How forecasts expressing uncertainty are perceived by UK students

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Uncertainty is inherent in all weather forecasts (National Research Council, 2006). It may be expressed as an indication of the likelihood of an event (e.g. '60% chance of rain') or in the provision of a range of possible outcomes (e.g. 'a maximum temperature of 18–22°C'), in contrast to deterministic forecasts that provide a definitive statement (e.g. 'top temperature 20°C'). In the USA, the public have had access to probabilistic forecasts of precipitation from the National Weather Service (formerly the Weather Bureau) since 1965 (Murphy *et al.*, 1980; Murphy and Winkler, 1984; Monahan and Steadman, 1996), and a survey of the American public found that the chance of precipitation is the second most important component of a weather forecast (Lazo *et al.*, 2009). By comparison, probabilistic forecasts for the UK public are rarely provided by most forecasters, although the Met Office (2011) has begun to experiment with the best approaches for offering such forecasts. Indeed, parliament recommended that the Met Office should develop a *communications strategy … to enhance the ways in which it presents probabilistic weather forecast information* and recommended that broadcasters *make greater use of probabilistic information in their weather forecasts, as is done in the United States* (http://www.publications.parliament.uk/pa/cm201213/cmselect/cmsctech/162/16204.htm: item 13).

Expressing the uncertainty in forecasts can be useful to experienced users of weather information, helping to improve decision-making based on those forecasts (Nadav-Greenberg and Joslyn, 2009; Joslyn and LeClerc, 2012). For example, Savelli and Joslyn (2012) found that boaters in the Puget Sound area of Washington State may benefit from calibrated forecasts of uncertainty because they are then able to make their own assessment of risk, based on boat size.

A question is whether users such as the general public would understand and prefer uncertainty forecasts provided in a specific, focused context. Greater implementation of probabilistic forecasts may be hindered by a view that the public does not understand them (World Meteorological Organization, 2008), a view supported by evidence that the public often misinterprets what the percentage refers to (Murphy *et al.*, 1980; Gigerenzer *et al.*, 2005; Morss *et al.*, 2008; Joslyn *et al.*, 2009). In particular, the public may misinterpret probabilistic precipitation forecasts as the percentage of area expected to be covered by precipitation or as the percentage of time that precipitation will occur, rather than as the probability of precipitation from many possible realizations of the weather. Nevertheless, some evidence does suggest that the greater exposure to probabilistic forecasts in the USA has led to a better understanding of such forecasts (Gigerenzer *et al.*, 2005).

Another factor preventing more widespread adoption in the UK may be negative feedback from segments of the public over the language of probabilities. For example, the Plain English Campaign – who are *fighting against jargon, gobbledygook and other confusing language, while promoting crystal-clear language* – awarded the Met Office a 2011 Golden Bull award for their attempt to introduce more probabilistic forecasts. This award is given *for the year's 'best' examples of gobbledygook,* and the award citation was for *empowering people to make their own decisions* by using the technical systems for *the probabilities of precipitation* (Plain English Campaign, 2012).

As a small step towards a better understanding of how the UK public perceives uncertainty within weather forecasts and a comparison with published results in the USA, this article focuses on the results of a survey designed to understand individuals' perceptions, interpretations and uses of weather forecast information.

Method

A survey was conducted at the University of Manchester during autumn 2010. Participants filled out an anonymous survey during an untimed testing session. A total of 92 students participated: 62 second-year undergraduates in EART20170 Computing, Data Analysis and Communication Skills and 30 third-year undergraduates in EART30551 Meteorology (Schultz *et al.*, 2012). These students were primarily in the earth- and environmental-science programmes, but had little prior academic experience with meteorology. As the results from the two groups were similar, they were combined into one dataset.

The survey questions were drawn from previously published studies in the USA by Morss *et al.* (2008, 2010), Joslyn *et al.* (2009), and Joslyn and Savelli (2010), with minor modifications (e.g. to adapt the questions to Celsius instead of Fahrenheit, and improvements in wording). Because the questions had been used previously, they were not pre-tested within the UK. The surveys presented participants with a series of human-behaviour questions designed to test four themes:

1. Perceptions of uncertainty in deterministic forecasts
2. Uses of forecasts in hypothetical decision-making scenarios
3. Interpretations of probability of precipitation forecasts
4. Preferred ways to receive forecast uncertainty information

Perceptions of uncertainty in deterministic forecasts

Surveys conducted in the USA indicate that most people expect uncertainty in deterministic forecasts (Morss *et al.*, 2008; Joslyn and Savelli, 2010; Savelli and Joslyn, 2012). For example, in a survey of the general

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public, 95% of participants inferred uncertainty in deterministic high-temperature forecasts, with the most popular range being about ± 1 degC selected by over 40% (Morss *et al.*, 2008). A question modelled after that in Morss *et al.* (2008) was asked of the UK participants: *Suppose the forecast high temperature for tomorrow for your area is 20°C. What do you think the actual high temperature will be?* Participants could select 20°C, write in a range that the high temperature may fall between, or respond 'other' and provide a written response.

As in the results from the USA, 85 of the 92 UK participants (92%) predicted that the temperature was likely to fall within a range, whereas only 3 (3%) believed that the high would be exactly 20°C and only 4 (4%) provided a written response. Excluding these four, 47% of the responses were centred on 20°C, with the most common being 18–22°C (Figure 1(a)). Interestingly, this result is similar to the accuracy of Met Office forecasts: the Met Office (2012) claims that 89% of its maximum temperature forecasts for the current day are within ± 2 degC of the actual temperature. Figure 1(b) shows the results from the 53% of participants who provided a forecast range not centred on 20°C, indicating a bias towards lower temperatures in their expectation of uncertainty: only 8 (9.1%) were biased high (positive ranges) compared to 39 (44.3%) biased low (negative ranges). These results are consistent with the biases found in surveys by Joslyn and Savelli (2010) and Savelli and Joslyn (2012).

For those participants who provided ranges, the lowest temperature in the range was 10°C and the highest 32°C (the participant responded 28–32°C, possibly indicating that the respondent did not understand the question or did not take the survey seriously). This large range suggests variability among individuals when applying uncertainty to deterministic forecasts (Morss *et al.*, 2008). They also suggest some inexperience among participants in knowing that a forecast of 20°C would be quite unlikely to verify at either 10°C or 32°C (or an extreme distrust of the forecast!). The four responses to this question omitted from the calculations included such write-in answers as *mostly dependent on time of day, wind and cloud cover* or *20°C is an estimate of general area; cloud cover and wind can change the temperature.*

Uses of forecasts in hypothetical decision-making scenarios

Hypothetical scenarios can be used as tools for understanding possible uses of forecast information (e.g. Morss *et al.*, 2008, 2010; Joslyn and Savelli, 2010; Schultz *et al.*, 2010). The survey asked participants to indicate how likely they were to take protective action given different types of weather forecasts in three hypothetical decision-making scenarios.

The first scenario was a deterministic forecast, originating from Joslyn and Savelli (2010): *Imagine that it is December and you have a favourite potted plant outside that would be damaged by freezing temperatures. The nighttime low temperature for the next night is predicted to be 0°C (freezing).* When asked whether they would bring the plant inside, 84% of the participants said 'yes', suggesting that they believed the risk of temperatures 0°C or lower was high enough to warrant protective action. Participants were then asked to write in what they thought the nighttime low might be; 50% wrote in 0°C (Figure 2(a)). Participants were then asked to write in temperatures for the following two statements: *I would not be surprised if the nighttime low temperature was as high [low] as __°C.* Most of the answers were within 5 degC of 0°C (Figures 2(b) and (c)), further evidence that participants expected uncertainty from a deterministic forecast.

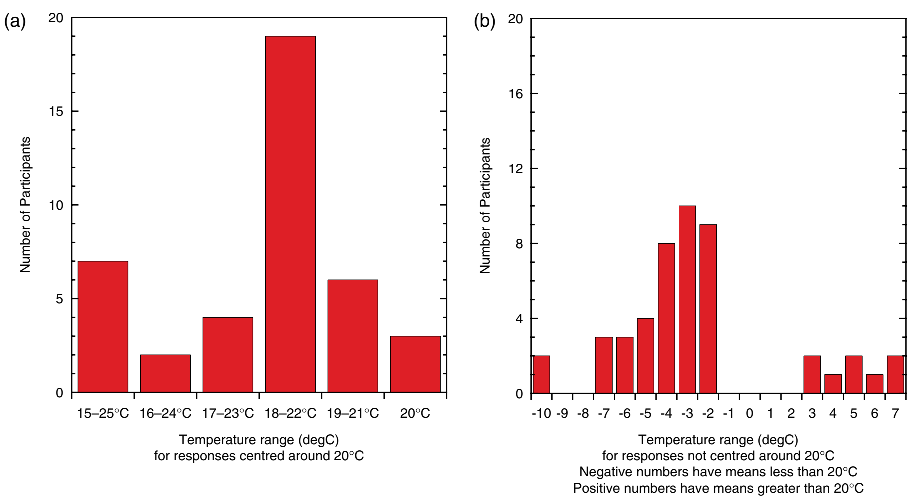

Figure 1. Participants' responses (N = 88) to the open-ended question, 'Suppose the forecast high temperature for tomorrow for your area is 20°C. What do you think the actual high temperature will be?' (a) 41 responses (47%) that are centred around or equal to 20°C. (b) 47 responses (53%) that are not centred around 20°C. For (b), a temperature range of –5 degC could represent 17–22°C or 15–20°C, for example.

Although the question being asked for Figure 2 was similar to the one for Figure 1 (i.e. asking the extent to which people expect or infer uncertainty in a deterministic forecast), many more people provided a deterministic interpretation of the forecast in the question associated with Figure 2 (cf. 3% in Figure 1(a) and 50% in Figure 2(a)). Another difference is that the responses in Figure 1(b) indicated that participants generally responded by providing a range with a mean less than 20°C, whereas the responses in Figure 2 indicated relatively little bias. The reasons for these two differences are not clear, but may be a result of the way the questions were worded or the format of the required answer. For example, the multiple-choice question in Figure 1 forced participants to decide between 20°C only, or a range. In contrast, the question in Figure 2 forced them to identify a specific temperature that they would expect. Therefore, most participants did not see a reason to bias their response above freezing or below freezing (Figure 2(a)). Given this result, further investigation into why these specific wordings might result in different types of responses is warranted.

The second scenario involved a probabilistic forecast, originating from Morss *et al.* (2010): *Imagine that it is August and you are organizing an outdoor picnic planned for tomorrow. At what forecast chance of rain for tomorrow would you decide today to move your picnic indoors?* Participants could choose to not take action, or to take action at a 10%, 20%, 30%, …, or 100% chance of rain. The most frequent response was moving the picnic indoors at 60% chance of rain, although 7% would take no protective action today (Figure 3(a)). Similarly, the same question asked in a larger survey of the public in the USA yielded a maximum at 50% with a sharp drop off at smaller values, and 4% not moving the picnic (Morss *et al.*, 2010).

The third scenario also used a probabilistic forecast, from Joslyn and Savelli (2010): *Imagine that it is August and you work with elderly people who could become ill if temperatures are 40°C or higher. At what forecast chance of such temperatures would you prepare?* The majority of participants chose to take action at 10–50% probability (Figure 3(b)).

Comparing these two examples (Figures 3(a) and (b)), participants would tend to take action in the 40°C scenario at lower probabilities than for the picnic scenario, with

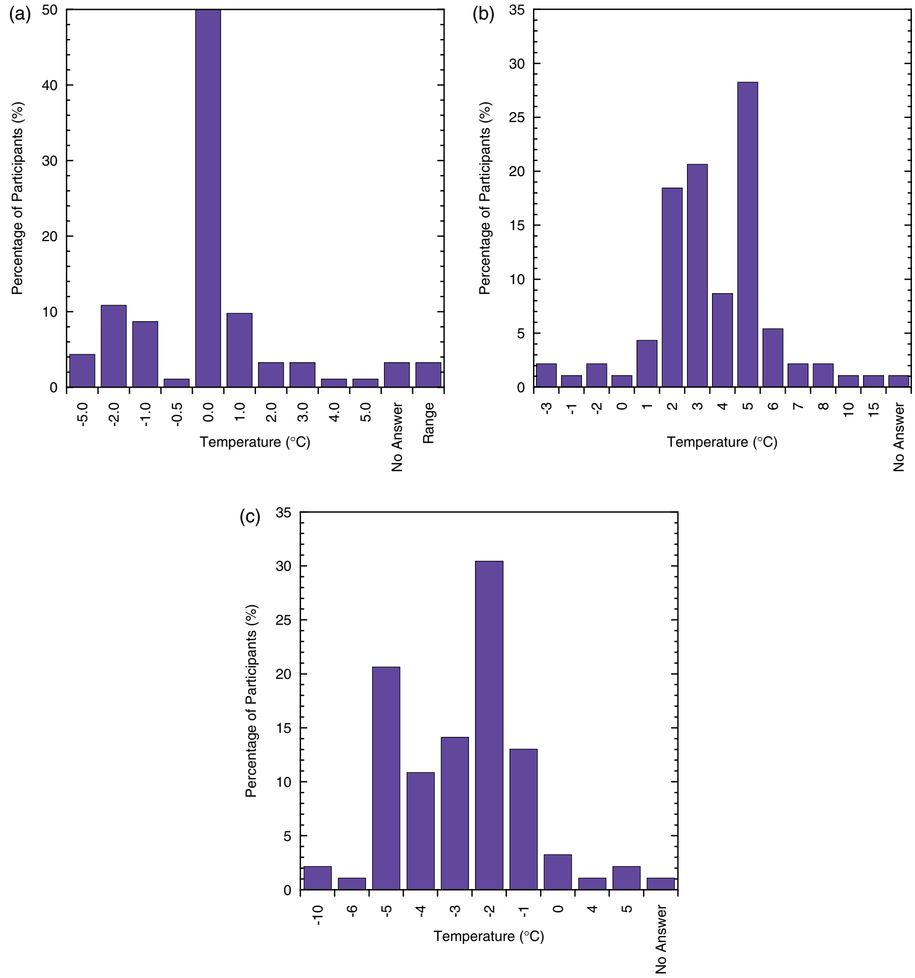

Figure 2. Given a temperature forecast of 0°C, participants' responses (N = 92) to the questions/statements (a) 'What do you think the nighttime low temperature will be on the next night?', (b) 'I would not be surprised if the nighttime low temperature on the next night was as high as __°C', and (c) 'I would not be surprised if the nighttime low temperature on the next night was as low as __°C'.

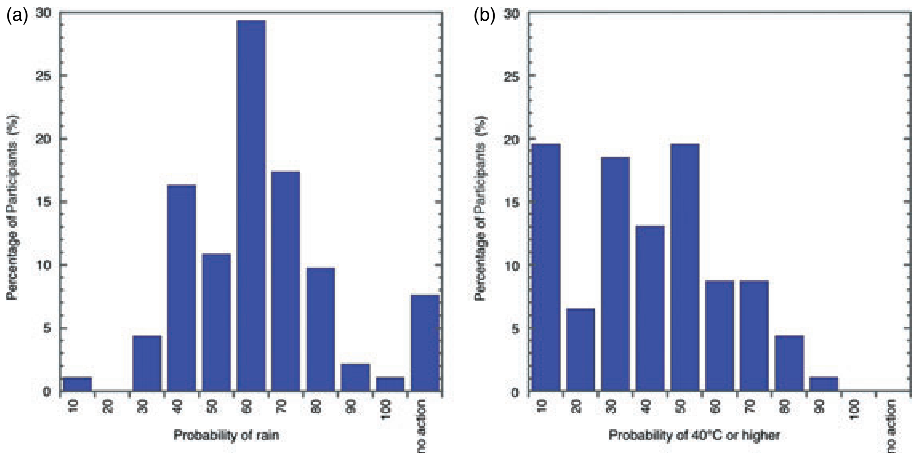

Figure 3. Participants' responses (N = 92) for (a) at what forecast probability of rain they would take protective action for a planned picnic, and (b) at what forecast probability of temperature ≥ 40˚C they would take protective action working with elderly people.

these two distributions being statistically different (Student's t test, $p < 0.0001$). Perhaps participants perceived greater risk and more severe consequences in the high-temperature scenario for elderly people than being rained out at a picnic. Furthermore, the broad distributions in both scenarios (Figures 3(a) and (b)) indicate the wide range of choices that different people would make given the same scenario, confirming the results of previous work in the USA (Joslyn and Savelli, 2010; Morss *et al.*, 2010).

Interpretations of probability of precipitation forecasts

To investigate participants' interpretations of probability of precipitation forecasts, we asked a survey question drawn from Murphy *et al.* (1980), Morss *et al.* (2008), and Joslyn *et al.* (2009): *Suppose the following text is the forecast for tomorrow: 'There is a 60% chance of rain'. In your own words, please explain what you think this means. Please be as specific as you can.* The results were classified into groups which, where possible, were similar to those previously published in Gigerenzer *et al.* (2005) and Morss *et al.* (2008) (Table 1). Where participants provided multiple interpretations in their response, the dominant or most specific interpretation was the one into which the response was classified.

Most participants (66%) restated the forecast in one of four ways. Only 4% provided an interpretation similar to *If tomorrow happens ten times, six of them would be rainy*. In previous studies, restatements have also been the most popular response to similar open-ended questions about the interpretation of probability of precipitation forecasts (Murphy *et al.*, 1980; Gigerenzer *et al.*, 2005; Morss *et al.*, 2008; Joslyn *et al.*, 2009). One possible explanation may be that restating the forecast implies that participants thought they sufficiently understood the probability forecast as presented; another may be that they did not know and were unwilling to expose their lack of knowledge, although this was only a few percent in previous studies (Murphy *et al.*, 1980; Morss *et al.*, 2008; Joslyn *et al.*, 2009). Additionally, Murphy *et al.* (1980) suggested that participants' lack of adding further interpretation to the forecast implies they were willing to use numerical probability of precipitation forecasts. Nevertheless, restating the forecast as a percentage does not necessarily mean it was interpreted correctly. For example, when participants chose to be more specific with their responses, it was common for them to think that the percentage related to areal, temporal or precipitation amount (Murphy *et al.*, 1980; de Elía and Laprise, 2003), although those were not common interpretations in our data (Table 1). Therefore, in line with these previous studies, the numerical restating of the probability forecast does not highlight what the participants perceived the 60% to mean.

Preferred ways to receive forecast uncertainty information

The mass media (e.g. local television, newspapers, radio stations) have made weather forecasts easily accessible to the public (Tan, 1976; Hayden *et al.*, 2007) in a variety of different presentation methods and formats (World Meteorological Organization, 2008). Therefore, individuals are provided with the opportunity to pick and mix forecasts from sources that suit their understanding and needs (Demuth *et al.*, 2011). Given this potential variety in the delivery and presentation of forecasts, how would people prefer uncertainty forecasts to be presented? Three questions were aimed at addressing preferred wordings to possible uncertainty forecasts.

First, participants were asked their preference when presented with a deterministic weather forecast and a simple type of uncertainty forecast from evening news programmes on two different television channels (question originating from Morss *et al.*, 2008).

Channel A: *The high temperature will be 25°C tomorrow*.

Channel B: *The high temperature will be between 24°C and 26°C tomorrow*.

Participants could choose that they would prefer the forecast given by channel A, channel B, that they liked both channels, that they did not like either forecast or that they did not know. Similar to the results in Morss *et al.* (2008), most participants (56% + 14%) would prefer or be willing to receive the uncertainty forecast presented here compared to 20% that prefer the deterministic forecast alone (Figure 4), although the lack of a random order for the response options may confound that result.

Secondly, participants were asked to select their preferences in a more detailed scenario in a question originating from Morss *et al.* (2008): *The high temperature for tomorrow will probably be 30°C. However, a cold front may move through during the day, in which case the high temperature tomorrow will be 20°C. Based on this weather scenario, for the options listed below, would you like the forecast given in this way?* Participants were presented with seven examples of how the forecast could be worded (Figure 5) and were asked whether they liked the forecast presented in this manner (yes or no). The deterministic forecast 7 was the least popular option with only 13% of participants liking this wording. This result was substantially lower than the 35% of participants who preferred the deterministic forecast in the Morss *et al.* (2008) study from the USA. The top three choices gave an explanation of the weather leading to the uncertainty, receiving 78%, 76%, and 67% favourable ratings. The next three choices explained that there could be a range or the possibility of two different temperatures, receiving 57%, 41%, and 36% favourable ratings. In particular, consider forecasts 3 and 6, which present the same information probabilistically, but 3 explains the reason for the uncertainty. Much as in Morss *et al.* (2008), forecast 3 is liked by nearly twice as many participants as forecast 6 (Figure 5). As discussed in Morss *et al.* (2008), these results suggest that providing a simple explanation may be a way of communicating forecast uncertainty many people like, at least as a supplement to other uncertainty information. Given the limited nature of this study, however, further testing of these results is needed in other contexts.

Third, to assess participants' preferences for ways of communicating probability of precipitation forecasts, a question originating from Morss *et al.* (2008) asked, *All the choices listed below are the same as a probability of rain of 20%. For the options listed below, do you like this information given this way? Please think about each option separately (i.e., do not compare each option to the*

Table 1

Responses from 92 participants interpreting the statement 'there is a 60% chance of rain tomorrow'.

Interpretation	*Example answer*	*Participants (%)*
Restatement: worded	*It is likely to rain.*	37
Restatement: probability or relative frequency	*There is a 60% chance it will rain tomorrow.*	14
Restatement: probability and reverse	*There is a 60% chance of rain tomorrow or there is a 40% chance it will not rain tomorrow.*	11
Weather conditions causing or associated with rain	*Cloudy, and windy. Even if it is rainy tomorrow, it won't last a long time.*	8
Forecast or forecaster	*There is a good chance it will rain but the forecast is not certain.*	5
Restatement: reverse	*There is a 40% chance it won't rain.*	4
'Days' interpretation of reference class	*If exactly the same weather conditions occur on 10 days, 6 of these days will experience rain in any amount or length of time.*	4
'Areal coverage' interpretation of reference class	*In roughly 60% of areas it is likely to rain whereas 40% of places will have no rain.*	3
Personal	*It is more likely than not that in my area that I will experience rain at some point during the forecast period.*	3
Relative probability	*It is more likely to rain than not as figure is above 50% but still not very certain of rain as figure isn't close to 100% chance of raining.*	2
Use	*It will rain tomorrow, as we are in Manchester. Take a brolly!*	2
Other	*There is only a 50% chance to rain anyways: either it rains (50%) or not (50%).*	2
Deterministic forecast	*It's going to rain at some point during the day.*	2
Temporal coverage interpretation of reference class	*Just over half of the day there will probably be rain.*	1

Percentage does not equal 100% because of rounding.

others listed). For each question, circle either Yes or No. By far, the most popular format was 'chance of rain tomorrow is 20%' with 90% of participants saying that they liked this format (Figure 6). The second most popular format was *There is a slight chance of rain tomorrow* with 65% in favour, and the third most popular format was *There is a 1 in 5 chance of rain tomorrow* with 33% in favour. The least popular format was *The odds are 1 to 4 that it will rain tomorrow* with only 7% in favour. These findings are consistent with those in Morss *et al.* (2008) from the USA. The responses indicate that, even in the UK where probability forecasts are less commonly used, participants preferred the probability forecasts, similarly to that preferred in the USA.

Generality of results

This survey was given to 92 undergraduate earth- and environmental-science students at the University of Manchester. Can these results be generalized to the general public? The same survey was also given to 126 undergraduate students (generally non-science students) in an introductory weather course at the University of Washington, Seattle, USA, in autumn 2010. These results, not presented here, are quite similar to those from the University of Manchester. Furthermore, many of the questions asked in this survey were also asked in surveys administered by Morss *et al.* (2008, 2010) and Joslyn and Savelli (2010), yielding similar results and providing some support for their generality. Nevertheless, surveys of this type should be extended to the UK population as a whole to examine generality, to obtain a larger sample size, and to probe further some of the results presented here.

Implications for communicating forecasts

Although studies suggest that many members of the public can interpret probability of precipitation forecasts in a general sense (i.e. 70% is higher than 30%), the specific meaning of the forecasts remains unclear to many (Murphy *et al.*, 1980; Gigerenzer *et al.*, 2005; Morss *et al.*, 2008; Joslyn and Savelli, 2010). Furthermore, data from other studies indicate some ways that modifying the presentation of forecasts can enhance clarity. Three examples follow. First, Joslyn *et al.* (2009) found that users better understood the forecast when the probability of *no precipitation* was communicated (e.g. '30% chance of precipitation, but 70% chance of no precipitation'). Second, Gigerenzer *et al.* (2005) suggested that forecasts should make clear to what the probability refers (e.g. '6 out of 10 days like today would produce rain'). Third, distilling the complexity

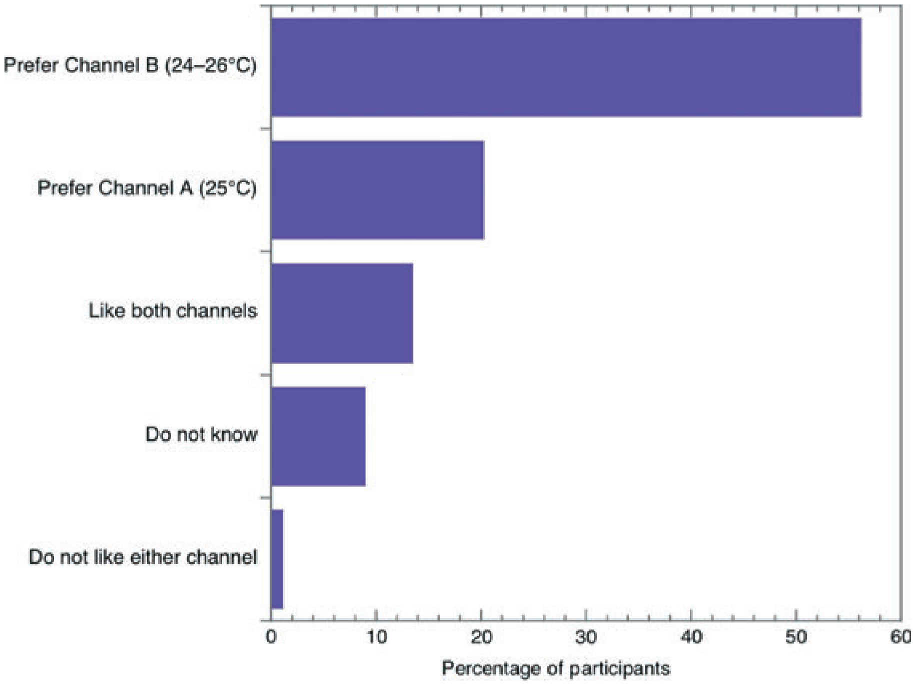

Figure 4. Participants' responses (N = 92) to the style of presentation of uncertainty they would prefer in a forecast. See text for details.

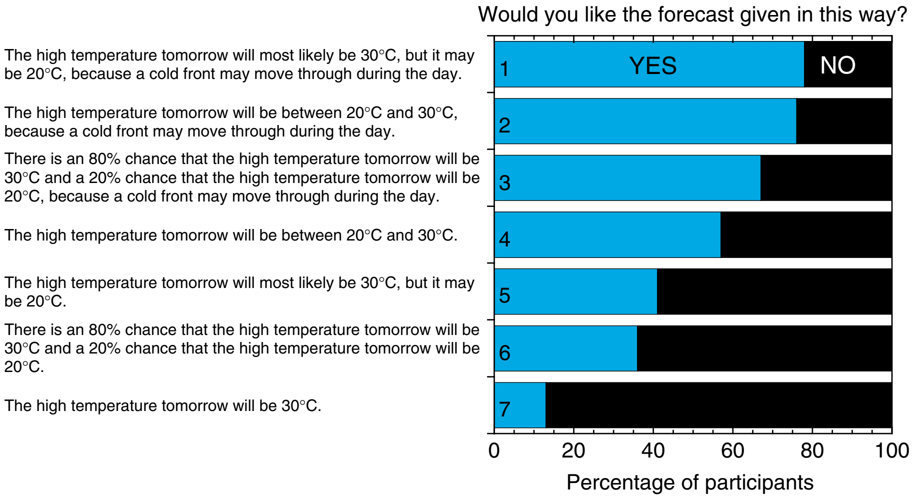

Figure 5. Participants' responses (N = 92) to the questions shown. See text for details.

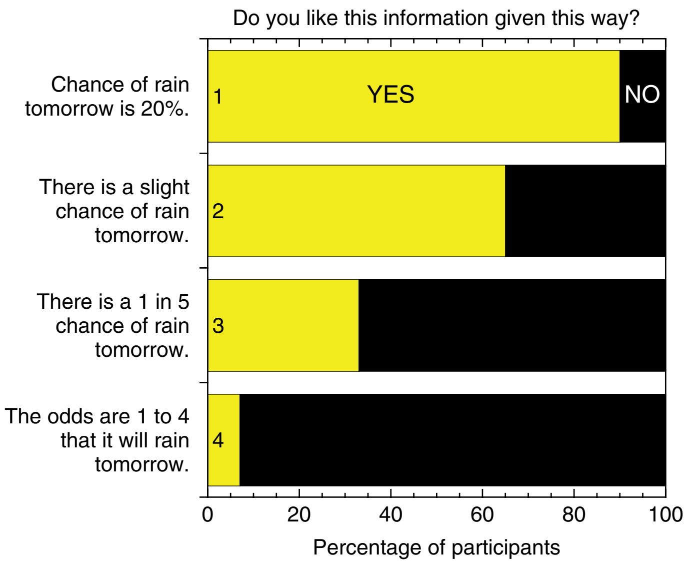

Figure 6. Participants' responses (N = 92) to the questions shown. See text for details.

of a day's weather into a single icon is a poor substitute for the knowledge that meteorologists have about the forecasted weather (e.g. Kahl and Horwitz, 2003; Ryan, 2003a; 2003b; Le Blancq, 2012). For example, pie charts filled 25% with raindrop icons to represent a 25% probability of precipitation confused users who thought that 25% of the area would be covered by rain or 25% of the time it would be raining (Joslyn *et al*., 2009), similar to some of the responses in Table 1. Building on these three examples, we propose that when uncertainty, and more specifically probabilistic, forecasts are first revealed to a new audience such as the public, it will be helpful to clarify the meaning and use of these new formats. Finding innovative, yet simple, ways to communicate uncertainty and probabilistic forecasts will go a long way to improving public understanding and to alleviating confusion and misunderstanding (Ryan, 2003b; Gigerenzer *et al*., 2005; Novak *et al*., 2008; AMS, 2008; Demuth *et al*., 2009; Mass *et al*., 2009; Hirschberg *et al*., 2011; Le Blancq, 2012).

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