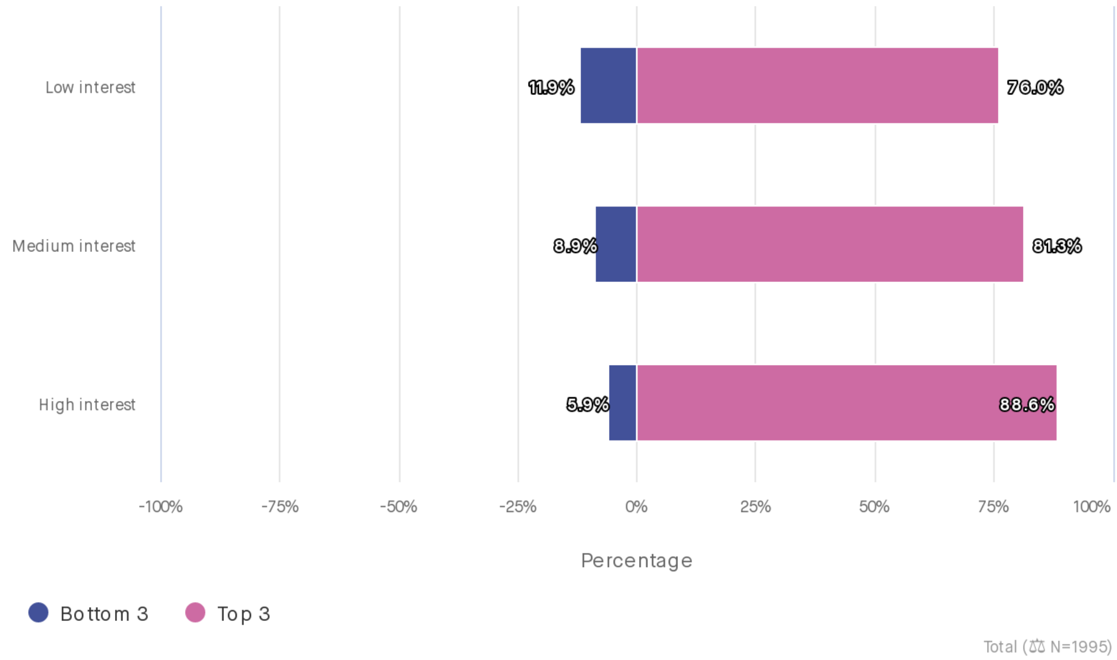


Figure A6: Answers to the question "How strongly do you agree with the following statement? "I am also interested in information about the uncertainty of the forecast in a severe weather warning, such as the probability of occurrence (e.g., "The probability that a level 4 storm will actually occur is 80% (very likely)")." – divided by education level (a) and weather interest (b). Bottom 3 includes ratings between 1-3, top 3 include ratings between 5-7.

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