Oh no, it's raining!

A Study of how Information in Online Weather Reports is Interpreted, Integrated, and Used in Everyday Decision-Making by Laypeople

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Scientific environment

This study was performed at the Norwegian Meteorological Institute (MET Norway) in close collaboration with the Department of Physics and Technology at the University of Bergen. Three months of the PhD study was spent at the University of St Andrews in Scotland. In addition, a few days were spent at the University of Stavanger.

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You tread the path with me and are the light of my life.

Home is behind, the world ahead,
And there are many paths to tread
Through shadows to the edge of night,
Until the stars are all alight.
Then world behind and home ahead,
We'll wander back and home to bed.
Mist and twilight, cloud and shade,
Away shall fade! Away shall fade!
Fire and lamp, and meat and bread,
And then to bed! And then to bed!

(Tolkien, 1994, p. 76)

And Jonas, now I can spend even more time playing with you!

Perspective: The history of weather forecasting

For the interested reader, this chapter provides supplementary information regarding the historical development of weather forecasting and communication of the forecasts. This background may help place the work described in this PhD study within a wider context.

Information on future weather conditions has historically been important to people in industries such as farming, fishing, and sailing. Because of their dependence of the weather, people have always attempted to predict the weather (Smits, 2009a). Different approaches, based on various ideas, concepts and models have been implemented with varying success. Meteorologists were not available to issue weather forecasts in previous centuries, but experience accumulated over generations was used to predict the weather for millennia. For example, weather sayings date to Assyria and Babylonia, and runic calendars were employed for centuries (Smits, 2009a). Information was communicated orally and by symbols carved into wood or stone. Predictions provided few details and were highly uncertain.

The use of almanacs as early as the 3rd century was a primitive attempt to incorporate science into weather forecasting (Smits, 2009b). The idea was that weather was closely associated with star and moon phases and would repeat when these phenomena repeated. Daily weather predictions were made based on previous weather observations, for example, for one year in the future (Smits, 2009b). Words and symbols printed on paper replaced carvings in wood and stone in one-way communication between scientists and laypeople. The scientific approach should have represented an improvement over traditional knowledge. However, it was not until the middle of the 19th century that weather predictions were simplified and presented as climate information in the Norwegian almanac. As Carl Fearnley, professor in astronomy, said in 1865: “The predictions were not just useless, they were misleading” (Smits, 2009b, p. 12). Scientists now understood the conceptualization used for the predictions was flawed.

The Crimean War (1853-1856) is recognized as the beginning of modern weather forecasting, as scientists began to realize that weather systems moved from one location to another. The novel concept was that if you could observe weather in different places and send the observations by (recently invented) telegraphy, people could be warned of future weather events. Several countries established meteorological institutes and began to “hint” about the weather for the following day. Although it was incomplete, this method of conceptualization was no longer flawed and enabled more certain predictions than before. Forecasts were now communicated using various approaches. For example, texts were placed in central locations. In Norway, symbols were attached to trains traveling from Christiania (Oslo). The institute informed people that the forecasts were incorrect 2 out of 10 times and that the accuracy of the forecasts decreased for locations far from Christiania (Smits, 2009c). Some early predictions of weather (19th century) were called probabilities and indications rather than forecasts (National Research Council, 2006).

In 1919, Vilhelm Bjerknes and the Bergen School of Meteorology invented the Polar Front Model. This model was based on similar concepts but enabled a more complete conceptualization. The interpretation of meteorological observations enabled weather forecasts with greater accuracy. As meteorology evolved during the 20th century, the uncertainties in the forecasts were by some viewed as a weakness (National Research Council, 2006). The more precise predictions became deterministic and were providing a single value for parameters, without statements of uncertainty (National Research Council, 2006). However, presenting uncertain information as certain may be misleading (May, 2001).
In the 1970s and 1980s, computer-based weather forecasts (numerical weather predictions) became more prevalent in operational forecasting (Lynch, 2008). Computer power has continued to increase, which enables more complete conceptualizations, improvements in models and predictions that are made hours, days, and weeks in advance. The improvements in models should reduce uncertainty in the predictions. Although most forecast information still is deterministic, there is a movement toward again including more uncertainty information (National Research Council, 2006; Joslyn & Savelli, 2010).

Weather forecasts are continuously communicated through new media such as radio, television, and the Internet. Written and spoken words as well as symbols and other graphics are employed. The popularity of online weather reports has increased, and multimodal forecast information dominates communication, which (in a historic perspective) primarily consists of one-way communication from experts to laypeople. This study intends to encourage meteorology to keep up with the new trend of more two-way communication between experts and laypeople. Such a dialog can help create and provide useful information that can inform people's decisions.

Abstract

Different people in different occupations depend on weather forecasts to plan their work and recreational schedules. People with no expertise in meteorology frequently interpret weather forecasts and uncertainty information. These non-experts apply their prior knowledge and experiences in a variety of fields and their abilities to synthesize different types of information to interpret forecasts. Initial studies of communication and the interpretation of forecasts and uncertainty information focused on separate pieces of information rather than the situations of ordinary users. In this study, situations of typical users are simulated to increase the ecological validity when examining how different user groups interpret, integrate, and use information from online weather reports in their everyday decision-making. First, qualitative interviews of twenty-one Norwegians from five different user groups (farmers, exterior painters, tour guides, and upper secondary school teachers and students) were conducted. Second, sixteen upper secondary school students participated in an eye-tracking study. Immediately after this study, the participants were asked to verbalize their thoughts (think out loud) when viewing the gaze data. Semi-structured interviews were conducted to ensure the collection of rich data. In this study, the participants were given weather forecasts from one selected online weather report (www.Yr.no), which served as a basis for both data collections. The verbal data were analyzed by assigning codes and categories to the transcribed statements.

The main findings of the study are as follows: a) For each representation, such as tables, diagrams, numbers and symbols, a set of strengths and functions (affordances) was ascribed and exploited by the participants. b) Only part of the representations that provided forecast and uncertainty information at the website was used by each participant. c) Nuances such as color and the number of drops were important in the interpretations of the weather symbols and forecast uncertainty, which were sometimes interpreted differently than intended by the forecast provider. d) Prior knowledge affected the participants' interpretations and even superseded the given information in

apparent conflicts. e) The interpretations were also affected by the integration of information from different representations, which was performed to create a dynamic picture of the weather and to control and compare information. f) The decision-making process influenced the construction of different reading paths and the selections of representations in different situations. g) The participants used a varying amount of information in their decision-making; their selection was dependent on the importance of the envisaged activity and the weather conditions for the day. h) Additionally, in situations in which the participants had a lack of experiences, this lack provides a possible explanation for why part of the information was occasionally not understood and used. i) Evaluations of weather dynamics and the degree of certainty in the forecast were disregarded when quick decisions were made.

Some implications of the findings for communication and future research are as follows: a) Providers of online weather reports should take care in the details of the information they present because such nuances may be interpreted as substantial information. b) Uncertainty information should be easy to understand and use, and the benefits of this information should be clear to enable users to interpret the degree of certainty as intended. c) Information communicated in online weather reports should enable the use of different decision-processes. d) A comprehensive use of multimodal information in communication appears to be an advantage when information is used by different users in different situations. e) However, some users should be guided and supported to facilitate the interpretation, integration, and use of information from multiple representations in situations where they lack experiences and/or aim for an elaborate decision process. f) One possibility to support persons that lack experiences and have low situation awareness might be to provide consequences and impacts of forecast weather. g) Notably, forecast providers should take into account the needs of the forecast users. h) To achieve this goal, users' needs should be addressed in a co-production process. i) Future studies should investigate the situations of typical users and different decision-making processes.

List of publications

Sivle, A. D., Kolstø, S. D., Hansen P. J. K., & Kristiansen, J. (2014): "How do laypeople evaluate the degree of certainty in a weather report? A case study of the use of the web service Yr.no", Weather, Climate, and Society, Vol. 6: 399-412. ©American Meteorological Society. Used with permission.

Sivle, A. D. & Kolstø, S. D. (In press): "Use of online weather information in everyday decision-making by laypeople, and implications for communication of weather information", Manuscript accepted for publication by Meteorological Applications. Used with permission.

Sivle, A. D. & Uppstad, P. H.: "Students' meaning-making when reading multimodal science information", Manuscript in review by Visual Communication. Used with permission.

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Outline of the thesis

Chapter 1: In addition to motivations for the study, background information on multimodal reading and meaning-making, human decision-making, risk and uncertainty, and communication between experts and laypeople is provided.

Chapter 2: Certain methodological considerations are presented. An explanation of the interviews and eye-tracking and a discussion of the strengths and weaknesses of the interviews and eye-tracking as methods are provided. Finally, there are two short discussions of generalization of findings and study ethics.

Chapter 3: The three papers of the study are introduced.

Chapter 4: A summary of the lessons learned from the study is provided, before I discuss research-based weather communication, communication and learning of terms, and decision-making and accidents.

Chapter 5: A brief concluding summary and suggestions for future studies are provided.

Aims of the thesis

The overarching aim of this study was to identify different interpretations, integrations, and uses of the weather forecasts and uncertainty information on the website www.Yr.no (hereafter: Yr.no). Selected user groups were included in the study to identify a variety of forecast interpretations and to determine whether their interpretations were as intended by the forecast provider when making decisions for everyday weather-dependent activities. Moreover, the study aimed to identify the representations (e.g., tables, symbols, and verbal text) that were used, and the reasons for integrating and using various representations.

This study is motivated by and provides insight into the communication process between forecast providers and the end-users and discusses the implications of the findings for the communication of information in online weather reports.

Research questions

To fulfill the aim of this study, the following question was articulated:

How is information in online weather reports interpreted, integrated, and used by laypeople when making everyday decisions for weather-dependent activities?

To address this question, three research questions are presented and answered. Answers to the first question, which is addressed in the first paper, provide insight into how information on the website was interpreted and integrated by laypeople. Evaluating how previous knowledge and experience were employed in the interpretations enabled the formulation of suggestions regarding how to design the communication of the forecasts. The second question, which is addressed in the second paper, provides insight into how forecast information is used by laypeople in different everyday situations when making decisions regarding weather-dependent activities. Answers to the third question, which is addressed in the third paper, is a more theoretical contribution to how non-experts access and use multimodal weather information. This study provides a deeper understanding of how laypeople make meaning in online weather information by exploring their reasons for using different pieces of information in a decision-making context.

The research questions (RQ) of the study are as follows:

1) *How is information in an online weather report interpreted and integrated by laypeople with respect to the degree of certainty, and how is previous knowledge employed in the interpretations?*

2) *What factors influence the amount of information used by laypeople in (hypothetical) everyday situations involving the use of online weather forecasts, and how is complex and uncertain information from Yr.no handled when making decisions for weather-dependent activities?*

3) *What reasons do laypeople give for: a) reading the various representations on a multimodal website, b) constructing reading paths, and c) making transitions to another representation?*

1. Setting the scene

1.1 Introduction

First my personal and professional motivations for this study are presented in Section 1.2. The first and third research questions concern the reading of multimodal information and meaning-making, and Section 1.3 is giving an overview of theory on these topics, including interpretation and integration of information. The second research question addresses decision-making. Literature from three areas, decision theory, risk communication, and science communication, is also highlighted by von Winterfeldt (2013) as relevant to bridging science and decision-making. For this reason, Section 1.4 discusses theory on information processing and human decision-making, and rationality. In Section 1.5, background on risk and uncertainty is presented. Finally, all research questions relate to public communication. Therefore, Section 1.6 provides an overview of models that describe communication between experts and laypeople.

1.2 Motivations for this study

1.2.1 My motivations

After finishing my master's degree in meteorology, I began working as a weather forecaster at the Norwegian Meteorological Institute (MET Norway) in 2006. One of the things I loved about this job was the daily contact with end-users and the amount of feedback they provided. Most people did not indicate that they were satisfied with a forecast; rather, they described problems that were attributed to an inaccurate (perception of the) forecast. Their feedback is useful because we (the meteorological society) make attempts to improve the quality of our forecast. Over time, my interest in the communication aspect of the forecasting process increased, especially regarding the words and sentences used to write a text forecast or when talking to newspaper or radio journalists. In 2007, MET Norway and the Norwegian Broadcasting Corporation (NRK) began to provide forecasts on the new web service Yr.no, which involved a shift to a greater use of graphics (e.g., symbols) to express the forecasts. My interest in communication also shifted toward graphical forecasts. To learn more about communication, I began taking part-time teacher education in 2009. When working as a forecaster, I experienced the feeling of having a clear impression of weather developments and of communicating a clear message to the public from time to time. However, I also received feedback from users who were unsatisfied with the forecast on such occasions. Thus, it seemed that some users interpreted the forecast differently from what I had intended. Other forecasters described similar experiences. I spent some time in the library and online to research the field of forecast communication. Unfortunately, I could not find as much information as I could like, and was not satisfied. After completing my teacher education in spring 2011, I was confident that improvements in the communication of weather forecasts were possible. I was ready to pursue a PhD to investigate the communication of weather forecasts to the public. My goal was to learn how laypeople interpret, integrate, and use information in online weather reports when making decisions, and I hoped the results could be used to improve communication.

I find some limitations concerning the extent of the study worth mentioning. The Norwegian Meteorological Institute communicates their forecasts in several media. For example, weather services to governmental agencies are communicated at the web-service halo.met.no, and forecasts for military purposes and civil aviation have other channels. Weather forecasts to the public are communicated at the web-service Yr.no, in addition to on radio and at television. Extreme weather events are communicated in all channels, but in separate forecasts. To limit the scope of my PhD-thesis, I aimed to study non-experts` use and interpretation of weather forecasts communicated at the web-service Yr.no for everyday decision-making about weather dependent activities. For this reason weather forecasts and decision-making involving extreme weather events and huge decision stakes were not included.

1.2.2 Professional motivations

Information from weather forecasts can help people take appropriate actions to protect their lives, property (Schultz et al., 2010) and well-being, that is, to make informed decisions. Informed decision-making leads to desirable outcomes and prevents unnecessary costs to society (Pielke & Carbone, 2002). The study of how people make decisions based on information from weather forecasts is important to improving the communication of forecasts. Improved communication can contribute to increased forecast value for users (Stuart et al., 2006) and help them make informed decisions. However, there is limited understanding of how information from weather forecasts is applied in decision-making (Morss et al., 2010). Previous studies are primarily concerned with interpretations of independent forecast information and do not address the situations of typical users. Thus, how laypeople make decisions in the context of a full weather report should be explored (Morss et al., 2010). As of May 07, 2016, the top five (in terms of daily visitors and page views) weather websites in the world are Weather.com, Accuweather.com, Wunderground.com, Weather.gov, and Yr.no (Alexa, 2016). All five sites include multimodal information, that is, they feature different forms of representation, such as tables, symbols, maps, diagrams, and verbal text forecasts. The integration of information from different representations may affect decision-making and is interesting to study in more detail.

The atmosphere is chaotic; it is “sensitive dependent on initial conditions” (Fjelland, 2002, p. 160). Because the initial conditions (meteorological observations) are not precisely known, it is impossible to provide a prediction of the future conditions of the atmosphere with certainty, i.e., the forecast is more or less uncertain, although models are continuously improving and there are an increasing number of observations. The trend is to include more uncertainty information in weather reports (Joslyn & Savelli, 2010); the top five weather sites provide uncertainty information in addition to single-valued forecasts. When considering the hourly presentations of weather forecasts for a given area, it can be easy to forget that weather forecasts remain predictions and, therefore, are uncertain. The communication of forecast uncertainty has considerable potential value to society and users of such forecasts and could enable more informed 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 are not well understood. How different types of uncertainty information are interpreted and how single-valued forecasts are interpreted in the context of uncertainty should be explored (National Research Council, 2006; Morss et al., 2008).

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AFRICA AMERICAS ASIA PACIFIC EUROPE MIDDLE EAST

Italy Orders Jail Terms for 7 Who Didn't Warn of Deadly Earthquake

Alessandro Bianchi/Reuters

L'Aquila on April 6, 2009, when a quake struck, killing 309 people.

By ELISABETTA POVOLEDO and HENRY FOUNTAIN

Published: October 22, 2012

The Telegraph

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Belgian tourism officials 'suing weather forecaster over rain predictions'

Tourism officials at several Belgian resorts plan to sue the weather service about a long-term forecast for a rainy summer which led to widespread holiday cancellations.

The Belgian seaside resort of Knokke-Heist Photo: Alamy

By Martin Banks in Brussels

1:53PM BST 09 Jul 2012

Print this article

Figure 1: The article published on www.nytimes.com (left), October 22, 2012, tells the story of the seven Italian earthquake experts who were sentenced to prison for not predicting a deadly earthquake (Povoledo & Fountain, 2012). The article published on www.telegraph.co.uk (right), July 09, 2012, indicates that Belgian tourism officials plan to sue the weather service due to its long-term weather predictions (Banks, 2012).

It is important to communicate uncertainty and to avoid appearing more certain than you are for several reasons. In 2012, seven earthquake experts in Italy were sentenced to six years in prison for murder because they did not warn people about the risk of an earthquake (Figure 1). (Six of the experts were exonerated in November 2014, and the sentence of the seventh was reduced.) Could something similar happen to a meteorologist for not forecasting an extreme weather event? Some media reports indicate the possibility of legal action against weather services (Figure 1). Perhaps both forecast providers and the public can benefit from improved communication (of uncertainty). At the same time, it is important not to be too afraid of errors and not to expect forecasts that are never wrong. Meteorologists should communicate what they know and how certain they are about what they know. Improved communication of weather forecasts is expected to be of greater importance than improved model development in the future (Stuart et al., 2006). The present study seeks to contribute new knowledge concerning forecast communication to end-users by examining the communication of information (including uncertainty) in online weather reports.

The topic in this study is highly multidisciplinary. Meteorology, social semiotics, reading and literacy, science education, science and risk communication, decision-making and psychology are all among the potential fields of study to be considered. Writing the thesis was thus a challenging task due to tough choices in selecting literature to include and explore in light of the constraints limiting this work. In other words, although the following literature review is extensive, it is not exhaustive.

1.3 Multimodal reading and meaning-making

"People need a diverse set of cognitive, social, and emotional skills in order to understand the information that they receive and to interpret its relevance for their lives... They can acquire those skills through formal education, self-study, and personal experience" (Morgan et al., 2002, p. 2).

When a user receives a weather report, she must listen to it or read it to make meaning and utilize the information. Visual information (graphical representations such as tables, symbols, maps, graphs, diagrams, and photographs) dominate all of the world's top five weather sites (see above). In addition, all five sites provide verbal information. Thus, online weather reports, composed of multiple representations, are well suited for the examination of multimodal reading - that is, how the information is interpreted and integrated to make meaning of it. Moreover, all weather forecasts are uncertain, and users must assess the truth value of the information. Studying how people interpret and use information to make meaning in a weather report is valuable for understanding, and subsequently improving, communication and usability. In turn, improved communication can lead to improved decision-making.

In the following subsections, I summarize the following literature relevant to this work (RQ1 and RQ3 in particular): Multiple representations and multimodality (subsection 1.3.1); interpretation (subsection 1.3.2) and integration (subsection 1.3.3) of information related to multimodal reading; and, finally, truth value (subsection 1.3.4).

1.3.1 Multiple representations and multimodality

In recent years, graphical representations have been used more frequently and with greater variety for communicating information (McTigue & Flowers, 2011), for example in weather reports. Both paper and digital media texts are increasingly multimodal (Unsworth & Cléirigh, 2014). Graphics are assumed to help readers to focus on the reading material by guiding their attention (particularly to the illustrated parts) and to develop interest and motivation toward the reading material (Hannus and

Hyönä, 1999). The students in McTigue and Flowers (2011) believed that the purpose of diagrams was to represent visually what was in the text. Although this purpose is common, other not-considered purposes exist. For instance, graphics can convey unique information or serve as an orientational tool (McTigue & Flowers, 2011). If the reader does not know possible functions, the graphics might be undervalued (McTigue & Flowers, 2011). In the present study, the reading of a multimodal weather report is examined in more detail.

I introduce below two related concepts used in this study that provide an important background for multimodal reading and meaning-making: *multiple representations* and *multimodality*.

Writing from a science education perspective, Tang et al. (2014, p. 306) states that "*representations* are artifacts that symbolize an idea or concept and can take the form of for instance verbal texts, diagrams, graphs, and simulations". Representations are meaningful for the designer; however, to others, they are only a collection of writings and drawings initially devoid of any meaning (Tang et al., 2014). From Vygotsky's (1986) sociocognitive theory, representations are understood as tools that mediate social learning and human cognition (Tang et al., 2014). In other words, a representation is viewed as an intermediate agent, between the sender and the receiver of a message, contributing to the meaning-making process. In principle, this process also includes written words because these are also signs. The term *multiple representations* denotes the practice of representing the same concept or type of information through different representational forms (Tang et al., 2014). This situation exists for many weather reports, such as Yr.no, in which, for example, precipitation is represented by the use of verbal text, as symbols in a table, or as spatial information in a map or animation.

Modes are different culturally and socially produced physical resources for representing different aspects of a phenomenon (Kress, 2005). Thus, different representations of a phenomenon are expressed using different modes. There are many different modes, for instance sound, gesture, gaze, and layout (Jewitt & Kress, 2010). In the present study, the modes of words and graphics are examined. Lemke (2005) claims that different semiotic modalities are essentially incommensurable; in other words, for example, a verbal text cannot convey the same meaning as an arrow or a number. Moreover, Kress (2003) claims that different modes will typically have different affordances (explained more in detail below) (Bezemer & Kress, 2008). For example, in the verbal mode, a forecaster can report local rain showers without being more specific about their distribution. In the visual mode, however, a map must show the spatial distribution of the showers. In other words, a verbal and visual depiction of the same thing can be thought of as two different representations of the same phenomenon (Unsworth & Cléirigh, 2014). In scientific communication, meanings are typically made by the joint co-deployment of two or more semiotic modalities (Lemke, 2005); that is, the communication is *multimodal*. Sometimes, the information is presented almost simultaneously in the two modes, for instance a TV weather forecast in which the verbal and visual information is presented at the same time. At other times, the information is first read in one mode and presented later in another (Lemke, 2005), for example, due to the spatial organization of a website. In multimodal communication, concepts and information are not defined by the common denominator of their representations but by the union of meanings implied by all of these representations (Lemke, 2005). The meanings being constructed are joint meanings produced in the intersection of different modes, thus multiplying the set of possible meanings that can be made (Lemke, 2005).

Interestingly, all texts can be considered multimodal, but some texts are more multimodal than others are (Baldry & Thibault, 2010). For example, a verbal text creates meaning via the words but is also dependent upon a combination of for example font, color, and spatial (layout) resources (Baldry & Thibault, 2010). The use of headings, boldface and font size signals emphasis or significance (Lemke, 2005) and tells the reader how he should orient and where he should focus his attention.

The present study focuses on online weather reports, which typically are distinct multimodal texts that combine words and graphics. Thus, in the following, I specify whether I am referring to a text consisting of only words by referring it as verbal text. Otherwise, I use the term text when talking about distinct multimodal texts combining words and graphics.

Many multimodal studies are based on Halliday's (1978) theory of social semiotics (i.e., the study of sign systems and their use in meaning-making as a function of a social process (Tang et al., 2014)). Similar to multimodal studies, it is common in studies of multiple representations to consider the modality of representations (Ainsworth, 2006). Hence, many studies of multiple representations are also rooted in semiotics, an area Andersen et al. (2015) refer to as human meaning-making. In addition to this similarity between the two research traditions, Tang et al. (2014) note the use of different units of analysis as a difference between them. *Grain size* refers to such a unit of analysis, ranging from elements (fine grain size) such as words and paragraphs or lines and symbols to a representation as a whole (large grain size) (e.g., verbal text or a diagram) (Tang et al. 2014). Research on multiple representations is typically of large grain size and focuses on the relative effectiveness of single representations or combinations of these (Ainsworth, 2006; Tang et al. 2014). Research on multimodality is usually of fine grain size, and tends to consider how people integrate various modalities to produce meaning, and can help determine why a given configuration or type of representation is more effective than another is (Tang et al., 2014). For instance, although a multiple representation analysis can show that two different representations lead to different explanations, a multimodal analysis can reveal how and why the representations support different explanations (Tang et al., 2014). Conversely, a multimodal analysis alone would miss important contextual information from the multimodal representation analysis (Tang et al., 2014). In other words, it is important to consider both research traditions to understand readers' meaning-making and learning through representations, because each analysis plays a mutually complementary role in these processes. Thus, Tang et al. (2014) attempt to integrate research on multiple representations and multimodality by considering and integrating both analytical levels.

The present study attempts to expand on previous research by examining how (RQ1) and why (RQ3) different modes and representations in a weather report are interpreted and integrated by selected user groups of laypeople. Making meaning from multimodal texts, that is, *multimodal reading*, relies on comprehending not only verbal text (words) but also the graphics (Hannus & Hyönä, 1999; McTigue & Flowers, 2011). Thus, to master multimodal reading, readers must *interpret* and *integrate* information from several modes and representations found in the text (Solheim & Uppstad, 2011). In the following subsections, I review literature describing these two key processes, interpretation (1.3.2) and integration (1.3.3) of information.

1.3.2 Multimodal reading: Interpretation of information

From a behavioristic view of reading, meaning resides in the text itself, and the goal of the reader is to reproduce that meaning (Dole et al., 1991; Pearson & Cervetti (2015). This view of reading was dominant prior to the mid-1960s (Pearson & Cervetti, 2015). Thereafter, research on reading comprehension has resulted in a new understanding and a different view of reading. Now, reading is typically viewed as a more complex process (Dole et al., 1991) in which the text, the reader, the social and cultural context, and the task all are important variables in the meaning-making process (Pearson & Cervetti, 2015). In contrast to the behavioristic view, cognitively based views of reading emphasize that all readers use their existing knowledge and cues from the text and situational context in which the reading occurs to construct meaning from the text (Dole et al., 1991; Pearson & Cervetti, 2015). Interpretation is a key process for making meaning when reading (Dole et al., 1991). The reader must interpret elements of a representation (fine grain size) and interpret the representation as a whole (large grain size) to make meaning of the information. Building on Halliday's systemic functional linguistic (1985), Lemke (2005) argues that all such meaning-making is organized around three generalized semiotic functions. The process of how this meaning-making occurs is described below in the context of Lemke's (2005) presentational, orientational, and organizational functions.

When making meaning of a text, the reader identifies the elements she recognizes and constructs a *presentation* of what elements are being shown (Lemke, 2005). Interpretations of what we see are not fixed; words and graphics are relatively empty entities, to be filled with meaning (Kress, 2005). For example, when viewing a weather report, a line with a pointed head can be recognized as an arrow.

The reader *orients* to this presentation and orients it to others, establishing the tone between the reader and the text/sender (Lemke, 2005). The interpretation of elements in a representation depends upon the person, task and situation in addition to historical and cultural conventions (Kress & van Leeuwen, 2006; de Vries et al., 2009). For example consider an arrow in a weather report. A girl daydreaming of her boyfriend whom she is head over heels in love with might interpret this arrow as a sign of love (refers to Cupid's arrows in classical mythology). The same, or another, girl reading the weather report and planning for windsurfing might interpret an arrow as a sign to illustrate the speed and direction of the wind. In other words, interpretations are not made in a void. The reader orients to what she sees and who the sender is (orientational function) and assesses the information as good or bad and as necessary or irrelevant. She also evaluates its certainty (Lemke, 2005, Knain, 2015). The orientation is done in the context of larger social relationships between the reader and the sender and against the background of other information known in the particular community and available to the reader (Lemke, 2005). Meaning made with one representation depends upon prior meanings made with preceding representations across space and time (Tang et al., 2014). When the situation is familiar, little effort in interpretation is required (Knain, 2015). Then, the reader has experiences from similar situations and expectations of what appropriate interpretations are (Knain, 2015). For example, a weather report is a specific text genre, and a person knowing this genre is more likely to interpret an arrow as a sign of wind and not as a sign of love because of expectations related to this genre and experiences from similar situations. Moreover, the meaning of a representation is constantly transformed by its users; the more it is used in a community, the more fully and finely articulated its meaning becomes (Jewitt, 2008). Thus, meaning is made through use in the social life of a particular community, differs among societies (Kress & van Leeuwen, 2006; Jewitt 2008), and more than one relevant interpretation is possible (Pearson & Cervetti, 2015). In other words, readers can interpret information in a weather report differently. For example, in this study, local knowledge is found to be important when interpreting a weather report. A person can have different experience with westerly winds where he lives (e.g., it typically rains) and where he is on holiday (e.g., it is sunny). Hence, when reading a weather report indicating westerly winds, he has two possible interpretations - either rain or fair weather. When interpreting the information, he must consider the local context (where he stays) to select the more consistent interpretation. Notably, one representation can hold several elements, and it is possible to make meaning of one element and not another. For example, when reading a table on Yr.no, it is possible to make meaning of the precipitation information without understanding the wind information. How selected users interpreted multimodal information on Yr.no and how they called upon prior knowledge in their interpretations is examined in the present study (RQ1). The reasons provided by the participants for reading the different elements in the weather report are also examined (RQ3).

When making meaning of a text, the reader also creates an *organized* structure of related elements (Lemke, 2005). Grammar involves how elements are combined into a meaningful whole (Kress & van Leeuwen, 2006). In linguistics, the following two theories have been employed most often: Chomsky's Universal Grammar (UG) and Halliday's Systemic Functional Linguistics (SFL) (Bavali & Sadighi, 2008; Almurashi, 2016). These two theories have been developed almost independently of one another, and although there are differences with respect to grammar, they seem to complement each other (Bavali & Sadighi, 2008). Systemic Functional Linguistics has been useful in educational research and has been applied to interpret the grammar of semiotic modes other than words such as visuals (Almurashi, 2016). Hence, this view on grammar is adopted in this study. Similarly to the manner in which the grammar of language describes how words combine in clauses and sentences, visual grammar adds structure and meaning to otherwise unspecific graphics by allowing these graphics to be organized and interpreted according to conventions (Lemke, 2005; Kress & van Leeuwen, 2006; Baldry & Thibault, 2010). Building on Halliday's systemic functional linguistic (1985) grammar is not viewed as a set of formal rules for expressing meaning (i.e., a UG view); rather, grammar is the realization of meaning (Bavali & Sadighi, 2008; Knain, 2015). We shape experiences into meaning with grammar (Knain, 2015); hence, grammar relates to Lemke's (2005) semiotic functions. Graphics are not intuitive (McTigue & Flowers, 2011), and visual language is not universally understood but rather is culturally specific; for example, Western visual communication is affected by our convention of writing from left to right (Kress & van Leeuwen, 2006). This feature of visual space affects the meaning that the reader ascribes to compositional patterns; for example, the horizontal structure of images exhibits similarities to the sequential structure in language (Kress & van Leeuwen, 2006). Therefore, in addition to interpreting the elements of a representation, it is necessary for the reader to understand the representational system to comprehend the representation as a whole - which elements the reader prefers to read in relation to which other elements, and what goes with what. This organization of verbal and visual elements into regions and a whole, and the relationship between regions and the whole, is explained by Lemke (2005) as the organizational function. Some representation systems are challenging to learn spontaneously due to their high level of formalization, and difficulties are especially patent in the learning of science and mathematics (Echeverría & Scheuer, 2009). Understanding the system involves knowing how to process the information in the representation, and different representations require different processes (de Vries et al., 2009). For example, finding the maximum wind speed in a wind/time diagram at Yr.no requires the reader to decipher the coordinate system and the two axes of the system. Finding the maximum wind speed in a table requires a different process. In this system, the data are arranged in rows and columns, and these must be comprehended by the reader to make meaning of the information. Thus, a reader might understand that the arrows indicate the wind speed, but if he does not understand the table as a system, it is not possible to determine what the wind speed is at a certain point in time. If the reader lacks context or knowledge of the representational system, it can be impossible to make meaning due to the (spatial, temporal, material or cultural) distance between the producer and the user of the system (de Vries et al., 2009). Hence, understanding the representational system also relates to Lemke's (2005) orientational function. Lemke (2002) claims that people typically focus consciously only on the presentational function. For the orientational and organizational function, people typically rely on familiarity and automate their use unless in special circumstances (orientational function) or for professional users (organizational function) (Lemke, 2002). In the present study, the participants provide reasons for using different representations in a weather report with multiple representations (RQ3). The results from this study can therefore contribute knowledge concerning the understanding of representational systems.

The second key process of meaning-making related to multimodal reading is integration of information, and this process is described in the next subsection.

1.3.3 Multimodal reading: Integration of information

Similar to other interactive multimodal texts, online weather reports are not primarily linear but are relatively open in their organization; they are not meant to be read according to a unique implied sequence (Lemke, 2005; Yerushalmy, 2005). These texts are not only multimodal; rather, they are hypermodal, in which the text is organized in a web of pages (Lemke, 2002). Although the sender may attempt to control the reader's course of action through text organization (Yerushalmy, 2005), the process of reading multimodal information is discontinuous and generates certain expected and other unexpected *reading paths* (Baldry & Thibault, 2010). What is considered important is claimed to be culturally determined; therefore, members of different social groups are likely to construct different reading paths (Kress & van Leeuwen, 2006). Rather than following a linear sequence, the reader may jump to various clusters of elements in a fixed sequence. Readers use these clusters and the relationships between them to make meaning in a specific context, that is, meanings are developed along the reading path. Because the clusters are not separate but are *combined and integrated* to form a complex whole that cannot be reduced to its separate parts, combining them can have a synergistic effect that cannot be derived from either mode separately (Baldry & Thibault, 2010; Unsworth & Cléirigh, 2014). The elements to be integrated can be located in the same representation (fine grained), or in different representations (large grained). The elements can hold information about the same concept or phenomenon conveyed in different modes, for example wind speed and direction expressed by both words and arrows in a table. Alternatively, the elements can hold information about different phenomena, for example, precipitation expressed by symbols and wind speed and direction by words and arrows. Both alternatives are present in the reading material used in this study (Yr.no), and are exploited by the participants.

Integration of elements relates to *modal affordances,* an important concept in social semiotics. Each of the available modes for representation provides specific possibilities and limitations (affordances) for communication (Kress, 2005; Bezemer & Kress, 2016) and for a representations' meaning-making potential (Tang et al., 2014). Different types of meaning are made available via different modalities (Kress et al., 2001; Tang et al., 2014). According to the functional specialization of language and graphics (Lemke, 2005), verbal language is good at communicating differences and (sequential) relationships and allows or affords a person to make categorical types of meaning (Lemke, 2005; Tang et al., 2014). For instance, a verbal weather forecast affords the reader the information to make meaning of what situation causes the precipitation or what type of precipitation is forecast. Conversely, written language has not evolved to communicate degree, quantity, continuous change and covariation very well; other modes exists that are better suited (Lemke, 2005; Tang et al., 2014;

Unsworth & Cléirigh, 2014). Spatial information in a map (a visual modality) affords a person the opportunity to make meaning of how much precipitation is forecast. Rather than adding graphics to words, words and graphics can be integrated to create cohesive meaning (Baldry & Thibault, 2010).

There are potential benefits for meaning-making of integration of different modes. Lemke (2005) claims that the integration of elements occurs in an interplay of the presentational, orientational, and organizational aspects of meaning (presented above) and suggests that this interplay contributes to meaning-making in three ways: *componentially*, *combine*, and *cross-modulate*.

First, each semiotic modality can contribute *componentially* to each functional aspect of meaning. For instance, the concept of identification can be used to model the verbal-visual relationships that jointly construct presentational meaning (Unsworth & Cléirigh, 2014). Either the language or the image can be the point of departure to identify the other. For instance, a girl has heard that cumulus clouds cause rain showers but does not know how these clouds appear. If reading a caption helps her identify this cloud type in an image, the language's function is to supplement the image by identifying and decoding (glossing) the image (Unsworth & Cléirigh, 2014). Recognizing these clouds can help this girl make her own judgment concerning whether it will rain on a day when a chance of rain is forecast for the place in which she is living. If written language appears without an image in a text, the language is only visualized by the reader based on her experiences related to the actual phenomenon or some prior visual representations of it. Then, if any part of the language is unfamiliar to the reader, it remains uncoded visually. Alternatively, a boy has seen a cumulus cloud but does not know the cloud's name. In this case, the image's function is to supplement the language by identifying and visualizing the language. Therefore, monomodal texts demand more from the visual or verbal experience of the reader than do multimodal texts. If the text does not gloss unfamiliar image segments or unfamiliar language elements are not visualized in images, inexperienced readers in the field can face significant difficulty (Unsworth & Cléirigh, 2014).

Second, functional specialized meaning resources in one semiotic modality *combine* with those for a different function in another semiotic modality to modulate any aspect of the meaning of the joint construct. In the example above, reading a verbal text can contribute to making meaning of which cloud types are present (presentational function), and this meaning can be combined with examining an image, contributing to making meaning of where the clouds are/where it rains (organizational function).

Third, each semiotic modality can internally *cross-modulate* (change or adjust) meanings across functional aspects. For instance, building on the same example, reading a verbal text can contribute to making meaning of which cloud types are present (presentational function). However, the reader orients to who the sender is (orientational function) and assess how certain the information is. Based on in this assessment, he might adjust his meaning. In the present study, the participant's previous knowledge (experiences) used in interpretations is identified – as far as this knowledge came to the fore, and how and why the information is integrated and used (RQ1 and RQ3).

Similar to the fine grained level (presented above), Ainsworth (1999) provides a framework for potential meaning-making through integration of information across representations. Research on multiple representations recognizes that different representations can *complement* one another, *constrain* interpretation, or help *construct* a deeper understanding of the domain (Ainsworth, 1999). Multiple representations can provide both benefits and challenges for the meaning-making process (de Vries et al., 2009). A representation is never the "whole object" (Kress & van Leeuwen, 2006), because all representations are partial, focus on certain aspects and contribute to the construction of meaning in various ways (Jewitt, 2008; Echeverría & Scheuer, 2009). Because they have different modal affordances, words and graphics can together represent more aspects of a phenomenon than they can alone. For example, a picture of the sky can provide visual information on how different clouds appear, a table can provide information about different cloud characteristics (height, name), and a verbal text can provide information on how the different clouds develop over time – supported by a diagram with vectors showing air movement. Together, these representations can provide a broad picture of the phenomenon "cloud" in a weather report. Thus, several representations can be used to *complement* one another (Ainsworth, 1999; de Vries et al., 2009). In addition to providing complementary information, they can support complementary processes by focusing on different modal affordances (Ainsworth, 1999). The extended information provides complementary representation through its place in the larger text organization (organizational function), and the reader orients the information to other viewpoints in other texts (orientational function) (Lemke, 2005; Unsworth & Cléirigh, 2014). Several representations can also avoid or resolve misunderstanding via *constraining interpretation*, either by using a familiar representation to support the interpretation of a less familiar one or by exploiting the inherent properties of one to constrain the interpretation of another (Ainsworth, 1999). To *construct a deeper understanding* of the domain, readers must understand the relationships between the representations (Ainsworth, 1999; de Vries et al., 2009). This relationship is a sort of enhancement that can be achieved if one representation provides information such as how, when, where, or why in relation to another (organizational meaning) (Unsworth & Cléirigh, 2014). By identifying correlations and patterns across various representations, readers can develop a deeper understanding of the underlying structure of the domain being represented. For example, by reading the wind arrows in a table and the words "breeze", "gale", or "storm" in a verbal text forecast, the reader can identify a pattern in which a certain wind arrow is connected to the use of a certain word and thus develop a deeper understanding of the structure. This understanding might be further refined by acquiring real life outdoor experiences and new readings of the forecasts. How information in different representations is integrated and the reasons for this integration are examined in this study (RQ1, RQ3).

Graphics have the potential to enhance reading comprehension (McTigue & Flowers, 2011) resulting from a deeper and more effortful processing of text content. A possible explanation for why graphics enhance comprehension is related to human memory; according to Hannus and Hyönä (1999), it is well established in research on human memory that memory is improved if both a verbal and visual representation can be constructed of the stimuli. For example, the memory of the illustrated text will be richer in detail than the memory for reading material consisting of verbal text alone (Hannus & Hyönä, 1999). However, the potential benefits of graphics can be impaired by superficial or inadequate processing or if graphics makes the text more complex (Hannus & Hyönä, 1999; McTigue & Flowers, 2011). Integration of information is the greatest challenge associated with the reading of multimodal information (Ainsworth, 2006). There are typically few or no textual cues that indicate explicit connections (references in the text, e.g., labels or captions) between representations to help guide the reader, and this lack can make integration of information more demanding (Hannus & Hyönä, 1999; Holsanova et al., 2009; McTigue & Flowers, 2011). Thus, in addition to comprehending the different parts of the text, the reader must determine which pieces of the text are related and integrate these pieces (Hannus & Hyönä, 1999; McTigue & Flowers, 2011). Challenges reading and comprehending the text also relate to decision-making. Particularly with a nonlinear and highly visual text such as Yr.no, the reader must decide in what order to read the different parts, what information is relevant to the task, and what information is superfluous (Hannus & Hyönä, 1999; McTigue & Flowers, 2011). This selection relates to RQ2 and RQ3 in the present study.

In general, multimodal texts are the dominant form of communication in our society. Analyzing this type of text provides a foundation for both designing and criticizing the texts (Baldry & Thibault, 2010). By analyzing multimodal texts, we can determine how combinations of representations can provide more meaning together than via individual representations (Baldry & Thibault, 2010). According to Unsworth & Cléirigh (2014), considerable past research addresses how graphics construct meaning.

However, little has specifically addressed the relationships between graphics and words to show how the visual and verbal modes interact to construct integrated meanings (Unsworth & Cléirigh, 2014). More research is needed to achieve a greater understanding of multiple representations and multimodality (Tang et al., 2014). Additionally, studies focusing on readers' reasons for selecting information and the cognitive processes involved in integrating and comprehending information from representations are rare; more research is needed (Holsanova, 2012; Mason et al., 2013). Tang et al. (2014) suggest using an integrated framework considering representations as whole and modal affordances in the analysis of learning with representations. Thus, it was interesting in my data collection to consider not only how different representations are interpreted but also how and why information from different representations was integrated and used (RQ1/3).

In the final subsection, I review literature concerning the truth value of texts (1.3.4).

1.3.4 Truth value

Knain (2015) claims that the ability to convey nuances in terms of degrees of certainty is perhaps the most important characteristic of scientific texts. Expressions of doubt and uncertainty are commonly used in scientific texts such as weather reports. In linguistic communication, verbs (for example, "may") and their related adjectives (for example, "possible" and "certain") indicate the degree of certainty in statements (Kress & van Leeuwen, 2006). Qualifying terms are also used; for example, "dream" or "belief," which indicate a low degree of certainty in Western culture, or the contrasting "reality" or "fact," which indicate a high degree of certainty (Kress & van Leeuwen, 2006). People routinely assess the truth value of messages (Kress and van Leeuwen, 2006); the truth value that is assigned to the message is determined by the values and beliefs of a person and his social group. which relates to Lemke's (2005) orientational function. The concept of truth value is equally important in visual communication. Graphics can represent people and things as they are or as they are imagined. People's assessments of the truth value of graphics are also dependent upon what is considered real in the social group. Based on a naturalistic view of reality, people assign a high truth value to things that they can see with the eye; for example, a picture with colors that appear similar to the colors we see in nature. However, digital technology is open to easy manipulation of pictures (Knain, 2015), and this ease might reduce the truth value assigned to them. Decontextualizing an object reduces the truth value of the message; the same situation applies to a high degree of abstraction. A scientific view of reality is based on generalizations and typical conditions (Knain, 2015); for example, a diagram can be assigned a higher truth value compared with a picture in the social group. In science, what is real is what is known through the methods of science. Kress and van Leeuwen (2006) note that diagrams and maps can be naturalized for lay readers (to increase the truth value of the message), for example, by showing them in perspective, adding color, and placing them into a context. How the participants assess the degree of certainty in a weather report (RQ1) and which uncertainty information from the text they use (RQ2 and RQ3) are examined in the present study. More literature on uncertainty is presented in Section 1.5.

1.4 Human decision-making

Empowering people to participate in a democracy and make informed decisions is considered an important achievement for both public communication and multimodal reading.

All humans make numerous decisions every day, and information about present and future weather conditions plays an important role in many of them. Prior knowledge related to weather and our experiences with sun, rain, snow and wind in different situations, affecting our emotions about different circumstances, are likely to affect the decisions we make. Studying how humans make decisions is important for improving communication of weather information between experts and laypeople.

Some of the decisions we make are unconscious. For example, when I put on a pair of shoes, I automatically put the left shoe on my left foot and the right shoe on my right foot. However, I am conscious about the choice of which shoes to wear; that choice depends upon my schedule for the day in combination with the weather conditions. When I walk and have to cross a road, I look to my right and then to my left for traffic. Then, I decide, based on my estimate of the risk, whether to walk calmly, to run fast, or to wait for passing cars. If my friend run, I am might be more likely to run myself. The road may be slippery because of snow or ice, and that brings another piece of information into consideration. Personally, I would be influenced by negative feelings brought to mind recalling earlier incidents in which I ran into a puddle and ruined a pair of new shoes. I do not want that to happen again. All of these choices are examples of everyday decisions. Although my life is at stake when crossing the road, I make the decision with little effort. I can do so because I have acquired experience from making similar decisions for years, making the risk known, or at least appear controllable, to me. Occasionally, we have to make decisions with higher uncertainty, making them more effortful. For example, in a situation with low temperatures and strong winds last winter, I had to decide whether to bring my wife and newborn son to a place with more secure heating in case of a loss of electricity in our own house. I spent much time and effort considering the pros and cons of several options before I made my decision to stay home. This decision was influenced by not only weather forecast information and its associated uncertainty but also media reports and associated costs (baby crying all night in new bed) and benefits (secure light and heating) from changing residence, in addition to positive feelings related to earlier events with similar weather conditions that went well and my conversations with other persons.

In the following subsections, I summarize the literature on decision-making relevant to this work (particularly RQ2): theories of information processing in the human brain (subsection 1.4.1.); information search and decision-making behavior (subsection 1.4.2.); and perspectives on research on decision-making and rationality (subsection 1.4.3.).

1.4.1 Information processing in the human brain

"Thinking is a process in which different pieces of information (cues) are combined and transformed into a useful product such as an idea, an estimate, a decision, or a solution to a problem" (Dijksterhuis et al., 2014, p. 355). However, thought processes can vary. According to Dijksterhuis et al. (2014), individuals can think quickly or slowly, associatively or logically, and consciously or unconsciously. The literature on thought processes is useful background information to the present study, to understand information processing and decision-making behavior better.

Many researchers appear to agree that there are two types of information processing involved in human decision-making. Type 1 is autonomous and does not require working memory processing (the function for temporarily storing and manipulating information). Type 2 requires working memory processing and enables hypothetical thinking and mental simulation (Evans & Stanovich, 2013). In addition to these defining features, the two types of processing have several associated features.

Intuition (Type 1) operates quickly and automatically with little or no effort and handles output information (integrating input information and producing preferences). However, reasoning or analysis (Type 2) is conscious, governed by rules, relatively slow, deliberate, effortful, and handles input information (controlled search of information, making sense of information, and integrating the information) (Slovic et al., 2004; Betsch & Glöckner, 2010; Kahneman, 2011; Evans, 2012; Evans & Stanovich, 2013; Dijksterhuis et al., 2014). This general view is, however, a simplification. Notably, fast processing alone does not automatically indicate intuition (Evans, 2012). For example, individuals may adopt experience-based techniques (heuristics), allowing a decision to be made quickly by means of following simple decision rules rather than intuition. Because these procedures require conscious calculation, they are considered Type 2 processing (by some researchers, see discussion below) (Evans, 2012). Intuition is typically considered unconscious. Betsch and Glöckner (2010) also expand on the general view, providing interesting additions related to the type and amount of information to be processed and to processing time. Analytic processes are sequential and consume time; hence, an increasing amount of information is automatically supposed to take a longer time to process. Betsch and Glöckner (2010), however, argue that if the information is coherent (e.g., all information favors one option and speaks against other options), decisions are easier to make. If additional information increases the coherence of one option, then decision time should decrease as the decision becomes easier (although it is more information to consider, and vice versa). For example, if I look at a symbol indicating cloudy but dry weather and then read a verbal text expressing a possibility for local rain showers, adding information from rainfall radar can make it easier for me to decide when this information supports one option.

Whereas earlier studies discussed affect (a feeling that something is good or bad) and emotions as unhealthy influences on decision-making that cloud judgment and increase susceptibility to temptation, studies from the last two decades are beginning to highlight healthy influences (Reyna & Farley, 2006). There are strong indications that affect and emotions can serve as information in decision-making (Slovic et al., 2004), shaping the gist of information (Reyna, 2012), serving as a spotlight for directing our attention, helping to trade-off between decision alternatives, and as motivation for actions (Peters, 2006; Dickert et al., 2014). Additionally, the latter view acknowledges that affect and emotions allow people to learn from experience (the consequences that follow their actions) acquired when making decisions (Reyna & Farley, 2006). Learning leads decision outcomes to become "marked" by positive and negative feelings, providing information about what to choose and what to avoid (Peters, 2006), and thus influencing the construction of preferences. Studies have found that individuals differ in how they react affectively and to what extent they rely on intuition (Slovic et al., 2004). Dickert et al. (2014) expands on the difference between emotion and affect; affect typically refers to the first automatic response (Type 1 processing), whereas emotions usually are conscious and object-related (Type 2 processing). Emotions are typically more intense than affect. For example, as a child, my feet were often wet and cold because of improper footwear. When snow is forecast, these situations from my childhood give rise to a negative feeling (affect), and I automatically (by intuition) know that I want to wear waterproof shoes - the option that for me is marked with a positive feeling or, alternatively, the option that allows me to avoid a situation with negative feelings. In other situations, when strong winds almost blew the car I was driving off the road, I was very anxious. This intense feeling of fear, which is related to specific incidents of which I am conscious, is a likely reason why I prefer not to drive in strong winds.

Although affect and emotions are likely to be an important part of many weather-related decisions, the interviewees in the present study do not report directly on affect and emotions. There are, however, a handful of exceptions. For example, one interviewee reported that she on occasion had experienced gale force winds when sailing and that she experienced such situations as unpleasant. For her, this experience marked decision options with gale force winds with negative feelings, and she wanted to avoid these situations when sailing. A likely reason for the lack of utterances concerning affect and emotions in this study is the focus on conscious search and usage of the provided forecast information. Asking the question, “how does it make you feel?” can help elicit direct responses on affect and emotions in future studies (Peters, 2006). However, the interviewees do report on their experiences related to weather, and these experiences are affected by, and cannot be separated from, affect and emotions. Thus, affect and emotions are to some extent indirectly included in this study.

Note that there are three ongoing discussions related to dual-process theories of particular interest to this study: first, a discussion concerning whether Type 1 and Type 2 processes are distinct cognitive systems or two modes of thought; second, a discussion about the role of unconscious thought; and third, a discussion whether intuition and heuristics are the same.

First, researchers discuss whether Type 1 and Type 2 processes are two modes of thinking (related to differences in personality and culture) or two different cognitive systems (related to brain architecture). In the first view, intuition and analytic processes run in parallel, each providing a response (Evans, 2012). If responses conflict, the conflict must be resolved by relying on either intuition or analysis. Based on findings in their study from 2010, Betsch and Glöckner argue that intuition and analysis are two distinct cognitive systems. This view is supported by converging evidence (Evans & Stanovich, 2013). Most importantly, Betsch and Glöckner (2010) claim that a decision is made by neither intuition nor analysis; rather, intuition and analysis guide different types of sub-processes. The second view means that decision-making is neither automatic nor controlled but reflects both processes, both giving important contributions (Betsch & Glöckner, 2010). Whereas the depth of the analysis can vary, intuition always works in the mental background (Betsch & Glöckner, 2010). Occasionally salient information in the environment and accessible information from the memory provide input information sufficient to reach a decision without any analysis (Betsch & Glöckner, 2010). This situation can exist for many routine decision situations that typically do not require additional information search (Betsch &

Glöckner, 2010), for example, when I walk from my car to the entrance door and automatically choose the shortest path. This situation appears to occur when encoding information is easy (Betsch & Glöckner, 2010). If I walk under more challenging conditions, for example, when it is windy and the sidewalk is slippery, I acquire information about my environment and conduct a brief analysis before reaching a conclusion about where to put my feet. In the present study, the same participants were found to use different types and amounts of information for different decision situations, indicating that the depth of their analyses varied.
From the second point of view, both types of processing are active when we are awake (Kahneman, 2011; Evans, 2012). Usually, Type 2 processing adopts suggestions (impressions, intentions, preferences, associations, and feelings) from Type 1 processing with little or no modification (Kahneman, 2011). Type 2 processing operates in a low-effort mode. Occasionally, Type 1 processing encounters difficulties. Then, Type 2 processing increases its effort to solve the task (Kahneman, 2011; Evans & Stanovich, 2013). We consider this process to be conscious thought.

Fuzzy-trace theory has refined the dual-process theories by studying the effects of memory representations. According to fuzzy-trace theory, in a given situation, verbatim (exact words, numbers, or pictures) and gist (essential meaning of words, numbers, or pictures) memory representations are separately encoded from the environment (Reyna, 2012). Gist representation of information supports intuition and is always used in decisions, whereas the extent to which verbatim representation, supporting analysis, is used will vary (Reyna, 2012; McFall, 2015). Memory representations are directly relevant to the present study. For example, when a person views a weather forecast in which 10 mm of rain is forecast, this information can be encoded and stored as heavy rain (gist representation) and 10 mm rain (verbatim representation). Importantly, if a person is unable to interpret 10 mm rain because he lacks relevant experiences, then it is difficult to encode the gist representation, and decision quality could suffer.

Second, the discussion on conscious versus unconscious thought is important in relation to the interviews conducted in the present study. In their critical review on the role of unconscious thought in decision-making, Newell and Shanks (2014) claim that unconscious thoughts have limited influence, and that conscious thought is the primary driver of behavior. Whether unconscious thought actually exists or our mind simply benefits from a period of distraction when solving a problem is an old question. However, there are studies in recent decades suggesting that unconscious thought actually occurs (Dijksterhuis et al., 2014). Newell and Shanks (2014) do agree that there are differences between intuition-based and deliberation-based decisions, taking Simon's (1992) view that intuition is recognition and relies heavily on prior experiences. Thus, in line with dual process theories, intuitive decisions are fast and effortless because they are made based on recognition in situations in which the cues are readily apparent (Newell & Shanks, 2014). For example, the situation provides a cue (clouds), the cue provides us access to information stored in memory (likely to rain when that type of cloud is visible), and the information provides an immediate answer (wear waterproof shoes) (Newell & Shanks, 2014). Because the cue is readily apparent there are no intermediate cognitive steps, and the decision does not feel effortful (Newell & Shanks, 2014). In other situations, our decisions shift to become more deliberate and we are aware of the intermediate cognitive steps by which information is processed, for example, when the cues are not so readily apparent or when information in memory is more absent or more difficult to access (Newell & Shanks, 2014). A cue can then be the amount of rain forecast in a weather report. Agreeing about the duality of Type 1 and Type 2 processes, the main critique from Newell and Shanks (2014) is that the role of unconscious thought has been inflated and given too much explanatory power in decision-making. They claim that much of what is considered unconscious thought actually is conscious; the challenge is for researchers to use methods that can make people/experts elicit factors influencing their decision-making (Newell & Shanks, 2014). For example, Newell and Shanks (2014) question to what extent individuals are aware of the information that is triggering their decision at the point of choice (proximal cues) compared with information in the past (distal cues) that might have caused the current information (thoughts) to be present at the point of choice. This concern is also valid for the interviews in this study, in which it is possible that I do not manage to elicit all of the interviewees' thoughts and thus mix up conscious and unconscious thoughts. In a response to the critical review, Bernacer et al. (2014) problematize that Newell and Shanks (2014) do not consider habit learning. Through habit learning, a fundamental feature of decision-making (Bernacer et al., 2014), particular actions transfer from conscious to unconscious performance. For example, when I walk from my car to the entrance door in the winter season and there is snow on the trees, I must decide whether to use the shortest path under the trees or a longer path avoiding the trees. I have bad feelings related to earlier incidents in which snow fell off the trees and on my head and went down the back of my neck. Because of these feelings, I make conscious decisions in the start of the winter season to walk the longest path to avoid the possibility of falling snow from the trees. Later on, this choice becomes a habit and I unconsciously decide to walk the longest path. In another response to Newell and Shanks (2014), Baumeister et al. (2014) call on researchers to stop pitting the conscious against unconscious and instead ascertain how the two work together. All agree that more research is needed before strong conclusions can be drawn on the role of unconscious thought (Newell & Shanks, 2014).

Third, the terms heuristics and intuition are used differently. On the one hand, Dijksterhuis et al. (2014) use heuristics as an example of Type 1 processing, such as the affect heuristic (influence of a person's current emotion and affect on a decision) or the availability heuristic (reliance on immediate examples coming to a person's mind). On the other hand, Betsch and Glöckner (2010) claim that heuristics do not cover the potential of intuitive thought. Rather, heuristics seem to be a simplification of analytic thought, coping with cognitive limitations by leaving out the most effortful information processes and reducing the amount of information considered by reducing complex judgments to simpler ones (Betsch & Glöckner, 2010). An example of such a heuristic would be the satisficing heuristic (information search stops when a "good enough" option is found) (Simon, 1955). Betsch and Glöckner (2010) believes there is much more to intuition than reducing task complexity; in contrast to Type 2 processing, intuition is unconstrained by the amount of information and cognitive capacity and thus capable of processing and integrating multiple pieces of information without noticeable cognitive effort. The discussion might be more about the definition and usage of the word heuristic than about how Type 1 and Type 2 processes work. In their review of heuristic decision-making, Gigerenzer and Gaissmaier (2011) claim that heuristic processed can be both unconscious and conscious. In such a view, heuristics can be both Type 1 and Type 2 processing. I take this view in this study. For example, the affect and availability heuristics are about (unconscious) recognition and associations and are thus Type 1 processing. The satisficing heuristics are concerned with (conscious) use of simple rules for information search and stoppings, and are thus Type 2 processing.

Whereas most of the decisions we make take seconds, minutes or perhaps hours, we occasionally take days or weeks to reach a decision. Recently, Dijksterhuis et al. (2014) proposed prolonged thought as a third type of processing (Type 3). Although the framework for prolonged thought remains crude, it has interesting features worth mentioning. According to Dijksterhuis et al. (2014), prolonged thought processes typically involve three separate stages. First, we collect information and consciously think about it for a while. Thereafter, we put the whole aside and do not consciously engage in it (unconscious thought). Finally, all of a sudden, a solution presents itself to the consciousness, and we are able to make a decision. According to Dijksterhuis et al. (2014) Type 3 processing is characterized by being unconscious, very slow, exploratory, and able to organize and handle large amounts of information. Importantly, Type 3 processing is goal-dependent and is claimed to work only when we want it to work. Type 2 (first, conscious stage, and most effortful) and Type 3 (second, unconscious stage, and less effortful) processes can work with different aspects of the same problem. In very slow processes, there might be several iterations between Type 2 and Type 3 processes before a conclusion is reached. In other words, Type 1, Type 2, and Type 3 processes can coexist and work together in our minds.

Initially, Type 3 processes do not appear to be influential for everyday decisions related to weather because we are rarely aware of a weather event more than hours or perhaps a few days in advance, giving us little time to think about it. Obviously, there is a possibility that prolonged thought plays a role in decisions related to extreme weather events or seasonal phenomena such as monsoon rain. These high-consequence events are often communicated to the public several days in advance even when the probabilities are low. This information gives people time to take action and time to think over what to do, allowing for Type 3 processes. Such decisions, related to severe weather, are not considered in this study. There is, however, also a possibility that prolonged thought plays a role in many everyday decisions. For example, if I plan for holiday travel, I may initially view the weather forecast for several possible destinations and study this information together with other relevant information. Thereafter, unable to decide immediately between two or three good options, I put the delicate problem away for a while. Some days later, I suddenly know where I want to go. I may also check forecast updates for a period of time before I make my decision. In the present study, this behavior would be denoted "prolonged usage" of forecasts. It is possible that prolonged usage also involves prolonged thought, but this is not discussed in the interviews.

The literature indicates that there is an interplay between all three types of processing used in decision-making to a varying extent depending upon the situation and, perhaps, upon the individual. Although intuition, analysis, and prolonged thought refer to different cognitive systems rather than different decision-making strategies, it is assumed that people use different strategies to obtain input information, that is, for information search related to Type 2 processing (Betsch & Glöckner, 2010). Interviewees in the present study are provided forecast information, and I study their conscious use of this information. In the following, I delve further into the literature on human decision-making behavior to elaborate on (conscious) information search in decision situations, which is importantly related to the weather forecast usage studied.

1.4.2 Information search and decision-making behavior

Although huge amounts of information are processed by intuition continuously and unconsciously, there is also a controlled search of input information which is important for analytic processing. As mentioned above, the depth of the analytic processes varies. Thus, the amount of information to be searched and processed consciously will vary and can depend upon the situation and restrictions in time and the capacity of the working memory. Variations in information search and usage are suggested to be related to certain types of decision-making behavior and are of interest to the present study.

It appears that some individuals habitually adopt a maximizing behavior across several decision situations (Schwartz et al., 2002). *Resolute maximizers* typically spend much time and effort searching a huge amount of information to compare all available alternatives to find what they consider the best option (Misuraca et al., 2015a). Such behavior indicates an in-depth analysis (Type 2 processing). Misuraca et al. (2015b) speculate that maximizers' behavior may be driven by their tendency to focus on tomorrow, reflecting their tendency to consider not only the immediate but also the long-term consequences of their choice. Misuraca et al. (2015b) found a positive correlation between maximizing behavior and the capacity to comprehend and use basic probability and numerical concepts (numeracy). This correlation might mean that maximizers are more likely to make analytic trade-offs and comparisons than are less numerate individuals (Misuraca et al., 2015b). However, regret aversion - the desire to avoid potential regret - might have an effect on maximizing behavior (Schwartz et al., 2002; Parker et al., 2007; Misuraca et al., 2015a). *Fearful maximizers* focus their attention on the fear of making wrong or non-optimal decisions, and this focus can result in an almost endless search for information without moving forward toward a decision (Misuraca et al., 2015a). Facing an abundance of options might lead a maximizer to choose almost arbitrarily just to complete the decision process (Schwartz et al., 2002). Maximizers might also more often than others postpone their decisions, to search for more information and ponder possibilities (Parker et al., 2007). Although not mentioned in the literature, this postponement appears (in some situations) related to prolonged thought (Type 3 processing). Additionally, maximizers would attempt to avoid relying on feelings and instincts (Slovic et al., 2004).

Other individuals appear to adapt a satisficing behavior habitually, attempting to find an option that they consider satisfactory or "good enough" (Schwartz et al., 2002). Unlike the maximizers, the satisficers would select only a few criteria that they consider important, and once they find an option in which these criteria are met, they are satisfied because the threshold of acceptance is crossed (Misuraca et al., 2015a). *Less ambitious satisficers* have lower standards and search and process less information than *more ambitious satisficers* (Misuraca et al., 2015a). Both types of satisficing behavior indicate a more concise analysis (Type 2). Regret aversion is not considered a problem to satisficers because they seek a "good enough" rather than the "best" option (Schwartz et al., 2002). Likewise, added options are not typically problematic to satisficers because the added options only provide new possibilities to find an option that crosses their threshold of acceptance (Schwartz et al., 2002). For example, rejecting a formerly chosen option for a higher-ranked one, which is possible through prolonged thought or prolonged forecast usage, can make a satisficer move in the direction of maximization without having maximization as a deliberate goal (Schwartz et al., 2002). Similarly, Misuraca and Teuscher (2013) suggest that many options have an effect on satisficers, leading them to behave more like maximizers, engaging more cognitive resources and making more comparisons. Apparently, the availability of options also relates to coherence: if the new information does not favor one option, decisions are more challenging to make (Betsch & Glöckner, 2010). Interestingly, Jain et al. (2011) found in their study that satisficers made use of fewer cues and paid less attention to irrelevant cues (i.e., noise), enabling them to perform better than maximizers in a decision task. However, previous research provides mixed evidence on who makes superior decisions, and results might differ in situations when maximizers do better or worse (Jain et al., 2011).

There is a discussion of whether satisficing and maximizing can be measured on one scale and are opposite ends of a continuum (e.g., Schwartz et al., 2002) or whether they should be measured as separate dimensions, independent of each other (e.g., Turner et al., 2012; Misuraca et al., 2015a). The discussion relates to how satisficing and maximizing behavior correlate to measures of, among others, happiness, perfectionism, optimism, and regret. The interviewees in the present study do elaborate on what information they use and why they use it, but they do not report on their happiness and so on. Hence, this discussion is outside the scope of the present study. More important for this study appears to be an agreement that a greater amount of information is considered in the decision process for maximizing than for satisficing behavior. Although individuals might tend to adopt a certain type of behavior more often than type, it is not very likely that this behavior is adopted in all situations (Janis & Mann, 1977; Schwartz et al., 2002). This view is in accordance with dual-process theories, in which the depth of the analysis is supposed to vary, as described above. Thus, independent of the discussion, individuals most likely have variations in their information search and processing with respect to effort and accuracy across different situations. These variations are assumed to depend upon environmental, task, and personal factors, allowing individuals to achieve a high level of decision accuracy even under processing constraints (e.g., time pressure) (Betsch & Glöckner, 2010). This study does not contribute to the discussion of whether maximizing and satisficing behavior are separate dimensions. In this study, in which handling the complexity of information in different decision situations is the focus, variations in the amount of information used are discussed.

Importantly, both satisficers and maximizers are interested in the quality of their decisions and can have high and ambitious standards (Misuraca et al., 2015a). However, satisficers are not willing to invest the extra time and effort required to move from the “good enough” option to the “absolute best” (Misuraca et al., 2015a).

Misuraca et al. (2015a) expand previous studies on decision-making tendencies by proposing a third type of individual behavior, the minimizers. These individuals are uninterested in the quality of their decisions, and they choose the option that meets the absolute minimum criteria, with minimal effort expended (Misuraca et al., 2015a). *Indolent minimizers* and *parsimonious minimizers* are both characterized by a quick and superficial evaluation of alternatives (Misuraca et al., 2015a).

Both satisficing and maximizing behavior are considered analytic processes because they are conscious. Intuition - building on experience – is also a part of the decision process through unconscious integration of emotions, affect, preferences and so on. Information search and decision-making behavior is closely linked to different perspectives in research on decision-making. In the following subsection, I examine more closely different perspectives adopted in research on decision-making.

1.4.3 Perspectives on research on decision-making and rationality

The long history of research on decision-making has led to several competing models and a theoretical battle between different camps or perspectives.

There are three major competing models in research on decision-making (McFall, 2015):
Optimizing is the oldest (dating back to the 17th century) and likely most well-known perspective, focusing on economic models and maximizing expected utility. Decision-making has been considered one of the supreme disciplines of conscious thought, and the maximization principle of utility theory pushes to the extreme the idea that decisions require (intense) deliberation (Betsch & Glöckner, 2010). Many *classic models of rationality*, such as the optimizing model, view the human mind as having almost unlimited knowledge and computational capacity. Making decisions based on a classic view of rationality requires substantial computational capacity (Gigerenzer et al., 1999): For each alternative, all possible consequences should be listed. Each of the consequences should be assigned a probability. The utility of each consequence should

be estimated to select the alternative with the highest expected utility and to make an optimal decision. This type of decision-making requires an unlimited information search and describes how ideal people should make decisions (normative). The optimizing perspective can be useful and is much used in experimental settings (the amount of information provided to the participants is, however, limited in the experiments), most likely because it is a simplification of real-world problems and allows researchers to compare decision outcomes across individuals. However, an increasing number of empirical findings question its validity as a model of human behavior (Oppenheimer & Kelso, 2015). As holes continue to develop in this paradigm, Oppenheimer and Kelso (2015) propose a that possible a paradigm shift in research on human decision-making began during the past half century, in which information-processing models have started to emerge as reasonable alternatives to economic models. In this new paradigm, the specific information available to the decision-maker, and how that information is sampled, retrieved, integrated, and used, is considered. Such models are closer to the approach taken in this study.

As early as in the 1950s, Simon (1955) doubted whether optimizing (the first perspective) could serve as a descriptive model of human decision-making, believing that individuals would require supernatural computing powers to implement this principle (Betsch & Glöckner, 2010). Simon, developing a bounded rationality approach, suggested individuals employ simple rules allowing them to reduce cognitive effort (Betsch & Glöckner, 2010). There are two main camps focusing on information processing and actual rather than ideal decisions, and the main theoretical battle stands between these two perspectives: the heuristic-and-biases camp (the second perspective), who argue that humans are prone to systematic errors in judgment, and the satisficing/naturalistic decision-making camp (the third perspective), who argue that humans are adept at decision-making. The *heuristics and biases* perspective is descriptive and focuses on the reasoning and arguments that influence people's decisions (Tversky & Kahneman, 1974; Shafir et al., 2000). In some situations, people are assumed to apply heuristics and rules of thumb for judgment intuitively rather than optimizing (Jungermann, 2004). However, research from this perspective also focuses on errors by people when they use heuristics instead of optimizing (Klein, 2011). Optimizing is viewed as the normative model for decision-making, sharing the same classical view on rationality as in the first perspective (Gigerenzer & Goldstein, 1996).

In reality, humans have limited time, knowledge and computational capacity (Gigerenzer et al., 1999), and this affects our decision-making. This vision of rationality, defined by its fit with reality is referred to as *ecological* or *bounded rationality* (Gigerenzer et al., 1999). This rationality leads to the third perspective (*satisficing* or *naturalistic decision-making*) in research on decision-making, which is descriptive instead of normative. These models of decision-making, which are based on the view of bounded rationality, involve a limited information search (Gigerenzer et al., 1999); a stopping rule that is guided by heuristics indicates when to stop searching for more information. Simple decision rules facilitate decision-making. As soon as a satisficing alternative is obtained, a "good enough" decision can also be obtained.

The two competing camps agree that Type 1 and Type 2 processing are both important in human decision-making (Kahneman & Klein, 2009). However, their views on rationality differ, and this disagreement stems from whether the use of intuition improves or degrades the quality of decisions. The heuristics-and-biases camp concentrates on intuition arising from (according to their view on rationality) inappropriate application of heuristics (and heuristics, e.g. the availability heuristic, are considered Type 1 processing in this camp), whereas the naturalistic decision-making camp concentrates on intuition derived from expertise or genuine skill. In the following, a more balanced discussion of both the benefits and the flaws of intuitive thought is provided. Intuition is recognition (Simon, 1992), and when people learn elements and patterns in a new situation and how to act appropriately, valid intuition might develop (Kahneman, 2011). However, intuitions are not always derived from true or relevant experience, which can produce low-quality intuitive judgments (Kahneman, 2011). Independent of the viewpoint of rationality, the use of heuristics might not solely produce high-quality or low-quality intuitive judgments. Instead, heuristics is dependent upon the quality of the experiences and skills of the decision makers, which should be acquired through prolonged practice in a sufficiently predictable environment (Kahneman, 2011). With relevant experience, decision makers develop more patterns in their mind, which enables recognition of more situations and rapid and accurate intuitive judgments (Klein, 2011). For example, it is suggested that tourists, due to their unfamiliarity with the local environment, may be more vulnerable to being surprised by flash flooding (Becker et al., 2015). Weather forecasting can be considered a sufficiently predictable environment for the development of intuitive skills of satisfactory quality. In their study of Navy forecasters, Joslyn and Jones (2008) discovered that the most experienced forecaster had a more complete mental representation of the atmospheric conditions, including both spatial and temporal components, compared with the novice forecasters. Thus, the more experienced forecaster was able to recognize more atmospheric patterns than the novice forecaster, which enabled the more experienced forecaster to make faster and better intuitive judgments when making a forecast. This view on valid intuition, arising from true expertise based on relevant experience, is also in line with fuzzy-trace theory, which describes gist representations of information to be increasingly important when they are informed by increasing age and experience (Reyna, 2012). Thus, it appears that the focus on participants' prior experiences with weather in the present study is important because it relates to the validity of intuition. According to Dijksterhuis and Nordgren (2006), valid intuition might also arise from prolonged thought (Type 3) processes based on extensive unconscious thought (the deliberation-without-attention effect). Note that Newell and Shanks (2014) question whether the deliberation-without-attention effect is due to disadvantages conferred on conscious thought due to experimental procedures rather than hypothesized advantages of unconscious thought.

People are involved in many different types of decision processes, and there are different views on the rationality of individuals' decision-making. For example, decisions can have fatal consequences or go awry because of ignorance. However, such results do not necessarily mean that the decisions were irrational; rather, the decisions could require knowledge or information that the decision-maker did not have (Reyna & Farley, 2006). The aim of the present study is to describe decision processes, not to judge whether these are good or bad, or rational or not rational.

According to Eiser et al. (2012), the traditional economic and heuristic models of human decision-making inadequately describe decision-making under uncertainty; both paradigms fail to incorporate factors that are critical to much real-life decision-making. Affect and emotions are quite recently incorporated into decision research (Lerner & Keltner, 2001). Work by Slovic et al. (2004) on the affect heuristic (Eiser et al., 2012) is of special interest to decision-making under uncertainty. Because the weather forecasts used in the present study included uncertainty information, the participants had to make decisions under uncertainty. Therefore, I examine more closely the theory on risk and uncertainty related to decision-making and communication in the next Section to expand on these important topics.

1.5 Risk and uncertainty

All science and all predictions of the future have uncertainty (National Research Council, 2006; Fischhoff & Davis, 2014), which explain why expressing nuances in terms of degrees of certainty is common in scientific texts (see subsection 1.3.4). Many classifications of uncertainty exist (e.g., see Riesch, 2012). Traditionally, the classifications have focused on where uncertainty derives from, with a main distinction being made between uncertainty arising from natural variability inherent in the system (aleatory) and uncertainty arising from incomplete knowledge (epistemic) (Strand & Oughton, 2009; Riesch, 2012). Paradoxically, when the understanding of a problem grows richer, the uncertainty may increase because research reveals processes that had not previously been understood and that were not described realistically in the models (Morgan et al., 2009). For weather predictions and many natural hazards (e.g., flooding, snow avalanches, tsunamis, and earthquakes), there is a growing understanding of the underlying laws (Hirschberg et al. 2011; Kunz et al. 2011). Thus, epistemic uncertainties can be reduced (to a certain level) by collecting more data of higher quality and improving the models (Der Kiureghian & Ditlevsen, 2009; Kunz et al. 2011; Daipha, 2012). However, the predictions will remain uncertain, for example, because of unpredictable variations in the systems and the chaotic nature of the atmosphere (aleatory uncertainties) (May, 2001; Challenor et al., 2010; Kunz et al. 2011). Historically, the focus of uncertainty analysis has been on quantifiable aspects, with uncertainties represented using statistics (Strand & Oughton, 2009). There are, however, also other and less quantifiable aspects of uncertainty (Strand & Oughton, 2009), for example, ignorance (Funtowicz & Ravetz, 1993) and indeterminacy (Wynne, 1992). These aspects of uncertainty are discussed in subsection 1.5.3. Most importantly, uncertainties should be communicated properly to enable people to make informed decisions.

In the following subsections, I present theory on risk, uncertainty, and decision-making (subsection 1.5.1.); decision-making related to weather and uncertainty (subsection 1.5.2.); risk communication (subsection 1.5.3.); and finally communication of uncertain weather information (subsection 1.5.4.)

1.5.1 Risk, uncertainty, and decision-making

"All decision-making involve risk at some level, at minimum they involve the risk of being the wrong decision to have made" (Breakwell, 2014, p. 85).

Many classifications of risk and uncertainty exist (e.g., see Riesch, 2012). One known mathematical definition of the concept is: risk is a product of the likelihood that a harm will happen and the magnitude of the consequences (Eiser et al., 2012; Riesch, 2012; Bodemer & Gaissmaier, 2014). In other words, it is only possible to calculate the risk if harm and likelihood is known and can be quantified. Harm refers to threats to humans and things they value (Bodemer & Gaissmaier, 2014). Because the harm may occur but is not inevitable, individuals can seek to avoid or limit the harm (Breakwell, 2014). If the likelihood of the harm is known (e.g., risk of car accident for a given population), this situation involves decision-making under risk (National Research Council, 2006; Eiser et al., 2012). However, there might be uncertainty over the likelihood of an event and uncertainty over the magnitude of the consequences (Eiser et al., 2012). The case of uncertain or unknown likelihood or uncertain consequences is called decision-making under uncertainty (National Research Council, 2006; Eiser et al., 2012). All weather forecast information is uncertain; hence, the participants in the present study made decisions under uncertainty. Therefore, uncertainty is a focus of all three papers in this study.

Natural hazards represent risks in our lives (Bodemer & Gaissmaier, 2014), with flooding representing one of the leading causes of death associated with natural disasters (Becker et al., 2015). The World Meteorological Organization (WMO) defines natural hazards as severe or extreme weather and climate events (e.g., hurricanes). However, more general discussions exist concerning who determines what is harmful and how harmful it must be (Breakwell, 2014). In other words, more normal weather events, which I focus in the present study, also can be considered harmful events.

Slovic et al. (2004) suggested that humans use two types of processing to comprehend risk: Risk-as-feelings and risk-as-analysis. This distinction is in line with a large body of dual-processing theories (Dickert et al., 2014). *Risk-as-feelings* is considered by Slovic et al. (2004) a human's most natural and common means of responding to danger, relying on associations linked by experience to emotions and affect. This response is pleasure-pain oriented and represents risk as a feeling, telling us whether something is safe (Slovic et al., 2004). Risk-as-feelings is linked to intuition, or Type 1 processing, and is of interest for decisions made under all weather conditions. For example, when we are trying to decide whether we should host a barbeque party when a thunderstorm is forecast, there is an automatic search in memory for similar experiences and related emotions. If activated feelings are unpleasant, they motivate actions to avoid reproducing those feelings. Some interviewees in this study provided examples of such behavior. *Risk-as-analysis*, however, is analytical and oriented to what is sensible, using probability calculus, formal logic and scientific deliberation (Slovic et al., 2004; Slovic et al., 2012) and is clearly linked to Type 2 processing. Importantly, analytic reasoning cannot be effective unless guided by emotion and affect (Slovic et al., 2004). Although in-depth analysis is important in some decision situations (e.g., hazard management), it appears that emotions and affect serve as orienting mechanisms, helping us to navigate efficiently in the complex and uncertain world in which we are living (Slovic et al., 2004). In the present study the participants are asked to report on how they evaluate uncertainty in the forecasts they are provided. People are not always conscious about consulting affect in decision processes (Slovic et al., 2004), which may explain why the interviewees in the present study typically did not report on affect, but rather on conscious thought processes (Type 2). This result is similar to the challenge described by Newell and Shanks (2014), suggesting that people are not always aware of the information triggering their decisions, and it is challenging for researchers to make people elicit all factors influencing their decision-making. Additionally, how to produce clear and replicable empirical evidence on unconscious thought processes is much discussed; research on the topic remains premature (Newell & Shanks, 2014). Another possible explanation for the lack of utterances concerning affect and emotion in the present study is that the interviewees are not asked directly that lack. Hence, even when they are conscious about their feelings, they may not find them worth mentioning; I speculate that it is easier to talk to a stranger about facts than about feelings. Although the participants typically do not report on their feelings, they do report on their experiences and these are closely linked to feelings. Thus, feelings are indirectly a part of the analysis in this study.

A person can be either *risk-seeking* (accept high uncertainty) or *risk-averse* (want to reduce or avoid uncertainty) in a specific decision situation. Research has found that affect and emotions play a role in whether we are risk-seeking or risk-averse. Several studies have found an inverse relationship between interpreted risk and benefit, implying that if feelings toward an activity are favorable, risk is judged as low and benefits as high (Slovic et al., 2004). Thus, if a person has positive feelings about an event, she will typically view it as having more benefits and fewer costs (Eiser et al., 2012). For example, a considerable number of Australian flood victims entered floodwater for recreational purposes (e.g., swimming, playing, or bathing) and likely underestimated the dangers (Becker et al., 2015). By studying specific emotions, Lerner and Keltner (2001) expand on studies that link affect and emotion to decision-making. Different appraisals of certainty and control moderated and mediated emotion effects (Lerner & Keltner, 2001). The authors found that fear and anger due to these differences have opposite effects on how risk is interpreted; fearful people expressed pessimistic risk estimates and risk-averse choices (which relates to a sense of uncertainty and a lack of control), whereas angry people expressed optimistic risk estimates and risk-seeking choices. Similarly, a positive mood (happy people) typically leads to more optimistic risk estimates (Lerner & Keltner, 2001). However, Västfjäll et al. (2014) found that, when studying the 2004 south Asian tsunami, a positive mood occasionally led to risk taking and occasionally to risk aversion.

Additionally, if one has not experienced a disaster, reliance on personal experience can lead to an underestimation of risk (Eiser et al., 2012).

Interpretation of risk always occurs in a social and cultural context (Bodemer & Gaissmaier, 2014). Similarly, in their model of protective action decision-making, Lindell and Perry (2012) claim that, in addition to the warning, the process starts with environmental cues (e.g., sights, smells, or sounds) and social cues. The social processes are important, and risk messages can have a social amplification or attenuation, depending upon the attention from media, people's conversations with one another, and so on (Eiser et al., 2012; Becker et al., 2015). Risk interpretation and action is also influenced by our trust in others, and laypeople may need to rely on information from experts (Eiser et al., 2012). Thus, communication is important because it can influence and possibly improve trust in experts (Eiser et al., 2012). For example, earthquake decision-making (low-probability and high-consequence) relies on effective communication of risk and uncertainty, but what is effective varies with type of decision-maker (Bostrom et al., 2008). Different types of visualizations have different effects on interpretation of risk; graphical displays of comparative risk (e.g., bar graph) increase risk-aversion for low-probability events relative to presenting numbers alone by weakening awareness of the upper bounds of the probabilities of adverse outcomes (Bostrom et al., 2008). Graphical displays can help people with low numeracy; however, graphics can also arouse emotions and overemphasis on negative consequences and can lead to risk aversion (Spiegelhalter et al., 2011)

Previous research has shown that our decisions are highly influenced by contextual factors such as emotion and affect (Västfjäll et al., 2014). In their study of the 2004 south Asian tsunami, Västfjäll et al. (2014) found that people used the affect elicited by thinking of the natural disaster (tsunami) to infer the risk of an activity in other domains. Thus, the affect elicited by major environmental events such as a hurricane or other natural disasters is likely to influence everyday decision-making (Västfjäll et al., 2014). Natural disasters can induce affect (they are likely to elicit negative affect) and different ways to think about risk (Västfjäll et al., 2014). Thus, people's recent experiences with extreme weather can influence their everyday weather-related decision-making. For example, one participant in this study said that in the time after a flood in which his house was water damaged, he was more worried when a large amount of rain was forecast. These feelings might subsequently lead him to examine forecast information more carefully. However, as discussed earlier, feelings are not studied directly in the present study.

In this study, the focus is on everyday decisions and non-extreme weather conditions, in which risk is relatively low. Forecast uncertainty, however, is important in this study and requires closer examination.

1.5.2 Decision-making related to weather and uncertainty

"A weather forecast, however skilful, has no intrinsic value unless it can be used to make decisions that bring some benefit to the end user" (Mylne, 2002, p. 307).

Indeed, weather forecasts have become important for both daily and hazardous-weather decision-making, with users ranging from members of the public to professionals (National Research Council, 2006). There is always an uncertainty associated with weather forecast information (what, where, and when), and if communicated, this uncertainty can be expressed qualitatively or quantitatively. Numerical probability statements are commonly used to express uncertainty in risk science and weather forecasting (National Research Council, 2006; Handmer & Proudley, 2007). The National Research Council (2006, p. 12) claims in their report that "the failure to provide forecast uncertainty information can contribute to damage and loss of life". Delaying decisions until certainty increases is not always possible, and we cannot assume that the information needed will become significantly more certain in a time frame that is realistic for decision-making (Dietz, 2013). If not provided, people attempt to estimate forecast uncertainty themselves (Joslyn & LeClerc, 2012). The participants' evaluations of forecast uncertainty and their own estimates of uncertainty are central in the present study (particularly in paper 1).

The ability to cope with natural hazards and everyday weather depends upon several factors, among them the interpretation of probabilistic information (Broad et al., 2007) and the use of this information in decision-making. Numerous studies have shown people to have difficulty addressing probability and risk (National Research Council, 2006; Nadav-Greenberg et al., 2008; Spiegelhalter et al., 2011). Problems interpreting probabilities might occur when the class of events referred to is not specified. For example, “a 30% chance of rain” can be interpreted as “rain 30% of the time”, “rain in 30% of an area”, or “rain in 3 out of 10 cases” (Gigerenzer et al., 2005). This and other challenges have led to suggestions to replace numerical probabilities with verbal expression (e.g., rain is likely). There are, however, challenges related to use of verbal probability expressions. The numerical likelihood ranges people assign to common verbal expressions are wide (National Research Council, 2006), most likely wider than is appreciated by forecast providers. The numeric interpretation of verbal expressions also depends upon contextual factors such as the base rate of the event (e.g., a good chance of rain is typically interpreted as more likely in London where it rains often than in the Gobi Desert where it rarely rains) and the severity of the event (e.g., a good chance of a hurricane can be interpreted as more likely than a good chance of a breeze) (Wallsten et al., 1986; National Research Council, 2006). Providing both numerical and verbal expressions of probability, such as in the reports from the Intergovernmental Panel on Climate Change (IPCC), is recommended by Morgan (2014). This recommendation is important because without quantification, different verbal expressions of uncertainty can mask important differences between the experts using them, in addition to being interpreted differently by users (Morgan, 2014). Providing both may provide an opportunity to narrow the range of interpretations (e.g., Budescu et al., 2012), in which one representation may constrain the interpretation of the other (as discussed in subsection 1.3.3 with reference to Ainsworth, 1999), and the verbal expression (which represents the essential meaning of numerical values) may shape the gist representation.

Despite indications that probabilistic information can be demanding for laypeople to interpret, several studies have focused on how individuals make weather-related decisions and whether the uncertainty information provided in the forecasts enabled users to make improved decisions (e.g., Roulston et al., 2006; Joslyn et al., 2007; Joslyn et al., 2009; Joslyn & Nichols, 2009; Roulston & Kaplan, 2009; Morss et al., 2010; LeClerc & Joslyn, 2012). Many of these studies were conducted in controlled contexts in laboratories or with surveys from a cost-loss perspective. As discussed earlier, the economic models are flawed with respect to human behavior, and Morss et al. (2010) report that not all participants in their study made decisions according to the cost-loss model. However, the models are viewed as a useful tool when studying the usefulness of probability forecasts. The simplified decisions allow comparison between deterministic (single-valued outcome) and probabilistic (multi-valued outcomes) forecast information (Mylne, 2002) and between probabilistic information in different formats (e.g., probability versus frequency). Probabilistic forecast information is usually found to have greater value for users than is equivalent deterministic information (Mylne, 2002; Joslyn & Nichols, 2009; LeClerc & Joslyn, 2012), suggesting that understanding the information is not really a problem. Another possible explanation for the improved decision-making is that people use probabilities as triggers to make decisions and thus do not need a precise interpretation but a functional understanding; for example, action may always be taken at a 70% chance of rain or higher (Handmer & Proudley, 2007). This explanation is supported by Konold (1989), who found that values sufficiently over (under) 50% were interpreted as “it will (not) rain” and mapped them to a yes or no decision, whereas values of approximately 50% were interpreted as “the forecaster doesn`t know” and did not serve as useful information. Making decisions using such simple rules is similar to the idea introduced by Simon (1955) with the satisficing heuristic. Visual displays of uncertainty information are assumed particularly helpful to both experts and laypeople (Nadav-Greenberg et al., 2008). To improve decision-making, presentation format should be compatible with the task to reduce the cognitive processing required to incorporate uncertainty information (Joslyn et al., 2009).

Small probabilities are found to be particularly challenging to interpret. In some cases, they are overestimated; in others, they are rounded down to zero (National Research Council, 2006). LeClerc and Joslyn (2012) expand on previous studies, suggesting that odds ratio is more suited than both deterministic and probabilistic information to communicate the relative risk in the case of rare but extreme weather, whereas probabilistic information is superior in normal (not extreme) weather conditions. People can underestimate personal risk in the case of rare but extreme events, due to availability heuristics (examples of precautionary actions, such as access to storm shelter, come easily to mind), affective factors (such as overoptimism), past experience (recent events play a greater role and rare events are more distant), or cultural worldviews (National Research Council, 2006; LeClerc & Joslyn, 2012; Morss et al., 2016). Deterministic forecasts might lead to more false alarms and to distrust in forecasts. However, this possibility is debated. Whereas some studies on hazards (hurricanes, tornados, and floods) suggest no cry-wolf effect or a negative influence of false alarms on an individual's decision to take protective action against future events, other studies (on tornados) provide alternative and more complex results (Trainor et al., 2015). For example, Trainor et al. (2015) found in their study that a substantial portion (almost 20%) of the sample believed that false alarms were unjustified, misinformed, or even lies, and this belief could lead to mistrust in future events. Importantly, if people like their local weather providers and believe them to be providing a good service, they tend to believe that there are fewer false alarms than there actually are (Trainor et al., 2015). Nevertheless, uncertainty information may increase trust in forecasts, because such forecasts seem less "wrong" than single-valued forecasts failing to verify (Joslyn & LeClerc, 2012). Over 70% of the respondents in O´ Hanrahan and Sweeney's (2013) study also found uncertainty information to increase confidence in the weather forecasts. However, some of their respondents thought such probabilities would be meaningless and confusing, or that they should only be used for severe weather (O´ Hanrahan & Sweeney, 2013). In the case of severe weather, Joslyn and LeClerc (2012) suggest odds might be better to stimulate precautionary action than percentages. However, odds should be used with care. Even when they stimulate action, they might also lead to an increased false-alarm ratio because odds can be very persuasive for taking action; however, there will not always be a strike (Joslyn & LeClerc, 2012). Importantly, probabilistic forecasts should be sufficiently sharp to provide precise and useful information for decision-making (Joslyn & Savelli, 2010).

The participants in the aforementioned studies concerned with uncertain decision-making were typically asked to pretend that they were managers or forecasters and thus to make (high-stakes) decisions as though it were their professional responsibility. Moreover, the studies were concerned with the use of selected pieces of information detached from the context of a real weather report and did not represent normal user situations. Although studying authentic real-world situations is impossible, normal user situations are replicated in this study by using holistic forecast information and allowing participants to talk about their own everyday decision situations. In fact, the most frequent use of weather forecasts is related to leisure activities (Demuth et al., 2011). Most weather-related decisions are everyday decisions (e.g., planning for a trip or clothing) (Silver, 2015), and such non-severe weather has been much less addressed in previous research (with important exceptions) (Demuth et al., 2011). Recent studies have begun to address the use of weather information for leisure activities; for example, Savelli and Joslyn (2012) study communication of weather forecast information to recreational boaters and Rutty and Andrey (2014) study weather forecast use for winter recreation. Understanding such decision-making requires, at a minimum, describing the information used (Rutty & Andrey, 2014). The present study aims to be a contribution to this area of research, focusing on information processing rather than taking a cost-loss perspective. Note that the participants in this study are told to report on their use of information provided in weather reports; there may be other sources of information they use privately that are not included in this study.

The role of analytical (conscious) processes in the interpretation and use of uncertain weather information in decision-making has typically been overestimated whereas affect and emotions have been ignored (National Research Council, 2006), which is also a flaw for the present study. A few participants in the interviews reported emotions when interpreting the forecast information. For example, one participant was scared of driving when snow was forecast, which might explain why forecast information was explored in more detail in such cases. These reports are very rare, and they are not elaborated on. There is a possibility that the interviewees did not report more emotions because they did not make true decisions, but rather described hypothetical decisions in which conscious thought prevailed. The eye-tracking study (i.e., paper 3), in which the decision-situation is more authentic, may be better suited for eliciting affect and emotions. However, the eye-tracking study is not about decision-making, but about reading. In future research, eye-tracking followed by think-aloud and interviews might be a more suitable approach than interviews alone to elicit participants' emotions when interpreting and using forecast information. Moreover, in future studies, the participants should be asked directly, "how does it make you feel?" to help elicit their responses about feelings (Peters, 2006).

My personal experiences as a forecaster, people's calls and e-mails to MET Norway, and the results from this study all indicate that people's interpretations of weather forecast information vary. People interpreting forecasts too differently can have a negative effect on decision-making, such as setting out on a fishing expedition when the forecast indicates an impending storm. In general, most of our judgments are appropriate most of the time (Kahneman, 2011). At the same time, media reports suggest that decisions with unintended fatal consequences are occasionally made (discussed in Section 4.3). Informed decision-making, however, produces desirable outcomes, avoids unnecessary costs to society (Pielke & Carbone, 2002) and can be helpful in protecting people's interests, lives and property (Hirschberg et al., 2011). Improved communication can contribute to an increased forecast value for users (Stuart et al., 2006) and help to enhance people's decision-making. In the following subsection, I present an overview of existing research on risk communication relevant for this study.

1.5.3 Risk communication

Risk communication has been a growing field since the 1980s (Kasperson, 2014), emerging from two stand-out reports: The 1989 report "Improving Risk Communication," from the National Research Council, and the 1985 report entitled "The Public Understanding of Science," published by The Royal Society. To achieve the desired level of public understanding, the committee suggested a proper science education for all (Royal Society & Bodmer, 1985). Understanding the nature of risk and uncertainty was considered "an important part of the scientific understanding needed for everyday decisions in our personal lives" (Royal Society & Bodmer, 1985, p.10). Notably, the public understanding of science discourse does not only focus on school education. In the report, British scientists were told that they had a duty to communicate with the public about their work (Royal Society & Bodmer, 1985), "aiming to reverse a tendency for scientists to retreat into their shells" (Miller, 2001, p.115). One motivation for the communication was to "make people understand" (Davies, 2008). The emphasis was on the public's attitudes toward science, assuming better knowledge and understanding of probabilities would engender positive attitudes and more support for science: "the more you know, the more you love it" (Bauer, 2009, p.4). Although there might be some relationship, the correlation between knowledge and attitudes is not confirmed, particularly not for controversial issues (Bauer, 2009). Rather than being more positive, attitudes that are based on knowledge seem to be more resistant to change (Bauer, 2009). In contrast, for some public understanding of science realists, attitudes are related to emotions rather than to knowledge. Hence, scientists have to "sex up" evidence to attract public attention (Bauer, 2009). "The critique of the public understanding of science focused on the deficit models of knowledge or attitude, claiming that negative attitudes are neither an expression of lack of knowledge nor of good judgment" (Bauer, 2009, p. 5).

Risk communication is viewed as a dialog conducted to help facilitate a more accurate understanding of risk among people and, relatedly, the decisions they make to manage them (Àrvai, 2014). However, although this definition of risk communication is widely accepted, it is often practiced differently (Àrvai, 2014). Despite the growth of risk communication in the past 30 years, Kasperson (2014) argues that the practices appear little changed. Àrvai (2014) claims that risk communication continues to be often viewed as a means of simply educating people and correcting "misconceptions" about risk, and argues that risk communication must be more decision-focused to be truly effective. Because different people are worried about different aspects of the risks and attach the uncertainty to different objects, Riesch (2012) claims that risk communication strategies often fail to convey the information that people actually find important.

In traditional risk analysis and communications, the focus has been and still is on the quantitative aspects of uncertainty (Strand & Oughton, 2009). In recent decades, however, science has been coping with increasing uncertainties resulting from a complex interplay between new technologies, cultural and political development, and the natural environment in badly structured extensive problems (e.g., hazardous wastes, the greenhouse effect and ozone depletion) (Funtowicz & Ravetz, 1990; Beck, 1992; Wynne, 1992). These problems affect environmental systems on a global scale, and the existing models for risk analysis and communication are not considered adequate or effective for handling them (Wynne, 1992; Funtowicz & Ravetz, 1993; Turnpenny et al., 2011; Meadow et al., 2015). Shifting the focus to preventive strategies for integrating environmental criteria into decision-making (i.e., the precautionary principle) exposes not only more uncertainty but also fundamentally different types of uncertainty (Wynne, 1992). When "facts are uncertain, values in dispute, stakes high and decisions urgent" (Funtowicz & Ravetz, 1993, p. 744), approaches aiming at a more transparent treatment of (epistemic and ethical) uncertainty are suggested, one of the most influential approaches being *post-normal science* (Funtowicz & Ravetz, 1993; Strand & Oughton, 2009; Turnpenny et al., 2011; Blanchard et al., 2014). The uncertainties associated with these types of extensive problems are generally less quantifiable and are described as partial ignorance ("we know what we don't know", or "known unknowns") or total ignorance ("we don't know what we don't know", or "unknown unknowns") (Strand & Oughton, 2009). These limitations to models could for example arise because some aspects that we know of have been omitted because of extrapolations from data or limitations in the computations, or because of things we suspect could occur but about which we do not have sufficient knowledge to be able to include them in the model (imaginable surprises) (Riesch, 2012). Despite remarkable progress in weather forecasting over the past 50 years some challenges remain (Lynch, 2008), and it is possible to find examples of uncertainties associated with partial ignorance in weather forecasting. Polar mesoscale cyclones (polar lows) are small but intense lows north of the polar front, with thunderstorms, heavy snow, and strong winds (Rojo et al., 2015). These are examples of an extreme weather phenomenon that may impact coastal and maritime activities (Rojo et al., 2015). Polar low forecasts have improved lately by using, for example, synoptic and climatological rules along with high resolution numerical weather prediction models for predicting their development and movement, and satellite imagery for identifying existing polar lows (Turner et al., 2003). Nevertheless, polar lows are still difficult to forecast due to their relatively small size and rapid development away from conventional observing sites (Rojo et al., 2015). In other words, even though meteorologists are aware of, and increase their knowledge of, the phenomenon, it is not always possible to forecast polar lows with enough lead time for people to take protective action.

Post-normal science is based on the principle that ignorance cannot be easily accounted for using standard statistical methods or by traditional probabilistic risk analysis; thus, qualitative methodologies are required to characterize the (unknown) uncertainties and make our ignorance explicit and usable (Funtowicz & Ravetz, 1993; Strand & Oughton, 2009). In communication, addressing acknowledged inadequacies (i.e., partial ignorance) can be done through informal, qualitatively formulated acknowledgement or by listing the factors that have been left out of the model (Riesch, 2012). In the case of polar lows, this means that forecast providers must communicate that the uncertainty in the forecast is not only whether it will be, for example, breeze and 3 or 5 millimeters of rain. Something completely different can happen due to a ("known unknown") polar low - it can possibly become heavy snow and strong winds.

The unknown inadequacies (i.e., total ignorance) are difficult to address because we do not actually know what they may be, and we are currently constrained by the limits of our imagination concerning what could possibly go wrong (Riesch, 2012; Blanchard et al., 2014). We can however acknowledge through simple humility that it is always possible that we are mistaken (Riesch, 2012).

In addition to ignorance, studies indicate that scientists, partly depending on their scientific background, interpret data differently in situations characterized by high system complexity and thus express a diversity of opinions on a specific issue (Strand & Oughton, 2009). Moreover, the identification of the system to be studied, as part from its wider context, might influence the identification of relevant data and conclusions. When problems of defining the relevant system are a central characteristic of scientific research, the corresponding uncertainty is denoted as indeterminacy by Wynne (1992). Indeterminacy means that there is no unique way of defining the system to be studied and/or acted upon (Strand et al., 2010). Consequently, indeterminacy is associated with the questions that do not even get asked (Curry, 2011); that is, investigating a restricted set of uncertainties, due to system definition, and leaving others invisible. For example, if an agreement exist that many people in coastal areas need improved wind forecasts, how should this challenge be identified as a system and how should the challenge be approached? A meteorologist could see this as a question of increasing the quality of the numerical weather predictions by increasing model resolution. Another meteorologist could argue that better predictions of polar lows are essential to the case. Importantly, how the system is defined will influence which information/knowledge that is produced and which uncertainties that are made visible, and the communication of this information and uncertainty.

In situations when facts are uncertain and decision-stakes are high, Funtowicz and Ravetz (1993) suggest we should establish and maintain a dialogue among the various interested parties. According to Wesselink and Hoppe (2011), post-normal science has been suggested implemented as a scientific method, which, in addition to focus and communicate more in-depth on uncertainties, to improve the relevance and the quality of information using extended peer review in which all of those with a stake in the issue are invited to participate in the dialogue. For example, Morss et al. (2005) study how flood risk managers make decisions in complex settings and with high stakes, and suggest that understanding how the different participants interact can be a key component in generating usable science. Traditional experts should be flanked by, and interact with, an extended peer community of those affected by or with special knowledge of the issue (Turnpenny et al., 2011). A transparent discussion of all forms of uncertainty is welcomed in these dialogues (Blanchard et al., 2014). This process with stakeholder involvement and dialogue was noted as a co-production of knowledge (Meadow et al., 2015), a process that is more closely discussed in subsections 1.6.2 and 1.6.3.

In sum, there are two contributions from post-normal science I find of special interest for weather forecasting: First, risk communication is important and (all types of) uncertainty needs to be discussed and communicated, and second, all with interest in an issue should be invited to participate in a dialogue to co-produce knowledge. By doing this, people's knowledge and local experiences, and also their needs, can be recognized and the information produced and communicated can be relevant and useful. In practice, co-production of all information is difficult. For weather forecasting, I mean that co-production should be considered useful for how forecasts (and uncertainty) are communicated and for making the forecasts relevant, not the technical aspects and the production of the forecasts themselves.

Although interesting, the qualitative aspects of uncertainty (ignorance and indeterminacy) are not further discussed in the present study. Rather, the co-production model is focused.

Àrvai (2014) suggests two-way dialog as a way forward for risk communication in general rather than the dominating one-way transmission of risk information from experts to laypeople. Sharing everything that experts know about risk uncertainty can be counterproductive for decision-makers. For instance, before Hurricane Sandy, more than 500 different warnings, forecasts, and advisories were issued (Bostrom et al., 2016). However, in this sea of available information, some members of the public still failed to receive a key message (Bostrom et al., 2016). Moreover, the participants in the present study occasionally left out evaluation of forecast uncertainty. Thus, the public does need to know the uncertainties that really matter concerning the magnitude of a risk and its management (Kasperson, 2014), in situations where this is important to them. Interpretations and assessments of risk are value-laden and subjective and make decisions no less problematic; experts and laypeople have much to learn from one another (Àrvai, 2014; Kasperson, 2014). For instance, laypeople should learn what experts know about the hazards they face, and experts should learn how laypeople conceive risk, how emotions influence risk assessment (Àrvai, 2014), and the influence of values/goals and judgments about trustworthiness of sources. Learning from one another could increase trust (Dietz, 2013). A large body of decision-research has shown that people tend to leave out key information when thinking about risks and, instead, utilize a variety of judgmental heuristics (Àrvai, 2014). Accordingly, how to communicate uncertainties to decision-makers remains challenging (Kasperson, 2014). Morgan et al. (2002) argue that the design of risk communication often relies on intuition and conventional wisdom; some of these communications have worked well, whereas others have been less successful. To meet this challenge, Morgan et al. (2002) developed a method that reflects both the natural science of how risks are created and controlled and the social science of how people comprehend and respond to such risk - a *mental model approach*. How to conduct mental model research is outlined in subsection 1.6.3. From mental model research, it is clear that understanding interpretations can be very helpful in improving communication (Kasperson, 2014). This study focuses on understanding users' interpretations (relates to RQ1) and uses (relates to RQ2) of uncertain weather information.

There have been several interesting recent attempts to improve severe weather risk-communication. Severe weather warnings are becoming increasingly risk-based as

forecasters aim to communicate both the uncertainty in the forecast and the likely levels of the impact of severe weather (Neal et al., 2014). For instance, in 2014 the National Weather Service in the U.S. implemented large-scale use of impact-based warnings designed to improve severe weather risk communication. The warnings use expanded and more specific wording with respect to the hazard, source, and impact of the forecast storm that clearly identifies potential threats (Casteel, 2016). Similarly, the UK National Severe Weather Warning Service issues warnings with three colors based on the likelihood of the severe weather event and its expected impact (Neal et al., 2014). The warnings are designed to inform both the public and government with defined level of response to different levels of warning (i.e., colors) (Neal et al., 2014). Adding text to the warning that specifies hazard, source, and impact information is consistent with the risk communication literature (Casteel, 2016). Impact-based forecasting is also encouraged by the WMO; in its guidelines on impact-based forecast and warning services, it recognizes that “it is no longer enough to provide a good weather forecast or warning – people are now demanding information about what to do to ensure their safety and protect their property” (WMO, 2015, p. 1).
Casteel (2016) claims that research has shown that effective warning messages must both be viewed as personally relevant and spur one to take protective action. In fact, personalization of risk plays a crucial role because it has been linked to an increased likelihood of taking protective action (Casteel, 2016).

These issues make uncertain information interesting and important to study, and the weather forecasts included in the data collection of this study contain deterministic and probabilistic information. The uncertainty information in the forecasts used in this study is presented with words, numbers and graphics. Regardless of people’s format preferences, a fundamental question is whether laypeople obtain the information from the uncertainty information that the forecasters intend (Handmer & Proudley, 2007). In the following subsection, I summarize earlier research on how laypeople interpret uncertainty information conveyed in different formats in weather reports.

1.5.4 Communication of uncertain weather information

Data and uncertainty can be communicated in multiple ways using different representations, such as words, numbers, or graphics, and can be adjusted to different end-users needs and capabilities (Spiegelhalter et al., 2011). Although most weather forecast information remains deterministic, there is a movement toward again including more uncertainty information (National Research Council, 2006; Joslyn & Savelli, 2010), and a great deal of research exists on uncertainty communication. Three issues concerning communication of uncertainty include which *format* to use (words, numbers, or graphics), the choice of perspective in presenting information (*framing*), and the inclusion of *reference class* (Spiegelhalter et al., 2011). Note that all of these issues are concerned with the quantifiable aspects of uncertainty. To my knowledge, other aspects of uncertainty (ignorance and indeterminacy) are not usually discussed in relation to communication of uncertain weather information, although such a discussion could be interesting for events in which decision-stakes might be high such as extreme weather or in flood management (e.g., see Morss et al., 2005).

Here, I present examples related to *format*. Probabilities have a long history in weather forecasting. In 1965, the first operational probabilistic forecasts were produced in the U.S. These probabilities of precipitation were in the beginning subjective predictions by the meteorologists. A few years later, they became model-based calculations (National Research Council, 2006). Particularly since the 1990s, degree of certainty in a forecast is objectively calculated by using ensemble prediction systems (EPS). By running a series (ensemble) of forecasts (e.g., the model is run 51 times by the European Centre for Medium-Range Weather Forecasts) with slightly different initial states, it is possible to calculate probabilities about future changes in the atmosphere (Lynch, 2008) and to overcome some of the error introduced by the chaotic nature of the atmosphere (Lynch, 2008). However, a challenge is the reliability of the probabilities calculated in the EPS systems (Atger, 2004). An 80% chance of rain does not mean it will rain 8 out of 10 times (Hamill 2012), and the forecast uncertainty is often underestimated (Hirschberg et al., 2011). This challenge is due to systematic errors in the ensemble (Hamill 2012). The probabilities must be calibrated using comprehensive post-processing to produce more reliable probabilities (Atger, 2004; National Research Council, 2006). For example, "if the observed frequency in the past was 30% when the forecast probability was 40%, the calibrated probability will be 30% when the raw probability is 40%" (Atger, 2004 p. 628). Thus, a main goal of EPS forecasting must be to provide reliable percentages such that an 80% chance in the model corresponds to an 80% chance in the real world. In my experience (e.g., the Royal Society meeting "Handling uncertainty in weather and climate prediction" in which I attended to in 2012), whether it is a good idea to communicate percentages before this goal is accomplished is also occasionally discussed. However, percentages are already in use, and they are unlikely to be removed. Importantly, these should be calibrated before being used.

There are indications that relative frequencies (3 out of 10) might be a more effective communication format than probabilities, because they are easier to connect to people's experiences (Gigerenzer, 1996; National Research Council, 2006). There is evidence that the frequency format increases the saliency of very small risks, highlighting individual occurrences and making them more imaginable (Joslyn & Nichols, 2009). However, Joslyn and Nichols (2009) found the opposite in their study of wind speed, in which the probability format was superior to the frequency format. Studies showing the advantages of frequencies are typically conducted in health research (e.g., biomedical screening), and it is speculated that it might be easier to interpret 1 out of 10 persons than 1 out of 10 days with similar atmospheric conditions (Joslyn & Nichols, 2009). Another important format conveying forecast uncertainty is the "cone of uncertainty", used by the National Hurricane Center (NHC) in the USA to illustrate the potential geographical range of a tropical cyclone (Broad et al., 2007). However, this approach to communicating probabilistic information leads to a variety of interpretations and many people underestimate the risk of the hurricane in their vicinity (Broad et al., 2007). Moreover, Ash et al. (2014) found that different visual design choices in the "cone of uncertainty" resulted in differences in self-reported fear and anticipated protective responses when viewing a tornado warning.

Graphical displays of uncertainty may help people process the information; however, the quality of the presentation is suggested to be a critical factor in decision-making (MacEachren et al., 2005). There are numerous ideas and suggestions about how to use and manipulate visual variables (e.g., size, color hue, color value, color saturation, orientation, texture, clarity, and shape) to alter existing symbology (intrinsic techniques) to depict uncertainty (Bostrom et al., 2008; Kinkeldey et al., 2014). Adding new objects (extrinsic techniques) to the display to depict uncertainty, for example error bars, is another possibility (Bostrom et al., 2008; Kinkeldey et al., 2014). Intrinsic approaches are assumed to be better for communicating overall uncertainty, whereas extrinsic approaches are suggested to be used for specific or locational uncertainties (MacEachren et al., 2005). However, for natural hazards, most of these techniques are not empirically tested about how they are interpreted by users and whether they are helpful or disruptive in decision-making (Bostrom et al., 2008). Despite all attempts, many of the alterations are demanding to interpret, mixed results indicate that visualizing and representing geospatial information uncertainty remains a challenge, and there is no consensus on the best means of communication (MacEachren et al., 2005; Bostrom et al., 2008; Kunz et al., 2011; Kinkeldey et al., 2014; Stauffer et al., 2015). For heterogeneous user groups such as the public, providing multiple types of information (Becker et al., 2015) and allowing users to customize the visualizations according to their needs appears to be beneficial (Kunz et al., 2011). For example, the most effective color palette likely depends upon the user task, that is, on who the end-users are and on their visual constraints, prior knowledge, and requirements (Stauffer et al., 2015). Notably, a number of studies have shown that what users prefer to view at is not necessarily the same as what works best for them (Kinkeldey et al., 2014). Some studies report that adding uncertainty information overwhelmed users and had negative effects on map readability and decision-making, whereas other studies suggest that including uncertainty information clarified the information rather than cluttering it (Kinkeldey et al., 2014). Even in situations in which uncertainty information are assumed to be beneficial to the end-users, they have to accept the additional effort to incorporate it into their decision-making processes (Kinkeldey et al., 2015). In summary, communicating uncertainties to laypeople remains a relevant challenge (Spiegelhalter et al., 2011).

Multimodality, however, might be an advantage when communicating uncertainty and you want people to understand one fact in isolation (Fischhoff et al., 2002; Morgan et al., 2009) because users seem to respond well to multiple types of display of the same information (Spiegelhalter et al., 2011). Most previous studies of uncertainty communication are of percentages. In this study, other ways to express uncertainty (intervals and colors) are included in the multimodal reading material for the participants. Hence, this study should add a relevant contribution to the existing body of research. In the last Section of the theory part of the thesis, I focus on the literature on communication between experts and laypeople and on models to carry out and to improve this communication. This literature might not be directly related to the research questions and the aim of the study. However, the literature is related to how to conduct the research and to the motivation of the study (i.e., the communication process) and thus to the discussions of the findings.

1.6 Communication between experts and laypeople

At the beginning of the study, I received a question from my main supervisor: "What do you think about the rationality of laypeople?" I admit that I was unsure whether the end-users of forecasts were able to comprehend the information, and I occasionally used words such as "wrong," "don't know," "misinterpretation," and "misunderstanding." After discussions with my main supervisor and considerable thinking, I realized that years of work as a weather forecaster had made me biased. I thought that the forecasters were right and that end-users sometimes were wrong in their interpretations. Could it be the other way around? Could the forecasters miscommunicate the forecasts, thus leading to unintended interpretations of the information? I realized the potential for such miscommunication. Did I use my colleagues and myself as a model audience, presenting information that I found interesting without remembering what it was like to be a novice in the field? de Bruin and Bostrom (2013) suggest that such an approach may cause miscommunication of information. Most importantly, I now realize that both the sender and receiver of a message have a responsibility for the message to be understood, and this potential should be achieved through a dialog process.

Although they have evolved as separate academic fields, science education and science communication share common goals; they both seek to educate, entertain and engage the public with and about science and prepare individuals to make informed decisions (the emphasis on these aspects may, however, vary) (Baram-Tsabari & Osborne, 2015). In the following subsections I summarize the literature on the development of science education and public communication relevant to this work: Science literacy and deficit models of communication (subsection 1.6.1); public participation and dialog models of communication (subsection 1.6.2); and the literature on carrying out and improving communication (subsection 1.6.3).

1.6.1 Science literacy and deficit models of communication

With the advent of technologies such as nuclear fission, artificial satellites circling the earth, plastics and pesticides since World War II, "science with its applications in technology was recognized as the most characteristic feature of modern society" (Hurd, 1958, p. 13). Because of the many new achievements in science in this period, Paul deHard Hurd introduced the term *science literacy* in 1958 (Hurd, 1958) as a goal for science education. Hurd (1958), who considered education in science essential for effective citizenship, called for a reinvention of school science curricula. The need for education in science for all was recognized by a national committee of scientists and engineers appointed by President Dwight Eisenhower in 1959; the committee saw the need for a democratic citizenry that understand science for intelligent democratic participation (Hurd, 1998).

Initially, science literacy discourse was primarily introduced for curriculum planning for educating the broad proportion of students not likely to become scientists (Roberts, 2007). Since Paul deHard Hurd introduced the term in 1958, many definitions of science literacy have been advanced but not always with the same meaning (Holbrook & Rannikmae, 2009). Although there is no agreement on the meaning of science literacy, there appear to be two major existing views (Holbrook & Rannikmae, 2009). Most definitions have focused on identifying the science valuable for students over a lifetime (Roberts, 2007). This view (Vision I), focusing on content knowledge, remains prevalent (Roberts, 2007; Holbrook & Rannikmae, 2009). In this view, individuals are required to hold a certain amount of scientific knowledge (Roberts, 2007). This idea of science literacy attributes a knowledge deficit to the public (Bauer, 2009). The science literacy discourse is criticized for focusing on factual and conceptual knowledge, arguing that the essence of science is the methods, not the facts (Bauer, 2009). Another critique of the science literacy idea is its ignoring of the significance of other types of knowledge (Bauer, 2009). This narrowing down of the student's experience with the breadth of science is found problematic with Vision I

(Roberts, 2007). Similar to the science literacy discourse, the idea behind the public understanding of science discourse is that of a public deficit (Bauer, 2009).

My early perspective, which has been typical in national weather services for several decades, had certain similarities to such a "*deficit model*" of science communication (Daipha, 2012); describing the public as having a cognitive deficit and being ignorant or scientifically illiterate (Ziman, 1992). Deficit models adopt a top-down communication process in which experts fill a knowledge vacuum in the general public (Davies, 2008). The main purpose of the communication is to "make people understand," that is, to "educate" them (Davies, 2008) and increase their science literacy (Miller, 2001). Communication is considered a one-way process, that is, a transfer of information/knowledge from scientists to laypeople (Trench, 2008). The experts set the information agenda, and *push* information to potential users (Dilling & Lemos, 2011). According to a deficit model view, reception of the information should result in a predicted effect on the receiver (Davies, 2008). Davies (2008), talking to scientists about talking to the public, discovered that scientists describe communication as difficult and dangerous because the public might misunderstand and misuse science. Holbrook and Rannikmae (2009, p. 276) argues, "The use of literacy is still appropriate, but it is necessary to relate it to an appreciation of the nature of science, personal learning attributes including attitudes and also the development of social values". The term literacy, in addition to its use in science communication models, has been developed further in recent years and is presented in the following subsection.

1.6.2 Public participation and dialog models

In the early 2000s, the concept of science literacy has seen a renaissance (Bauer, 2009), and the concept has been rephrased as *scientific literacy*. This second view, Vision II, focuses on embedding science subject matter in situational contexts (Roberts, 2007). This view (as with Vision I, although more implicit in that view) recognizes "that scientific literacy relates to enabling citizens to effectively participate in the real world" (Holbrook & Rannikmae, 2009, p. 279). However, the need to consider economical, aesthetic, political, ethical and social perspectives, in addition to science, in understanding an issue is emphasized (Roberts, 2007). This mentality is similar to the way of thinking originating from approaches such as post-modern science in the 1990s (see subsection 1.5.3). Additionally, the view on transfer of knowledge (the ability to extend what has been learned in one context to new contexts, Bransford et al., 2000) is different in Vision II (transfer is "problematic") than in Vision I (transfer is "easy"). Hence, Vision I and Vision II provide different views of what it means to be scientifically literate (Roberts, 2007), and Vision II meets some of the critiques raised for Vision I. The trend in Vision II is toward less attention to purely understanding science, more attention to functionality and developing students' ability to read and reflect critically on the information in media reports, and toward making informed personal decisions in the face of uncertainty (Bransford et al., 2000; Holbrook & Rannikmae, 2009; Roberts & Bybee, 2014). This trend is similar to the new trend in risk communication described above (subsection 1.5.3), and a true dialogue with users is appreciated in some recent work related to communication of weather information (e.g., Morss et al., 2005). The Vision II perspective has informed this study, enabling a broad view of knowledge of potential relevance for interpreting weather forecasts and a better informed discussion of possible implications of results for school science.

Norris and Phillips (2002) argue that the ability to read science is important for the lifelong learning of nonscientists beyond their formal science education. Although a person can learn by trial and error, word of mouth and apprenticeship, science is unthinkable without text, and the inability to read and write will limit a person's potential to acquire scientific knowledge (Norris & Phillips, 2002). However, results from the 2006 PISA test (focused on scientific literacy) indicate low engagement in leisure reading of science (Kjærnsli et al., 2007). Engagement in reading is considered crucial for achievement in reading literacy; better readers tend to read more (Brozo et al., 2007; Wigfield & Guthrie, 2010). Additionally, due to the shift in communication from written text to digital multimodal texts with images, scientific literacy should encompass more than the ability to handle written and spoken language (Jewitt, 2008). In an extended view on literacy, Kress and van Leeuwen (2006) consider being visually literate important because visual communication has become dominant. The meaning of a visual representation differs among societies and social groups (Kress & van Leeuwen, 2006). Being able to comprehend visual information is important also in science texts (McTigue & Flowers, 2011). Few studies have addressed the relationship between images and language to show how visual and verbal modes interact to construct integrated meaning in multimodal texts (Unsworth & Clèirigh, 2014). This study examines the reading of a multimodal science text and how verbal and visual information is integrated (RQ1/3), thus aiming at contributing new knowledge in this field.

In an update to the comprehensive review presented in Roberts (2007), Roberts and Bybee (2014) argue that the terms scientific literacy and science literacy have played a less significant role in literature in the last decade. For instance, the terms have limited presence in the U.S. Framework for K-12 Science Education from 2012 and in the framework for Assessment of Science in PISA 2015 (Roberts & Bybee, 2014). Both documents are reducing the attention to personal and societal perspectives (Roberts & Bybee, 2014). By staying strictly with scientific and engineering aspects of the issues, these documents do what Sadler and Zeidler (2009) warned about; that is, they assume that knowing science will automatically enable students to transfer knowledge to a variety of situations (Roberts & Bybee, 2014). Some studies exist that examine how people actually use science in daily life (e.g., see Ryder (2001) and Aikenhead (2006)) and sociocultural studies of literacy (a social view of literacy) pay specific attention to the contexts in which scientific information is used (Sørvik & Mork, 2015); nonetheless, additional studies are needed (Roberts & Bybee, 2014).

Although there appears to be a reduced focus on functionality and personal decision-making in science education/school curriculum planning, this emphasis remains in science communication and in weather communication. Davies (2008), talking to scientists about talking to the public, also discovered that some scientists describe communication as a context-dependent process in which experts inform a particular and knowledgeable public and empower them to participate in a democracy and make decisions. In this model, which holds similarities to Vision II rather than deficit models, science is no longer perceived as a special type of knowledge that is only misunderstood by ignorant people (Ziman, 1992). Instead, the public voice should not be ignored because it facilitates a two-way communication process (Davies, 2008). This perspective is typical for *dialog models* of science communication (Miller, 2001). A viewpoint in which the science communicator adjusts to the needs of the general public (and not vice versa) is considered valuable in *pull* models of communication. Here, potential users of the information set the information agenda (Dilling & Lemos, 2011). The downside of pull models is that decision-makers may demand information that is not feasible or scientifically robust (Dilling & Lemos, 2011). This downside is possibly greater for certain members of the public who do not necessarily know what is useful information in a given situation than for professional decision-makers (e.g., policy-makers, or water managers). In a second viewpoint, scientists provide scientific knowledge, and the public contributes local knowledge and understanding of the specific problem to be solved (Miller, 2001). This dialog, or *co-production*, requires iterativity between experts and users (Dilling & Lemos, 2011) to achieve a communication that both acknowledge. Dilling and Lemos (2011), reviewing over 30 empirical studies focusing on seasonal climate forecast use, argue that usability is a function of how the information is produced (push) and how it is needed (pull) in different decision contexts. For instance, there is empirical evidence that successful use of climate forecasts is due to the creation of forums or networks in which forecasters and potential users repeatedly participate together (Dilling & Lemos, 2011). Providing usable information therefore requires bridging differences between what providers think is useful and what is actually usable in practice (i.e., to understand the decision context), such that the information is not overshadowed other types of information and other priorities (Dilling & Lemos, 2011). The level of trust of users in the forecasts and the level of skill of the information presentation influence usability; additionally, the accessibility and the timing of the release of the information can be critical for whether it is usable. Decision-makers should be given sufficient time to prepare but not so much time that information is forgotten (Dilling & Lemos, 2011). The time needed to prepare will vary; for example, Carr et al. (2016) found that emergency managers preferred to receive storm information earlier prior to storm landfall than what residential participants did. Accessibility is influenced by language, graphical representations, and format (Dilling & Lemos, 2011).

Co-production takes time and resources to do well, and Meadow et al. (2015) claim that, currently, a limited numbers of scientists undertake it. Notably, Dilling and Lemos (2011) argue that there often is a lack iterative meetings between producers and users because neither of them "own the problem" of creating usable information. Thus, a key challenge to producing usable information is to determine who is responsible for owning the process of connecting scientists/forecasters and decision-makers. In the last subsection, I present a model described in the science/risk communication literature suggesting how communication can be improved through co-production of communication materials.

1.6.3 Communication, decision-making, and this study

One important aspect of communicating (uncertain) weather forecast information is to inform decisions, both high-stakes decisions (e.g., about extreme weather events and big consequences for the society) and low-stakes decisions (i.e., for the society; individuals may experience stakes to be high if their economy or life is threatened). In this study, everyday decisions made by non-experts are the focus. To inform people's decisions, communication must reach people with the information they need and in a form they can use (de Bruin & Bostrom, 2013; Fischhoff, 2013). Dietz (2013) and von Winterfeldt (2013) claim that decisions involve both facts (including uncertainties and expert opinions) and values (goals, objectives, and tradeoffs) whereas most science communication focuses on facts. If science communication is intended to inform decisions, it must be competent with respect to both scientists' facts and decision-makers' values (Dietz, 2013; Fischhoff & Davis, 2014). According to Dietz (2013), research on public participation suggests that an iterative process linking science and public participation can help decision-making address both facts and values. Such a dialog (i.e., scientific studies in which people are interviewed about their values, experiences, and needs, not everyday conversations) can help to understand the local context and constraints on decision-making and clarify which conflicts are about differences in values, about differences in interests, and about different understandings of the facts (Dietz, 2013). Similarly, Fischhoff (2013) claims that for communication to inform decision-making, it is important to maintain a dialog and listen to the end-users. Building on the mental model approach from Morgan et al. (2002), de Bruin and Bostrom (2013) and Fischhoff (2013) propose using a mental model research approach to improve risk communication and science communication. Rather than relying on experts' intuition, communication materials should be based on evidence from research including both experts and end-users (de Bruin & Bostrom, 2013). Fischhoff (2013, p. 14034) suggests that four interrelated tasks must be fulfilled to achieve useful and effective communication:

1) Experts identify the information most relevant to the decisions people face

2) Experts determine what people already know

3) Experts design communications to fill critical gaps

4) Experts evaluate the adequacy of the communications

Repeating tasks 1-4 generates an iterative process. This model targets experts who seek to develop communication materials with the goal of informing individuals' decisions (de Bruin & Bostrom, 2013; Fischhoff, 2013). Thus, experts establish and lead the process; however, laypeople's interests are addressed by including their needs, knowledge, and values in the development of the communication materials.

Table 1: The relation between the four tasks in the mental model approach and the aim and motivation of the present study.

<table>
<tr><th>Mental model approach tasks</th><th>Study</th><th colspan="2">What</th></tr>
<tr><td>Task 1</td><td>-</td><td colspan="2"></td></tr>
<tr><td rowspan="3">Task 2</td><td rowspan="3">Aim</td><td rowspan="3">Identify different interpretations, integrations, and uses of weather information</td><td>RQ1</td></tr>
<tr><td>RQ2</td></tr>
<tr><td>RQ3</td></tr>
<tr><td>Task 3</td><td>Motivation</td><td>Insight into the communication process between forecast providers and end-users</td><td></td></tr>
<tr><td>Task 4</td><td>-</td><td colspan="2"></td></tr>
</table>

The present study is motivated by the idea of gaining insight into the communication process between forecast providers and end-users, that is, into how to achieve useful and effective communication. All four tasks in the mental model approach are important and interesting. Nevertheless, due to the constraints limiting this work, I concentrated on the second and to some extent the third task (Table 1). Related to the *first* task, de Bruin and Bostrom (2013) suggest conducting a literature review and consult an expert panel to identify what people must know to make informed decisions (expert decision model). Different users of weather reports are likely to need different information. Therefore, it is relevant to identify which parameters are to be communicated. For example, most weather reports include information on temperature and precipitation; fewer include information on wind gust or the altitude of the cloud cover. In the data collection, what information each participant uses is discussed. However, the focus is on which representations that are used, not whether they are interested in temperature, precipitation, or other parameters. Moreover, information other than weather information such as environmental (e.g., signs or barricades) or social (e.g., others' actions or conversations with others) cues might be important when making weather related decisions (e.g., see Morss et al., 2005; Becker et al., 2015). This point is also briefly discussed in the interviews in the present study in relation to decision-making processes. However, to limit the study, I do not spend time identifying what information should be presented in weather reports (there are other studies discussing the importance of different potential components of weather reports e.g., Lazo et al., 2009; Rutty & Andrey, 2014). Rather, I use one selected online weather report (Yr.no) as a case and study how the information in this report is interpreted, integrated, and used. Thus, in the data collection, the aim is to determine what people already know (lay decision model). This *second* task is performed by conducting semi-structured interviews, as suggested in the mental model approach, and by recordings of participants' eye-movements. de Bruin and Bostrom (2013) also suggest conducting follow-up surveys with larger samples. Such surveys should be conducted in future research to examine the prevalence of the results from this study. After analyzing the data, I discuss (in the papers and this extended summary) ideas how communication can be designed to fill gaps; that is, the *third* task (which relates to the motivation of the study). However, the discussed design of the communication material is not accomplished via a systematic comparison of an expert and lay decision model, as suggested by de Bruin and Bostrom (2013). Importantly, a comprehensive approach to communication would include not only principles of judgment and choice but also how feelings can both aid and undermine communication (Fischhoff, 2013). Finally (the *fourth* task), Fischhoff (2013, p. 14037) suggests communication is "adequate if it (i) contains the information that recipients need, (ii) in places that they can access, and (iii) in a form that they can comprehend". This testing whether resulting communication is effective (in terms of facilitating understanding and informed decision-making) should involve an iterative dialog by repeating tasks 1-4. This iterative process is not a part of the present study.

Bostrom et al. (2016) claim that it is critical to incorporate in the forecast development process a more comprehensive understanding of what essential aspects of extreme weather risks various citizens lack knowledge of and a deeper expertise on risk communication and decision-making. For risks under personal control, successful communication can help people to identify those risks that are sufficiently large to warrant some of their limited time and attention (Morgan et al., 2002). Because people's time is short, they cannot learn about, much less influence, all risks (Morgan et al., 2002). Improving forecast products based on feedback from users and other professionals with a better understanding of the social and behavioral contexts of how the information is used may help address such disconnects (Bostrom et al., 2016). By making such an improvement, it is possible to create and communicate useful weather information through co-production, as proposed by Dilling and Lemos (2011).

In designing a communication, especially in situations involving severe weather and big consequences for the society, qualitative aspects of uncertainty (ignorance and indeterminacy) can also be important factors to discuss in a dialogue with stakeholders. We may want to focus in particular on how the design was developed, what the uncertainties with the parameters are, what was the choice of models available, why this particular model was chosen, what possible inadequacies were not modeled and finally what are the plans for action should unforeseen consequences occur (Riesch, 2012). At times information may be theoretically useful or useful in a general sense, but might not be used because it does not, for example, fit certain decision goals (Dilling & Lemos, 2011) or because uncertainty complicates already difficult judgements (Morss et al., 2005). For example, flood managers making decisions in complex environments may find the best information they can quickly, make the decision required, and then moving on (Morss et al., 2005). Managing risk and uncertainty in this zone requires extended consultation with a wider community and involves assessing social values and scientific facts and expertise (Grinnell, 2015).

2. Methodological considerations

The main aim of this study was to gain insight into different interpretations, integrations, and uses of the information in online weather reports (see also Table 2): *How did persons from selected user groups interpret, integrate, and use the information when they made everyday decisions regarding weather-related activities?* Did the interpretations differ from the intention of the forecast provider? In the beginning of this study, I articulated research questions (RQ1 and RQ2) based on these ideas. With my quantitative background, I admit I was initially seeking the opportunity to conduct a survey and perform a statistical analysis. However, I soon realized the challenge of creating a quantitative design in this study: How can I develop an adequate survey without knowing which possible interpretations of the information to establish as response alternatives? Those alternatives would have been very limited (the interviews revealed several factors affecting the interpretation of information that I had never previously considered, such as the importance of cloud color in weather symbols). Instead, I reviewed the literature on methodology and spoke with experienced researchers who were familiar with different methods in order to obtain suitable methods to answer the research questions (see Table 2 for an overview of the study design). I learned about the strong agreement regarding the use of qualitative methods and the importance of beginning with interviews, for example as suggested in the mental model approach (de Bruin & Bostrom, 2013). Qualitative, semi-structured interviews were suitable for this study due to the lack of previous research in this area and to answer the specific research questions concerned with the participants' mental models and their interpretations of phenomena (Johannessen et al., 2010; de Bruin & Bostrom, 2013).

In the following, considerations related to the interview study are provided (Section 2.1). Thereafter (Section 2.2), there are considerations regarding a second data collection using eye-tracking equipment (see Table 2). Reflections related to generalization of the study findings are provided in Section 2.3. Finally, there are some considerations related to the study ethics (Section 2.4).

Table 2: Overview of study aim, motivation, and design.

Study	*What*		*How*	*Who*
Aim	Identify different interpretations, integrations, and uses of weather information	RQ1	Qualitative interviews	21 interviewees (Table 4 – App.B)
		RQ2		
		RQ3	Eye-tracking Think-aloud protocols Qualitative interviews	16 participants (Table 5 – App.D)
Motivation	Insight into the communication process between forecast providers and the end-users		Discussions of implications of the study findings	

There is an ongoing discussion among researchers regarding which terms that should be used to describe the quality of qualitative research. For example, in the 1980s Guba and Lincoln substituted reliability and validity with the concept of trustworthiness (Morse et al., 2002). Kvale and Brinkmann (2009) argue that the traditional terms reliability and validity are meaningful and are used also in everyday language. Thus, similar to Kvale and Brinkmann (2009) and many qualitative researchers in Europe (Morse et al., 2002), these terms are used when discussing quality of data and findings in the present study. Importantly, to avoid missing serious threats to the reliability and validity, quality of the study is focused from the very beginning rather than taking a post hoc evaluation approach (Morse et al., 2002; Kvale & Brinkmann, 2009).

2.1 The interview study

A major feature of qualitative interviews is that they focus on ordinary events in natural settings (Miles & Huberman, 1994). Data can be collected in close proximity to a specific situation by emphasizing a specific case. The influences of the local *context* are considered and not eliminated (Miles & Huberman, 1994). By mimicking normal user situations, high ecological validity can be achieved (Hannus & Hyönä, 1999).

One of the advantages of interviews is the ability to collect rich descriptions of personal interpretations of phenomena (Miles & Huberman, 1994) and to allow the interviewees to express the beliefs (i.e., the mental models) they use in interpreting the information (Morgan et al., 2002; de Bruin & Bostrom, 2013). The interviewer is the instrument that is used to collect the data. He must decide which questions to ask, and how to ask them. Therefore, the interviewer should be knowledgeable about the theme of the study and have good conversational skills (Kvale & Brinkmann, 2009). These skills should be practiced by performing interviews to become an effective (instrument) and *experienced* interviewer.

One objection associated with interview studies concerns the use of *leading questions*, which sometimes reduce the possible range of answers and the validity of the interview findings. However, leading questions that are employed systematically to control the reliability of the informants' answers are considered an advantage of qualitative interviews and may contribute to valid knowledge (Kvale & Brinkmann, 2009). Guiding criteria exist regarding how to conduct qualitative interviews to achieve reliable and valid data. Ideally, interpretation and validation should be performed during the interview (Kvale & Brinkmann, 2009): The first ideal—*interpretation* —can be achieved by repeating the different versions of the same question. This variation gives the interviewer the opportunity to interpret the meanings of the informants' responses in a preliminary analysis as the interview is conducted. By asking different versions of the same question, the interviewer can test the reliability of the answers (are the answers similar?) and *validate* (the second ideal) his interpretations of the informants' answers. Spontaneous, prolific, specific and relevant answers from the informants contribute to high-quality interview data (Kvale & Brinkmann, 2009).

Interviews are sometimes accused of being subjective because the questions and interpretations of informants' responses are influenced by the context and are highly *person dependent* (Kvale & Brinkmann, 2009). In the following Section, I discuss my efforts to acquire experience, avoid leading questions and subjectivity, and achieve high-quality interview data.

2.1.1 Experience, preparations, and rich descriptions

With the exception of a few interviews that were conducted late in my undergraduate studies, I had no experience with interview studies. Fortunately, I received support from the literature and supervisors. In September 2011, I conducted a pilot study. The pilot study was important to practice interview techniques and gain experience as well as to test the interview guide and check practical details (where to sit and how to use the digital voice recorder) (van Teijlingen & Hundley, 2001). A month after the pilot study, I conducted the first interviews of the main study. The first part of the data collection occurred in October and November 2011. These eighteen interviews were transcribed and analyzed, and some patterns in the data were identified. To verify the reliability of the findings and determine whether saturation was attained, three final interviews were conducted in May 2012. Breaks between the interviews were allowed in order to reflect on the technique, questions, and analysis (Kvale & Brinkmann, 2009). By doing this, I was able to improve my skills as an interviewer.

Some may question whether an inexperienced interviewer such as myself can collect rich descriptions of personal interpretations, integrations, and uses of weather forecast information. The average length of the interviews in this study was 44 minutes, which suggests the collection of rich descriptions. The subject of the study may have improved the flow of the dialog. Weather is a harmless and familiar subject for conversation between two strangers. A more experienced interviewer could collect even richer descriptions because he would have been a finer "instrument." Similar to a quantitative study, a better instrument (e.g., thermometer) facilitates the collection of more precise data (e.g., degrees Celsius in decimal numbers instead of integers). A more experienced interviewer would ideally not collect different data but rather richer descriptions. That said, my background as a meteorologist and experience as a forecaster makes me knowledgeable about the theme of the study, which is advantageous. As a result, I am capable of identifying interesting interpretations, integrations, and uses of weather and uncertainty information and I can follow-up the most interesting utterances with relevant questions (Kvale & Brinkmann, 2009). An experienced interviewer without a background in weather forecasting may not have noticed the same distinctions. Few people are experienced in both forecasting and interviewing, and the study must be conducted with the resources available.

2.1.2 Dialog, interpretation, validation, and leading questions

A phenomenological interview design is suitable to examine people's interpretations of a phenomenon (weather forecasts) (Kvale & Brinkmann, 2009). An open approach is important in this design because the informants' descriptions of phenomena should not be restricted by the interviewers' prior understanding. The phenomena should be described as perceived by the informants in their lifeworld (Gubrium & Holstein, 2000; Kvale & Brinkmann, 2009). In this study, the interviews were centered around actual information from a weather report using one selected online weather report (Yr.no) as a case. By contextualizing the dialog rather than having a dialog based on memory of how the forecasts look, a typical normal user situation was simulated and the ecological validity of the data was strengthened.

The desire for an open approach in the phenomenological design also indicates that the interview guide should not be too structured. In this study, the dialog in the interviews was based on a semi-structured interview guide that facilitated the discussion of new and unexpected interpretations of weather forecast information. The questions were planned to generate thematic knowledge and encourage open conversation (Kvale & Brinkmann, 2009). However, I considered the order of the questions in the pilot-study to be unsatisfactory, because it resulted in too much repetition and division of the dialog. This outcome was improved in the final pilot interviews after changing the order and re-articulating and clarifying some of the questions. Clear questions increase the reliability of a study (Hansen, 1996). Related to cultural manifestations there are different ways of saying things (Fontana & Frey, 2000). This means that different informants are likely to interpret the same question differently. Therefore, the articulation of questions may exhibit some variation among informants (Kvale & Brinkmann, 2009). In this study, the questions were (orally) refined to achieve similar perceptions by the informants.

Active vocabulary differs from passive vocabulary; it is easier to recognize something (passive) than to recall it (active). Thus, I tried to avoid "putting the answer in the mouth of the informant" (Hansen, 1996, p. 211). Instead, the informants were always asked open-ended opening questions (refer to Appendix A), to facilitate new interpretations of information. By doing this, I also avoided asking leading questions suggesting specific ideas (de Bruin & Bostrom, 2013) and narrowing the range of possible answers (Fontana & Frey, 2000). An example of an open question from one of the transcribed interviews is as follows:

Interviewer: *What time would you expect the rain to begin, based on the forecast?*
Informant: *I would have been pessimistic regarding six o'clock in the morning, based on the first gray cloud symbol. Even though the forecast indicates dry weather, it shows a gray cloud.*

The open questions in the interviews were followed by additional questions as necessary to clarify informants' responses or to validate my interpretations of their answers. This process is exemplified in the following sequence from the same transcription:

Interviewer: *You expect rain even if there are no raindrops in the symbol?*

Informant: *Yes.*

Interviewer: *So, the color of the cloud has an influence?*

Informant: *It does. Sometimes when it is light rain, this is not a large enough amount of rain to put raindrops in the symbol.*

These questions cannot be planned in advance of the interviews. The opportunity for the interviewer to verify his understanding of the informants' answers during the data collection is an important advantage of qualitative interviews (Kvale & Brinkmann, 2009) because it contributes to a common understanding between the interviewer and the informant. By clarifying the informants' responses I was able to increase the validity of my interpretations and construct a more certain foundation for the analysis of the data (Kvale & Brinkmann, 2009).

2.1.3 Interview knowledge and person dependency

In an interview, the interviewer and the informant engage in a dialog. It is not possible or desirable to plan all questions in advance. Therefore, the dialog may follow different paths for different informants. In a qualitative interview, the interviewer serves as the instrument in the data collection (Kvale & Brinkmann, 2009). A different interviewer will most likely engage in another dialog with the same informant based on the same interview guide (Kvale & Brinkmann, 2009). The two interviewers should obtain the same information regardless of the path in the dialog. Another interviewer with the same research questions should ideally not end up with different knowledge. This situation highlights the issue of reliability and can be compared with the use of two instruments; such as thermometers in a quantitative study. The two instruments are supposed to yield similar measurements. However, the uncertainty associated with these instruments may result in small differences in the measurements.

In the real world, for two different researchers to obtain the same information and knowledge would be very difficult. To make it possible for another researcher to replicate my study, I needed to make it as transparent and clear as possible. Therefore, the background, theory, methods and data analysis are detailed in the papers to enable other researchers to take the same view and use the same methods when evaluating or replicating my study. This approach should enable two researchers to obtain similar (and not overly individual-dependent) outcome.

In addition, my ideas were tested via social interaction at seminars and conferences and by code-checking by a colleague. My interpretations of informants' utterances were verified and challenged. If my ideas differed from the ideas of others, they were adjusted according to feedback from these other people in the environment. If my ideas corresponded with the ideas of others, they were consolidated. This iterative process reduced the possibility of individual dependency in the study.

2.1.4 Paper versus screen

Another challenge experienced in this study was related to the authenticity of the weather forecasts. The use of real forecasts and holistic forecast information would increase the validity of the study. Therefore, forecasts from the Yr.no website were selected for the interviews. Printouts were selected to ensure interesting forecasts and because they offered a basis for comparison among different informants' answers. Because printouts were used, interactive functions in the form of animations and "mouse over" interactivity were not included. However, the interviewees expressed that these functionalities were rarely used, and the loss of information pertaining to interactivity seems insignificant for the purposes of the study. Thus, the use of printouts only slightly reduced the validity of the study. In this study, the possibility to compare answers and the assurance of interesting forecasts were determined to be more important. The use of printouts also eliminated the risk of troublesome Internet connections.

Because I wanted the printouts to provide a basis for comparison among the answers, I had to select forecasts from one location for all informants. All forecasts pertained to

Stavanger; all informants were familiar with the city, but none lived there. A problem regarding the use of forecasts for Stavanger, compared with the informants' hometowns, was that it was more difficult for them to use local knowledge, which can reduce the validity of the study. However, some informants interpreted the forecasts as if they were forecasts both for their hometowns and for Stavanger, which mitigated this problem.

2.1.5 Possible improvements

I am very satisfied with the use of qualitative interviews as the primary method in this study because the method provided valid data and reliable findings for the first and second research questions. However, I suggest the following improvements for future studies:

First, I would have considered including more user groups in the sample. By doing this, I would win some and loose some. The inclusion of other groups that are familiar with and dependent on weather forecasts or groups that are not dependent on weather in their daily lives would allow for a greater number of interpretations, integrations, and uses to be discovered in the interviews. However, the number of informants that were used in this study resulted in a rather large amount of data. Thus, the inclusion of more user groups would require reduction in the number of members in each group or in each location, to avoid ending up with more data than it is possible to handle (Kvale & Brinkmann, 2009).

Second, I would have performed a more thorough analysis of the first interviews at an earlier time. It is strongly recommended (Miles & Huberman, 1994) to cycle back and forth between existing data, and collecting new data to fill in the gaps. However, I was unfamiliar with qualitative analysis, which was challenging. Because of this, the first analysis of the first interviews was somewhat superficial. Spending more time on the first analysis may have improved my skills as an interviewer and contributed to richer descriptions.

Third, as suggested by Peters (2006), I would have asked the participants directly about their feelings. Additionally, to help elicit their responses, I would have asked them about their values and how these could have influenced their decision-making.

2.2 The eye-tracking study

After the interviews were conducted and analyzed, I had some time to consider the next step. Data were needed to answer the third research question (RQ3), and these data were not obtained in the previous interviews. As I reviewed the literature on the reading of multimodal texts, I became interested in eye-tracking methodology, which is commonly employed in studies involving reading (Hannus & Hyönä, 1999; Solheim & Uppstad, 2011). After careful consideration, I decided to use this technology in the present study. Eye-tracking provided the opportunity to use more authentic texts (i.e., interactive forecasts) compared with the interview study. With this technology, I was able to study real-time online weather forecasts (on the Yr.no website). The use of eye tracking enabled me to complement previous interviews by examining the participants' use of forecasts in a specific (although still hypothetical) situation versus the use of an expired forecast. The primary aim for this final data collection was to investigate the participants reasons for reading the various representations, constructing the reading paths, and integration of multimodal information. This approach is slightly more theoretical compared with the examination of interpretations and decision-making processes. However, both data collection methods related to forecast and uncertainty information and provides a foundation for improving our knowledge about interpretations, integrations, and uses of online weather information.

Eye-trackers have shown themselves valuable in diagnostic studies of reading and information-processing (Duchowski, 2002). The advantage of using eye-tracking technology in reading studies is the ability to examine the participants' eye movements when reading authentic texts in real time. One the one hand, high-quality eye-tracking data are dependent on properties of the eye-tracker (Holmqvist et al., 2011): Generally, a higher *sampling frequency* (measured in hertz) can provide more precise data but makes the eye tracker more expensive and more restrictive for the participants. For example, an eye tracker with higher frequency may require restraining the head movement of the participant with forehead and chin rests. The required sampling frequency for a study is dependent on a combination of these elements. Today's eye trackers are available in the range from 30 Hz up to 2000 Hz (e.g., a 50 Hz eye tracker records 50 individual gaze points per second). On the other hand, the quality of the data is dependent on participant-specific properties (e.g., mascara and calibration) and the *recording environment* (e.g., light and movement) (Holmqvist et al., 2011): Stable light in the room increases data quality because changing light conditions are likely to alter the pupil size and thus decrease precision (the ability of the eye tracker to reliably reproduce a measurement). Movement can also decrease data quality; for example, vibrations caused by mouse-clicks or a person walking around may decrease the precision of the measurements. Other types of noise, such as sounds, may distract the participants and should be avoided. *Participant-specific properties* primarily affect accuracy (the difference between the true gaze position and the recorded gaze position). Manufacturers typically refer to an accuracy of <0.5°, or 5 mm at a distance of 70 cm as the accuracy of their eye trackers. However, accuracy should be measured by performing a calibration of the equipment for the individual participants in each study. Because accuracy is highly dependent on the characteristics of each participant, such as whether they wear glasses, their eye-color, and their eye physiology, it is likely to vary. Participants should not be allowed to wear mascara because the software that identifies the pupil (of the eyes) may be confused by other large, dark areas. In addition, large head movements or position changes after calibration will reduce the accuracy of the measurements.

A persons' visual attention, and thus the eye-tracking data, are sensitive to the *task* the person are given (Yarbus, 1967; DeAngelus & Pelz, 2009) (see also Figure 2). An appropriate task should be engaging to ensure that the participants are distracted from the fact that they are conducting a study. The task should also have a plausible cover story to prevent the participant from trying to guess the nature of the experiment (Johansson et al., 2006; Holmqvist et al., 2011).

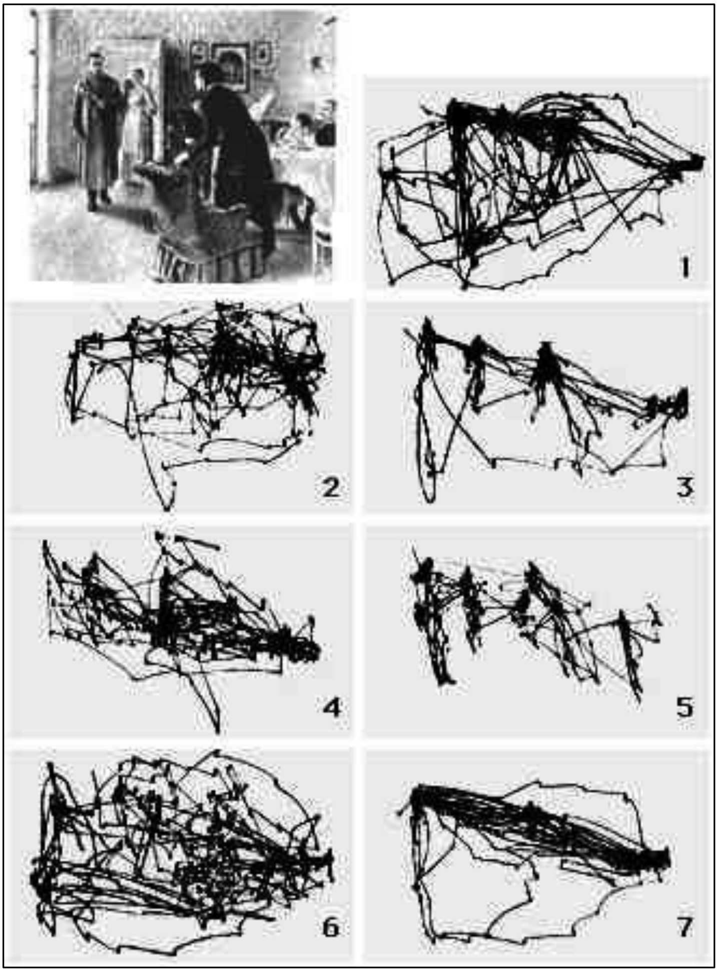


Figure 2: "Seven records of eye movements by one subject. 1) Free examination. Before the subsequent recordings, the subject was asked to 2) estimate the wealth of the family; 3) give the ages of the people; 4) surmise what the family had been doing before the arrival of the 'unexpected visitor'; 5) memorize the clothes worn by the position of the objects and people in the room; 6) memorize the location of the people and objects in the painting; and 7) estimate how long the 'unexpected visitor' had been away."
Reused (Figure 109; Yarbus, 1967) with permission from Springer.
This person performed seven different tasks (1-7), viewing the painting "An Unexpected Visitor" for three minutes in each task. The figure shows that the eye movements depended on the task he was engaged in (Yarbus, 1967).

According to the *eye-mind assumption*, the information currently being viewed is what is being processed because the direction of gaze is closely related to the focus of attention (Just & Carpenter, 1980; Duchowski, 2007). However, it is possible to move attention without moving our eyes (Rayner, 1998). Thus, a basic limitation of eye-tracking data is that it is not possible to use the data to deduce what people think (Holmqvist et al., 2011): Do long gaze durations correspond with a high information value for the participant or with difficulties in information intake? *Verbal data* should be collected to avoid forming invalid conclusions regarding reasons for the participants' eye movements (van Gog et al., 2005; Holmqvist et al., 2011; Bucher & Niemann, 2012). The participants are commonly instructed to verbalize their thoughts (thinking out loud) either during (concurrent reporting) or immediately after (retrospective reporting) the eye tracking recording (van Gog et al., 2005; Holmqvist et al., 2011). A concurrent think-aloud may alter the eye movements during a task, whereas a retrospective think-aloud may suffer from loss of details from memory, which may explain why less information is typically elicited with the latter method (van Gog et al., 2005; Holmqvist et al., 2011). Additionally, the ability to think aloud can be expected to vary among participants, and participants produce different amounts of verbalization. Thus, it is crucial to provide the participants with appropriate instructions regarding how to verbalize their thoughts, to practice this approach prior to the task, and to encourage silent participants when they stop talking (Holmqvist et al., 2011).

2.2.1 Sampling frequency and choice of eye tracker

Eye-tracking equipment is expensive. After several inquiries, I was fortunate to borrow equipment from another university (University of Stavanger). This university has a reading center with several different eye trackers. On two occasions, I spent a day at this university and discussed the study with an experienced researcher. We agreed to use a 50 Hz eye tracker for the data collection. We chose a 50 Hz eye tracker instead of a faster eye tracker because a 50 Hz eye-tracker is considered to be fast enough to study the reading of a text on the level of detail required by this study. This eye tracker consists of two remote cameras, which enable the participants to read the texts on an ordinary computer screen and to move their heads relatively freely compared to a faster eye tracker. Because this eye tracker was portable, I was able to visit the participants. Thus, the study simulated an ordinary reading situation, which increases the validity of the study.

2.2.2 Participants and the recording environment

All sixteen participants were students at the same upper secondary school. Using a sample with students from the same school enabled me to keep the equipment at the same location throughout the data collection. Because I borrowed the equipment, I had to be sure to conduct the study during the two-week period. At the school, there were always students interested in participating if another participant became ill or could not participate for other reasons.

Figure 3: The eye-tracking equipment used in this study. My chair and computer are shown on the left, and the participants' chair and computer are shown on the right. The eye-tracking hardware is located behind the computers (the black box).

The eye-tracking equipment was set up in a sound- and light-isolated room at the selected upper secondary school (Figure 3) to minimize the risk of disturbance (Holmqvist et al., 2011; Mason et al., 2013). In this room there were few distracting sounds or movements. The mouse and two cameras were located on the same table. The participants made few mouse clicks, and the slight vibrations caused by the clicking did not cause a problem. The room had no windows, which created stable light conditions and increased the precision and data quality.

2.2.3 Participant-specific properties and accuracy

An experienced researcher from the University of Stavanger taught and trained me how to use the eye-tracking equipment. I also practiced using the equipment for a few days at home prior to the pilot study. Two upper secondary school teachers participated in the pilot study. Different set-ups were tested, which allowed me to find the best place to sit during the eye-tracking and the subsequent collection of verbal data. In addition, some minor technical issues were discovered and needed to be resolved. The pilot study gave me the opportunity to practice the calibration process, for example, to determine the height and distance from the screen that provided the best data quality. The eye-tracking study was conducted for two weeks in May 2013. The eye-tracking equipment was calibrated for each participant until each gaze position could be validated with a deviation less than 0.5°. An accuracy that exceeded the recommended maximum deviation of 0.5° was achieved (Holmqvist et al., 2011). The participants were informed in advance that they could not wear mascara. However, make-up remover was provided if make-up was worn. In addition to the calibration, the participants practiced how much they could move their head and body before the software was unable to identify their pupils. The task was also designed such that it was not too time-consuming. When lesser time was spent on performing the task, the participants experienced fewer problems maintaining their position in the chair. This situation contributed to higher accuracy and improved data quality.

2.2.4 Study design and task

The study design was as follows (see also Table 2 above): 1) Participants' eye movements were recorded as they were provided online weather information with which to *perform a task.* 2) Participants were asked to *think aloud* when looking at a replay of the eye-movements. 3) A semi-structured *interview* was conducted to clarify the meaning of participants' actions. The task involved the request for advice: *which day should a close friend of the participant choose to paint a house* based on the actual weather forecast. This task provided a plausible cover story to the participants, which was recommended to prevent their guessing of the nature of the experiment (Johansson et al., 2006; Holmqvist et al., 2011). I also had the impression that the participants thought the task was engaging, which distracted them from the fact that I measured their eye movements (Holmqvist et al., 2011). I expected the students to not be overly familiar with outdoor painting. This assumption may reduce the time they spent solving the task. To obtain richer data, the students were also provided a text that briefly explained the most important weather parameters to be aware of when painting outdoors, which helped interested students to provide more informed advice.

2.2.5 Verbal data: Think-aloud and interviews

Retrospective think-aloud verbalizations, which are assumed to reflect the sequence and content of thoughts that mediate the completion of the task (Holmqvist et al., 2011), were preferred in this study. To reduce the risk of fabrication and the loss of details from memory (van Gog et al., 2005), a think-aloud was recorded immediately after the eye-tracking was completed. In addition, the time spent performing the task was considerably shorter than the suggested 10 minute maximum limit (Holmqvist et al., 2011). Exceeding the limit may cause an increased loss of memory. To encourage more details and improve the quality of the verbalizations, the participants were shown a replay of their eye-movements when thinking aloud (Holmqvist et al., 2011). Such use of cues is recommended in retrospective verbalizations (van Gog et al., 2005). In addition, all participants practiced a think-aloud in advance of the task. When practicing, all were talkative and produced rich descriptions. However, several participants barely spoke when asked to think out loud in the main study. Beside loss of memories from long-term memory (van Gog et al., 2005), one reason for this may be that they were distracted and intrigued by watching their own eye-movements. Observing your own reading behavior is interesting the first time that you view eye-tracking data. Thus, the participants were likely surprised and forgot to talk. Showing the participants examples of eye-tracking data in advance may alleviate this challenge. Importantly, the think-aloud protocols provided useful data for all participants.

The variation in the ability to think out loud was not surprising, because this variation is described in the literature (Holmqvist et al., 2011). For this reason, qualitative semi-structured interviews were planned and an interview guide was constructed. While the participants solved the task, I watched their eye movements on another screen, which enabled me to prepare individual questions for each participant based on their actual information use in addition to questions from the interview guide. To notice all information used by each participant was challenging, especially all their attempts to integrate information. Because their eyes moved rapidly, I did not manage to record all of my questions. This problem was partly solved by replaying the eye movements during the interviews, which provided another look at the data. However, this action affected the flow of the conversation. The dilemma was whether I should spend some time viewing the recording and writing questions before the participant was told to think aloud. However, this process may result in the loss of details in participants' memories. After all, the interviews provided the opportunity to elaborate on the participants' attempts to use and integrate information. These interviews supplemented the think-aloud protocols and provided high-quality data.

2.2.6 Possible improvements

I am very satisfied with the use of eye-tracking technology as a method for answering the second research question because the method provided high-quality data. However, I recommend the following improvements.

The sample selection was crucial performing the study with the available resources. Although the sample revealed interesting differences in information use, I would like to conduct a similar study with a more varied sample or a sample of more experienced users. Other user groups may use other/more information and may perform the task differently. I would also like to conduct other studies with different tasks.

I reflected on both the eye movements and verbal response, but a more systematic analysis was not feasible during the two weeks of recordings. If I owned my own eye-tracking equipment or had been able to borrow the equipment for a longer period of time, I would have preferred to work with one or two participants each day instead of three or four participants. In addition, I would implement a one-day break to begin analyzing the data, which would have simplified the identification of interesting interview questions.

2.3 Generalization

"One criticism about qualitative studies is that it is difficult to generalize findings to settings not studied" (Firestone, 1993, p. 16). This concern is also valid for the present study. Valid data and reliable findings in this study show the existence of a variety of interpretations, integrations, and uses of weather information; however, no claims are advanced for the frequencies of occurrence in the wider public. According to Kvale and Brinkmann (2009) and Firestone (1993) there are three typical arguments for generalizing from data: 1) sample-to-population extrapolation, 2) case-to-case transfer, and 3) analytic generalization. In practice, sampling has been linked with survey research, case-to-case translation with qualitative methods, and analytic generalization with experimental methods (Firestone, 1993). In the following I provide a short discussion of how the three arguments relate to the present study.

The *sample-to-population* argument relies on probability theory; thus, this is a statistical generalization (Yin, 2014). If the sample is drawn randomly from the population of interest, sampling theory can be used to make inferences about how characteristics of the sample reflect the larger population (Firestone, 1993; Kvale & Brinkmann, 2009). Such sampling requires large populations and large samples (e.g., 1000 respondents). With this requirement in mind, Firestone (1993) argues that sample-to-population extrapolation does not apply adequately to qualitative work primarily because the samples are too small. Additionally, it is challenging to have large samples in qualitative studies due to the large amount of data to analyze (e.g., the "1000-page question", Kvale & Brinkmann, 2009). Moreover, the sample in qualitative interview studies is normally not random; rather, it is selected based on other criteria (Kvale & Brinkmann, 2009). For instance, in this study I sought variation in interviewees backgrounds by purposeful sampling (Johannesen et al., 2010) to achieve a variety in forecast interpretations.

However, rather than generalizing the findings from interview studies, follow-up surveys with larger samples should be conducted to examine the prevalence of the specific beliefs expressed in the qualitative interviews (de Bruin & Bostrom, 2013). In these surveys, the articulation of the questions can be informed by findings from the interviews. However, a major difficulty related to the first argument is that it is difficult to sample all of the things that must be sampled to make a generalization (Firestone, 1993). For instance, in this study, my experience is that it is difficult to involve persons who find it hard to interpret and understand some weather information, possibly because people do not want to show what they do not know.

Case-to-case transfer is the argument most closely associated with qualitative research (Firestone, 1993). This type of generalization occurs when a person in one setting considers adopting an idea from another study (Firestone, 1993). Thus, the transfer of findings from one case to another is performed by the reader. Therefore, as noted in subsection 2.1.3., the researcher must provide rich, detailed descriptions of the case allowing the reader to understand the study context and assess the match between this situation and their own. These descriptions should describe a broad range of background features, aspects of the processes studied, and outcomes (Firestone, 1993). Case-to-case transfer appears to be the most useful argument to be used for the present study, with rich descriptions of background theory and motivations provided in the papers and in this thesis. The present study use one selected online weather report (Yr.no) as a case and studies how the weather information in this report is interpreted, integrated, and used. I find this website, however, to have similarities in design and presentation with other websites presenting weather information. Thus, the findings from the present study might also be interesting for other weather websites, for instance concerning designing weather symbols (e.g., take care in the details of the information presented because nuances such as cloud color and number of drops might be interpreted as substantial information). These similarities can be found across national borders, so the findings can be equally as interesting for Norwegians as they can be for international websites. However, the findings are more related to everyday decision processes than to extreme weather situations involving higher decision stakes. Additionally, some of the findings might have interest for science educators because reading is studied and many of the participants are upper secondary school students.

Finally, Firestone (1993) and Yin (2014) suggests that *analytic generalization* can be helpful for qualitative researchers. This argument is about generalizing own results to a theory rather than to a population. The generalization can take the form of for example lessons learned or principles that may be applicable to other situations (Yin, 2014). Analytic generalization is facilitated by specifying the conditions under which a study is performed (Firestone, 1993). One approach to generalizing analytically, which is particularly appropriate for extending and refining theories, is to select a critical case or a deviant case (Firestone, 1993). This selection would also help specify under which conditions a theory holds, by considering similarities and differences between the case and the theory (Kvale & Brinkmann, 2009). In the present study, an example of a suggestion for a small refinement of a theory can be found in paper 3 in which a new operationalization of multimodal reading (seven or more fixations in one AOI) was suggested. The earlier operationalization (Holmqvist et al., 2011), suggesting reading be present if at least three fixations satisfy the detection conditions, was not sufficient to detect multimodal reading in the present study.

For end-users for whom findings must hold "on average" and exceptions are allowed, for instance politicians and managers, Firestone (1993) argues that analytic generalization appears superior to case-to-case transfer.

2.4 Ethics

"Because the objects of inquiry in interviewing are human beings, researchers must take extreme care to avoid any harm to them" (Fontana & Frey, 2000, p. 662).

According to Fontana and Frey (2000), ethical concerns in qualitative research have traditionally revolved around the topics of *informed consent* (receiving consent by the participant after having been carefully informed about the research), right to *privacy* (protecting the identity of the subject), and *protection from harm* (physical, emotional, or any other type).

This study submitted the obliged notification forms to the Norwegian Centre for Research Data (NSD). NSD commented on the study plans, and the plans were adjusted accordingly to ensure that the ethical requirements were fulfilled. All participation was voluntary. To ensure that people participated voluntarily and that they were informed about the purpose of the study, they had to provide their written consent. Additionally, the participants could withdraw without cause at any time, as recommended (Johannesen et al., 2010). Each participant in the interview study and in the eye-tracking study is anonymized and to maintain their privacy no personal data are reported in the project. An interview can be a vulnerable situation for the interviewee. Therefore, to protect the participants from harm, I tried always to be careful and not to let them feel stupid. With this approach, I also calibrated the social distance between me and the interviewees (Sennett, 2004) and created a space in which they could speak freely (Kvale & Brinkmann, 2009). According to The National Committee for Research Ethics in the Social Sciences and the Humanities (NESH, 2010), such a space is important because a goal is to minimize stress on the informants.

In addition, a positive effect of participating in the study could be that the participants felt that they learned something new during the interview or eye-tracking session.

3. Introducing the papers

The overarching aim of this study was to identify different interpretations, integrations, and uses of the weather forecasts and uncertainty information on Yr.no. Based on experience, I knew that some users experienced difficulties with some weather information and that the information was interpreted differently at other times. Thus, I aimed to discover intended as well as unintended but informative interpretations, and a variety in integrations and uses of the weather information. To fulfill the aim of the study, a question was articulated:

How is information in online weather reports interpreted, integrated, and used by laypeople when making everyday decisions for weather-dependent activities?

To address this question, three research questions were developed (presented in the Outline Section), and each paper contributes to one of these research questions (Table 3).

The first paper focuses on how the information on Yr.no is *interpreted and integrated* by laypeople (emphasizing uncertainty). The second paper focuses on how the information is *used* in everyday decision-making processes. The third paper focuses on the reading process, that is, how laypeople make meaning by *interpreting and integrating* information in a multimodal science text.

Additionally, the study is motivated by the communication process between experts and laypeople. I already knew the web service was very popular with millions of users each week. Therefore, I assumed not only to identify unintended forecast interpretations, but also methods for communicating weather information that appealed to a large group of users and that could be used as examples of good practice for other websites. Therefore, *implications of the findings for the communication process* are also discussed in the three papers (Table 3).

Table 3: Overview of study aim and motivation, and the relation between the research questions and the three papers.

Study	*What*		*Where*
Aim	Identify different interpretations, integrations, and uses of weather information	RQ1	Paper 1 (interpretation & integration)
		RQ2	Paper 2 (use)
		RQ3	Paper 3 (interpretation & integration)
Motivation	Insight into the communication process between forecast providers and the end-users		All papers (discussions)

In the following Sections the three papers in the study are introduced, with basis in the abstracts in paper 1 (Section 3.1), paper 2 (Section 3.2), and paper 3 (Section 3.3).

3.1 Paper 1

Many people depend on and use weather forecasts to plan their schedules. Ordinary people with no expertise in meteorology are frequently called upon to interpret uncertainty with respect to weather forecasts. With this in mind, the first study addresses two main questions (i.e., RQ1 of the thesis): 1) How do laypeople *interpret* online weather reports with respect to the degree of certainty and how is previous *knowledge* employed in this interpretation? 2) How do laypeople *integrate* information in weather reports to determine the degree of certainty? This qualitative study is based on semi-structured interviews with 21 Norwegians from selected user groups (farmers, exterior painters, tour-guides, and upper secondary school teachers and students). The results are as follows: a) Only a portion of uncertainty information was used. b) Symbols were sometimes ascribed different meanings than intended. c) Interpretations were affected by local experiences with wind direction and forecast quality. The informant’s prior knowledge prevailed in the event of a conflict with forecast information, and an expected range of uncertainty was often inferred in single-valued forecasts. In addition, 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. Based on these findings, implications for the communication process are discussed: A clearer presentation of uncertainty information, a clear intent of all nuances in information, a comprehensive use of multimodal information and the consideration of users' needs can help improve the communication of forecast uncertainty. The diversity of user approaches makes forecast uncertainty more difficult to communicate and provides possible explanations for the challenges in communicating uncertainty.

3.2 Paper 2

The second paper is based on the same interviews and the same data as the first paper. However, the focus of the analysis differed. Previous studies regarding how people use weather forecasts to schedule activities were primarily concerned with the use of selected pieces of information detached from the context of a full weather report. Therefore, the second study contains two areas of focus (i.e., RQ2 of the thesis): 1) *factors influencing the amount of information from a full weather report that are used* by laypeople for everyday decision-making and 2) how the *complexity in information in a full weather report is handled* in the decision-making processes. In this qualitative study, semi-structured interviews were conducted. In the sample consisting of 21 persons from Norway, farmers, exterior painters, tour guides, teachers, and students were included to obtain a fair variance in the number of user situations. The qualitative, semi-structured interviews were centred on a multimodal weather report from the online web-service Yr.no. In this study, a varying amount of information was used by the participants in their decision-making; furthermore, the amount of information used appears to depend on a) the importance of the envisaged activity and b) the suitability of the weather conditions. The amount of information (i.e., complexity) must be reduced to make a quick decision, which typically was accomplished by c) choosing a suitable starting point and leaving out evaluations of d) weather dynamics and e) forecast uncertainty. Based on these findings, implications for the communication process are discussed. Communicating a multiplicity of representations in weather reports appears favourable for enabling the use of different types and amounts of information such that it allows both quick and more elaborate decision-making processes.

3.3 Paper 3

Earlier studies of multimodal reading typically focused on successful reading rather than how meaning is made. The third study examined how sixteen upper secondary students made meaning of online information that presented weather forecasts using a variety of representations, and three research questions were focused (i.e., RQ3 of the thesis): 1) What reasons are given for *reading the various representations* in a multimodal website? 2) What reasons are given for *constructing reading paths*? 3) What reasons are given for making a *transition from one to another representation*? The students participating in this study were told to advise a friend, who was planning to paint the exterior of his house, based on the online information. Eye-tracking equipment was used along with think-aloud protocols and qualitative interviews for data collection. The eye-tracking data support the verbal data, indicating that (a) the participants ascribed a set of affordances to each representation, (b) decision-making processes influenced the construction of reading paths, and (c) the participants' reasons for making transitions between representations were to control and compare information. Possible advantages of multimodality were typically not exploited. Related to the communication process, it is discussed that guiding the reader among various representations may help her integrate information, but only in situations where she aims for an elaborate decision process.

4. Discussions and implications

The results from the three papers are discussed collectively, and this discussion is based on the theories presented in Sections 1.3, 1.4, 1.5, and 1.6, i.e., multimodal reading and meaning-making, human decision-making, risk and uncertainty, and communication between experts and laypeople, respectively. After summing up the lessons learned from the present study (4.1) I discuss research-based weather communication (4.2) and the difficulties inherent in communicating and learning terms (4.3), before a discussion of accidents, rationality, and decision-making is provided (4.4).

4.1 Lessons learned from the present study

The overarching aim of the study is to identify different interpretations, integrations, and uses of online weather information in everyday decision-making by laypeople. As suggested by de Bruin and Bostrom (2013) when using the mental model approach, qualitative interviews are conducted on selected user groups. According to the four-task model for achieving useful information and effective communication presented in subsection 1.6.3, the contribution of this study is to determine what people already know, i.e., the second task in the model (Table 1). In the following, I summarize the main findings related to the three focuses of the study (interpretation, integration, and use) and note interesting topics to be discussed. Because the study is motivated by and provides insight into the weather communication process, these discussions also relate to the third task of the model (subsection 1.6.3), i.e., design of communication (Table 1).

As described above, one focus of the study is how laypeople *interpret* online weather information to be used in everyday decision-making. Interpretations of information are examined primarily in the first and third paper of the study (Table 3) and by using qualitative interviews (Table 2). The use of interviews is recommended in the mental model approach to elicit people's mental models (de Bruin & Bostrom (2013). The interviews conducted in this study provided rich descriptions of personal interpretations of weather forecast information and provided valid data and reliable findings (see Section 2.1 for a discussion). In the third paper, it is found that for each representation, such as tables, diagrams, numbers and symbols, a set of strengths and functions (affordances) was ascribed and exploited by the participants. Related to interpretations of information, a finding from the first paper is that symbols were occasionally ascribed different meanings than those intended by the forecast provider. Nuances such as color and the number of drops were important in the interpretations of the weather symbols and forecast uncertainty. Participants typically interpreted the degree of certainty differently (more or less uncertain) than was intended by the forecast provider. The interpretations were also affected by the integration of information used to predict the time and location of precipitation, which was performed to create a dynamic picture of the weather and to control and compare information. How these findings can be used in the *design and communication of graphical weather information* is discussed in Section 4.2. For example, one possible implication of this study is that providers of online weather reports should take care in the details of the information they present because such nuances may be interpreted as substantial information. Although the present study uses one selected online weather report (Yr.no) as a case, the study should be informative for other providers of weather information. After all, there are many similarities between weather and weather forecasts around the world. The diversity of uses, needs and situations found in this study indicates that it is demanding to establish effective communication of weather information to the public. Thus, communication to a wide variety of user groups must be a part of the discussion in Section 4.2.

To limit the study, the three papers concentrate on how graphical representations are interpreted, and verbal information is only briefly mentioned. However, all participants in the study also reported on their *interpretations of verbal information*. Verbal information remains an important part of weather reports around the world, for instance in all of the top five weather sites. Therefore, I find it interesting to discuss challenges related to the learning and communication of verbal texts. This discussion is provided in Section 4.3.

The second and third focus of the study is how laypeople *integrate and use* online weather information to be used in everyday decision-making. These focuses are closely related and are examined in all three papers. From the mental model approach, qualitative interviews are recommended and used in the data collection. Additionally, eye-tracking technology is used in this study as an innovative approach to study integration and the use of online weather information (Table 2). The method provided high-quality data (see Section 2.2 for a discussion) and was a fine addition to the interviews. There are several findings in the three papers related to these two areas of focus. Only a portion of the provided information on Yr.no is used by each participant. What information and how much is used appears to be influenced by the participants' decision-making processes. Their selection was dependent upon the importance of the envisaged activity and the weather conditions for the day. Evaluations of weather dynamics and the degree of certainty in the forecast were disregarded when quick decisions were made. Interestingly, in the second paper, it is found that even when using little information and making quick decisions, users state reasons for their choices and thus appear rational in the sense of bounded rationality, choosing a reasoned and apparently suitable strategy in each situation. Nevertheless, there is anecdotal evidence that *accidents with fatal consequences* occasionally do happen in weather-related decisions. Forecast providers should try to understand possible reasons these accidents occur (when these accidents are related to evaluations of the weather conditions) such that they can assist people in making high-quality decisions. A discussion is provided in Section 4.4.

The importance of *experiences* in interpretation of visual and verbal information stands out from the first research question, from the three papers, and from this discussion as worthy elaboration. For example, it is found in the first paper that local experiences with wind direction and forecast quality affected the participants' interpretations. The participant's prior knowledge prevailed in the event of a conflict with forecast information. Moreover, an expected range of uncertainty is often inferred by participants in single-valued forecasts. This finding supports earlier findings (similar results have been found for temperature, precipitation, and wind speed; e.g., Morss et al., 2008, 2010; Joslyn & Savelli, 2010), but also extends earlier findings to the case of weather symbols. Although it also relates to decision-making processes, not having the necessary prior knowledge is a possible explanation for why part of the representations that provide forecast and uncertainty information on the website is occasionally not used by the participants. Further research is needed to examine this in more detail. Nevertheless, I believe that it is of special interest to discuss how forecast providers can help those persons that lack certain types of experiences in interpreting forecast information and thus to make informed decisions. This topic is discussed as a part of Sections 4.3 and 4.4.

4.2 Research-based weather communication

How can findings from existing and future research be used in the design and communication of graphical weather information to support informed and effective decision-making? In the following discussion, I use weather symbols from the top five global weather sites (refer to subsection 1.2.2.) and the World Meteorological Organization (WMO) as a point of departure. These websites use slightly different depictions of the weather; for example, searching these websites for a forecast for New York City (June 17, 2016) resulted in the six different weather symbols, which are shown in Figure 4.

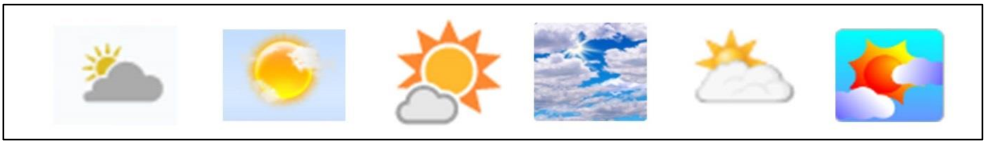


Figure 4: Weather forecast for New York City, June 17, 2016. The weather symbols (and descriptions) are from Weather.com (partly cloudy), Accuweather.com (partly sunny), Wunderground.com (partly cloudy), Weather.gov (partly sunny), Yr.no (partly cloudy), and Worldweather.wmo.int (sunny periods).

Five of these six sites provide worldwide weather forecasts (Weather.gov provides national forecasts for the USA). Using a standardized set of symbols worldwide to avoid differences in interpretations may seem appealing. After all, to a great extent, weather has similar types of variation throughout the world; rain (and snow) falls with varying intensity, sunshine or clouds cover part of the sky, and the wind force will vary according to the Beaufort wind scale. WMO (2006) claims that using a set of standardized symbols facilitates easy interpretation. However, because visual language is culturally specific and differs among social groups (Kress & van Leeuwen, 2006), using a standardized set of weather symbols worldwide should not guarantee similar interpretations. Users of these websites are not one homogeneous group. Rather, there is a diversity of groups, uses, needs and situations making it challenging to establish effective communication of weather information to the public. For example, in the present study symbols were occasionally ascribed interpreted as having different meanings than were intended. Therefore, I discuss some challenges to the idea that standardized symbols worldwide facilitate easy and similar interpretations.

In the present study, prior experiences with weather and forecasts were found to enable the participants to interpret the forecast information. Color, number of drops, and other nuances of symbols were important for interpreting the symbols and assessing the degree of certainty in the forecast. Similarly, the number of snowflakes was found to affect the interpretation of the symbol in a study reported by the National Research Council in the USA (2006). Additionally, for the participants in the present study, prior experiences were found to prevail in the event of a conflict with forecast information. This finding is consistent with earlier research findings in which existing knowledge can and often does prevail over textual information when there is a conflict between the two (Dole et al., 1991). With these findings in mind, a person interested in the forecast for New York City and scrutinizing the weather symbols from the six different websites in Figure 4 could have interpreted them differently. For example, she might have interpreted the first symbol as chance of rain showers because of the large, gray cloud and the small sun, and the last two symbols as mostly sunny without chance of rain (due to the larger sun and the white color of the clouds). Although the weather symbols in Figure 4 are slightly different, the forecast descriptions are similar (partly cloudy/partly sunny). If forecast providers are not careful with all of the details in the symbols, when such nuances are interpreted as intended communication by the users of the information, unintended interpretations can result.

One possible approach to avoid unintended interpretations and to narrow the range of interpretations is to combine the weather symbols with verbal descriptions (as exemplified above). In the present study, it was found that the participants occasionally integrated information from different representations, such as symbols and verbal text. Verbal descriptions of symbols also must be interpreted in light of the users' experiences; consequently, reading the descriptions does not guarantee similar interpretations of the symbols. However, integrating information from different representations has several potential benefits. Ainsworth (2006) argues that multiple representations can be used to constrain and complement information and to construct deeper understandings. These three functions are exemplified in the following three hypothetical texts/descriptions written to support graphical weather information:

- *Warning: The amount of rainfall this evening on the coast might be 30 millimeters, not 5 millimeters as expressed in the symbols and the numbers.*

This text can be used to constrain the interpretation of automatically generated symbols and numbers (e.g., in a table) by providing similar but corrected information. Note that the reader must understand the constraining representation (i.e., the text) to be able to exploit this function (Ainsworth, 2006).

- *An intense and fast-moving low-pressure system is likely to cause heavy rain on the coast this evening, which might arrive earlier than expected.*

This text can be used to complement the symbols in a table by providing other information about dynamics that might be difficult to express using symbols.

- *There will be heavy rain this evening, that is, 25-35 millimeters of rain.*

This text provides the opportunity to construct a deeper understanding of the underlying structure of the numbers in a table. To be able to understand the connection between the numbers and the names of different rainfall amounts (e.g., light rain and heavy rain), the reader should be able to translate across the representations and integrate the information.

Forecast providers should be aware of all possible functions. They may benefit from having a plan for using various representations, because different user groups and different situations are likely to benefit from different functions. For example, specialized terms (providing additional information to professional users) might be used when the aim of the verbal text is to complement the information communicated by the symbols in a table. However, everyday language (easy to understand for all users) can be used when the aim of the verbal description/text is to constrain the interpretation of symbols in a table. WMO (2006) exploits these functions when it emphasizes that subjective descriptive verbal terms provided in addition to the standardized symbols should reflect differences from one country to the next. For example, 30 millimeters of rain might be described as heavy rain for one location (e.g., New York City) whereas the same amount of rain could and possibly should be described differently and as less severe for another location (e.g., Bergen). Considering local experiences and social and cultural differences facilitates possible improvement compared with providing one description associated with one symbol. For example, it is conceivable that a person living in New York City (121 days and 1174 mm average annual rainfall) and a person living in my hometown in Norway, Bergen (213 days and 2250 mm average annual rainfall), would interpret worldwide standardized symbols differently. By suggesting using a range of descriptions with one symbol WMO attempts to handle one concern by using one set of symbols worldwide. However, to be effective, also the verbal descriptions must be read.

In this study, verbal text was only read occasionally. The participants were asked how they reached a decision concerning their conduct of various activities. All participants exploited the strengths of different representations, such as reading symbols in tables because they considered time-ordered tables to be efficient when seeking weather data for a specific location and point of time. Participants were able to adjust the amount and type of information according to the situation. Occasionally, they used and integrated information from several representations and evaluated the degree of certainty in the forecast prior to making a decision. This finding indicates that a selection of representations is an advantage for online weather sites when communicating to several user groups or when communicating to users of forecasts in different situations. Multimodal weather reports enable users to access preferred representations that they understand and that fit their particular and actual decision-making situations. However, information overload must be prevented (Klein, 2011), not least in light of the increased use of weather applications (apps) on smartphones (e.g., Rutty and Andrey, 2014). Betsch and Glöckner (2010) argue that if all information favors one option and speaks against other options, decisions are easier to make. Nevertheless, too much information can produce distractions (when information is irrelevant in a specific situation), which might create difficulty in making a decision. For example, two participants in the eye-tracking study experienced difficulty when searching a web page for a period of time because the site provided excessive information and they did not know where to locate the information that interested them. Because many decisions are based on brief views of the websites and because information overload should be prevented, it appears that providing an abundance of information is not necessarily efficient in all situations. Still, suggestions to improve communication should be co-developed with potential end-users, and followed by evaluations of the usefulness of the communications (e.g., Dilling & Lemos, 2011).

In other words, another (but not mutually exclusive to the one above) possible approach to prevent unintended interpretations and to narrow the range of interpretations of weather symbols is to approach the details with care when designing the symbols and to have an explicit intention for every nuance in the information presented. The participants in this study used local experiences with weather to interpret the weather symbols. Hence, I propose that developing a large set of symbols in which a range of local experiences are considered and providing users the opportunity to customize the website by choosing a subset of symbols suitable to their experiences and needs can contribute to reducing unintended interpretations. The subsets may or may not contain some of the same symbols, depending on whether common features can be found for several groups/cultures. For example, are white clouds always associated with dry weather and gray clouds with a possibility of rain? More research is needed to answer this and other questions related to the possibility of providing different sets of symbols to different user groups. In the process of developing and evaluating the symbols, the users' needs and viewpoints should be obtained and recognized.

Moreover, it was found in this study that the symbols often reminded the participants of real-world experiences. This result can explain why the participants occasionally experienced difficulty correlating experiences and symbols when the experiences and symbols were inconsistent with each other, which is a possible reason for the variety of interpretations. Importantly, what seems consistent for a meteorologist is not necessarily perceived as consistent by a layperson. Consistency in representation is considered crucial for effective communication (National Research Council, 2006). Thus, information that appears contradictory across representations should be avoided. For example, a white cloud in a symbol without drops combined with the possibility of precipitation (e.g., a numerical precipitation interval, 0-1.5 mm) made a forecast ambiguous for some participants in this study. As a result, the potential advantages of a multimodal communication approach and integrating information were reduced.

Despite the challenges associated with public communication of weather information, I find a promising example of consistent communication across social groups and national borders in severe weather warnings (see subsection 1.5.3). Several European Meteorological Services (e.g., UK MetOffice, Meteoalarm – alerting Europe for extreme weather, and soon MET Norway) are starting to use the same colors in their severe weather warning systems. This approach consists of a four-color system that indicates degree of severity and actions needed (Figure 5). Because the colors used are similar to the colors used in traffic lights worldwide, I speculate that interpretations with little variation across social groups are likely to be achieved. This assumption should at least hold for the gist of the message, since the association between red and danger is bolstered over time in different contexts. This association may even emerge from a biologically based tendency to view red as a danger signal (Elliot et al., 2007). In other words, the interpretation of colors in warnings and risk messages can be different from interpreting weather symbols and not rely on local experiences to the same degree.

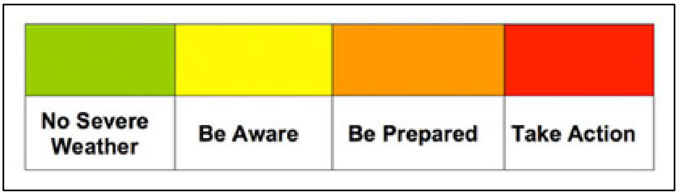


Figure 5: Basic messages associated with each of the colors used for weather warnings provided by the National Severe Weather Warning Service in the UK (MetOffice, 2015, Dec 11).

Regardless of whether risk and uncertainty or deterministic weather information is being communicated, more attention and multidisciplinary research is needed. If forecast providers knew how people interpreted graphics and symbols (weather symbols, wind arrows, and uncertainty information, for example), and the results from the present study contribute in that respect, the providers could use this information to improve their communication and for designing symbols. This potential improvement is increasingly important because visual communication is becoming more dominant (Kress & van Leeuwen, 2006), particularly in weather reports, and improved communication provide an opportunity to reduce variation in the interpretations of graphical weather information, leading to more effective decision-making. The design and communication of weather symbols and other forecast information should be accomplished through extensive and iterative dialog with different groups of end-users to facilitate the co-production of useful information (e.g., Dilling & Lemos, 2011; de

Bruin & Bostrom, 2013). For example, the communication model based on the mental model approach and described in subsection 1.6.3 could be used as a point of departure to elicit peoples' thoughts about local weather experiences and interpretations and about their uses of and needs for weather information. Then existing information can be adjusted according to new knowledge acquired through research. For example, a new rain symbol that provides more nuanced forecasts was recently introduced on Yr.no (Figure 6).

Moreover, if the decision-stakes in certain situations are in the high end of the scale, additional aspects of uncertainty (e.g., ignorance) as well as social values should be considered in dialogue with a wider community of the end-users (Grinnell, 2015).

Nå regner det litt mindre på yr.no

Vekk med paraplyen? Med nye symboler på yr.no, kan folk få inntrykk av at det blir mindre regn.

Foto: Nathalie Lecornu-Baërt/NRK

En liten regndråpe har forsvunnet. Det kan bety mye for deg som bruker yr.no.

For første gang kan du se dette symbolet i yr.no sine varsler: En sky med bare en eneste regndråpe.

Tidligere har regn vært markert med enten to eller tre dråper - og det kan ha gitt et litt for «vått» inntrykk på brukeren.

– Åh, endelig, jubler turistvert og yr-bruker Jan Eira da yr.no ringer for å fortelle om endringen. Han er en av dem som har etterlyst litt «tørrere» nedbørsymboler på yr.no.

– Blir skremt

Turistverten på Geiterygghytta har tidligere hevdet at langtidsvarsler på yr.no har fått turister til å avlyse ferien i siste liten.

Særlig synd er det dersom det kommer mindre regn enn det yr.no har gitt inntrykk av.

Tre typer regn:

NRK

Astrid Rommetveit

astrid.rommetveit@nrk.no

Publisert 03.06.2014 13:38.

2

Siste saker frå yr.no

Nå regner det litt mindre på yr.no

- Nå kommer finværet til Nord-Norge

Figure 6: "Now it rains a little bit less on Yr.no". This article (Rommetveit, 2014) describes the introduction of a new weather symbol on Yr.no. In addition to the previous symbols with two and three raindrops, the new symbols only have one raindrop, which provides a more nuanced description of the weather conditions conveyed to end-users.

If you want to communicate something to a specific user group, a dialog with that group is required to develop and find a communication system that is satisfactory to all. However, the public consists of an extensive variety of user groups. Maintaining a dialog with all possible user groups and reaching agreement about a communication system is thus not a feasible solution. Importantly, communication with the public is more demanding than communication with specific user groups. Multimodal weather reports, which enable different information to be communicated by using different representations, can provide a partial solution to this challenge.

4.3 Communication and learning of verbal information

Other verbal information than the descriptions of symbols mentioned in the discussion above is also used in weather reports. When presenting weather forecasts, meteorological terms are still frequently used, such as “low pressure system,” “warm front,” and “cold front.” A possible reason for why using such terms in forecasts remain popular is because they are precise, which is a characteristic of scientific terms (Hyde, 2008). If both the receiver and the sender of a message use and understand the scientific terms, the range of variation in interpretations of forecast information can be reduced, which might result in more effective and precise communication and informed decision-making. However, understanding scientific terms can also be an obstacle for many people (Wellington & Osborn, 2001). For example, some participants in this study indicated that they did not understand the term “low-pressure system” in the verbal text forecast. Problems might result either because the terms were never learned/understood in school, or because it is demanding to transfer knowledge from one type of situation (terms learned in school) to another (authentic texts and situations in daily life) (Anderson et al., 1996; Bransford et al., 2000). Without initial learning of the terms, transfer cannot be expected (Bransford et al., 2000). The demanding nature of knowledge transfer is highlighted by the fact that teachers in this study, who have the expected theoretical knowledge, also had problems making this transfer. People may have knowledge that is relevant to a situation but not activated (Bransford et al., 2000). Because we all hold a great deal of knowledge, we do not always know exactly which knowledge we have to use in each new situation without specific guidance (Bransford et al., 2000). Summarized, this means that attempting to reduce one problem (diversity of interpretations) introduces another problem (understanding the terms).

Although it is generally acknowledged that scientific terms are difficult to learn (Wellington & Osborn, 2001), the use of these terms is nonetheless prevalent in weather forecasts. Another possible reason (that I have heard at several occasions) for their use is the belief that people will learn, for example, the term "low-pressure system" if it is repeated frequently enough in forecasts, even if it is not explained. Of course, peoples' awareness of these terms depends on their interest in them and on the strength of other concerns competing for their attention (Beard & Wilson, 2013). Thus, some people may learn the terms due to interest or the need to know and are triggered to look them up. To people who are not familiar with the terms, they may be empty words meant to be filled with meaning (Kress, 2005). Thus, looking at or listening to a term is not the same as learning the term; such a transmission of ideas and knowledge does not occur (Millar, 2004). For learning to occur, the term must be explained. The learner must also assume an active role and be able to relate to the word (Millar, 2004) by interpreting it in terms of prior knowledge and experiences with the phenomena involved (Dole et al., 1991; Norris & Phillips, 2002; Beard & Wilson, 2013). Thorsheim et al. (2016) argue that before students can make meaning in science terms they need examples and observations serving as references from specific situations and bringing life to the terms. Such activities, in which students make first-hand experiences with the phenomena, are distinguished as suitable to trigger off interest and engagement (Skaftun & Solheim., 2014). When a person engages with an experience and reflects on what, how and why the situation occurred, she can learn from the experience (Beard & Wilson, 2013).

We do not learn from experience. We learn from reflecting on experience.

(Dewey, 1933, p. 78)

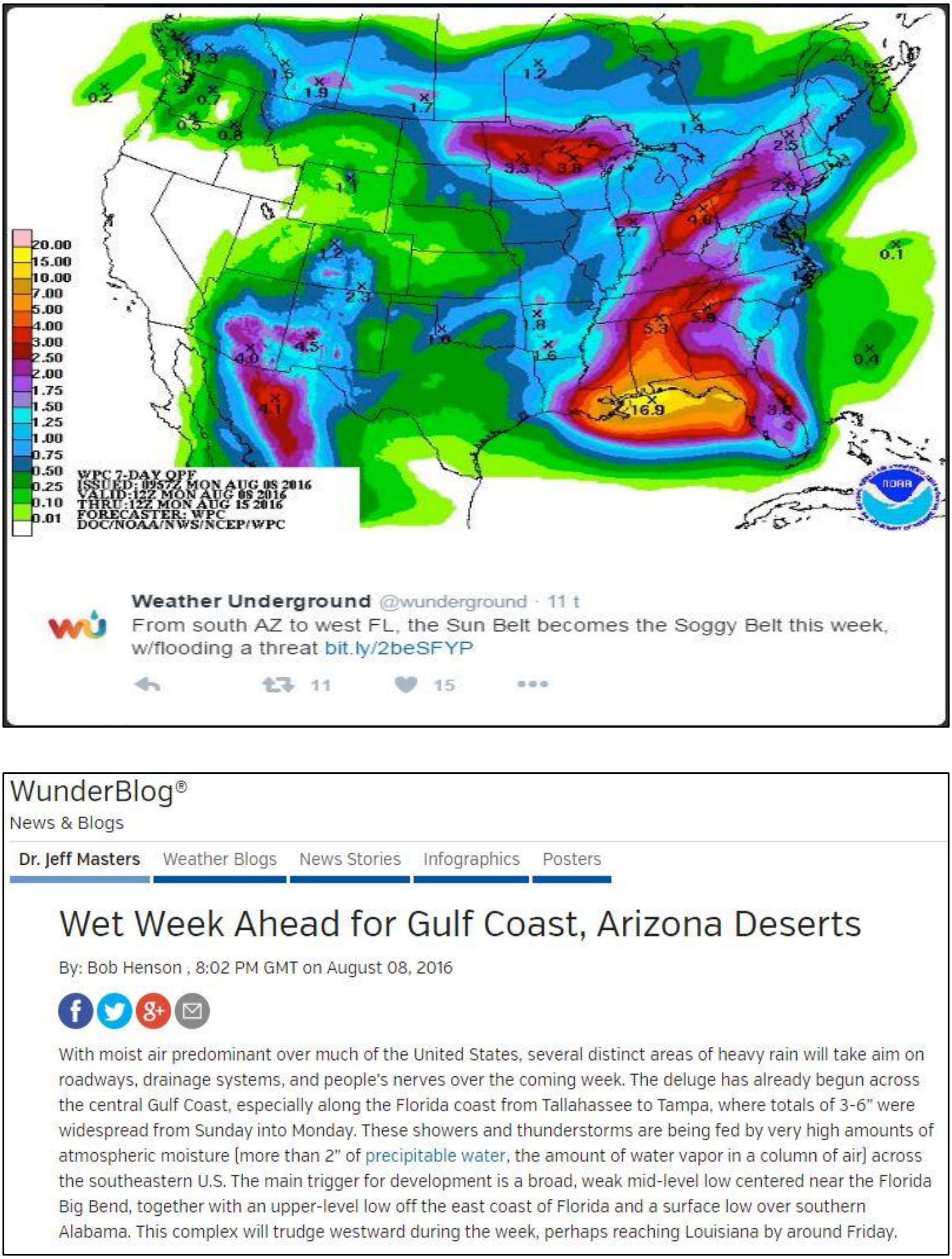
Other people will not learn terms because they are not interested or (think they) do not need to know the terms. For example, some of the participants in this study disregarded the verbal information and did not reflect on their experiences. To teach all members of the public the meanings of specific terms is thus demanding. Persons who are not familiar with the language are excluded (Martin, 1993). These user groups are more likely to benefit from the use of everyday language in forecasts. They may consider everyday words to be more relevant, which may engage them to reflect on their experiences. An everyday language may improve forecast readability and the understandability of the message.

The participants in this study stated that they engaged in activities such as skiing, haying, exterior painting and car driving. In these activities, the participants acquired experiences with weather phenomena. Importantly, two different people do not experience or perceive an event in exactly the same way, which creates unique experiences (Beard & Wilson, 2013). Because people have different experiences, more than one relevant interpretation is possible for everyday words and even for precise scientific terms. Pennesi (2007) also found that multiple meanings of weather terminology exist among different groups of people (Powell & O'Hair, 2008). For example, three relevant interpretations of the term "low-pressure system" in this study were rain, warmer weather in the autumn and westerly winds. This relates to Lemke's (2005) orientational function for meaning-making, the interpretation is done against the background of other information available to the reader such as the local context. The relevance of the interpretation depends on the relevance of prior experiences. Several participants in this study associated low-pressure systems with inclement weather and high-pressure systems with fair weather, which is an appropriate association. However, in Norway, which is a narrow country with steep mountains and deep fjords, this association may nevertheless not always hold. As discussed in subsection 1.4.3, intuitions not derived from true or relevant experience can produce low-quality intuitive judgments (Kahneman, 2011). Additionally, as discussed in subsection 1.4.1, relevant experiences are important to encode gist representations (the essential meaning) of information. Gist representations support intuition and is always used in decisions (Reyna, 2012; McFall, 2015). Thus, to learn the complete meaning and implications of the terms, and to make high-quality intuitive judgments, extensive practice is required to acquire relevant experiences. Professional end-users may have great interest in the terms and may have had experiences that resemble those of meteorologists. These user groups have experiences from relevant situations and expectations of what are appropriate interpretations (Knain, 2015). Thus, they can make rapid and accurate intuitive judgments (Klein, 2011), and take advantage of the terms used in weather forecasts.

Some persons might be interested to learn but struggle to acquire relevant experiences, and can benefit from being assisted by the forecast providers. For example, tourists are typically more unfamiliar with the local environment (Becker et al., 2015). Hence, being supported in situations where they lack local experiences may potentially have benefits for their decision-making and seen as worth the struggle. However, according to Millar (2004), first-hand experiences with phenomena are required to fully understand such phenomena because real events contain more information than any representation or combination of representations. Nonetheless, video recordings of real-world events can support learning (Millar, 2004). For example, video-recordings can be used to show people events that they did not experience (Millar, 2004), or events they have rare experience with. Therefore, one possibility might be to provide the end-users of forecasts with short videos that show actual weather events or examples of wind speeds. The videos might help people with rare experience with a phenomenon to calibrate their individual experiences with other examples; for example, a video that demonstrates the effect of a gale or a storm or the difference between 5 mm and 30 mm of rain per hour. According to Aadland et al. (2016), it is well agreed that the learning situation should be context specific to the situation where the knowledge is supposed to be applied for the most effective learning to occur. Thus, to be helpful, the videos must be relevant for the end-users, for example, by showing examples from their country with corresponding vegetation and weather. Another challenge with videos is that they are not likely to provoke as strong affect and emotion as when being in the actual situation. Activated feelings motivate actions to (avoid) reproducing those feelings (Slovic et al., 2004). Thus, videos will neither allow people to learn from the experiences nor to "mark" decision outcomes by positive and negative feelings in the same way as real experiences do. Feelings are linked to intuition and considered to be human's most natural and common way to respond to danger (Slovic et al., 2004); thus, using videos will not necessarily inform decision-making.

Another challenge is that meteorologists typically forecast (with words or symbols) rain when stratiform clouds are expected and forecast showers when cumuliform clouds are expected. Meteorologists are interested in the processes that cause precipitation, even when a day with rain and a day with extensive showers are characterized by similar conditions. However, using their own experiences and local way of talking about rain and showers, the participants in this study uniformly interpreted rain as a continuous event and showers as intermittent events. This finding was similar to their interpretations of the rain symbol and the shower symbol. Thus, as the divergent interpretations of graphical information, there appear to be inconsistencies in verbal language usage between experts and laypeople. To help users interpret forecasts consistent with forecasters' intentions, improved language that incorporates everyday words instead of scientific terms when describing processes could be developed. For example, the phrase "area of rain/clouds" could be used instead of the term "low-pressure system" to describe a phenomenon in an everyday language that will most likely enable laypeople to acquire relevant experiences. This change may also make the text more consistent with interpretations of symbols and prevent the communication of what might appear to be contradictory information. Notably, Betsch and Glöckner (2010) argue that if the information is coherent decisions are easier to make.

How much meteorology people need to understand to be properly informed should be carefully considered (Pennesi, 2007). Pennesi (2007) argues that in some cases "translating" scientific information into common terms improves comprehension more than using public education programs. I agree, and do not think that the omission of scientific terms will foster stupidity in the public (i.e., a deficit view); on the contrary, using such terms likely makes persons who are unfamiliar with them feel stupid. Moreover, if a person is unable to interpret a term because he lacks relevant experiences, then it is difficult to encode the gist representation, and decision quality could suffer. However, modifications of the language should be considered with care because scientific terms can convey information that everyday words cannot. For example, "low-pressure system" may communicate supplemental information about dynamics as well as changed air-pressure to persons who are familiar with the term. If comprehension is improved sufficiently, this should justify sacrificing technical accuracy somewhat (Pennesi, 2007). Here, the meteorological society is facing a dilemma which rather than being solved may result in a trade-off between using scientific terms and using everyday language. From a communication perspective, a possible solution might be to provide scientific terms and everyday language that is adapted to different user groups (this approach is more resource demanding). This duality in language use is emerging in several national weather services, where verbal forecasts presented at the websites and in Twitter messages often make use of and alternate between a technical language and everyday language (e.g., Figure 7). Additionally, the use of Twitter also allows for a dialogue with end-users and to answer using similar words and language as the user ask the questions in.



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Wet Week Ahead for Gulf Coast, Arizona Deserts

By: Bob Henson , 8:02 PM GMT on August 08, 2016

With moist air predominant over much of the United States, several distinct areas of heavy rain will take aim on roadways, drainage systems, and people's nerves over the coming week. The deluge has already begun across the central Gulf Coast, especially along the Florida coast from Tallahassee to Tampa, where totals of 3-6" were widespread from Sunday into Monday. These showers and thunderstorms are being fed by very high amounts of atmospheric moisture [more than 2" of precipitable water, the amount of water vapor in a column of air] across the southeastern U.S. The main trigger for development is a broad, weak mid-level low centered near the Florida Big Bend, together with an upper-level low off the east coast of Florida and a surface low over southern Alabama. This complex will trudge westward during the week, perhaps reaching Louisiana by around Friday.

Figure 7: In this Tweet (upper panel; Wunderground.com, 2016) from Wunderground.com, an everyday language is used. The Tweet ends with a link, leading the reader to Wunderground.com's Blog. In this Blog (an excerpt is presented in the lower panel of the Figure; Henson, 2016), a more technical language is used allowing certain interested readers to get more (and more precise) information.

Thus, scientific terms can be used by persons who are familiar with them and by persons who are willing to learn them. For others, an everyday language is likely to be easier to learn and understand, and may lead to better communication. To achieve useful information and effective communication, the information should be co-produced through a dialog between forecast providers and end-users (e.g., see Dilling & Lemos, 2011; Fischhoff, 2013). Increased attention to the transfer and application of textbook knowledge in school may also be beneficial for addressing the language challenge in communication between experts and laypeople. For example, knowledge that is learned in multiple contexts is more likely to support flexible transfer than knowledge learned in a single context (Bransford et al., 2000).

4.4 Rational decision-making and accidents

The results from the three studies indicate that only parts of the information provided in the forecast were integrated and used by participants, and that different participants were integrating and using different parts of the information. What information and how much information was utilized apparently depended less on participant's reading skills and more on the actual decision-making situation (the person, the weather conditions, and the task/activity). Because they used only parts of the information, the participants did not obtain the richest possible understanding of the forecast, and they typically evaluated the degree of certainty in the forecast differently from the intended meaning. However, being rational in a bounded rationality paradigm does not require reading all of the available information. The participants in this study state reasons for their choices and appear rational in the sense of bounded rationality. Thus, the participants appeared rational in their decision-making processes and made reasoned and apparently suitable decisions in each situation. For example, one participant did not have adequate experience and understanding of wind speed and as a result she did not use this information. The participant did not attempt to learn about wind precisely because the envisaged activity was not dependent on wind speed in any respect. This description of a decision-making process as a rational process in which certain available information is purposely omitted contrasts with the deficit model of science communication, which considers the public to be cognitively impaired and ignorant (Davies, 2008).

Må reddes ned

Hovedredningssentralen i Sør Norge har ikke mer å gjøre på høsten enn andre årstider.

- Det er veldig variabelt hva vi må ut på, men som oftest bistår vi politiet med leting etter folk som har gått seg vill eller fast. På høsten er det også en del som blir overrasket på grunn av mørket, sier Ben Vikøren, redningsleder på Hovedredningssentralen Sør Norge.

Marius Haugaløkken. FOTO: PRIVAT

Dette bekrefter Marius Haugaløkken. Han er vert på Gjendesheim Turisthytte ved foten av Besseggen.

- Ikke alle er forberedt på at det blir fortere mørkt og kaldt om natten. Dette kan bli et problem om man bruker lengre tid på turen enn planlagt. Mine råd er derfor: Skal du i fjellet, så bruk egnet utstyr for fjellet. Husk også å ta med ekstra varme klær, hodelykt og ekstra mat i sekken, sier Haugaløkken.

Han forteller at 15-20 ganger i året må folk ha hjelp for å komme seg ned fra Besseggen. Det skjedde senest i helgen, da en gjeng ble overrasket av kulden og mørket.

- Ca 50.000 går Besseggen hvert år, så prosentandelen som må ha hjelp, er forsvinnende liten. Men for de som plutselig trenger hjelp, er det alvorlig nok, sier Haugaløkken.

Figure 8: Anecdotal evidence from the Norwegian newspaper Bergens Tidende, September 17, 2015, reporting that people are not always prepared and sometimes get surprised by cold weather at night, and need to be rescued (Dyregrov, 2015).

Although the participants in this study appeared rational in their decision-making, accidents with fatal consequences sometimes occur. For example, in each year since 2000, an average of approximately ten people have died while engaging in outdoor activities (climbing, skiing, canoeing, kayaking, sailing, and surfs) in Norway (Horgen, 2013). Some of these accidents occurred during strong winds and inclement weather (Horgen, 2013; Aadland et al., 2016). Besides inaccurate weather forecasts, one possible reason for these accidents is that the decisions to do the activity or what precautions to take, required knowledge or information that the decision-maker did not have (Reyna & Farley, 2006). Aadland et al. (2016) suggest that other reasons also exist. Anecdotal evidence from media reports indicates that inadequate planning is a potential cause of accidents in outdoor activities (Figure 8).

Those involved in these incidents may have made hasty decisions. However, the participants in this study employed more elaborate decision-making processes when the activity was important to them. They also exploited a clear set of functions with respect to the representations they employed, and they integrated information when they had to compare and control information. Thus, another possible reason for the accidents is that people make rational (i.e., reasoned) decisions but lack relevant experiences and/or do not know that a particular situation may require a more exhaustive examination of the weather forecast. Apparently, only a fraction of judgements leads to weather-related accidents and the need for rescue services, and the present study includes a relatively low number of participants. This means that the patterns found in the participants' decision-making processes in this study are not necessarily representative for the persons having accidents. Nevertheless, a main challenge is to know which situations and activities require more in-depth use of forecasts. This challenge is exemplified by one participant who used to drive a boat along the Norwegian coast. The participant stated that she tried to read the wind arrows in the forecasts but was unable to fully understand and relate this information to the different wind speeds. Instead, the decisions she made in performing the activity were based on her observations of waves, which is a rational decision in the sense of being reasoned. The weather conditions along the coast of Norway can change rapidly, and an impending storm can surprise anyone if the forecast is not read. Although this participant made a rational decision (i.e., reasoned), the lack of consideration for wind speed information indicates a lack of understanding of the seriousness of the situation; that is, low situation awareness (Aadland et al., 2016). There is also anecdotal evidence from media reports that some people hiking in the Norwegian mountains, especially non-residents, may not be familiar with rapidly changing weather conditions and thus dress improperly (Figure 9). If one has not experienced a disaster, reliance on personal experience may lead to an underestimation of risk (Eiser et al., 2012). Thus, if these persons have never experienced really bad weather before that may contribute to underestimating the risk in these situations.

– Turister som kommer langveis fra har som regel begrenset tid i området, og da skal det mye til for å stoppe dem, sier operasjonsleder Kjetil Føyen i Vest politidistrikt til NTB.

Frivillige redningsarbeidere har trådt til for å få dem i sikkerhet.

– De tropper opp i olabukser og sandaler. De har aldri opplevd væromslag før, slik vi har i Norge, sier Jon Halvorsen, enhetsleder for redningstjeneste og førstehjelp i Norsk Folkehjelp.

Figure 9: Police officer Kjetil Føyen reports: “Tourists who have traveled over a long distance typically have limited time to undertake their activities in a certain area, and then it is difficult to stop them.” Jon Halvorsen from Norwegian People’s Aid continues: “They show up in jeans and sandals. They have never experienced such a change in weather.” Reported by the Norwegian newspaper Haugesunds Avis, August 09, 2016 (NTB, 2016).

Additionally, when people have traveled over a distance they sometimes have limited time to undertake their activities in this area. This may provide an explanation why the hikers mentioned in Figure 10 were still trying to reach the top of the mountain even though there was bad weather (strong winds, poor visibility, and heavy rain) and they were explicitly warned and advised by the local tourist office agents and others not to go. According to a representative from the Norwegian People’s Aid (Figure 9), who sent their Rescue Service to this area, many persons were improperly dressed for the bad weather. This resulted in several accidents.

Bad weather shut Preikestolen

August 8, 2016

SHARE

The popular Norwegian mountain ledge known as *Preikestolen* (The Pulpit Rock) was closed to hikers and other tourist traffic on Monday because of bad weather and extremely poor visibility. Norway's entire West Coast was getting hit with another deluge of heavy rain.

"We warned folks against hiking up to Preikestolen all day," Audun Rake of the local tourism promotion agency *Lysefjorden Utvikling*, told Norwegian Broadcasting (NRK). "Despite the weather, people were still trying to go."

Preikestolen attracts thousands of visitors from all over the world, but on Monday afternoon, the trail was closed for the first time in memory because of bad weather.. PHOTO: Wikipedia

That prompted authorities to close the trail leading up to what's usually a spectacular vista point. Many hikers had already fallen along the way, and there was real danger they'd fall over the edge, and plunge to their deaths below.

"We've had reports of broken bones, one person with heart problems and several who were severely chilled on the trail," Kjetil Føyen of Norway's Southwest Police District told NRK.

Figure 10: Anecdotal evidence from the newspaper newsinenglish.no, August 08, 2016, reporting that certain people sometimes walk into the mountains even when they are explicitly warned not to do this due to bad weather (NewsinEnglish.no, Aug 08).

When facing a hazardous weather situation the individual's cultural worldview (Morss et al., 2016) and social processes, for example conversations with one another, are important and might have influenced their risk assessment and judgment (Eiser et al., 2012; Becker et al., 2015). Moreover, if a person has positive feelings about an event, she sees it as having more benefits and fewer costs (Eiser et al., 2012), possibly underestimating the dangers. This may well be the situation for tourists, looking forward to their holidays. People may want to try to go when they have first traveled to this mountain.

According to Endsley (2006), the main cause for most human errors is poor situation awareness (Aadland et al., 2016). Therefore, a lack of relevant experience may explain why some persons do not understand the seriousness of certain (not necessarily extreme) situations, which can lead to low-quality decision-making. A critical factor when interpreting the weather forecast is that the user understands the forecasts as well as the consequences such conditions would have in a given context (e.g., sea kayaking, Aadland et al., 2016). For instance, Aadland et al. (2016) suggest that some paddlers lack a basic understanding of the hazards they face and of their competence and skill to handle those situations. Consistent with the risk communication literature, forecasters are increasingly interested in communicating the likely levels of impact of severe weather (Neal et al., 2014; Casteel, 2016); that is, possible consequences of the forecast weather conditions. For example, when unusually extreme events are expected (a situation in which many people have rare experiences), Lejano et al. (2016) claims that communication must include reference to a specific context and recommendations for action.

Providing possible consequences of the forecast weather can assist people that lack certain types of experiences to increase their situation awareness, and inform their decision-making. Nevertheless, people need to acquire experiences on their own. Starting out with slightly more demanding weather conditions than they normally experience may be more sensible than jumping straight into the more extreme weather conditions.

To identify those situations in which exhaustive examination of the forecast is essential, experience with the activity and local weather conditions (including knowledge about physiographic conditions such as topology and fiords) is necessary.

If people recognize the seriousness of the situation, this study suggests that they will be able to adapt the amount and type of information and their decision-making process accordingly. However, forecast information competes with other types of information and may be seen as less important given the decision goals (Dilling & Lemos, 2011). As mentioned, positive feelings about an event (Slovic et al., 2004) or restrictions in time to undertake the activity may lead people to become more risk-averse. Therefore, as suggested by Dietz (2013) and von Winterfeldt (2013), communication must be competent with regard to both facts and values (e.g., goals and associated trade-offs that underpin preferences for one course of action) to inform decisions.

The participants in this study interpreted forecast (including uncertainty) information differently from one another and sometimes differently from the intentions of the forecast provider. At other times, the participants did not understand part of the information and were unable to use it or integrate it across representations. Such occurrences are also possible explanations for why accidents happen. Interpreting information differently from the provider's intention should be considered a communication challenge (not a misinterpretation) for which the forecast provider has the main responsibility. Therefore, in addition to continuing to improve the quality of their forecasting models, providers of online weather reports should focus on improving communication through co-production of symbols and other ways to communicate forecast information, to support informed decision-making. However, the end-users are also responsible for scrutinizing background information and experiences needed to understand the information. To fully exploit the advantages of the multimodal information in situations where this is beneficial for the individual, different representations should be used and integrated (Ainsworth, 1999).

Although the participants in this study appeared rational in their decision-making, the results revealed challenges associated with communication to a variety of user groups. There is no simple formula for effective forecast communication; what is appropriate and easily comprehended by one group may be unhelpful to others (Pennesi, 2007). Stephens et al. (2012) argues that a key challenge in communication of probabilistic forecast information is the balance between richness (i.e., the amount of information communicated) and saliency (i.e., presenting information in a way that is meaningful for the user). To communicate with the public, forecast providers should encourage a systematic dialog with forecast users (e.g., the mental model approach, Fischhoff, 2013), in which the public is separated and includes various user groups. Rather than taking a deficit view and asking how forecast providers can educate the public, the pertinent question is how the public can assist forecast providers. This study constitutes a contribution to this process by focusing on task 2 (and to some extent on task 3) in the mental model approach; however, additional research and dialog are required to enhance understanding the needs of different groups and to co-produce useful information (Dilling & Lemos, 2011).

5. Concluding summary

To summarize my work, I have developed the following questions having the origin in the four-task model suggested to achieve useful and effective communication (1.6.3): What can I share about "what people know" (the second task of the model); that is, the participants' current interpretations, integrations, and uses of online weather information? What can we learn from the results and discussions from this study related to "design of communication" (the third task of the model)? By answering these questions (Section 5.1), the main question in this study will also be answered: *How is information in online weather reports interpreted, integrated, and used by laypeople when making everyday decisions for weather-dependent activities?* Additionally, the answers can increase the understanding of the communication process between experts and laypeople, from which this study is motivated, and it can thus be a contribution in the development of useful and effective communication.

In Section 5.2, recommendations for future studies are presented, which may be of interest to other researchers.

5.1 Summary

First, when people ask me what I have achieved, I reply that I have investigated how laypeople make everyday decisions based on weather information, specifically, the information they use from online weather reports, and how they interpreted and integrated this information. Examining these issues improved our understanding of communication between experts and laypeople.

I will inform my *colleagues in weather forecasting* that forecast information is by some users interpreted close to the intended meaning. In addition, prior experiences, in combination with reflections on the meaning of symbols and words when comparing these with experiences, are critical to the interpretation of information. Because of differences in experiences and reflections, information was sometimes interpreted differently than intended. For example, when nuances such as cloud color and the number of drops in the symbols were interpreted as substantial information, the interpretations of end-users exhibited considerable variation. Additionally, some of the information was not integrated or used and/or not understood. The degree of certainty in the forecast was evaluated differently; not only deliberate uncertainty information given in the weather report such as precipitation intervals, but also the participants' own evaluations of for example cloud color and number of drops in a symbol. Communicating an accurate and purposeful degree of certainty in a weather report may be one of the greatest communication challenges of weather forecasting. Information from weather reports was used in decision-making regarding a variety of everyday activities. The decision-making process, e.g., its thoroughness, was dependent on the importance of the activity and the weather conditions of the day. The participants in the study appeared rational, i.e., reasoned, in their decision-making and the decision-making process was typically suitable for the actual situation. They also adjusted the type and amount of information that they used. When quick decisions were made, the degree of certainty was not evaluated and few representations were employed. In general, an inability to understand the seriousness of situations can degrade the quality of the decisions, which can be harmful, and even fatal. To achieve effective communication of useful information and informed decision-making, information in weather reports should be easy to correlate with prior experiences. For example, symbols and wind information must be nuanced and should appear realistically.

I would inform my *colleagues in web-service development* that the multiplicity of representations appears to be a great advantage for communicating weather forecast information to a variety of users. This feature enables everyone to obtain some information that they like and understand; they can also adjust the type and amount of information that they acquire to the actual decision-making situation. The participants ascribed a set of affordances to each representation and used representations that they preferred and considered efficient in each situation. Although information was sometimes integrated across representations to clarify or control and compare forecast information, the potential advantages of the multimodal information were not fully exploited. To facilitate the use and integration of several representations in situations where the users aim for an elaborate decision process, additional guidance can possibly direct and make them aware of possible advantages. Importantly, too much information should be avoided as this can produce distractions and even make the information more demanding to read. Improvements in communicating weather and uncertainty information and in finding appropriate solutions to support people who lack the relevant experiences to interpret and understand part of the information and the seriousness of the situation can assist people in making informed decisions and avoid unnecessary fatal events. For instance, although certain people seem to benefit from the use of scientific terms in weather reports, many users may benefit from the use of an everyday language which is likely to be more relevant and engage them to reflect on their experiences.

Similarities exist between Yr.no and the remaining top five global weather websites (Alexa, 2016) (i.e., providing multimodal information to users). Thus, this study is *informative for providers of online weather web services* despite its limitation in sample size. Due to the similarities in weather, some common features and principles for the development of guidelines for the communication of graphical forecast information may be feasible; however, local experiences and differences between social groups and cultures are also important in interpretations and should be acknowledged by forecast providers. Improved communication may provide an opportunity to reduce variation in the interpretations of weather information, leading to more effective decision-making. The findings and discussions from this study can be informative for research-based weather communication.

Finally, I would talk to my *colleagues in science education* about two types of *transfer* that I find important in relation to multimodal reading and literacy. The first type is transfer between representations. To master multimodal reading, readers need to make transfers between several representations and integrate the information. Making such transfers may be demanding, and in this study the participants did not always integrate information from different representations (of different reasons). Thus, possible advantages of multimodality are not exploited, and science educators may find it important to focus transfer between representations. The second type, knowledge transfer from one situation to another, is related to literacy. Some participants in this study indicated that they did not understand certain terms, wind speeds, and precipitation amounts. These problems might result either because the terms were never learned/understood in school, or because it is demanding to transfer knowledge from one type of situation to another. Teaching a subject in multiple contexts rather than in a single context, for example, is considered beneficial for transfer across contexts (Bransford et al., 2000). Increased focus on transfer of knowledge is important to how people actually use science in daily life; to functionality and to personal decision-making.

5.2 Future research

”Human beings are complex, and their lives are ever changing; the more methods we use to study them, the better our chances to gain some understanding of how they construct their lives and the stories they tell us about them” (Fontana & Frey, 2000, p. 668).

Other researchers can extend this study in future research. As suggested in the mental model approach (e.g., de Bruin & Bostrom, 2013), I also recommend the use of qualitative methods, such as the semi-structured interviews used in this study. Using qualitative methods enables the acquisition of information regarding the interpretation, integration, and use of information that is not otherwise easily noticeable. de Bruin and Bostrom (2013) suggest conducting follow-up surveys with larger samples. The results from the present study as well as future qualitative studies may be sought quantified and generalized by conducting quantitative surveys, based on the findings. Miles and

Huberman (1994) agree linking qualitative and quantitative studies is a strength, and claims that such triangulation enable the confirmation or corroboration of each other.

Additional research is required to improve the understanding of interpretation, integration, and use, as well as communication, of weather forecast information to the public. A dialog between forecast providers and various end-users is considered beneficial to this process. I highlight the following two main topics for future studies:

The first topic is *experiences*. To establish a foundation for research-based weather communication, a dialog among numerous user groups from different areas (with differences in weather) is necessary. This dialog should focus on forecast uncertainty as well as the situations in which prior experiences prevail over given information. It is also important to study which weather parameters are difficult to relate to and how to present information in a manner that is useful to people who lack certain types of experiences and have low situation awareness. Additionally, exploring different aspects of people's weather experiences (e.g., experiences with impact of weather, emotional impact, or experiences with property damage and financial losses) and how these can influence future behavior is important and should be focused in future studies, as recommended by Demuth et al. (2016).

The second topic is *representations*. In which situations is one representation considered sufficient, and when are several representations integrated and used? Does this decision vary among different user groups? Various user groups should be given several different tasks to evaluate the strengths and weaknesses ascribed to the different representations. Determining the best method for communicating forecast uncertainty information is of particular interest. If forecast providers are interested in the use of uncertainty information by laypeople when quick decisions are required, methods for effective communicating this information should be developed, preferably in a co-production process with the end-users enabling the production of useful information (Dilling & Lemos, 2011).

For both topics, *normal user situations* should be replicated and explored in the context of different activities and weather conditions. Tasks and restrictions should be adapted to enable both rapid and more elaborated decision-making processes.

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Paper 1

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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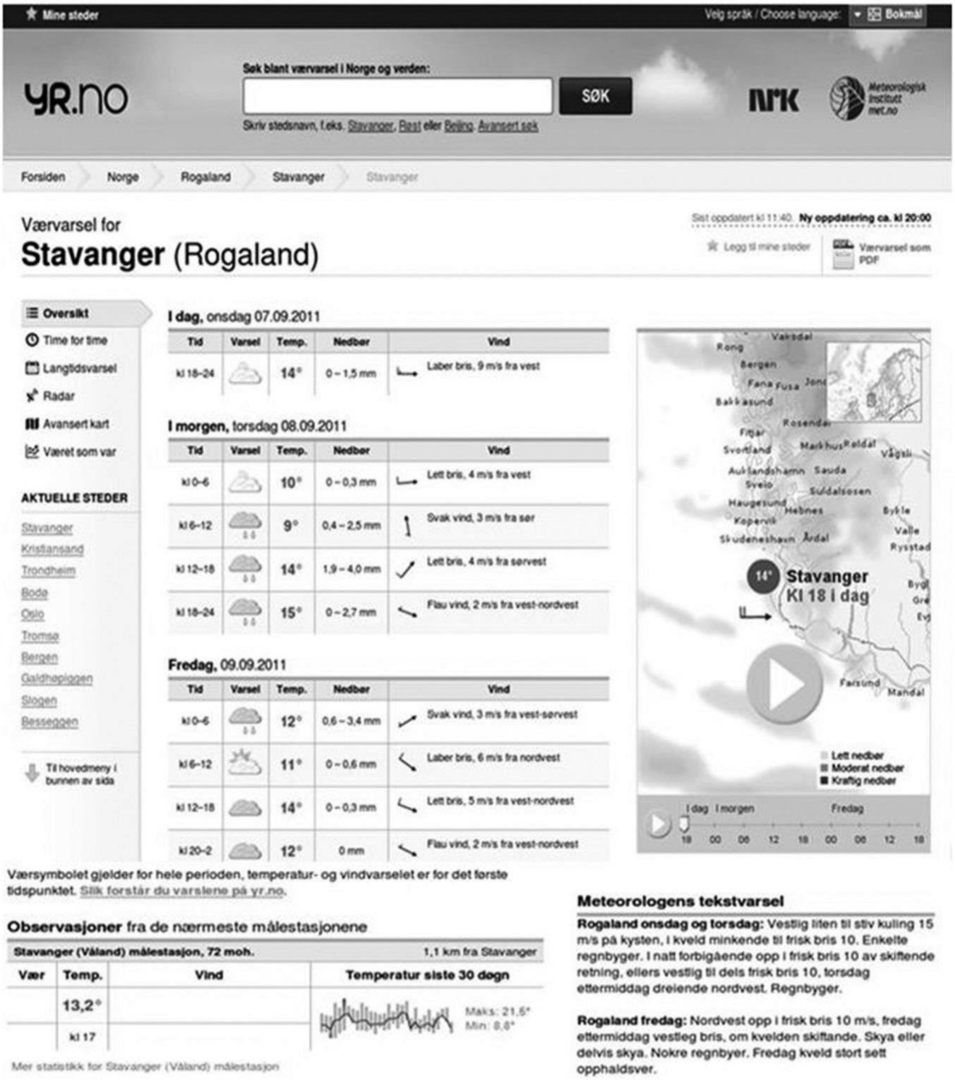

FIG. 1. Segment of the overview forecast page of the web service www.yr.no (YR). The forecast is in Norwegian because it is an authentic forecast used in the interviews. Included in the segment is a table with numbers and symbols, a map showing symbols and forecast precipitation, and the meteorologist's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

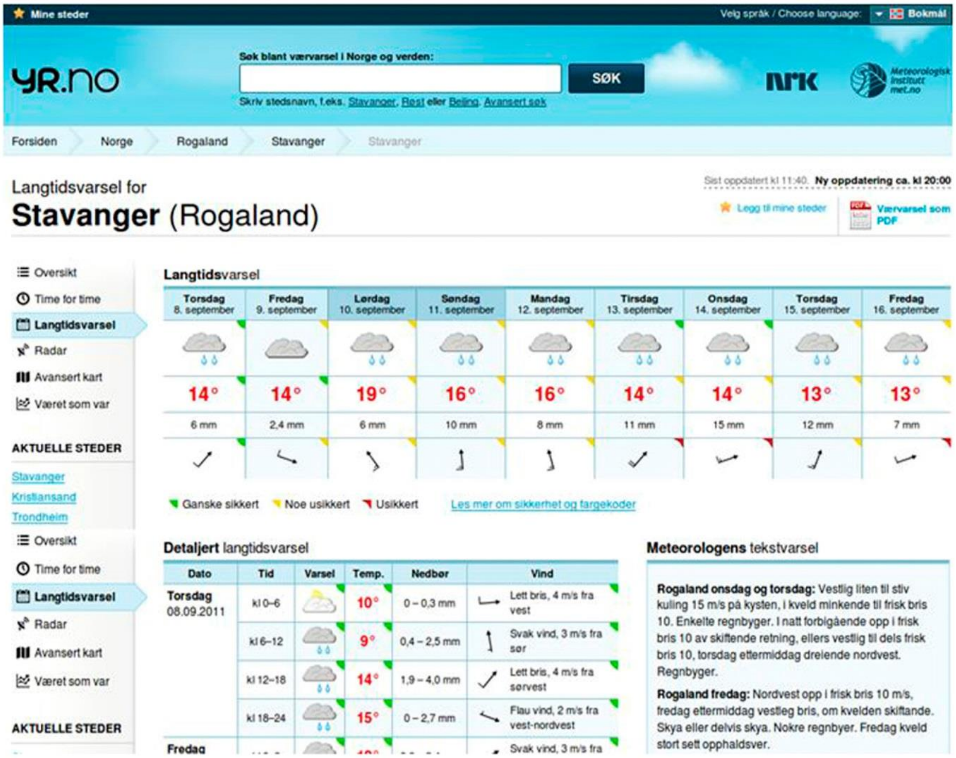

FIG. 3. Segment of the long-term forecast page of the web service www.yr.no (YR). Included in the segment are two tables (the lower one more detailed in time) with numbers and symbols and the meteorologist's written text forecast. Together with numerical precipitation intervals, the green, yellow, and 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 non-dynamic 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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II

Paper 2

Use of Online Weather Information in Everyday Decision-Making by Laypeople, and Implications for Communication of Weather Information

Running head:
Use of Weather Information in Everyday Decision-Making by Laypeople

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ABSTRACT

Many people use weather reports to plan their activities. Previous studies on this type of decision-making were primarily concerned with the use of selected pieces of information detached from the context of a full weather report. Therefore, this study contains two areas of focus: 1) *factors influencing the amount of information from a full weather report that are used* by laypeople for everyday decision-making and 2) how the *complexity in information in a full weather report is handled* in the decision-making processes. In this qualitative study, semi-structured interviews were conducted with 21 persons from Norway. Farmers, exterior painters, tour guides, teachers, and students were included in the sample to obtain a fair variance in the number of user situations. Interviews were centred on a multimodal weather report from the online web-service www.Yr.no. In this study, a varying amount of information was used by the participants in their decision-making; furthermore, the amount of information used appears to depend on a) the importance of the envisaged activity and b) the suitability of the weather conditions. The amount of information (i.e., complexity) must be reduced to make a quick decision, which typically was accomplished by c) choosing a suitable starting point and leaving out evaluations of d) weather dynamics and e) forecast uncertainty. Communicating a multiplicity of representations in weather reports appears favourable for enabling the use of different types and amounts of information such that it allows both quick and more elaborate decision-making processes.

KEY WORDS: Online weather report, multimodality, uncertainty, decision-making, communication.

1. Introduction

1.1 Background and research questions

Information from weather reports assist people in taking appropriate actions to protect life, property (Schultz *et al*., 2010; Rutty and Andrey, 2014), and well-being. Such informed decision-making leads to desirable outcomes and avoids costs to society (Pielke and Carbone, 2002). Studying how people make weather-related decisions is important to improving the communication of weather information. Effective communication contribute to increased information value for users (Stuart *et al*., 2006), informing them about the potential benefits and risks of their decisions and providing additional assistance in making informed decisions (Fischhoff, 2013). However, a limited understanding exists concerning how information from weather reports is used in personal decision-making (Morss *et al*., 2010), and everyday decisions are less focused than situations involving severe weather (Silver, 2015).

Online weather reports are typically complex in the sense of providing a great deal of information. The top five weather sites in the world (as of 15 August 2015), as calculated using the number of daily visitors and page views (Alexa 2015), are weather.com, accuweather.com, wunderground.com, weather.gov, and Yr.no. All five sites are multimodal texts composed of such representations as tables, symbols, maps, diagrams, and verbal text forecasts (e.g., Figure 1 and S1). In addition to single-valued forecasts, these sites provide uncertainty information in terms of probabilities of precipitation and numerical precipitation intervals. Yr.no (Yr is the Norwegian word for drizzle) is a collaboration between the Norwegian Meteorological Institute (MET Norway) and the Norwegian Broadcasting Corporation (NRK). A large amount of information is available. Statistics from Yr show that approximately 7 million visits or 5 % of all visits in July 2015 lasted between three and ten minutes (personal communication, 12 August 2015). Approximately 97 million visits or 71 % of all visits lasted 30 seconds or less. Consequently, most users do not use all of the information available on Yr. Certain users make quick decisions. More elaborate decisions are made on occasion. The large differences in time consumption suggests that different amounts of information are used in the decision processes. The differences in the amount of time taken to examine forecasts could be indicative of different user needs. Another reason could be that some users find the information to be ineffective, contradictory, or difficult to understand (Sivle *et al.*, 2014).

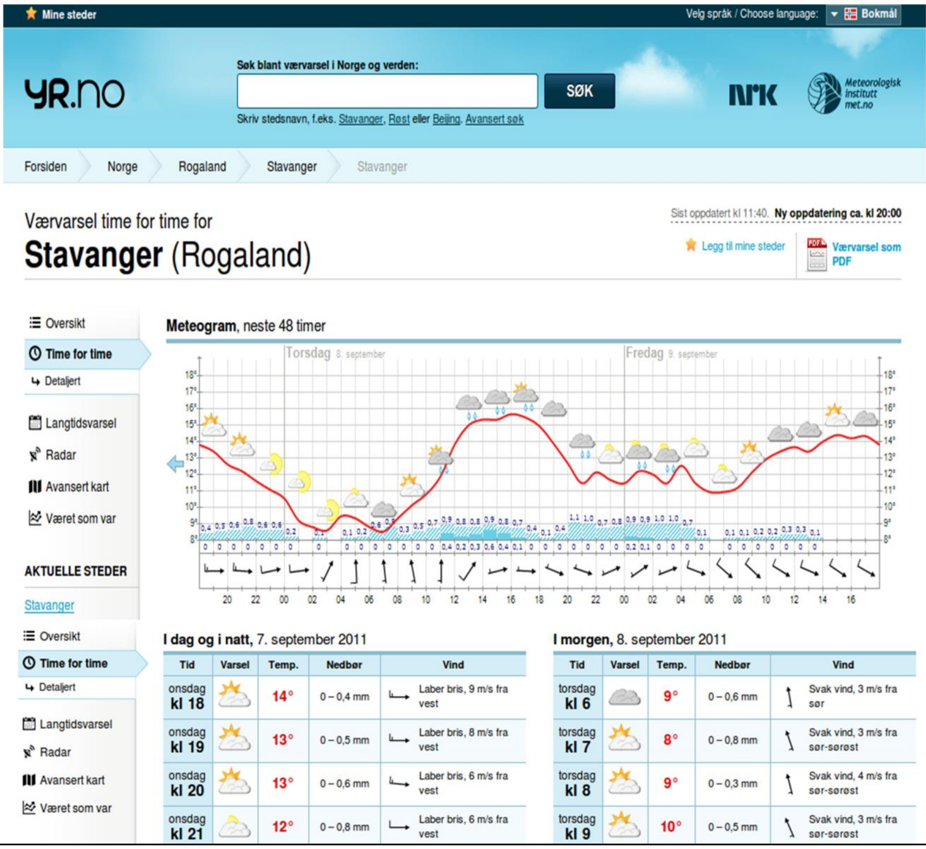

Figure 1: Segment of the hour-by-hour forecast page of the web-service www.Yr.no (Yr). Forecast is in Norwegian language since this is the actual forecast used in the interviews. Included in the segment is a diagram (meteogram) with symbols, a temperature graph and solid (blue) and hatched precipitation columns (colours online only). There is also a table showing numbers and symbols. Hatched precipitation columns and numerical precipitation intervals are meant to indicate uncertainty; solid (blue) precipitation columns are meant to indicate expected precipitation.

Previous studies on how members of the public make weather-related decisions have focused on the communication of uncertainty and probabilities in weather forecasting

(Roulston *et al*., 2006; Joslyn *et al*., 2007; Joslyn *et al*., 2009a; Joslyn and Nichols, 2009; Roulston and Kaplan, 2009; Morss *et al*., 2010). The primary concern of these studies was whether the forecast uncertainty information was understood and enabled forecast users to make better decisions. Probabilistic forecast information (multiple possible outcomes) is usually found to have greater value for users than deterministic information (single outcome) (LeClerc and Joslyn, 2012). Notably, the studies were typically concerned with the use of selected pieces of information detached from the context of a full weather report. Thus, these studies are not capturing the more common or everyday decision-making situations. As a result, understanding how laypeople make everyday decisions in the context of a full weather report is a subject that requires further study (Morss *et al*., 2010; Silver, 2015).

This qualitative study is designed to mimic normal user situations, by exploring the use of weather forecasts from Yr. The main focus is on identifying factors influencing the amount of information used by laypeople in decision-making related to different types of weather-dependent activities. How complex and uncertain information are handled in the decision-making process is further elaborated. Therefore, the following research questions (RQ) are asked when making decisions for weather-dependent activities:

RQ1. What factors influence the amount of information used by laypeople in everyday situations that involve the use of weather forecasts from Yr?

RQ2. How is complex and uncertain information from Yr handled?

The answers to these questions can contribute to the knowledge of how to communicate weather and uncertainty information to laypeople. The focus on Yr and how these forecasts are communicated are informative for other online weather web-services.

1.2 Theories on human information processing

Whereas economic models traditionally have been used in studies of decision-making, there has been a shift towards information processing related to human decision-making (Oppenheimer and Kelso, 2015). The specific information available to the decision-maker, and how this information is sampled, retrieved, integrated, and used, is considered.

Many researchers agree that there are two types of information processing involved in human decision-making. Intuition (Type 1) operates fast and automatic with little or no effort, whereas reasoning or analysis (Type 2) is conscious, governed by rules, relatively slow, and effortful (Kahneman, 2011; Evans and Stanovich, 2013). The literature indicates that there is interplay between the two types of processing in decision-making, to a varying extent depending on the situation, and perhaps, on the individual. Betsch and Glöckner (2010) claim that intuition and analysis both gives important contributions to decision-making processes. This view is supported by converging evidence (Evans and Stanovich, 2013). Whereas the depth of the analysis can vary, intuition always works in the mental background (Betsch and Glöckner, 2010).

Fast processing alone does not automatically indicate intuition (Evans, 2012). For example, individuals may adopt experience based techniques (heuristics), allowing a decision to be made quickly by the means of performing simple decision rules. Because these procedures demand conscious calculation, they are considered Type 2 processing (Evans, 2012). Analytic processes are sequential and consume time, and more information should take longer time to process. Betsch and Glöckner, (2010), however, argue that if the information is coherent (all information favours one option and speaks against another options) decisions are easier to make and decision time should decrease.

Type 2 processing is considered to handle controlled search of information and making sense of information, and it is assumed that people use different strategies for getting input information (Betsch and Glöckner, 2010). *Criteria* (basis for judgement) and *cues* (pieces of information) are the two variables describing the type and amount of information used in certain everyday decision-making situations, and which will aid answering the research questions.

There are strong indications that affect (a feeling that something is good or bad) and emotions may serve as information in decision-making (Slovic *et al*., 2004), directing our attention, helping trade-off between decision alternatives, and as motivation for actions (Dickert *et al*., 2014). Learning from experiences leads decision outcomes to become “marked” by positive and negative feelings, providing information about what to choose and what to avoid (Peters, 2006), and thus influencing the construction of preferences.

2. Method

Semi-structured interviews were the chosen method of data collection. The sample and the interviews are the same as employed in Sivle *et al*. (2014), and the text in subsections 2.1 and 2.2 (including Table 1, Figures 1, S2, and S3) are derived from there with minor modifications.

Although data from the interviews are qualitative, the analysis is primarily based on established categories and counting of variables and cases, and thus produces quantitative data, as described in subsection 2.3. However, no claims are put forth for the frequencies of occurrence in the wider public. Instead this study contributes to the identification of laypeople’s information use when making weather-related decisions.

2.1 Sample

The aim of the purposive sampling method was to capture as many different methods of using information provided on Yr as possible using the available study resources (Johannessen *et al.*, 2010). Interview studies that aim to identify a diversity of views existing on a topic typically include 5 to 25 informants (Kvale and Brinkmann 2009). To obtain a broad variance in the number of user situations, five user groups were included (Table 1). The study sought variation with respect to the demographic variables of occupation, education, age, and geographical residence across these groups. Informants were selected to address the potential influence of occupation differences. Farmers, exterior painters, and tour guides from the Norwegian Trekking Association use weather forecasts to make decisions in their occupations and were chosen among other likely user groups.

Table 1: List of informants in the study, from the five selected user groups (based on the occupation variable): farmers, tour guides, painters, teachers, and students. The informants are given pseudonyms to maintain their confidentiality. Residence area 1 has an extreme west coast climate (wet and windy), area 2 is characterised by "Norway`s best climate", and area 3 coincides with an extreme inland climate (dry).

Informant	Pseudonym	Residence area	Educational background (completed level)	Occupation	Age	Sex
1	Daniel	1	College	Farmer	50	Male
2	Arvid	1	College	Tour guide	40	Male
3	Albert	2	Upper secondary school	Painter	45	Male
4	Nils	2	College	Tour guide	45	Male
5	Gunnar	2	College	Farmer	42	Male
6	Kristin	2	Lower secondary school	Student	15	Female
7	Jon	2	University	Teacher	52	Male
8	Kjersti	2	Lower secondary school	Student	16	Female
9	Amanda	2	Lower secondary school	Student	16	Female
10	Siri	2	University	Teacher	42	Female
11	Anita	2	University	Teacher	58	Female
12	Steffen	3	University	Teacher	52	Male
13	Peder	3	Lower secondary school	Student	18	Male
14	Ruth	3	Lower secondary school	Student	18	Female
15	Lise	3	Upper secondary school	Tour guide	45	Female
16	Marta	3	University	Farmer	40	Female
17	Emil	3	Lower secondary school	Student	16	Male
18	Frode	3	College	Teacher	59	Male
19	Geir	1	College	Teacher	51	Male
20	Ulf	1	University	Tour guide	61	Male
21	Kennet	1	Lower secondary school	Student	19	Male

Lists of possible informants were drawn up based on the criteria, and schools and companies were identified and contacted by e-mail. Informed consent was obtained from those who agreed to participate. All informants in the sample were familiar with and used Yr. A pilot study with three interviews (1 student, 1 teacher, and 1 painter) was conducted to test and subsequently improve the interview guide.

2.2 Interviews

Interviews with 21 informants were conducted and digitally sound-recorded by the first author (sample shown in Table 1, pilot study not included). The interviews (I-1, Figure 2) were centred on printouts of one particular forecast from Yr consisting of four printed pages with different information/time-scales (front page (Figure S1), overview page (Figure S2), hour-by-hour page (Figure 1), and long-term page (Figure S3). Although not as authentic as online forecasts, printouts were chosen to ensure interesting forecast information and to offer a common basis for comparison across answers. The forecast was taken from Stavanger, a city with which all of the informants were familiar but in which none of them were living.

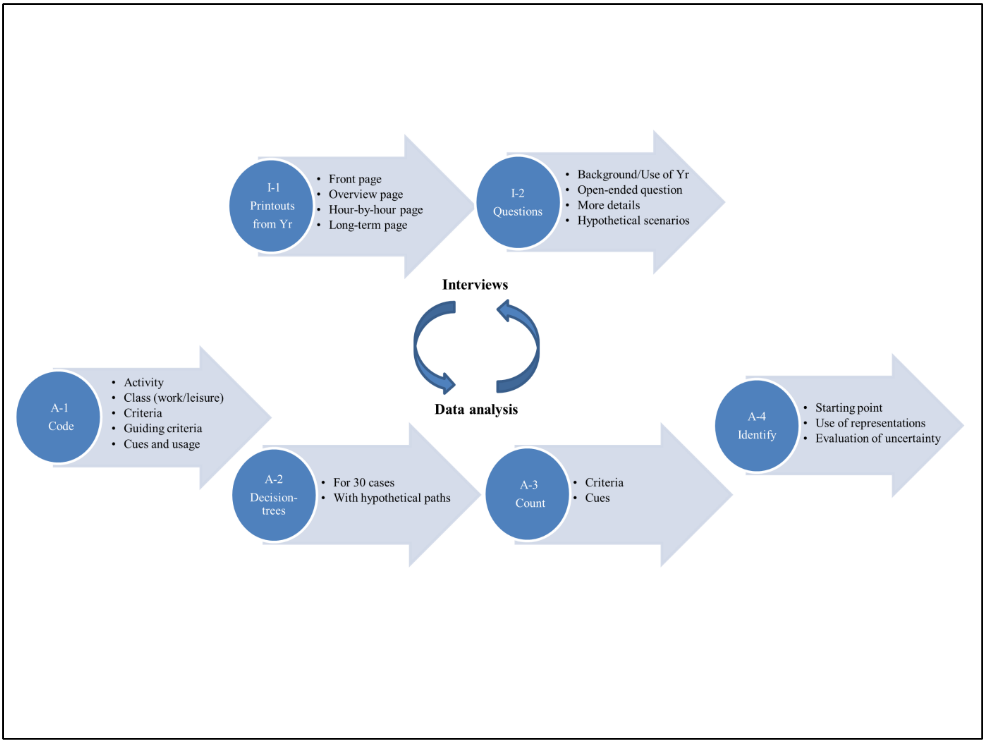

Figure 2: Flowchart showing the iterative process between interviews (I-1 and I-2) and the four main steps of the data analysis (A-1 to A-4): Coding of interview transcripts; make decision-trees based on the coding; use decision-trees to count variables and identify use of information.

Informants were first asked about their background and their use of Yr (I-2, Figure 2). The next question was open-ended: "When you look at this forecast, what can you tell about the weather in Stavanger?" With this open-ended question, informants were able to comment on as little or much of the information in the forecast as they wished. An open question in the context of a full weather report mimics a normal user situation, and the validity of the findings is strengthened. The informants typically identified an activity and related the forecast information to decision-making on their own. If not, the first question was followed by more detailed questions on the use of information in various situations. Certain informants were chatty, and only a few additional questions were required, but for others, several prompts were offered to elicit response. For example, informants were asked about their use of tables or diagrams (Figure 1), the uncertainty information that was represented by coloured triangles in the long-term forecast (Figure S3), and how they came to a decision for an activity. The informants were also allowed and encouraged to take as long time as they needed. *Hypothetical weather scenarios* were also discussed in the interviews where the informant elaborated on how she/he usually came to a decision for an activity using alternative forecast information (with different weather conditions) other than provided in the interview.

When asked, certain informants in this study said that they spent only a few seconds on Yr for every visit, while others spent from 2-5 minutes to 5-10 minutes, that is, consistent with the results in Section 1.1. Experience of time is affected by complexity of task; a task requiring a high mental workload is associated with underestimating the time they spent and vice versa (Misuraca and Teuscher, 2013). This means that the informants that reported they spent a short time actually might use even shorter time, and the informants spending a long time might spend even longer time. The informants who consented to be interviewed might be more interested in the weather than other users. These elements could lead the informants to use more information and more elaborate decision processes than the average user. Newell and Shanks (2014) question to what extent individuals are aware of the information that is triggering their decisions. They claim that the challenge is for researchers to use methods which can make people elicit factors influencing their decision-making. This is a concern also for the interviews in this study, where it is possible that not all the informant's thoughts are elicited. Thus, they may use more or other information in private than elicited in the interviews, and weather information might only be one of many components of decisions (Morss *et al*., 2005; Dilling and Lemos, 2011).

All interviews were transcribed verbatim by the first author.

2.3 Data analysis

The computer-assisted qualitative data analysis proceeded through four main steps (Figure 2):

First, all relevant and meaningful replies in the transcriptions were marked with a code name that described the content of the reply. To reduce the amount of data (Miles and Huberman, 1994), all replies concerned with a weather dependent *activity* were initially given a code name describing the activity (e.g., hiking), whether the action was movable or fixed in time, and whether the activity occurred recently (i.e., last couple of weeks). The activities were also *classified* into work-related activities (given the number 1, e.g., harvesting for a farmer) and leisure activities (given the number 2, e.g., fishing trip for a teacher).

In the following analysis, only already coded replies were addressed. The analysis of the transcripts identified criteria and cues used by the informants. These two variables aid in answering the research questions and explicitly give two predefined categories used in the coding process. Data were coded with respect to one variable at a time.

If the reply was concerned with a criterion for making a decision, it was given the code name "criterion", followed by the name of the weather element (e.g., temperature) in addition to the timing or duration of the event or the degree of certainty required. For example, the reply "fresh breeze is the strongest wind I accept at sea" is given the code name "criterion wind". Other criteria not related to forecasts were also coded, for example sufficient work capacity on the days in question. Additionally, when the informants expressed a success criterion for the activity that influenced their planning, this was given the code name "guiding criterion". Examples of such guiding criteria or emphasises are (own or others') safety or well-being. Guiding criteria were not predefined by the interviewer but were coded inductively according to replies made by the informants themselves.

Importantly, the weather forecast does not contain only one piece of information or cue. Rather, it is possible to go from one cue to the next, if necessary, based on the previous cue. Replies concerned with a cue that was used to assess criteria were given the code name "cue". This code name was followed by the name of the representation used (diagram, table, verbal text forecast, or map) and the name of the forecast page (A=front page, B=overview, C=hour-by-hour, and D=long-term). For example, the reply "I use the map on the overview page, especially if showers are forecast, to see how they move" is given the code name "cue map B". Other pages used were identified by the actual page name from Yr (e.g., Statistics). If the degree of certainty in the forecast was evaluated by building on the given uncertainty information or by other (own) methods, this was included in the code name. Cues other than those from Yr were also coded, for example direct referrals to affect and emotions, use of other sources of weather information or discussion of the forecast with other persons. Additionally, if the informants expressed details related to their usage of Yr and the reasons for this usage, this was given the code name "usage". Coded inductively, an example of such usage is prolonged use of the website over a period of time to find a suitable period in which to carry out a movable activity.

The replies were also assessed with respect to data quality, and vague and uncertain replies were omitted. The vague and uncertain sequences were replies in which it was difficult to understand what the informant meant, for example because of ambiguities or low sound quality in the digital recording or because the informants said that they used information in their decisions that they do not use privately. Four interviews (informants 6, 9, 17, and 18) were assessed as poor data due to scarce replies from the informants and were not included in the analysis (i.e., 17 useful participants).

Saturation is the point in data collection and analysis when information in new interviews provides no substantial change to the codes already developed (Guest *et al.*, 2006). Breaks between the interviews, where data were analysed and codes developed and adjusted, allowed the interviewer to notice when codes stabilised and thus to determine that saturation was reached. This iterative process is illustrated in Figure 2.

Second (Figure 2), the criteria and cues used in each activity for each informant were listed, and the information used to make the decisions was identified. To ease the counting of criteria and cues and to obtain a better display of the information used by the informants in the decision-making process, *decision trees* (Miles and Huberman, 1994) were built for each *case* (one activity for one informant constitutes one case). In total, 30 decision trees were constructed showing the criteria, cues, and decision alternatives (e.g., decide to paint or to postpone the job, Figure 3). It is possible to use either a single cue or to "drill down" into the forecasting information by going from one cue to the next. This process can be accomplished in a single visit or during several visits over time (prolonged usage) before making a final decision on whether to omit the activity (negative decision) or to undertake the activity (*positive decision*). Because hypothetical weather scenarios were discussed in the interviews, in certain cases, the informants elaborated on different paths (under alternative conditions) that would lead to a decision for that activity. Thus, the decision trees include several possible paths leading to a decision. In this study, the *minimum path* is considered the shortest possible path to a positive decision in counting the number of cues. Similarly, the *maximum path* is the longest path leading to a positive decision.

Real-world decisions are probably not as well-structured as presented in the decisions-trees. In real-world situations it is not solely conscious information use in the decision-processes, but a blend of intuition and analysis, where affect and emotions (e.g. based on prior experiences) also influence the decisions.

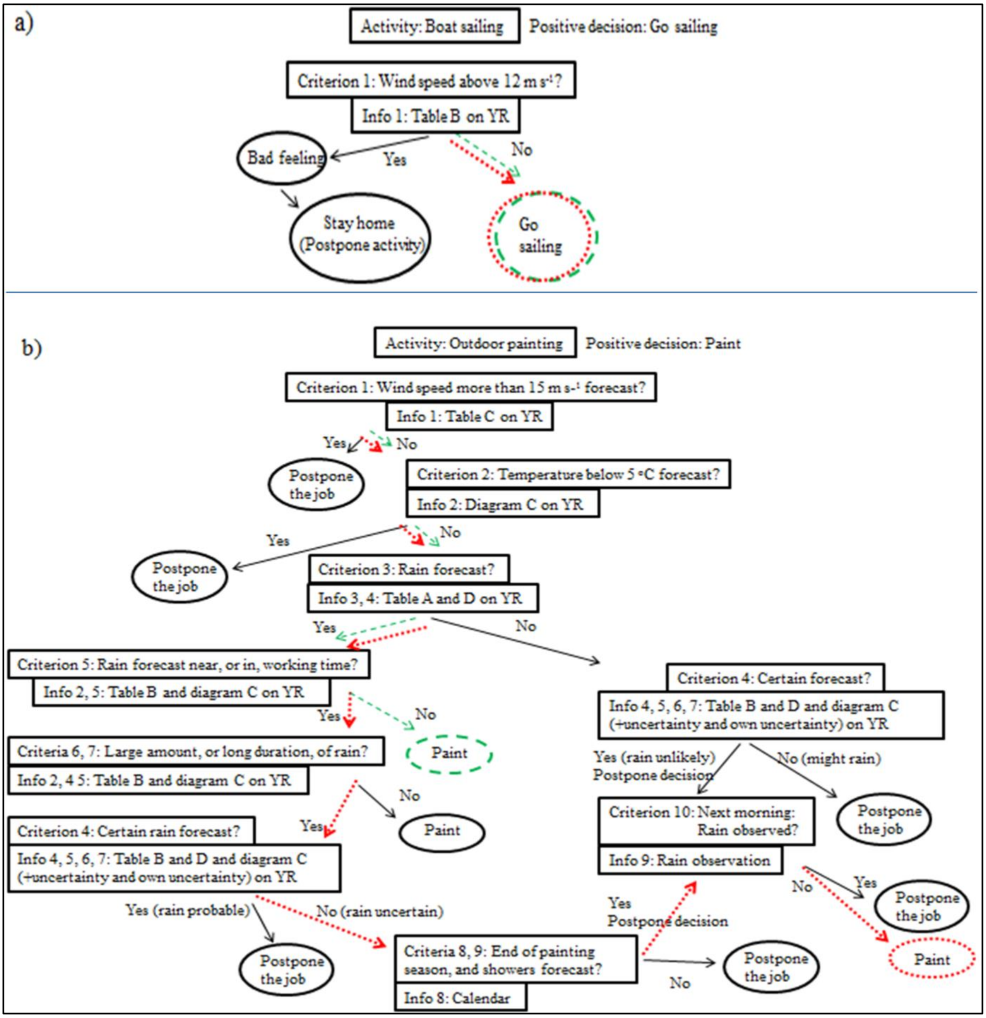

Figure 3: a) Decision-tree for the activity boat sailing, as explained by the teacher Anita. b) Decision-tree for the activity outdoor painting, as explained by the commercial painter Albert. Minimum path is shown with (green) dashed lines, maximum path shown with (red) dotted lines (colours online only).

Third (Figure 2), to answer the first research question, the number of criteria and cues were counted. Both the minimum and maximum numbers of criteria and cues that allowed for a positive decision were counted. For example, in Figure 3a, the minimum and maximum paths are equal, consisting of one criterion and one cue. In Figure 3b, the minimum path consists of four criteria and five cues, and the maximum path consists of ten criteria and nine cues. New cues included at a later point in time were included in the decision-trees and counted (e.g., see criterion 10 in Figure 3b). In contrast, a revisit to a previously checked (but updated) cue was not included. The count of criteria and cues is shown in Table 2.

Fourth (Figure 2), the decision-trees made it easier to determine what information the informants used as a starting point and when they included different representations and uncertainty-estimates in the decision-making process. This use of information is shown in Table 3. Thus, the decision-trees made it possible to discern how complexity in information was handled and thereby to answer the second research question.

Finally, three of the transcribed interviews (which contained six cases representing different activities and strategies) were analysed by another researcher in terms of the two variables to check for inter-coder reliability (Miles and Huberman, 1994). The number of agreements (similar codes) was divided by total number of agreements plus disagreements (all codes) to calculate reliability expressed in per cent (Miles and Huberman, 1994). This process yielded an inter-coder reliability of 74 % for the two variables, which is within the acceptable 70-90 % range (Miles and Huberman, 1994).

Based on the coding and counting and the decision-trees, Tables 2 and 3 indicate the amount and type of information involved in the decision-processes. The next two sections present the results of the analysis. Section 3 focuses on RQ1 and Section 4 focuses on RQ2.

3. Factors influencing the amount of information used

Table 2 shows the amount of information used by the informants in different decision-making situations. Sometimes decisions were made quickly using little information. The teacher Anita used one criterion for making her decision about sailing. Anita reported that she on occasions had experienced gale force winds when sailing, and that she found this unpleasant. For her, this marked decision options with gale force winds with negative feelings, as described by Peters (2006), and she wanted to avoid these situations. To make the decision, she searched a single cue, information on the wind speed on table B on Yr (Figure 3a).

Table 2: Identified guiding criteria, criteria and cues for the maximum and minimum decision paths for each activity identified in the analysis. Decreasing/increasing amount of information are indicated with arrows. An asterisk indicates the activity to be recently carried out by the informant. Class of activity (1: work-related, 2: leisure time-related) is also included. (The table is sorted according to the number of cues used in the maximum path.)

					Variables (max/min)			
Informant	**Activity**	**Action**	**Class**	**Guiding criteria**	**Criteria**	**Cues**	**Usage**	
20 Ulf	Summit tour	Fixed*	1	Others safety and well-being	7/7	10/10	Prolonged	Increasing
10 Siri	Hiking/skiing	Movable	2		5/5	10/10	Prolonged	information
3 Albert	Outdoor painting	Movable*	1	Economy	10/4	9/5	Prolonged	use
4 Nils	Mountain trip	Fixed*	1	Others safety and well-being	7/7	9/9	Prolonged	
15 Lise	Hiking	Fixed	1	Others safety and well-being	6/3	7/4	Prolonged	
5 Gunnar	Harvesting	Movable	1	Economy	6/5	7/5	Prolonged	
16 Marta	Outdoor concert	Fixed	1	Economy and others well-being	5/5	7/7	Prolonged	
14 Ruth	Hiking	Movable	2	Well-being	2/1	7/1		
1 Daniel	Haying	Movable	1		8/3	6/4	Prolonged	
13 Peder	Skiing, cross-county	Movable	2	Well-being	4/2	6/2		
7 Jon	Cycling	Fixed*	1	Safety and well-being	3/2	6/5	Prolonged	
1 Daniel	Hunting	Movable*	2	Well-being	7/1	5/2	Prolonged	
10 Siri	Cycling	Fixed*	1	Well-being	3/1	5/2	Single	
2 Arvid	Boat driving	Fixed*	1	Safety and well-being	3/2	5/2	Single	
21 Kennet	Skiing, downhill	Movable	2	Well-being	4/2	4/3	Prolonged	
20 Ulf	Car driving	Fixed*	2	Safety	3/1	4/1	Single	
1 Daniel	Holiday planning	Movable	2	Well-being	3/2	4/2	Prolonged	
12 Steffen	Fishing trip	Movable*	2	Well-being	3/3	3/3		
19 Geir	Hiking, school class	Movable	1	Others well-being	3/2	3/2	Prolonged	
5 Gunnar	Christmas tree cutting	Movable	1		3/2	3/2	Prolonged	
19 Geir	Lawn cutting	Movable	2		3/1	3/1		
10 Siri	Kayaking	Movable	2	Safety and well-being	2/2	3/3		
12 Steffen	Holiday travel	Movable*	2	Well-being	2/1	2/1		
19 Geir	Outdoor painting	Movable*	2		2/1	2/1	Prolonged	
21 Kennet	Holiday travel	Movable	2	Well-being	2/1	2/1		
8 Kjersti	Clothing	Fixed*	2	Well-being	2/1	1/1	Single	
16 Marta	Planting	Movable	2		1/1	1/1	Prolonged	
1 Daniel	Car driving	Fixed	2	Others safety	1/1	1/1	Single	Decreasing
3 Albert	Holiday booking	Movable	2	Well-being	1/1	1/1	Prolonged	information
11 Anita	Boat sailing	Movable	2	Safety and well-being	1/1	1/1	Prolonged	use

Informants often used more than one cue/criterion to make their decision. If the first cue/criterion did not allow for a decision, new cues/criteria were introduced until a decision was reached. These decisions were typically related to prolonged use of Yr (Table 2). If the activity was fixed in time, the informants had to make a final decision (carry out or cancel) based on a deadline prior to the activity. These users continued to watch the forecast updates for a period of time to be prepared for this decision. The informants checked forecast updates also if the activity was movable. In this case, the activity was postponed until they found a day/period during which their criteria were met. An example where more information was used is shown in Figure 3b, in which the painter Albert addressed the activity of outdoor painting. Albert had several criteria and cues that he checked before he could make a positive decision. He did not refer directly to affect and emotions, and there are just a handful of such reports by the informants. A likely reason for the lack of replies concerning affect and emotions is the focus on conscious search and use of the provided forecast information. However, it is likely that affect and emotions do influence decisions, one example being Anita (above). The interviewees do report on their experiences related to weather, and these experiences are influenced by affect and emotions. Thus, affect and emotions are indirectly included in this study.

There are two key findings related to factors influencing information use (RQ1): *the amount of information used depends on* a) the importance of the activity, and b) the weather conditions, the uncertainty, and the impact. These are presented next.

3.1 The importance of the activity influence the amount of information used

Informants from all three areas across the entire range of educational backgrounds, young and old, and male and female used both small and large amounts of information (Table 2). Factor(s) other than demography must therefore explain the amount of information used.

Certain activities discussed in the interviews were recently planned by some of the informants. This might have influenced them to remember additional details of the criteria and cues. However, as both small and large amounts of information were used by these informants (Table 2), recent experience with similar activities does not appear as a likely explanation for the amount of information used.

The importance of the activity appears to be a more likely explanation. Eight informants used different amounts of information for various activities (Table 2). These informants varied the depth of their analysis, as suggested in earlier research (Betsch and Glöckner, 2010). The tour guide Ulf said that he spent more time on Yr when planning for a hiking tour with paying participants than for other activities. This suggests that the amount of information used and time spent on Yr depends heavily on the envisaged activity. A possible explanation for this behavior is the desire to be efficient and at the same time use sufficient time and effort to make a comfortable decision depending on the activity. The results in Table 2 indicate that when the activity was work-related, and economy and safety were the guiding criteria, the informants tended to use more information. Siri said that she used more time and information when planning for an activity in which weather was crucial. Earlier research also shows that substantial cognitive effort is invested if the problem is important to the decision-maker (Jungermann, 2004). The teacher Geir used less information to make a decision on outdoor painting in his leisure time than the commercial painter Albert did in his work-time. The activity was probably not as important for the teacher, who was painting his own house, as it was for the painter, who was economically responsible for painting his customers' houses.

Interestingly, an important decision does not need to be work-related or related to an emphasis on economy or safety. Certain informants, in discussing leisure time activities such as hunting and skiing, expressed the view that well-being during these activities was important to them. As with work-related decisions, their information use in these situations tended to be high (Table 2), indicating that for a large amount of information to be used, it is sufficient for the decision-maker to judge the activity as being important.

3.2 The weather conditions, the uncertainty, and the impact are all important

A small amount of information was used for selected activities that were important to the decision-maker. For example economy was a guiding criterion in the commercial activity of Christmas tree cutting (Table 2). This observation indicates that substantial cognitive effort is not necessarily invested, though the decision is important for the decision-maker. Thus it appears that the amount of information used in complex real-life decision-making depends on factors in addition to the importance of the decision.

Certain informants used different amounts of information for the same activity depending on the weather conditions. A hunting activity is the clearest example of this change (Table 2). The farmer Daniel used less information when dry weather was forecast and more information if (uncertain) rain was forecast. Certain informants said they only had a prolonged use of forecasts if the weather conditions were uncertain or close to their criteria. Siri checked the forecast daily if it was uncertain and more infrequently if the forecast appeared with a higher degree of certainty and the weather conditions were favourable for the activity. Thus the results suggest that the amount of information used is not only dependent on the coherence of information (Betsch and Glöckner, 2010) and the activity but also depends on the suitability of the weather conditions for the activity. Certain activities (e.g., Christmas tree cutting) will proceed throughout many types of weather conditions and only a few weather parameters are of interest. The weather forecast only becomes crucial when the weather conditions are marginal.

The decision process appears to be related to the potential weather impact on the activity. When snow was forecast the tour guide Nils said that he could be obliged to cancel a hiking tour because the risk of avalanches. The teacher Jon said he had to use his winter bike instead of his summer bike if snow was forecast; nevertheless, although weather might slow down his speed and affect how he dressed and the equipment he used, he could still carry out the activity (unless the weather conditions were extreme). Presumably, this latter situation also relates to personal preferences or past experiences affecting their activity-related emotions (Slovic *et al*., 2004).

The results indicate that substantial cognitive effort is invested not only because the decision and activity is important for the decision-maker (Jungermann, 2004) but also because of the suitability of the weather conditions for the envisaged activity.

4. Handling complexity in information

There are three key findings related to *handling of complexity in information* (RQ2): a) a suitable starting point is chosen, b) weather dynamics are left out in quick decisions using little information, and c) forecast uncertainty is not evaluated in quick decisions.

4.1 A suitable starting point is chosen

Comparing situations involving use of little with larger amount of information, no difference is found for the informant's choice of starting point in searching for cues (Table 3). The degree of certainty was not evaluated, and maps and verbal text forecasts were not used as a starting point. Information from Yr is more often used as a point of departure than other types of information.

Table 3: Identified use of information (starting point, dynamics and uncertainty) for the maximum and minimum decision paths for each activity identified in the analysis. The additional information used in the maximum path is indicated with bold font. Decreasing/increasing amount of information are indicated with arrows. (The table is sorted according to the number of cues from Table 2.) (A=front page [Figure S1], B=overview [Figure S2], C=hour-by-hour [Figure 1], and D=long-term [Figure S3])

			Information used (bold font=additional in max path)			
Informant	Activity		Starting point	Dynamics	Uncertainty	
20 Ulf	Summit tour	Increasing	Table B		Table C, D	Own uncertainty
10 Siri	Hiking/skiing	information	Table D	Verbal text D, Map A	Table D, Verbal text D	Own uncertainty
3 Albert	Outdoor painting	use	Table C		**Table B, D, Diagram C**	**Own uncertainty**
4 Nils	Mountain trip		SeNorge.no	Map A		Own uncertainty
15 Lise	Hiking		Table B	Map A, Verbal text D	**Table D, Verbal text D**	**Own uncertainty**
5 Gunnar	Harvesting		Own observation	**Map A**		**Own uncertainty**
16 Marta	Outdoor concert		Table D	Verbal text D	Table D	**Own uncertainty**
14 Ruth	Hiking		Table B		**Table B, Table C**	**Own uncertainty**
1 Daniel	Haying		Table D	**Verbal text B**	Verbal text B	Own uncertainty
13 Peder	Skiing, cross-county		Diagram C		**Table B**	**Own uncertainty**
7 Jon	Cycling		Diagram C	Map A	Diagram C, D	**Own uncertainty**
1 Daniel	Hunting		Table D	**Map B**	**Diagram C**	**Own uncertainty**
10 Siri	Cycling		Table B		Table B, **Diagram C**	
2 Arvid	Boat driving		Table B	**Map B**		**Own uncertainty**
21 Kennet	Skiing, downhill		Table D	**Verbal text B**		**Own uncertainty**
20 Ulf	Car driving		Table B	**Map A**		**Own uncertainty**
1 Daniel	Holiday planning		Table (Statistics)	**Map B**		**Own uncertainty**
12 Steffen	Fishing trip		Table D			
19 Geir	Hiking, school class		Table D	**Verbal text B**		**Own uncertainty**
5 Gunnar	Christmas tree cutting		Own observation			
19 Geir	Lawn cutting		Table C	**Map (Weather Radar)**		**Own uncertainty**
10 Siri	Kayaking		Table B	Verbal text B		Own uncertainty
12 Steffen	Holiday travel		Table D			
19 Geir	Outdoor painting		Table D			**Own uncertainty**
21 Kennet	Holiday travel		Table D			
8 Kjersti	Clothing		Table B			
16 Marta	Planting		Table D			
1 Daniel	Car driving	Decreasing	Diagram C			
3 Albert	Holiday booking	information	Table D			
11 Anita	Boat sailing	use	Table B			

All informants were familiar with Yr, and it is likely that they knew from experience where to start looking for the information they needed. Choosing a suitable initial cue to assess a criterion is obviously time-efficient when addressing complex information and is particularly important for quick decisions. Identifying and using a small amount of information is one method for reducing the complexity of information and is used in quick decisions (Gigerenzer and Goldstein, 1996; Betsch and Glöckner, 2010). If the choice of starting point is made based on the experience, it is likely to be a method of handling the complexity in information on Yr, regardless of total amount of information used.

Another possible explanation for the choice of starting point is that the informants, learning from experience (Peters, 2006) go directly to a personally preferred representation such as an overview forecast, a table, or a map. Ruth and Lise preferred to use a table rather than a diagram. The choice of starting point is also likely to depend on the activity; the same informant can prefer different starting points for different activities. The farmer Daniel said that he begins by looking at the long-term forecast table when planning for haying, but uses the hour-by-hour diagram when planning for car driving. Different representations have different advantages (modal affordances) (Kress, 2010), and the reason for choosing a diagram as a starting point rather than a table could be that the diagram offers the advantage of communicating development over time. Daniel said that he uses the temperature graph in the diagram rather than numbers in a table to determine whether the temperature will be below the freezing point when he makes a decision about car driving.

4.2 Weather dynamics are left out in quick decisions

Although they were not used as starting point, maps/animations, verbal text forecasts, or both were used later in the decision process (Table 3). The results are consistent with the hypothesis that in situations in which informants use maps/animations and verbal text forecasts, they are more likely to make elaborate decisions. The dynamics in the movement of precipitation is a likely reason for using the map/animation and for reading the verbal text forecast (Sivle *et al.*, 2014). When not evaluating dynamics, weather is viewed as a static phenomenon, which in turn might ease the mental workload in the decision-making process. Disregarding the weather dynamics might be a way to reduce complexity or options in information when making quick decisions. The student Ruth said that she found tables more convenient than maps when planning for her hike because they appeared to be more specific and accurate by providing a forecast solely for her location.

The map and verbal text can hold information on causal relationships (e.g., between low air-pressure and rain), which make the information more intricate. Another hypothesis might therefore be that the map and/or verbal text forecast are found to be more demanding in interpretation by the informants than the tables and diagrams and are omitted for this reason. Kjersti found the map difficult to understand and did not use it. However, when making an important decision this information appears to be viewed as valuable and worth the struggle and is included in the process. The farmer Daniel evaluates verbal text forecasts when planning for haying, but not when planning for everyday car driving (Table 3). This observation indicates that the multiplicity of representations on weather websites is an advantage. Certain representations (e.g., tables and diagrams) give easy access to static information when making quick decisions; representations that provide more dynamic information and demand more interpretative work are included when the decision is important for the decision-maker.

4.3 Forecast uncertainty is not evaluated in quick decisions

None of the informants evaluated the degree of certainty in the forecast as a starting point when searching for a cue. Certain informants used the uncertainty information on Yr and/or made their own uncertainty evaluation, e.g., that the forecast is more uncertain for one week ahead than it is for tomorrow, later in the decision-making process (Table 3). Elaborate decisions were often made in these situations. Evaluating uncertainty requires the consideration of several hypothetical outcomes, which again requires heavy mental processing (Joslyn *et al.*, 2009b). Leaving out this evaluation can therefore ease mental processing and reduce complex information to a simple outcome (Janis and Mann, 1977; Joslyn *et al.*, 2009b).

According to Joslyn *et al.* (2009b) many persons unconsciously leave out uncertainty information. Table 3 indicates that uncertainty information is consciously left out when weather conditions are favourable or far from the personally set criteria. Uncertainty is included when weather conditions are close to the criteria. When making a decision about boat driving, Arvid evaluates the uncertainty if the forecast wind speed is force 6 or stronger but not when the wind speed is lower.

Another possible hypothesis is that people know that the weather forecasts are uncertain (Morss *et al.*, 2008) and unconsciously evaluate whether they can trust the forecast. This situation is similar to using intuition (Evans and Stanovich, 2013). When the forecast is far from their criteria, they rely on past experiences and recognition of similar situations and unconsciously evaluate it as sufficiently certain to rule out the chance for change in weather that will alter the decision. In such case, the user do not leave out information because it is mentally challenging but because there is no need for a further (conscious) evaluation, intuition take care of many routine decisions (Betsch and Glöckner, 2010).

5. General discussion

5.1 Summary: Information use in weather related decision-processes

The informants wanted to perform certain activities being more or less weather-dependent. They selected their preferred starting point, possibly based on their experience combined with personal preferences. If the forecast weather conditions were suitable for the activity or the activity was not judged important, they made a quick decision using little information. However, if the suitability of the weather conditions was less obvious or the activity was judged important (and its success weather dependent), a more deliberate decision-process with prolonged forecast usage was implemented. Based on the results, a possible hypothesis is that activity is more important than occupation, education, age, and residence with respect to the amount of forecast information used in weather-related decision-processes.

Reducing the amount of information (number of criteria and cues) to reduce complexity in information when making a quick decision was observed both in this study and in prior works (Gigerenzer and Goldstein, 1996; Betsch and Glöckner, 2010). A new finding in this study is that the choice of starting point might be interpreted as a method for handling complexity in information. Leaving out evaluations of dynamics and forecast uncertainty were two other such methods.

Leaving out such information can ease the mental processes involved in decision-making because fewer hypothetical outcomes must be evaluated. Another possible explanation is that the information used to describe the dynamics and uncertainty is more demanding and time-consuming to interpret than other information and is left out for that reason. The inclusion of dynamics and uncertainty also appears to be related to the suitability of the weather conditions of the day. If the weather conditions are obviously favourable or far from the criteria, the results suggest that there is less need to include this information.

Affect and emotions, e.g. based on prior experiences, and also intuition, is likely to play a part of the decision-processes. This means that real-world decision-processes are more extensive than and not as structured as described in this study.

5.2 Implications for communication of forecast information

5.2.1 Forecast providers should take into account the needs of the forecast users

According to the classical view on rationality, the use of economic cost-loss models is how decision-making should be performed (Shafir *et al*., 2000). In economic models the pros and cons of a large number of alternatives are compared in a throughout analysis. This means that in cases in which the informants in this study used a large amount of information, they acted close to this classical view of rationality. This study presents a description of information use in familiar everyday decision-making situations. In certain cases, informants used very little information and hence their actions differed from the classical view on rationality. When less information is required complexity is reduced (Betsch and Glöckner, 2010), which means that less cognitive work must be performed. Reducing complexity in information can save the decision-maker from confusion, delays, and wasted resources (Janis and Mann, 1977). Even if using little information and making quick decisions, the users state reasons for their choices and thus appear rational in the sense of bounded rationality, choosing a reasoned and apparently suitable strategy in each situation. This finding is in accordance with theories suggesting that individuals employ simple rules allowing them to reduce cognitive effort (Betsch & Glöckner, 2010) in situations with restricted time and resources. In this study, the informants Siri and Geir said that the amount of time and information they used depended on the importance of the activity, and they only spent a long time on Yr if the activity was important. Others did not bother using the map (Lise) or reading the verbal text forecast (Marta) unless the activity was sufficiently important and if they had time for it. It was not rational for them to spend much time and effort on the decision; it was more rational to make a quick decision.

A short visit is not necessarily related to quick decision processes. Instead, the short visit might be a component of prolonged use. The farmer Daniel typically spent 15 minutes on Yr once a day when planning for haying. Later the same day he spent a relatively short time checking forecast updates several times. Some of the long visits to Yr might also be because information is found contradictory or difficult to understand (Sivle *et al*., 2014), and hence more time is needed before reaching a decision. Five informants occasionally visited Yr only because they were interested in knowing what the weather would be and not because they were planning to make a decision. A similar result was found by Lazo *et al*. (2009). These visits might make the users more experienced and spending less time researching the weather in future decision-making.

Although lacking knowledge might lead to difficulties in interpreting weather forecast information (Sivle *et al*., 2014), diverging forecast usage is not necessarily related to a lack of knowledge or rationality. Many informants used different information amounts in different decision situations, suggesting that making quick decisions and not assessing forecast uncertainty is not an indication of lacking user rationality. There is mixed evidence whether quick or elaborate decisions are better or worse, and it might differ from situation to situation (Jain *et al*., 2013). Dilling and Lemos (2011) argue that usability is a function of how information is produced and provided and how it is needed in different situations. Successful communication typically involves interaction and iteration between (forecast) producers and users, and the end users should receive the information they need in a form that they can use (Fischhoff, 2013). The results from this study can aid science communication to value the perspective in which, for the information to be useful for a range of decision-making situations, the science communicator take into account the needs of the general public.

5.2.2 Information communicated in forecasts should enable different decision-processes

Many studies in weather-related decision-making are performed with limited and isolated forecast information (Section 1). In this study, informants instead used and combined several pieces of forecast information. Our results show that weather-related decision-making can consists of more than a cost-loss strategy, as indicated by Morss *et al*. (2010). At times, quick decisions using little information were made instead of elaborate decisions. In these situations forecast uncertainty was typically not considered. Arvid consciously left out an evaluation of forecast uncertainty when he was able to make a relatively quick decision about boat driving because forecast wind speed was lower than a certain threshold. Above this threshold he included uncertainty estimates and made a more elaborate analysis and decision (closer to a cost-loss strategy).

The fact that certain informants used notably little information and only one or two preferred representations while others used various representations in their decision-making, underscores the importance of using multiple representations in the forecasts (Sivle *et al*., 2014). If there are several representations to choose from (common between the top five weather sites), it is likely easier to adapt the type and amount of information to the actual decision-making situation. This requires that the different types of information communicate well enough to be used in decision-making situations of various complexities. For instance, provided with both deterministic and probabilistic forecast information the users can choose which information to use.

6. Conclusions

In this in-depth study the analysis reveal that the amount of information used by 17 informants in weather-related decisions depends on the importance of the activity and on the suitability of the weather conditions of the day. These factors were found to be more important to them than occupation, education, age, and residence. In quick decision-processes the complexity in the information must be reduced to make a decision. In addition to choosing a preferred starting point, the informants

accomplished this by leaving out evaluations of weather dynamics and forecast uncertainty. However, the results suggest it is important to retain this information in weather reports as it was used in elaborate decision-processes. The informants used different information according to their own judgments of the needs of the situations, implying that forecast providers should take into account the range of needs of the forecast users. Based on these results, the information communicated in the forecasts should enable the use of different amounts of information such that it allows informed decision-making. A multiplicity of representations could therefore be favourable for the employment of different decision-making processes.
However, some informants used very little information and made quick decision-processes. This may indicate that the existing graphics appear overwhelming for certain users. Therefore, how to simplify and deliver bespoke weather information would be an interesting next study, not least in light of the increased use of weather applications (apps) on smartphones (e.g., Rutty and Andrey, 2014).

To enable an in-depth analysis, this study includes a relatively small number of interviews, and only a small number of user groups are included. As the informants related to a real weather report, we believe the findings hold high validity. However, information from other informants, and decision-making in other contexts, might give additional findings and provide nuances to our findings. In addition, this study does not provide quantitative information on how often different decision-making patterns are used. Complementary studies are therefore needed in order to get a more comprehensive picture of lay-people's decision-making processes when using online weather information for deciding on everyday activities.

The informants in this study sometimes left out evaluations of forecast uncertainty; thus, it appears that additional research is also required to understand how forecast providers should communicate uncertainty information to users. An interesting research question is what happens if forecast providers in some situations solely provide probabilistic weather information. This might be tempting since there are experimental evidences that providing laypeople with uncertainty information can be beneficial for their decision-making (e.g., Roulston *et al*., 2006), and it is thinkable that probabilistic information can reduce forecast providers` risk of legal action against them compared to deterministic information. Will end users adapt and make more informed quick decisions, and hence benefit from the information? Will they instead be forced to use elaborate strategies in situations where they previously used quick strategies, and thus perhaps make more informed decisions but spend more time? Will some persons be incapable of making a decision at all and suffer from probabilistic information being provided? Existing studies give no answers to these questions. It is necessary to find forms of presentation for uncertainty information that allow for both quick and more elaborate decision-processes.

New research should explore how laypeople that make similar types of quick and elaborate decisions would use a forecasting parameter that is conveyed deterministically and probabilistically. It is necessary to carry out this research in such a way that task and restrictions are adapted to real-life quick decision-making processes. At minimum, normal user situations should be mimicked to allow both quick and more elaborate processes. For example, the decision-making should be performed with and without time restrictions and in the contexts of different activities and weather conditions. Future research should also consider the influence on intuition, affect, and emotions on the decision-processes.

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Supporting information

Figures S1, S2, and S3 show more details related to the front page on Yr, the overview forecast, and the long-term forecast used in this study, and is available online as supporting information (Note: included in this Phd-thesis after the references).

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Supporting information (Paper 2)

The interviews were centred on printouts of one particular forecast from Yr consisting of four printed pages with different information/time-scales. Whereas the hour-by-hour page is shown in Figure 1, Figures S1, S2, and S3 show segments of forecasts and uncertainty information from the three other pages of the web-service www.Yr.no (Yr) used in the interviews (The forecasts are in Norwegian language since this are the actual forecasts used in the interviews).

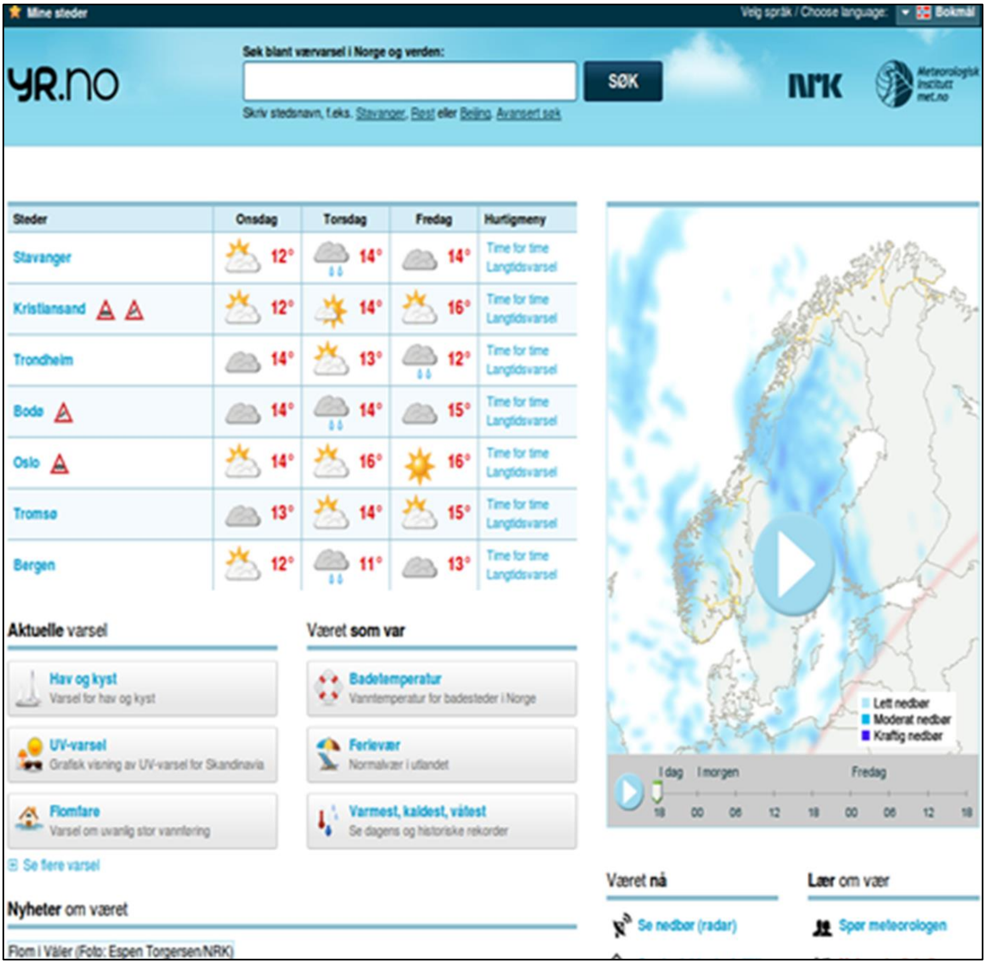

Figure S1: Segment of the front page of the web-service www.Yr.no (Yr). Forecast is in Norwegian language since this is the actual forecast used in the interviews.

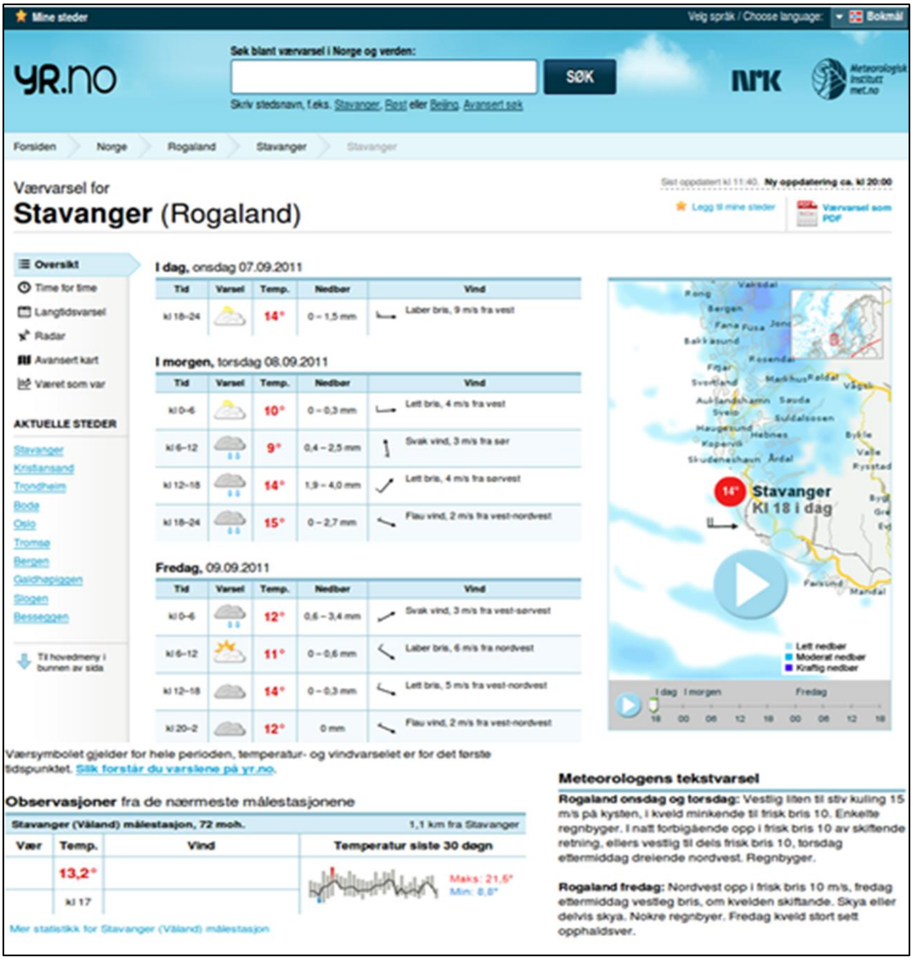

Figure S2: Segment of the overview forecast page of the web-service www.Yr.no (Yr). Forecast is in Norwegian language since this is the actual forecast used in the interviews.

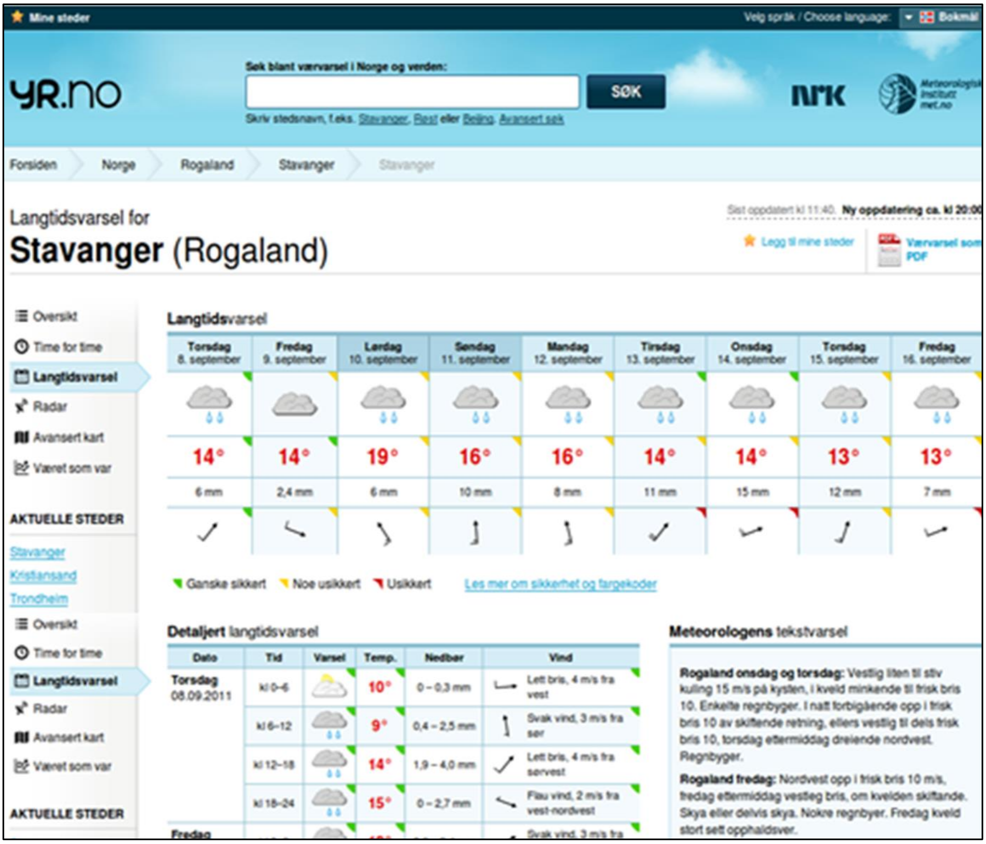

Figure S3: Segment of the long-term forecast page of the web-service www.Yr.no (Yr). Forecast is in Norwegian language since this is the actual forecast used in the interviews.