How Do Laypeople Evaluate the Degree of Certainty in a Weather Report? A Case Study of the Use of the Web Service yr.no

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ABSTRACT

Many people depend on and use weather forecasts to plan their schedules. In so doing, ordinary people with no expertise in meteorology are frequently called upon to interpret uncertainty with respect to weather forecasts. With this in mind, this study addresses two main questions: 1) How do laypeople *interpret* online weather reports with respect to their degree of certainty and how is previous *knowledge* drawn upon in this interpretation? and 2) How do laypeople *integrate* information in weather reports to determine their degree of certainty? This qualitative study is based on semistructured interviews with 21 Norwegians. The results show the following: (a) only a portion of uncertainty information was used, (b) symbols were sometimes ascribed different meanings than intended, and (c) interpretations were affected by local experiences with wind direction and forecast quality. The informants' prior knowledge was found to prevail in the event of a conflict with forecast information, and an expected range of uncertainty was often inferred into single-valued forecasts. Additionally, (d) interpretations were affected by the integration of information used to predict the time and location of precipitation. Informants typically interpreted the degree of certainty differently (more or less uncertain) than was intended. Clearer presentation of uncertainty information, a clear intent of all nuances in information, a thorough use of multimodal information, and consideration of users' needs can help improve communication of forecast uncertainty. The diversity of user approaches makes forecast uncertainty more difficult to communicate and provides possible explanations for why communicating uncertainty is challenging.

1. Introduction

Most weather reports that are intended for the public present single-valued (deterministic) forecasts. However, the trend is to include more uncertainty information in weather reports (Joslyn and Savelli 2010). According to statistics regarding daily visitors and page views (Alexa 2013), the top four weather websites in the world on 4 November 2013 were weather.com, accuweather.com, wunderground.com, and yr.no. All four sites use multimodal texts, which mean that they feature different forms of representation, such as tables, symbols, maps, diagrams, and written text forecasts (Fig. 1). Notably, they provide uncertainty information, in addition to single-valued forecasts. Probabilities of precipitation are presented in tables in three of the sites, whereas yr.no uses various graphics to present uncertainty in tables and diagrams (Figs. 2 and 3). In addition, all four sites use phrases (e.g., "light rain possible") in written text forecasts expressing uncertainty. Communication of forecast uncertainty is potentially of great value to society and to users of such forecasts and could enable more informed

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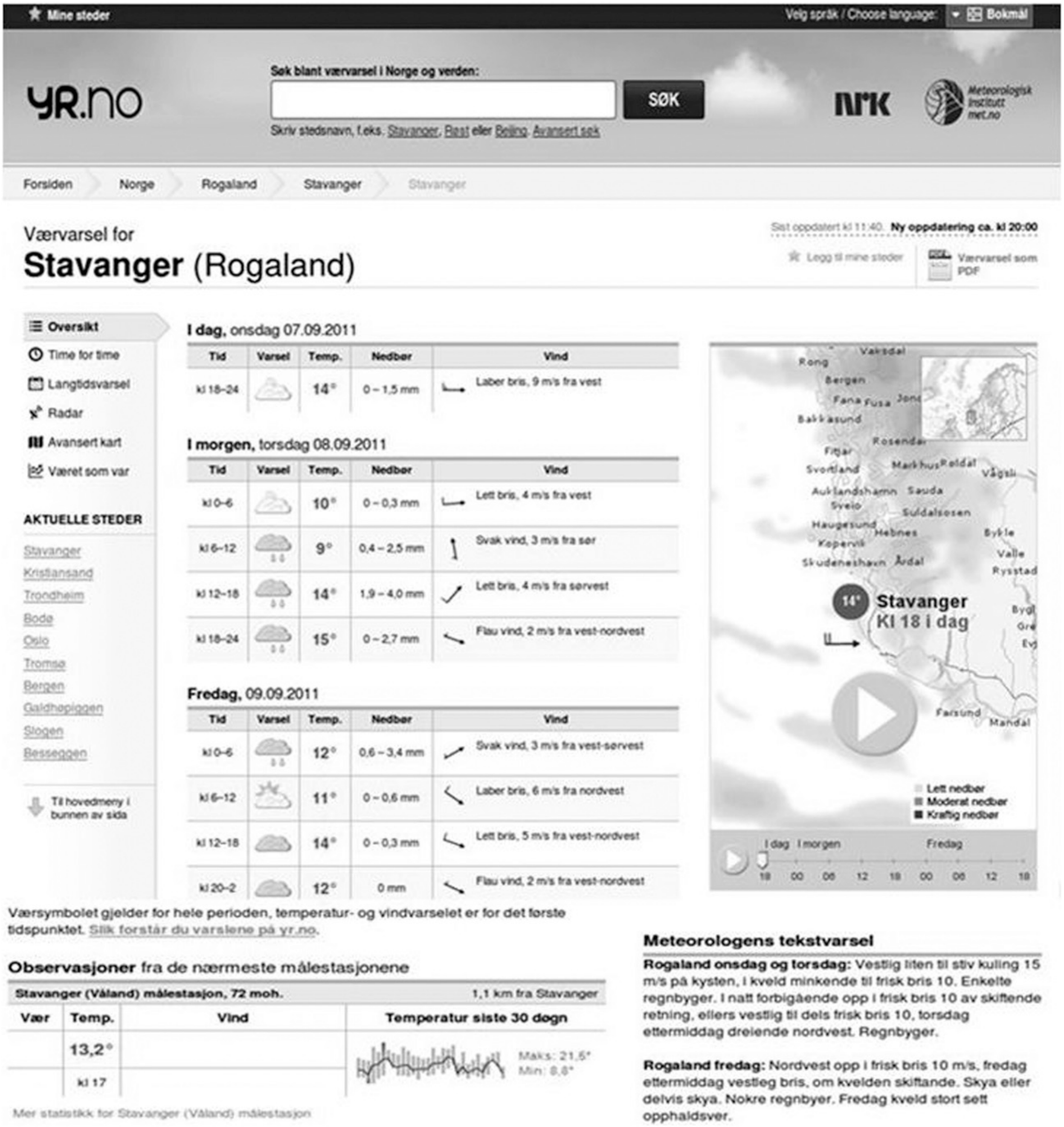

FIG. 1. Segment of the overview forecast page of the web service www.yr.no (YR). The forecast is in Norwegian because it is an authentic forecast used in the interviews. Included in the segment is a table with numbers and symbols, a map showing symbols and forecast precipitation, and the meteorologist's written text forecast.

decision-making (National Research Council 2006; Stuart et al. 2006; Hirschberg et al. 2011). However, the methods by which laypeople evaluate the degree of certainty in a weather report, to our knowledge, is still not well understood.

Recent studies have focused on the communication of uncertainty information in weather reports (Gigerenzer et al. 2005; Roulston et al. 2006; Morss et al. 2008; 2010, Joslyn et al. 2009; Joslyn and Savelli 2010; Peachey et al. 2013). However, these (mainly quantitative) studies are primarily concerned with interpretations of one type of uncertainty information: the probability of precipitation. Moreover, these studies are concerned with interpretations of single independent information and not normal

FIG. 2. Segment of the hour-by-hour forecast page of the web service www.yr.no (YR). Included in the segment is a diagram (meteogram) with symbols, a temperature graph, and solid and hatched precipitation columns. A table is also included that shows numbers and symbols. Hatched precipitation columns and numerical precipitation intervals are meant to indicate uncertainty; solid precipitation columns are meant to indicate expected precipitation.

user situations in the context of an authentic weather report. Notably, these studies indicate that laypeople have their own approaches to evaluating forecast uncertainty and infer an expected range of uncertainty into single-valued (temperature, precipitation, and wind speed) forecasts. It has been hypothesized that laypeople's experience with forecasts and the subsequent weather have affected their confidence in forecasts; therefore, laypeople know that forecasts are imperfect, and they infer uncertainty into single-valued forecasts (Morss et al. 2008; Hanrahan and Sweeney 2013).

Given the current level of knowledge, a qualitative approach is suitable for this study (Johannessen et al. 2010). Previous studies suggest examining not only how different types of uncertainty information are interpreted by laypeople (Morss et al. 2008) but also how single-valued forecasts are interpreted in the context of uncertainty (National Research Council 2006). In addition, hypotheses concerning the use of previous knowledge for inferring uncertainty into single-valued forecasts should be explored (Morss et al. 2008). Because the web service yr.no (www.yr.no; hereafter YR) contributes new types

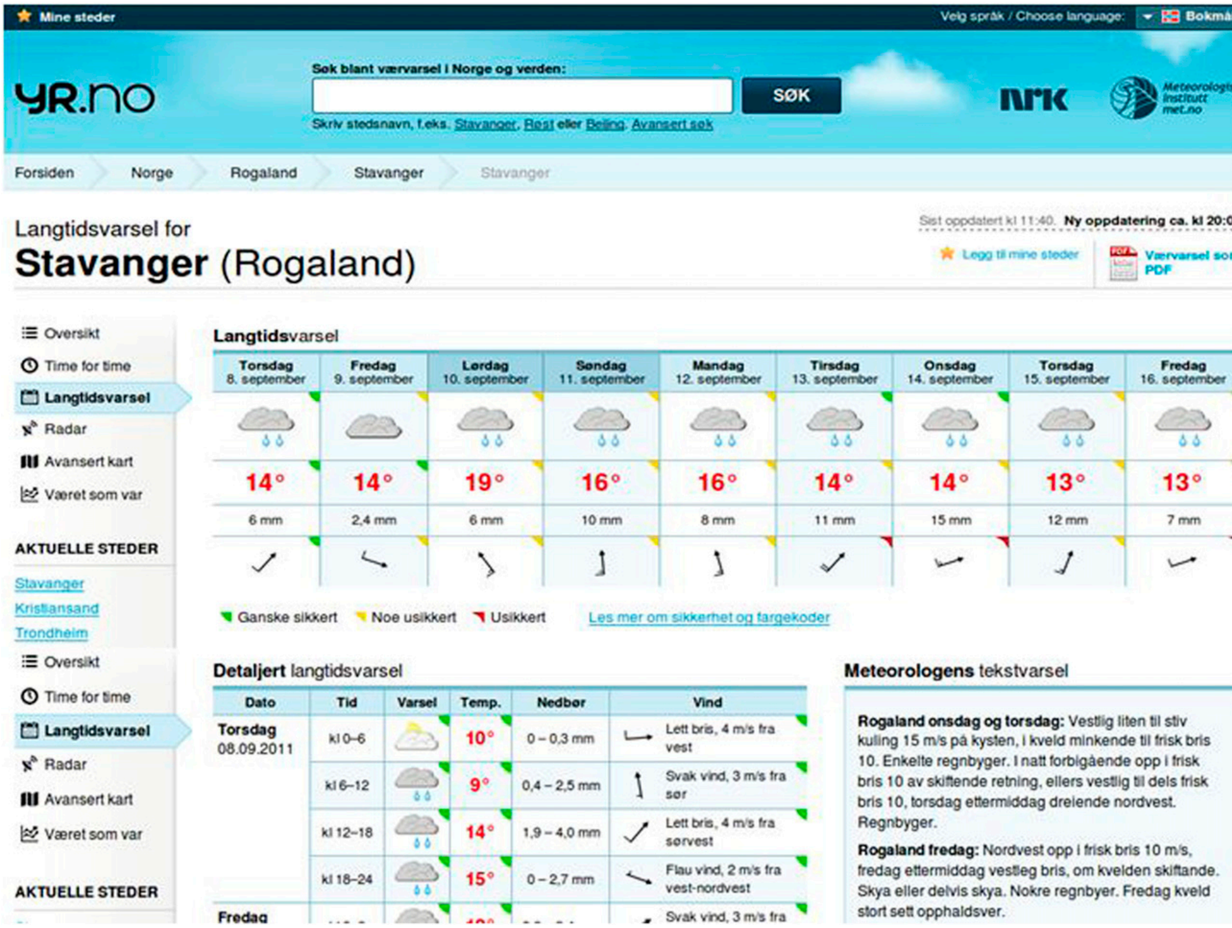

FIG. 3. Segment of the long-term forecast page of the web service www.yr.no (YR). Included in the segment are two tables (the lower one more detailed in time) with numbers and symbols and the meteorologist's written text forecast. Together with numerical precipitation intervals, the green, yellow, and red colored triangles are meant to indicate uncertainty. Explanations of green (rather certain), yellow (somewhat uncertain), and red (uncertain) colors are given between the two tables.

of uncertainty information that have not been previously studied, the YR site was selected for further analysis in this study. By using multimodal forecasts, it is possible to study how integrating information affects interpretations. This study is designed to explore different *interpretations* of single pieces of information (e.g., a cloud symbol) to evaluate the degree of certainty in the context of an authentic online weather report among selected users. The design of this study allows for the description of how these users draw upon previous knowledge (prior experiences and educational knowledge) when interpreting forecasts and how different pieces of information from the weather forecast pages are *integrated* (i.e., two or more pieces of information combined) to determine the degree of certainty. The research questions are as follows:

1) How is information in an online weather report *interpreted* with respect to degree of certainty, and how is previous knowledge drawn upon in the interpretations?
2) How is information in a weather report *integrated* to determine the degree of certainty?

2. Background and theory

The Norwegian Meteorological Institute's main channel for publishing weather forecasts to the public is YR, which is a multilingual website that is based on an open data policy and provides free weather forecasts for ~900 000 locations in Norway and ~8 million locations worldwide. The forecasts on the YR website are multimodal scientific texts that consist of different types of representations. Each representation is partial and provides an incomplete picture of the phenomena to be described, and the representations are often complementary to other representations (Echeverría and Scheuer

2009). Individual representations can provide different information regarding a particular aspect of a phenomenon (Echeverría and Scheuer 2009) and have different potentials for communicating information. For example, the shaded areas on the map in Fig. 1 provide information regarding the spatial distribution of precipitation, numerical intervals in the table provide information concerning the quantitative measures of precipitation (and uncertainty), and the meteorologist's written text communicates information with respect to the causal relations of precipitation (showers, or convectional rainfall). Presenting forecasts with a combination of several representations can therefore be useful in supporting a broad understanding of a weather phenomenon (e.g., precipitation). Simultaneously, the effectiveness of an approach using several representations depends on the ability of the reader to master multiple interpretive tasks (de Vries et al. 2009). Weak readers may find it especially difficult to interpret interrelationships among several representations (Roe 2008); as a consequence they may have greater difficulty building a broad understanding. In addition, experience with forecasts and weather may affect the interpretations of the representations, including representations of forecast uncertainty.

Uncertainty is prominent in weather forecasting. The atmosphere is chaotic (Lorenz 1963) and weather forecasts are sensitive to and dependent on the forecast's initial conditions (Fjelland 2002) and model formulations (Palmer 2006). Because the initial conditions (the state of the atmosphere) are not known with certainty and because forecasting models include some error, it is impossible to compute an error-free prediction of future atmospheric conditions. Generally, the degree of certainty in weather forecasts is dependent on the weather conditions of the current day (Hirschberg et al. 2011). To avoid a miscommunication of forecasts, it is important to clearly express uncertainty in weather reports (Joslyn et al. 2009).

One of the main challenges in communication is that the receiver must interpret the information provided. When a person reads a weather report, the information is not simply transferred to and stored by the reader. Words and images are relatively empty entities, to be filled with meaning (Kress 2005). Reading is an interactive process in which the reader creates meaning from the text and develops personal interpretations based on previous knowledge, experiences, and expectations (Dole et al. 1991; Norris and Phillips 2003). Accordingly, an interpretation of a forecast should be understood as subjectively constructed.

In addition, according to language theory, symbols do not have inherent meaning. Instead, symbols are imbued with meaning based on the way they are used in the context of certain cultural practices (Nemirovsky 2009). Consequently, different interpretations of symbols are possible. Because of differences in prior knowledge and cultural practices, the meteorological community would likely assign a somewhat different meaning to a symbol than would be assigned by end users, such as fishermen, farmers, or people living in places with unusual weather conditions. These potential differences make communication to a variety of user groups demanding; however, a user's various interpretations have the potential to inform efforts to improve communication. Becoming aware of the different methods employed by users to interpret symbols can hopefully lead to changes in the symbols used for multimodal weather forecasts to make them more effective in communicating the intent of the forecast providers and to reduce the range of interpretations by end users.

3. Methods

This study utilized a phenomenological interview design because such a design is well suited to studying people's interpretations of a phenomenon in the real world (Kvale and Brinkmann 2009). Within this design, qualitative interviews are used to understand the world from the perspective of the informants (Kvale and Brinkmann 2009). A qualitative study allows for the meaning of new interpretations of a phenomenon to be discovered through exploratory fieldwork and does not rely on quantifying known interpretations and creating generalizations (Miles and Huberman 1994). The data's richness and integrity, which are derived from considering more than one variable and account for the influences of local context, constitute the strength of qualitative studies (Miles and Huberman 1994). Semistructured interviews are the primary method of this study, and they allow for comparability across interviews because of a fixed set of questions and flexibility to follow up on new information discovered during the interview process (Johannessen et al. 2010).

A pilot study of three interviews (1 student, 1 teacher, and 1 exterior painter) and a preliminary analysis were conducted to test and subsequently improve the interview guide.

a. Sample

The strategic or purposive sampling was designed for capturing as many different methods of interpreting weather forecasts as possible with the available study resources rather than for making statistical generalizations (Johannessen et al. 2010). Typical interview studies used to identify the diverse views related to a specific topic include 5 to 25 informants (Kvale and Brinkmann

TABLE 1. List of informants in the study, from the five selected user groups (based on the occupation variable): farmers, tour guides, exterior painters, teachers, and students.

Informant	Fictitious name	Residence area.	Educational background (completed level)	Occupation
1	Daniel	1	College	Farmer
2	Arvid	1	College	Tour guide
3	Albert	2	Upper secondary school	Painter
4	Nils	2	College	Tour guide
5	Gunnar	2	College	Farmer
6	Kristin	2	Lower secondary school	Student
7	Jon	2	University	Teacher
8	Kjersti	2	Lower secondary school	Student
9	Amanda	2	Lower secondary school	Student
10	Siri	2	University	Teacher
11	Anita	2	University	Teacher
12	Steffen	3	University	Teacher
13	Peder	3	Lower secondary school	Student
14	Ruth	3	Lower secondary school	Student
15	Lise	3	Upper secondary school	Tour guide
16	Marta	3	University	Farmer
17	Emil	3	Lower secondary school	Student
18	Frode	3	College	Teacher
19	Geir	1	College	Teacher
20	Ulf	1	University	Tour guide
21	Kennet	1	Lower secondary school	Student

2009). This study included 21 informants. To obtain a broad variance in the number of user perspectives, five user groups were formulated (Table 1); however, experts with formal meteorological training and users of specialized forecasts, such as pilots and fishermen, were excluded.

This study sought variation with respect to the demographic variables of education, occupation, and geographical residence across these groups. Farmers, exterior painters, and tour guides from the Norwegian Trekking Association use weather forecasts to make decisions based on their occupation and were selected from other likely user groups. Importantly, these groups focus on different aspects of forecasts. For example, on a dry day, the farmer might focus on the chance of rain in upcoming days, whereas the painter might be interested in the nighttime low temperature and the tour guide might be interested in the maximum wind speed. Thus, their activities might influence their experiences and enable different interpretations. Upper secondary school teachers are not equally likely to use weather forecasts in their occupation; however, these teachers contribute to variation in educational background and were included in the sample. To increase the educational background diversity of the sample, upper secondary school students were included as a fifth user group. Physical and social environments may also affect a person's knowledge of the weather (Hansen 1996). As a result, a user's residence can be of importance in their interpretation of a weather forecast. Based on Hansen's criteria for variation of climate (1996), three areas of Norway are represented: area 1, which has an extreme west coast climate (wet and windy); area 2, which has "Norway's best climate" (as a total assessment of temperature, precipitation, and wind); and area 3, which represents an extreme inland climate (dry).

The lists of possible informants were developed based on occupational and locational criteria, and schools and companies were identified and contacted by e-mail. If the prospective informants agreed to participate, the leader of the school or company was asked to pass on the information. Informed consent was obtained from those who wanted to participate. All the informants in the sample were familiar with YR, and used the site when they searched for weather forecasts.

b. Interviews

In this study, 21 informants were interviewed (sample in Table 1, pilot study not included). The final interviews did not result in any important new ways of interpreting information; therefore, it was determined that a *saturation* in the types of interpretations had been reached (similar data had been heard before), and the interview process was ended (Kvale and Brinkmann 2009). All the interviews were conducted and digitally recorded by the first author either at the informants' offices or in meeting rooms at hotels or schools. The interviews were centered on printouts of four types of forecasts, including the YR front page, overview, hour-by-hour, and long-term, as shown in Figs. 1–3. Printouts were selected to ensure a range of interesting forecasts and because they offered a common basis for comparison across the informants' answers. All the forecasts were for Stavanger, a city all the informants were familiar with but where none lived.

The informants were initially asked questions pertaining to their background and use of the YR website. Afterward, the informants were shown the four printouts of forecasts from YR. The first question for all four of the forecasts was open-ended: ''What thoughts about the weather in Stavanger do you have when you look at this forecast?'' With this open-ended question, informants were able to comment with as little or as much information from the forecasts as they wanted. Moreover, asking an open question in the context of an authentic weather forecast instead of asking for their interpretation of single independent symbols provided a better replication of normal usage. Depending on the informant's answer to the first question, additional detailed questions regarding their interpretations and use of different information followed. Certain informants were extremely communicative and required a limited amount of additional questions, whereas others required several prompts to elicit responses. For example, respondents were asked how they arrived at an interpretation of the time at which rain would start and were questioned on their use of tables (Fig. 1), diagrams (Fig. 2), and uncertainty information, such as that represented in the colored triangles in the long-term forecast (Fig. 3). (The full interview guide translated into English with printouts is available on request from the first author.)

c. Data analysis

All interviews were transcribed verbatim. Interview transcripts were analyzed with respect to two foci based on the two research questions: the *interpretation* of one type of information with respect to degree of certainty (and the use of previous knowledge in these interpretations) and the *integration* of forecast information to determine the degree of certainty.

For the analysis, 14 interviews were randomly selected as a starting point. Systematic text condensation (Malterud 2003), a strategy inspired by the phenomenological analysis described by Giorgi (1985), was used as the foundation for analysis. The analysis proceeded through four main steps.

First, the 14 transcriptions were read to obtain an overview of the data.

Second, the transcriptions were coded inductively. In so doing, close readings of the data were used to derive codes (Thomas 2006). All the instances in the text that were related to one of the two foci of the study were marked with a code name to describe the content. All the coded utterances were inspected for signals of the informant's view as to the certainty of the information. The utterances were also assessed with respect to data quality. Vague utterances in which it was difficult to understand the informant's intent because of ambiguities or low sound quality in the digital recording were omitted. If the utterance addressed a single piece of information, it was included in the focus *interpretation.* For example, a phrase such as ''there might be a risk of rain on Friday . . . because there is a dark cloud and not a white cloud'' would be given the code name ''interpret as uncertain based on cloud color.'' Data concerning previous knowledge were not always explicit in the interviews, but implicit references were coded. The use of atypical lexicon (e.g., ''interval'' and ''maximum'') was interpreted as an indicator of an academic understanding, and references to experiences (e.g., ''see'' and ''usually'') were coded as indicators of prior experience. Similarly, if the statement addressed a combination of two or more pieces of information, then the utterance was assigned the focus *integrate.* For example, a phrase such as ''I look at diagrams for four locations in my area . . . If rain is not forecast for any of the locations, then it is certain'' was given the code name ''integrate locations to determine the degree of certainty.''

Third, codes pointing to similar ideas were grouped into categories. The categories were developed inductively during the analysis and had a more general character than the codes. The codes were reorganized into four main categories, and the codes in each main category were grouped into more specific subcategories containing two or more individual codes. For example, the two codes ''interpret as uncertain based on cloud color'' and ''interpret as uncertain based on number of drops'' belong to the subcategory ''nuances in single-valued symbols used to interpret degree of certainty.'' This subcategory belongs to the more general main category ''symbols interpreted differently than intended (because of nuances).'' Several tentative categories were developed and adjusted before consistency was attained, and they were grouped based on the two foci of the analysis (Table 2). Conducting the second and third steps was an iterative and time-consuming process.

Fourth, each subcategory and main category was given a description, and a quotation was selected to help clarify and communicate the content.

To improve reliability, four transcriptions were not analyzed until the first 14 were almost finished. Thereafter, three new interviews were conducted, transcribed, and analyzed. Thus, the analysis of the later interviews

TABLE 2. Factors influencing the layperson's evaluation of the degree of certainty in a weather report. The main categories and subcategories for the two foci of the study: Interpretation of information (a, b, and c), and integration of information (d).

(a) Only part of the uncertainly information used
Nuances in uncertainty information (colors, fill effects, intervals, and phrases) used to interpret degree of certainty
(b) Symbols interpreted differently than intended (because of nuances)
Nuance in single-valued symbols (cloud color, and number of drops and options) used to interpret degree of certainty
Interpretation guided by view of expertise (trust expert)
(c) Prior knowledge affects interpretation (and prevails over the given information)
Interpretation of degree of certainty affected by experiences with forecast quality
Interpretation of degree of certainty affected by experiences with local weather
Interpretation guided by view of expertise (don't trust expert)
(d) Interpretations affected by the integration (to create a dynamic picture)
Information integrated to decide time and location of precipitation and determine degree of certainty
Integration of information affected by understandability of information
Integration of information affected by apparent contradictory information

served as verification of the codes developed in the first 14 interviews. Only minor adjustments had to be made to the previously developed codes, which indicate high reliability. This check-coding increased clarity and supported the relative consistency of the coder's judgments over time (Miles and Huberman 1994).

Presented in the three next sections (4, 5, and 6) are interpretations of the information on the YR website and the informants' previous knowledge used in the interpretations along with YR's expressions of the intended meaning (YR 2013a,b) in parentheses for comparison. Participants provided justifications for integrating information from different parts of YR and for deciding not to integrate information. These explanations are described in more detail in section 7. YR does not present any intended meaning with the integration of information. For each subcategory, a sample of codes is presented as examples and support for the four key findings (section 4–7) (see also Table 2). The number of informants using each concept (i.e., belongs to a code) is provided in parentheses in the text. Although each identified interpretation might have been communicated by many interview participants, no frequencies are provided because quantitative generalizations cannot be inferred based on this small and purposive sample. All the informants expressed ideas that fit within several main categories, subcategories, and code names. The informants were given fictitious names to maintain confidentiality.

4. Only part of the uncertainty information used

At times, all the informants used nuances in uncertainty information (colors, fill effects, intervals, and phrases) to interpret the degree of certainty in the forecast. For example, hatched precipitation columns (5) and numerical precipitation intervals (13) (YR's intention: uncertain precipitation forecast) (Fig. 2), triangles with yellow and red colors (11) (YR's intention: somewhat uncertain and uncertain forecast, respectively) (Fig. 3), and phrases expressing uncertainty (possibility of or chance of) (8) were interpreted as an uncertain forecast or as the probability of an event. The solid precipitation columns (3) (YR's intention: expected precipitation) and triangles with green colors (9) (YR's intention: rather certain forecast) were interpreted as trustworthy forecasts. When using this information, the informants appeared to base their interpretations on an academic type of understanding. The words ''interval,'' ''uncertain,'' and ''expected,'' for example, were taken as indicators of this type of knowledge. Eight informants used all types of uncertainty information, whereas 13 informants used only parts of this information. However, none of the informants used all types of uncertainty information every time they visited YR. Sometimes they did not use any uncertainty information if they found other information to be sufficient, which might have resulted from them not seeing it, not seeing the benefits of it, or not understanding it. For example, four informants looked at only the cloud symbols in the diagram (Fig. 2) and did not look at the hatched precipitation columns. As a result, forecasts were sometimes interpreted with a higher degree of certainty than that intended and expressed by YR. This finding is consistent with previous studies on the interpretation of the ''cone of uncertainty'' in hurricane forecasts (Broad et al. 2007) and signals of uncertainty in popular reports of science (Norris and Phillips 1994).

5. Symbols interpreted differently than intended (because of nuances)

Cloud symbols were sometimes sufficient for informants to interpret a degree of certainty. When interpreting cloud symbols, all the informants used experience based on weather observations and weather forecasts to construct the symbol's meaning. The types of experiences included observations of precipitation (10) and cloud color (6), which were exemplified by the tour guide Nils: "When I look up and see white clouds outdoors, it doesn't rain from white clouds, so it has to be dry." There were differences in the interpretations of cloud symbols, which might result from different observations and experiences of weather. Sixteen of the informants used nuance (cloud color, number of drops and options) in the single-valued cloud symbols to interpret the degree of certainty that was expressed in the forecast; however, this was not YR's intention (YR did not intend to comment on uncertainty with the cloud symbols). For example, YR's intention was not for the gray cloud symbol to be used to indicate a greater likelihood of rain (YR's intention: cloudy). The symbol was interpreted as an uncertain forecast (5), which was shown by the farmer Marta: "There might be risk of rain on Friday…because there is a dark cloud and not a white cloud [in the symbol]." The symbols that include a sun and cloud mixed (3) (YR's intention: partly cloudy) or a cloud, sun, and drops (3) (YR's intention: rain showers) were interpreted as an uncertain forecast (6) because the forecast provided for more than one option: cloud, sun, or rain. By doing this, the informants' interpretation of a degree of certainty in the single-valued forecast was lower than intended by YR's signal. This result indicates that some of the symbols might miscommunicate for some users. At other times, the degree of certainty was interpreted as higher than that intended by YR's signal, which was exemplified by the difference in interpretations of the symbol that shows a cloud with two raindrops versus three raindrops (YR's intention: rain and heavy rain, respectively). These symbols were sometimes interpreted as more rain (12) and other times as a more certain forecast (3), or both (4). A similar result was found in a study from the United States that examined the interpretation of the symbol of a cloud with one snowflake versus a cloud with four snowflakes (National Research Council 2006). A possible explanation for interpreting degree of certainty as higher than intended by YR is provided by the farmer Daniel, who anticipated a large amount of rain (three drops) to be a more certain forecast than a small amount of rain (two drops).

There are indications that the interpretations of symbols and uncertainty information were guided by the users' view of expertise. In fact, 11 informants referred to meteorologists as authorities when they interpreted the degree of certainty in the forecast. The words "believe" (4) and "trust" (7) were considered to be indicators of a view of expertise when expressing trust in the forecasts. The farmer Marta provided such an example when asked to consider the long-term forecast:

> Marta: If that [the last day in a long-term forecast] was green [the color of triangle], then I would trust it…, that it was certain.
>
> Interviewer: Even if it was at the end [of the forecast]?
>
> Marta: Even if it was at the end, yes, because I don't know how to forecast the weather, and I think they [the forecasters] have seen on their satellite pictures that this is certain … I have faith in authorities.

Some informants trusted the forecast because they trust authority figures, which was a likely reason for the informants interpreting nuances in forecasts as trustworthy. For example, an informant might perceive the expert (the publisher of the weather report) as making a distinction between hatched and solid precipitation columns because he wants to convey information. If these nuances in information were substantial, then there would be no reason (seen from the users' perspective) for other nuances, such as cloud color, to be considered insubstantial. If similar nuances were observed in actual weather conditions, then the reasons to believe that the nuances were substantial in the forecasts would be strengthened.

6. Prior knowledge affects interpretation (and prevails over the given information)

For all the informants, the interpretations of degree of certainty were affected by experiences with forecast quality. The informants knew that forecasts could be uncertain, which was typically related to their experiences with prior incorrect forecasts. Lead time was recognized by informants as one of the factors that increases forecast uncertainty; weather forecasts were interpreted as more certain for shorter forecast lead times (9) and more uncertain for longer lead times (18). Similar results were found in a study from the United States (Joslyn and Savelli 2010). Notably, because of their experiences with prior incorrect forecasts, informants sometimes interpreted the degree of certainty as lower than YR signaled. For example, some forecast users applied prior experiences with forecast quality and these experiences were more significant in their interpretation than the triangles with colors intended to indicate uncertainty in the long-term forecast. Words such as "think," "experience," "assume," "inaccurate," and "usually" (17) were found in close reading of the transcripts and indicated that informants made use of prior experiences when considering the forecast quality to infer the degree of certainty of the forecasts. Experiences with forecast quality were sometimes more important than the information provided in the forecast. The farmer Gunnar provided an example when considering the long-term forecast:

> Interviewer: When you have a yellow [uncertainty] color on Sunday and a yellow color on Thursday some days later, do you think they are equally uncertain?
>
> Gunnar: No, that [Thursday] is more uncertain because it is further away. However, it is a green [uncertainty color] there [Wednesday], but that one is also uncertain, I think, because it is so many days ahead.

In addition, the informants inferred an expected range of uncertainty into single-valued forecasts. Temperatures (°C) (7), amount of precipitation (mm) (3), cloud symbols (3), and time (hour) (4) were all single-valued information interpreted as conveying uncertainty. The informants inferred an expected range into the single-valued forecasts. For example, the tour guide Lise commented: ''Rain is forecast at 8 p.m. However, it might start to rain a little bit earlier or later.'' The expected range varied between informants and similar results have been found for temperature, precipitation, and wind speed (e.g., Morss et al. 2008, 2010; Joslyn and Savelli 2010) but not for cloud symbols and time.

Similarly, informants sometimes interpreted the degree of certainty as lower than intended by YR when experiences with local weather affected their interpretation of the symbols. We considered informants' usage of ''experience'' and ''usually'' as indicating that they were applying their experience. Six informants used wind direction to evaluate the certainty of the precipitation forecast. The tour guide Arvid provided an example: ''If it [the forecast] shows a southwesterly wind and that it is partly sunny, and then I think it will be wrong because [in the event of southwesterly wind] it usually leads to rain.''

As previously indicated, interpretations were guided by the users' view of expertise. Eight informants did not always trust the forecast because meteorologists are not always correct, and the informants believe it must be difficult for meteorologists to make the forecast. The words ''wrong,'' ''difficult for them,'' and ''they are not always right'' (8) were considered indicators of a view of expertise when expressing distrust in the forecasts. The student, Amanda provided an example: ''I generally estimate plus or minus 5 degrees [Celsius] . . . because I think it is difficult for them [meteorologists] to forecast the temperature exactly.'' This distrust of the forecast because the informants sometimes distrust information from experts is a possible reason for why prior knowledge can prevail over forecasts. However, even informants who said they trusted the experts sometimes adjusted the forecast according to their prior knowledge. Therefore, these informants sometimes distrusted the forecast when there was a conflict with their prior knowledge.

The informant's prior knowledge was found to prevail over single-valued information and uncertainty information. This pattern of interpretation was consistent with earlier research findings that showed prior knowledge prevailing over information provided in text when there was a conflict (Dole et al. 1991).

7. Interpretations affected by the integration of information (to create a dynamic picture)

In their survey, Lazo et al. (2009) found that the time, location, and chance of precipitation were the most important pieces of forecast information. The significance of precipitation might explain why some informants in our study were often interested in weather dynamics. The dynamics (time and location of precipitation) were the main reason given for using the static and animated maps and reading the written text. Informants even created their own evaluations of dynamics by integrating nondynamic information (14), which was performed by creating a more dynamic picture (i.e., movement) of the weather than that provided by the single symbols that were initially viewed. For example, such informants considered the adjacent cloud symbols to obtain an impression of the weather that was forecast for the hours or days before and/or after the time they were interested in. The reasons offered for such behavior included anticipation that there might be a temporal displacement of the forecast (9), or the weather might be persistent, such as evaluating a dry day forecast in between three days with rain as uncertain (4). In addition, maps were used to supplement the tables to obtain an impression of how clouds and precipitation moved over the region (7). This feature appeared to provide a better dynamic picture than the information provided by tables and was used when informants thought there might be a locational displacement in the weather phenomenon in question. Three informants said that they read the written text forecast to obtain information regarding low pressure systems, which also provided supplementary information on dynamics that is not included in the tables. Informants explained that they sometimes consulted other web services as sources of weather information (5). Weather in a neighboring location was also used to determine the certainty of the forecast (1). The farmer Daniel explained:

> Daniel: So I look to see if there is approximately the same weather farther south, slightly better weather

there [looks at Kristiansand, which is below Stavanger in the forecast], then this is in a border area, so it is likely it will come, but it is not certain.

Interviewer: So you use current forecasts in neighboring areas to check the certainty of the forecast?

Daniel: Yes.

Integrating information made it possible for them not only to decide on the likelihood of the forecast but also to find additional detail as to when and where the weather was expected. Such behavior indicated that the informants evaluated the degree of certainty of the forecasts as lower than what was signaled by YR.

Certain reasons for not integrating information were identified. Six informants (four students and two teachers) cited understandability as a reason for not using parts of the information. This group had difficulties understanding precipitation amounts (millimeters) (3), wind speeds (meters per second), and directions (5) because they said that they did not relate to the numbers and wind arrows. In addition, the map was sometimes not used because it was easier to look at symbols (1), and the written text was sometimes not read because it was found to be ineffective (3) and the tables with symbols were easier to understand (3): ''There are many difficult words; it is sometimes hard to understand [the written text]'' (Kjersti, student).

However, 10 informants sometimes integrated the information to clarify what they thought was difficult to understand in the forecast. For example, maps (1) and tables (1) were used to clarify the written text forecast. The written text forecast could also be used to clarify a table (4).

Five informants found that certain combinations of information produced contradictory information, and they used this as a reason for not integrating information. These informants said that they found it difficult to use such contradictory information. More than one color on the triangles on the same day (e.g., symbol/green triangle and wind arrow/red triangle in Fig. 3) was interpreted as contradictory (1). A (white or gray) cloud in a symbol without drops combined with a numerical precipitation interval (e.g., 0–1.5 mm) or hatched precipitation columns were interpreted as ''playing safe'' (1) and made the forecast seem ambiguous (5). The painter Albert made the following comment when looking at the overview forecast:

Albert: ... when you look at the pictures [symbols], there is no precipitation, and then you look at the precipitation column [interval] and it says from zero to, but, so you kind of know, will it [rain] or is it... are the pictures [symbols] correct?

Interviewer: Who to trust the most, kind of, or...

Albert: The first impression is the pictures I look at, but then I see, gosh, it is not zero, so I have to observe the actual weather [I cannot use the forecast].

Information that was difficult to understand and information that appeared to be contradictory hampered the potential advantages of a multimodal communication approach.

8. General discussion

a. *Summary: How is the degree of certainty evaluated in a weather report?*

Previous studies on the communication of forecast uncertainty have focused on the probability of precipitation. In this study, other types of uncertainty information were explored. Notably, informants typically used only parts of the given uncertainty information, which sometimes resulted in interpreting the degree of certainty as higher (more certain) than intended (and signaled) by YR. Importantly, the results from this study show that people have several approaches to assessing the degree of certainty in a forecast that extend the use of uncertainty information. Interpretations of nuances in single-valued symbols, local experience with wind directions and forecast quality, and integration of multimodal information all influenced informants' evaluations of forecast certainty. When informants observed a conflict between information at YR and their own prior knowledge, the latter was found to prevail. They adjusted the forecast accordingly, and an expected range of uncertainty was often inferred into single-valued forecasts. The degree of certainty was typically interpreted as lower (more uncertain) than the degree of certainty intended by YR in situations where these approaches were used. In other situations, however, the opposite was true, such as when interpreting three drops in a symbol as a more certain forecast than two drops. An informant might use all the approaches, several of the approaches, or even none. The diversity in users' approaches, such as those above, makes forecast uncertainty more difficult to communicate, and provides some possible explanations for why uncertainty communication is challenging.

b. *Implications for uncertainty communication*

1) CLEAR PRESENTATION OF UNCERTAINTY INFORMATION

Interpreting the degree of certainty as lower than what was intended by the publisher and inferring uncertainty in single-valued forecasts might be beneficial (depending on how competent the user is) because weather forecasts always hold some degree of uncertainty. When uncertainty information is not provided, the users must guess (Fischhoff 1994). For example, informants sometimes inferred an expected range of uncertainty into single-valued precipitation amounts. The numerical precipitation intervals (where the expected range was estimated by YR) were typically adequately interpreted as intended by YR. Joslyn and Savelli (2010) suggested that this indicates that forecast providers might benefit from a greater degree of communication regarding forecast uncertainty. However, different interpretations of the information than what was intended by the author can be a challenge, as shown in the interpretation of the farmer Gunnar, who viewed the green color as uncertain because it was many days ahead. Similarly, previous studies found that probabilities of precipitation gave rise to divergent interpretations by various members of the public (e.g., Gigerenzer et al. 2005). In addition, there is no consensus as to which format should be used to present forecast uncertainty (e.g., probabilities, frequencies, odds, or expected ranges) among users (Peachey et al. 2013) or scientists (LeClerc and Joslyn 2012). Another challenge occurred when all the provided information was not used, such as when informants looked at only the cloud symbols in the diagram and not at the hatched precipitation columns. Uncertainty information should be easy to read, understand, and use, and the benefits should be clear such that users can interpret the degree of certainty as intended. In the literature on symbology/semiotics, there are several guidelines that explain on how to visualize uncertainty in geospatial information (MacEachren et al. 2005; Bostrom et al. 2008; Kunz et al. 2011). Except for certain robust known effects of color (e.g., red = danger) (Bostrom et al. 2008), there are few empirical studies of the visualizations of uncertainty, and there is no accepted best practice (Spiegelhalter et al. 2011).

2) All nuances in information should have an intention

When interpreting symbols, participants drew on their experiences related to actual weather. For example, the symbol with a cloud and no drops was sometimes interpreted as a chance of rain because the cloud was gray and not white. This is a natural association because gray clouds in the real world commonly signify rain. Symbology suggests using colors close to the viewers' experience when presenting a phenomenon (Bostrom et al. 2008). However, the use of color in cloud symbols is similar for the top four weather sites (see introduction) in the world; they all use nearly the same cloud color for dry weather and rainy weather. Thus, making the cloud color and precipitation more consistent in forecasts might provide less room for subjective interpretations.

When there is a conflict, it is likely that a user's prior knowledge will prevail over the information provided. For example, the tour guide Arvid trusted his experiences with local weather more than the cloud symbols provided in the forecast and evaluated the degree of certainty as lower than signaled in the forecast. Coherence between a representation and what people normally see (actual weather) influence trustworthiness (Kress and van Leeuwen 2006); some people might ascribe to such a forecast a higher degree of certainty than they would without coherence. Such a situation might lead to interpretations of weather and a degree of certainty that is more consistent with the intention of the publisher. The interpretation of symbols that diverge from the publisher's intention should be considered a communication challenge (not as misinterpretation) in which the forecast provider has the main responsibility. Although differences in interpretation make communication demanding, an awareness of such differences can contribute to better and more informed communication. For example, more nuanced symbols that use colors close to viewers' experiences might help avoid certain conflicts and provide less room for subjective interpretation.

3) Thorough use of multimodal information in communication

Some informants integrated information from several representations when interpreting the presented weather forecast. Because the additional representations were, to some extent, complementary, this approach produced a broad (and dynamic) picture of the weather that was used to clarify information and evaluate forecast certainty. Multimodality in forecast communication appeared to be an advantage for certain users of the online weather forecasts because these informants were able to select what information to use and combine different types of information. All the informants found some information that they liked and understood and some users combined several representations to obtain a richer forecast. One possible explanation for integrating information was that the forecasts were known to be uncertain (prior knowledge). For example, when evaluating the degree of certainty in the precipitation forecast, the farmer Daniel used his experiences with air pressure information provided in the map to supplement the hatched precipitation columns in the diagram. Therefore, multimodality might be a beneficial approach to communicate uncertain information because people appear to respond well to multiple displays of the same information (Spiegelhalter et al. 2011). In a similar example, LeClerc and Joslyn (2012) found that probabilities were useful in normal weather conditions, whereas odds performed better in situations with low probabilities and extreme conditions compared with decisions made in such conditions based exclusively on deterministic forecasts.

In situations with apparent contradictory information, such differences made it difficult to understand and use the information. For example, a white cloud in a symbol combined with a precipitation interval from 0 to 1.5 mm was interpreted as ambiguous. Conflicting forecast information can increase confusion, and the consistency of the representation is thus often crucial for effective communication (National Research Council 2006).

4) UNDERSTAND USERS' NEEDS

Improving our understanding of the differences among informants appears to be one promising research direction. Some informants in our sample might have lacked certain types of experiences and were therefore unable to relate to wind speeds and precipitation amounts. Alternatively, they might have had the required experience but did not systematically consider such information or were not triggered or stimulated by YR to use such information. In either case, this lack of weather awareness made it more difficult for some informants to understand the forecasts. Clearly, if the informant does not understand the information, it is not possible for them to use it to determine the degree of certainty in the forecast. In general, experience must be developed by comparing forecasts with actual weather so that symbols correlate correctly with weather situations and signals from forecast providers confer accurate evaluations of uncertainty. Difficulties in interpretation might arise because it is demanding to transfer knowledge from one situation (terms learned at school) to another (authentic texts and situations in daily life) (Anderson et al. 1996).

c. Conclusions

The results from this study supplement previous research studies regarding uncertainty communication in weather forecasting. Uncertainty information provided by the forecasts was partially used. In addition, several other approaches that were used to assess the degree of certainty in a forecast extended the use of uncertainty information and included: the interpretation of nuance in symbols, prior knowledge prevailing over forecast information, and the integration of information to determine the time and location of precipitation. Thus, the degree of certainty was often evaluated differently than intended by the forecast publisher. A clear presentation of uncertainty information, a clear intent with all nuances in information, thorough communication of multimodal information, and consideration of users' needs can contribute to improve the communication of forecast uncertainty.

Our focus on YR and how their forecasts are communicated can also be informative for other online weather web services. However, the qualitative nature of the data and analyses implies that claims cannot be made regarding the frequency of occurrence in the wider public. Our contribution is to have identified different approaches used by laypeople to evaluate the degree of certainty in a weather report.

More research is required for an in-depth exploration of the types of situations in which information is integrated or one representation is considered sufficient. Such an exploration might help forecast providers understand how to best use multimodal information in weather reports. Another topic for future research is the exploration of situations in which uncertainty information is used or omitted and when other approaches are used. Ideas regarding how to present expected ranges of uncertainty, for temperature, precipitation, wind speed, cloud symbols, and time should also be studied further. Finally, we suggest in-depth exploration of when and why prior knowledge prevails over forecast information.

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