Chapter 1
Introduction

Humans have, probably since the rise of our species, tried to understand weather and the driving forces behind this most visible power of nature. The appearance of skies inspired poets and philosophers of ancient times (Aristotle, 384 B.C. – 322 B.C.; Theophrastus, 373-286 B.C.; see for instance Taub, 2003). However, weather also threatened societies, exposing them to floods, draughts, thunderstorms, and crop failure. Human societies have learned to live with the weather, its seasonal changes and interannual variability. Understanding weather has been necessary for the survival of human civilizations and culture.

In today's complex societies that are globally interconnected on several levels, including media technology as a resource in infrastructure, human communication and advanced technical solutions, mankind meets challenges in which weather manifests its immense power over human existence and wellbeing, to the extent perhaps never met before in history. The weather insinuates itself into almost all dimensions of human lives and activities.

The causes of this are several. The first is that weather impacts many systems that support human activities, among which food production, energy production and consumption, and transportation can be mentioned. Second, human impacts on the physical environment, both redrawing the map of the natural environment and creating a new built environment, radically increases human dependence on the efficiency of these systems and our vulnerability to disturbances in performance of these systems. Moreover, living in the anthropocene era (e.g., Wikipedia, "Anthropocene"), which suggests that the effects of man on nature are transferred to geological time-scales, humans are faced with the challenge of adjusting to new environmental conditions, such as climate change, which may threaten systems supporting human activities.

As a consequence of this close dependency on weather, the weather-expert community strives to improve weather information. In this compilation thesis, media technology is explored as a resource for meeting the demands for improved weather information. All human activities are modified by the evolution of complex societies and large cities as well as by access to new media technology. I will address some aspects of human dependence on weather and particularly explore a concept that may assist us towards some of the goals of sustainable development of the global society.

The title of this thesis refers to exploration of new opportunities offered by interactive media technologies and one of the favorite subjects of conversation, weather. With the advent of interactive media technologies, we may ask how one of the most commonly shared topics of conversation may benefit from being brought online. Can interactive media technologies potentially contribute to improving weather information? "share weather" is hereby introduced as a concept based on the interactive Web (often denoted as "Web 2.0"), whereas the content is limited to the domain of weather information. In this compilation thesis I explore how "Web 2.0" might improve weather information based on eight related papers and theory on participation in online networks, including design and evaluation of the "share weather" concept.

Entering a new area of implications of Web 2.0, here focused on weather information, the papers are based on empirical research, while the thesis belongs within the multidisciplinary research field of media technology. The compilation thesis, accordingly, touches upon several other research areas including behavioral science and meteorological applications. Core theories are situated in media technology research and the compilation thesis aims at contributing to increased knowledge regarding individuals' participation in online networks. In this summary of the compilation thesis, emphasis is placed on motivation to participate in online networks, while the papers explore several aspects, such as feasible platforms for participation in "share weather" activities, quality of content supplied by individuals, and some societal implications.

It is relevant to mention that my background within meteorology, including experience as a practitioner, was a great source of inspiration to the topic. My participation in the research community of media technology created a fusion of experiences leading to new ideas and research questions on the concept of "share weather", and eventually resulting in this compilation thesis.

1.1 Why weather is relevant to media technology research and society

In the post-modern world, weather has an even greater impact on our lives than most people might consider. Besides inspiring poets and artists with colorful panoramic views and affecting our moods, weather impacts society to a considerable extent in many different and multi-facetted ways. It might, therefore, come as a surprise that current weather information services are based on methods, needs, and technical premises that arose in the mid-20th century. During the same time period information technologies have progressed, and the information market has changed since the first institutions of the industrial weather information economy (cf. Benkler, 2006) commenced a global exchange of weather data in the 1950s. The global weather observation network today still consists of over 10,000 weather stations administered by the World Meteorological Organization (WMO), responsible for the global exchange of meteorological data (WMO, 2009a).

Because weather often affects many decisions in our daily lives, weather information services are purchased, and, with new accessible mobile technologies, are becoming even more popular (Techcrunch, 2011, September 12). Every reader will be able to relate weather to planning of activities in daily life, such as wasting time in traffic delays or enjoying a sunny picnic.

Perhaps more important, weather information is becoming increasingly critical from a societal perspective. The need to create adequate weather forecasts is stronger than ever; humans are increasingly dependent on weather due to climate change (Milly et al., 2002) and increased vulnerability of complex societies (Changnon et al., 2000; Parry et al., 2007). Infrastructure and fundamental sectors of the modern society – agriculture, construction, energy, transportation, outdoor recreation – experience magnitudes of weather impacts of sometimes immense proportions and major concern (Paper I), weather-sensitive industries accounting for 10% of total production in some western countries (NRC, 2003), about $2.7 trillion only in the US (Weiss, 2002). Weather impacts as much as 25% of all production (Paper I). Severe weather events accentuate this dependence, sometimes dramatically (Paper I), at times reaching proportions of natural disasters, for instance the cost corresponding to $130 billion damage from the hurricane Katrina (see NOAA, 2009) and €13 billion annual costs related to extreme weather in Europe (European Environmental Agency, 2012). Already in 12th century France, the *courretiers de change* were concerned with the debts of agricultural communities (Wikipedia, "Stock market"), an event sometimes regarded as the appearance of the first financial markets, further illustrating how weather and weather-sensitive industries shaped our modern society. It is thus evident that the large impacts of weather on human activities and the built and natural environment create a great need for adequate weather information services, also confirmed by history (see Paper I). Development of media technologies was a determinant in their realization, while the driving force to "protect lives and property" is a highly salient incentive still today.

The first weather services commenced 150 years ago as small networks of telegraphic stations that exchanged weather information in order to provide storm warnings (Paper I). However, interest in weather is also the subject of *storytelling* (Benkler, 2006; Paper I) on the personal level, not only arousing human curiosity, but also representing an early media technology, because, if "the fundamental purpose of communication technologies from their ancient inception has been to allow people to exchange messages without being co-present" (Baym, 2010, p.2), "human speech" may be regarded a media technology. Several centuries prior to the inventions of technologies that could address the shortcomings of *storytelling*, such as synchronicity, weather was the subject of famous seamen and explorers (e.g., Robert FitzRoy, the captain on HMS Beagle during Charles Darwin's voyage; see Burton, 1986, or Cerveny, 2005), and philosophers of ancient times (e.g., Aristotle's *Meteorologica* and Theophrastus' *Book of Signs*), who also developed their own theories. Synchronicity was identified as an important constraint, and the idea of "seeing the weather together" (from Greek "synoptikos") – instantaneously and from several places – was born. These ideas left some imprints on terminology used in modern meteorology: the world wide observation network consisting of over 10,000 standardized weather observation stations that constitute a cornerstone of the international meteorological data exchange (WMO, 2009a) is named the *synoptic station network*, from ancient Greek "synoptikos", in translation: "to see together". The word "synoptic" might be striking, drawing a parallel from the ideas of ancient philosophers to Web 2.0. As Paper I suggests, the expert paradigm, meaning that, "no one knows everything, but everyone knows something" (Levy, 1997), can be rephrased into "no one (including professional meteorologists and meteorological expert systems) can observe, or see, everything, but everyone can observe something", for instance a piece of the sky. Today's interactive media technologies enable "seeing the weather together", a realization of an ancient dream of "synoptikos".

Storytelling is particularly interesting from the perspective of this compilation thesis due to associations with social interaction. While the current weather industry is shaped by the industrial information economy and governmental services in accordance with responsibilities of governments to warn the public of coming storms, floods and droughts (Paper I), this thesis explores new interactive media, including their components of socializing, i.e. digital storytelling, as a new way of transmitting weather information. In the light of the growing role of social media in crisis response, for instance during hurricanes (e.g., Katrina in 2006 and Sandy in 2012), flooding (e.g., Russia in 2011), earthquakes and tsunamis (e.g., the 2011 earthquake of the east coast of Tōhoku, Japan, and the 2004 Indian Ocean earthquake accompanied by serious tsunamis, the 2010 Haiti earthquake, and the 2008 Wenchuan earthquake in Sichuan, China), all of which are documented in literature on social media use, it can be assumed that the role of storytelling through social media, in which a large number of individuals may share their "weather stories" within a large community, will become considerable in the future; the rise of interactive social media of the 21st century might reshape the market for weather services and early-warning systems (Paper I).

Currently, about half of the Earth's population is connected through Web 2.0, corresponding to several billions of nodes (10^9) (ITU, 2013; ITU, "Internet users";

Internet World Stats, 2012), including hundreds of millions of smartphones (10^8) (ITU, 2013), and the rapid growth of mobile user prescriptions is predicted to soon reach the number of residents on Earth (e.g., BBC, 2012, October 12). Preconditions for sharing weather information between individuals exist also on the weather market, transforming it into an information economy market (Benkler, 2006); low-price weather stations and many connected individuals challenge the role of former gatekeepers, and barriers of the past (e.g., large initial investments) may be overridden.

The questions that arise are: How many will contribute, and how many will be motivated to share weather information? Can people observe weather accurately, and, if so, what might sharing weather information practices look like? The large number of connected points that can potentially exchange weather information might suggest the announcement of a new paradigm shift of "share weather" practices. This possibility is investigated using the work presented in the thesis. I introduce the concept of "share weather", and the compilation thesis aims at investigating the potential role of interactive media in sharing and improving weather data. We know that the rise of Web 2.0 is revolutionizing the opportunities to communicate; it also creates new practices that are quickly spread and embraced. Large volumes of information are co-located; individuals positioned at defined points in cyber-space may transfer information, via different Web 2.0 applications, to many others moving across physical space. Drawing from examples on emergency-like situations, for instance over twenty million Tweets between October 27 and November 1, 2012, associated with Hurricane Sandy (Techcrunch, 2012, November 2), it is evident that Web 2.0 has the potential of making significant contributions to the collection and communication of individuals' local observations of weather or consequences of weather.

When people collaborate online, the products of their work are usually referred to as *user-generated content*, or *UGC*, (e.g., Jenkins, 2006). Within the domain of weather and environmental information, the content generated by users (UGC) may be denoted *user-generated observations*, or *UGO*. User-generated weather observations (UGO), of course, represent a great challenge. Among many issues that need to be resolved, some are associated with the personal drive to participate in organized actions consisting of performance and documentation of user-generated weather observations. The aspect of understanding different individuals' personal incentives, which includes providing convenient tools for collection of user-generated weather observations, is particularly the focus in the summary of the compilation thesis. The research presented here thus belongs within the media technology research area of participation, collaboration, and co-creation in networks.

The question is why ordinary people would be interested in participating in observing weather in a systematic way and sharing that information with others?

The reasons might be found in both the present and the past. The task of examining people's interest in sharing weather information evidently requires a user-centered approach, because we must examine how people relate to weather on a personal level. Although some fundamental components of human societies (energy supply, food production, transportation of resources, people and commodities) strongly depend on weather, the indirect impacts of weather on individuals may not be as evident and direct in personal everyday life experiences. It can be assumed that interest in weather varies depending on individual preferences, geography, life-styles, and other individual properties. Some of these issues are addressed in the papers (Paper II, Paper IV and Paper VI). In addition, other sources of motivation such as survival (Paper I) and environmental concern might be suggested. While in the papers I briefly point out some difficulties related to engaging the public in difficult environmental issues, the summary of the compilation thesis develops this reasoning toward understanding potential motivations to share weather.

Many studies show that individuals are usually not concerned with problems that do not directly impact their everyday lives. Climate change may represent a perfect example. Despite the fact that nearly 90% of natural hazards are linked to climate extremes (WMO, 2009b) and climate change directly influences human chances for survival and protecting property in terms of preconditions for, let's say, agricultural production, most individuals would be concerned once an actual event occurs but not become involved actively in solving the initial problem. Most people admit the existence of the problem of climate change, and, occasionally as they are reminded of its seriousness, they may express serious concerns (e.g., Lowe et al., 2006). Most often, the great majority, however, do not take any action to solve environmental problems, this impasse often being attributed the social dilemma of a "tragedy of the commons" (Hardin, 1968). In striving to solve environmental problems related to climate change, the core challenge is *motivating* people to participate more actively. However, research and practice (Segerberg and Bennett, 2011) emphasize that, occasionally, large audiences can be engaged in participating in demonstrations and similar activities that are not concrete actions of solving the problem, but sometimes powerful enough to change environmental politics and influence decision-makers.

What might seem more encouraging from the point of view of the compilation thesis is that weather may be directly connected to individuals' everyday lives through the systems supporting human activities. The effects of weather on transportation are something that most people might consider themselves directly affected by. Adverse weather causes traffic flow decline and increased risk of hazards and, occasionally, life-threatening conditions (Paper II, Andreescu and Frost, 1998; Edwards, 1999; Eisenberg, 2004; Kilpeläinen and Summala, 2006; Norrman et al., 2000; Pisano and Goodwin, 2004). Every day, several hundred million people travel somewhere on the roads of Europe, while as many go on foot or by bicycle (UNECE, 2012; European Commission, 2012). Professional farmers, often threatened by loss of property due to adverse weather conditions (Paper I), constitute a small proportion in the industrialized countries, but one-third of the world's population still obtains its livelihood from agriculture (FAO, 2013). Due to the strong influence of weather on transportation and farming, sharing weather within these contexts is suitable for research. This compilation thesis, first of all, uses empirical results acquired within a context of transportation and severe weather conditions. From these results, I will further generalize on the acquired knowledge and results, in order to try to answer some questions regarding properties of future systems for sharing weather information between individuals and non-officials.

1.2 The aim of this thesis

This compilation thesis introduces the new concept of "share weather" in which individuals provide their local observations of weather. This information may potentially be used to improve weather information. The aim of the thesis is to explore how the new concept "share weather" may improve weather information. This inquiry initiates new questions, including: the accuracy of user input, motivational factors to contribute weather information, and design of systems for collection of user-generated weather data. Motivational factors represent a central issue throughout the discussion in the summary of the compilation thesis, while user input and design of appropriate systems are addressed in the papers of the compilation thesis. With this approach to the concept of "share weather", I intend to make a contribution to research on media technologies related to participation in online networks. However, some other missions are also included besides studying "share weather" as a specific domain amongst a large range of other online networks: introducing the concept of "share weather" as a new application in meteorological practice, and cautiously generalizing on the research findings to other possible areas of application for observing the environment. Given these multiple goals, it is natural to address a broad audience, reaching beyond conventional "Media Technology" research. The thesis therefore also intends to target the broad research community studying different network phenomena and the many application areas arising in the wakes of "Web 2.0". It is also my hope that the research presented here may inspire researchers and practitioners within meteorology, since the acquired knowledge might potentially serve as input to useful applications.

To summarize, the thesis aims at testing some new theory and methodology, hopefully contributing to evolving the research area of "Media Technology" as a multidisciplinary research field. The main contribution is acquiring new knowledge that can be added to previous research on participation in networks: accuracy of user input, motivation to share content in networks, and design of systems for collection of user-generated content. While positioning this thesis and the information subdomain focused on into the body of knowledge on networks and online behaviors, I also aim to develop some theory including generalizations of my findings onto the domain of environmental information.

Asking "why" sharing weather information is particularly highlighted in the summary of the compilation thesis. For instance, exploring why and how many individuals would be motivated to participate in "share weather" activities represent central issues. Also, as a natural consequence of the "why" question, the thesis adopts a holistic sustainability approach towards the socio-economic-environmental system. Other questions of this compilation thesis are related to "how" the concept of "share weather" might be realized in practice. This possibility is investigated through both the empirical studies of the papers and the discussion provided in the summary of the compilation thesis. Suggesting a new concept implies some proof of the feasibility of the concept. Exploring how "share weather" might be realized in practice not only requires new theory; this question benefits from some empirical testing. Therefore, the thesis aims at developing some new theory, rooted in established Media Technology research, and some new methods in order to explore the feasibility of "share weather" as a concept that might improve weather services. A tool for collection of weather observations, *Shareweather*, is designed and used in relational investigations, experiments, and evaluations on which this compilation thesis is based. As an additional task, the thesis endeavors to make a contribution to design theory through testing some of its methodology.

1.3 Research questions

My objective is to explore how sharing of weather data might contribute to improved weather information that can be utilized for different purposes. While weather data are already the subject of collaboration, even globally shared, this compilation thesis makes the delimitation of focusing on the role of individuals. Through defining the concept of User-Generated Observations (UGO), I introduce a "Web 2.0" based concept of "share weather" in which all individuals may be regarded as potential sources of weather information. The general question is reshaped into three research questions:

Q1. Is "share weather" a solution that can be used in order to improve weather information?

The first question explores the research topic through regarding currently available technologies and methods. The thesis argues that feasibility of "share weather" may be evaluated by making comparisons between the inputs and outputs of "share weather" and current services, respectively. In this way, major objectives are identified. The question is addressed theoretically, drawing from current knowledge and theories on participation in online networks, empirical results on quality of user-generated weather observations (UGO) presented in Paper IV, Paper V, and Paper VII, and discussion regarding potential levels of contributions based on findings of Papers IV-VIII.

As a consequence of Q1, two new questions arise: the problem of predicting potential levels of contributions (i.e., how many will contribute) related to motivational factors on the individual level, and methods for the collection of shared weather data.

Q2. Why might individuals be motivated to make contributions in terms of user-generated weather observations (UGO)?
Potential volumes of contributions are explored through studying potential sources of motivation, and assessing an expected level of contributions based on research on other online networks. Second, the summary of the compilation thesis develops a theoretical framework for studying motivation in "share weather" settings and then, applies the theory on the empirical results provided in the papers. Exploration of sources of motivation represents one of the essentials of the summary of the compilation thesis, which is intended to complement the work presented in the papers.

Q3. How can a "share weather" solution be designed?
In order to study "share weather" empirically, aiming at an evaluation of the feasibility of the "share weather" concept, we must first define the properties of a Web 2.0 solution for collection of weather information. What are the main components of a feasible weather information "Web 2.0" solution? Addressing this question may be regarded a part of a design process, and it should provide a specification of one feasible "share weather" solution, including methods for collection of weather data from individuals. While for instance Paper II presents one iteration, and Paper V presents several iterations of the design process, including a collection method, the summary of the compilation thesis describes the design process in full.

1.4 Outline of the thesis

The contribution of this compilation thesis consists of two parts: the papers, and additional theory on participation in networks developed in the summary of the compilation thesis. This second contribution of the summary of the compilation thesis uses existing theories on online community settings or networks and discusses potential motivations associated with the domain of weather information. Finally, drawing from the results presented in the papers and theories on what motivates different behaviors, I draw some conclusions regarding possible implications and what outputs may be expected from "share weather": How might the new concept of "share weather" improve weather information?

The compilation thesis is based on eight papers providing different aspects of "share weather", empirical data, and theory. A summary of the papers is presented in the next section of this introductory chapter, section 1.5. The major part of the empirical data was collected during a research project focusing on early-warning systems for travelers, funded by Vinnova (the Swedish Governmental Agency for Innovation Systems). Most studies were conducted in Stockholm, Sweden, with about 500 volunteering respondents. In the summary of the compilation thesis, I intend to complement the provided paper material with some reflections on methodologies, methods, and theory, with the main focus on individual motivation for co-creation of "user-generated observations" (UGO) and participation in "share weather" online "communities" or "networks". The theory and methodology sections are followed by discussions regarding possible wider implications of findings suggested by the empirical data presented in the papers. Table 1 provides an overview of the papers and corresponding research questions addressed in each paper.

The assignment of the thesis is, as inferred by the topic, to introduce the interactive Web (Web 2.0) within the context of weather information. These two different sides of "share weather" are explored separately based on available research. "Weather" is defined in 2.2.1 and explored in Chapter 2. Section 3.1 defines "Web 2.0" and "share weather", while for instance 3.3, 4.1 and 4.2 explore the concept of "Web 2.0". Then, I develop some new theory and contribute empirical research on integration of two research areas – Web 2.0, and weather. For example, new theory merging "Web 2.0" and "weather" is developed in 2.1.2, 3.7 and 4.5, while the papers contribute empirical results.

Exploration of "share weather" starts in Chapter 2, with focus on "weather". Chapter 2 also serves as problem identification of the compilation thesis. Section 2.1 provides an introduction to weather services and a first exploration of the domain of weather information viewed through a historical perspective of media technologies. Media technologies used for weather information services are outlined, referring to the historical and societal aspects discussed in Paper I. In order to limit the effects of weather on human activities, as most readers will be aware, a large range of weather information services is already available: media products for television, weather services on the Internet, weather apps for mobile devices, forecasts for energy production and consumption (heat distribution, hydropower, wind energy), agricultural forecasts, even financial instruments (weather derivatives), to name a few weather information service segments. Their service content is, however, generally based on weather observations collected through conventional methods, and in accordance with needs that had arisen by the mid-20th century. Chapter 2, therefore, proceeds with an overview of meteorological observations and other weather data. Major parts of Chapter 2, in particular 2.3, should be regarded as background on meteorological data and modeling of the environment, provided to readers who are particularly interested in this topic, although Chapter 2 is frequently referred to later in the text. The content of the thesis should be fully understandable even without including the whole content of Chapter 2; references given in the following chapters, mainly to sections 2.4 and 2.2.1, are thought of as fully complementary to the core of the thesis.

The core theory of the thesis is addressed in the following two chapters, Chapter 3 and Chapter 4. I start with an introduction of available theory on networks and collaboration between individuals in Chapter 3. Web 2.0 means active participation, involvement, and interaction, within a network of individuals; motivation to interact and sustain active participation and interaction within a network is therefore a determinant. Another issue is determining the quality of different user inputs. While quality of user input and design of a "share weather" application were studied through the work provided in the papers, motivation to participate in "share weather" is more thoroughly explored in the summary of the compilation thesis. Motivation and behavior in networks is therefore given considerable space in this text, in particular in Chapter 4.

Chapter 3 also discusses the concept of Web 2.0 and the multi-faceted nature of networks. After discussing concepts such as communities and networks, Chapter 3 explores the weather information domain: with new premises on the information market, in particular interactive technologies that were embraced as practice in the last decade: many new opportunities have arisen to measure weather variables and to distribute the acquired data increasingly quickly. This progress implies several changes in the networked weather information economy market (Benkler, 2006, and Paper I), in which infrastructure is available at low cost, values are created in the services, and the users may participate in creation of value and content. The question is how this change toward interactive weather information services will be manifested. What is the nature of "share weather" applications, and how can they add value when compared to current services? Many of these questions address objectives of a solution. The interactive Web 2.0 may include a range of different technologies, from short message service (SMS) that enable interaction through written text messages and smartphone applications that may include more advanced features of visual and audial character, to sensor networks that artificially measure different variables in the environment with high-speed transfer of information within the network. Opportunities for "share weather" are, theoretically, many. The great number of opportunities to collect information does not, however, confirm their practical realization. So, what do billions of connected individuals mean, how might such a vast number of individuals create weather information that can be really useful? While addressing the question *how* "share weather" systems might be designed (Q3), several related questions arise regarding the following: the accuracy of user-generated weather observations, collection methods, filtering. These issues encourage research on design of "share weather" artifacts, a question specifically addressed in Paper V, while the other papers provide important input toward design and evaluation of a "share weather" artifact. Chapter 3 provides a framework for objectives of a solution. It also presents additional theory and relates "share weather" to other research on collaboration in networks. Literature on online networks, although relatively extensive, derives from several research disciplines with different perspectives, usually with origins in theories regarding offline settings. Furthermore, Chapter 3 tries to provide an overview of suitable theories for exploring "share weather" and addresses one of the challenges of the research presented in the thesis, namely the lack of previous empirical studies and theory of the particular context of online sharing: weather information. In summary, Chapter 3 presents the research area, and narrows the research field of Media Technology towards the research inquiry of the thesis. In addition, it explains where the thesis may be positioned within the Media Technology research landscape, that is, its major contributions and aims from the perspective of the research field. One important aspect of Chapter 3 is a summary of different aspects of networks and theoretical approaches (Table 3) that serve as a framework for the coming design of a "share weather" solution. Thus Chapter 3 serves an important basis for the following chapters of the thesis.

The next chapter, Chapter 4, narrows the research focus towards a new important question introduced in the summary of the compilation thesis. It focuses on individuals and their motivation to participate (Q2). This chapter is aimed at providing theory explaining participation and drives for collaboration in networks. While accuracy of user input, methods, and design-related questions are extensively addressed in the papers, the strong individual perspective on "share weather", representing a primary aim of the thesis, implies that the design must include understanding of individual behavior in networks. Namely, Chapter 4 addresses the question about how many will contribute content to "share weather". A further question concerns the role of the individual in these settings, and (social) interactions taking place. Given its central position in the summary of the compilation thesis, motivational theory is presented in a separate chapter in which several dimensions of human behavior in networks are explored. First, I discuss possible approaches in motivational theory from the aspect of how individuals and networks are defined, including both structural and individual elements. This is an overview of available theories used for studying networks. Second, I explore the actual domain: weather information. Different sources of motivation relevant to the context of the research presented in the compilation thesis are discussed based on findings on motivation within related areas, with the purpose of drawing a suitable theoretical framework for the context of "share weather" networks. A framework addressing human interest in weather is eventually presented in 4.5 (Table 5). It is thereafter used for drawing objectives of a solution and also applied in some essential parts of the discussion provided in the thesis. Finally, motivation theory is related to environmental concern and some findings within natural resource management. These theories are central to understanding the context of human interest in weather information. Chapter 4 thus provides some new theory and tools for understanding individuals' behavior in networks and addressing the research questions of the thesis. It develops tools for exploring people's potential motivation to contribute weather information.

The next chapter, Chapter 5, focuses on methodology and methods. Another important contribution of Chapter 5 is the presentation and discussion of design theory, here related to the work presented in Papers II–VI. Chapter 5 discusses: the context of "share weather" in the empirical studies of the papers, general scientific methods and methodology used in the compilation thesis and in Media Technology, some new methods introduced in the empirical studies, design theory including its application in the empirical studies and ethical concerns that may arise while studying "share weather" within the selected context.

Discussion and conclusions are provided in Chapter 6. This chapter discusses paper findings (also summarized in 1.5) based on the theory presented in Chapter 3 and Chapter 4. Results are finally summarized in an overview of research questions and results (Table 10; see also Table 8), followed by a discussion on the presented research findings on design and evaluation of "share weather", the new Web 2.0 concept introduced in the compilation thesis.

Naturally, the thesis applied certain delimitations. These are outlined in section 1.6 of this chapter (Chapter 1) after presentation of papers in 1.5. Further details and discussion regarding delimitations are provided in section 3.8, associated with the context studied.

The outline of the thesis is displayed in Table 1, including two different ways of regarding the research process. One is associated with division according to their role in the thesis (partially consistent with the chronological order of presentation in the thesis). "*Core theories*" present current research in Media Technology, whereas the "*Contextual*" constitutes my contribution to the research field. Therefore, core theory is mainly represented by research on networks (Web 2.0), although with a small contribution of theory on meteorological applications and meteorology (weather). Media Technology *Core theory* is presented in Chapter 3 and Chapter 4 (see *Approach 1*, Table 1), whereas new theory that is developed in the thesis and the papers is associated with the context (*Contextual*).

Table 1. Overview of the thesis: summary of theories and outline of the thesis

<table>
<tr><td rowspan="8">Approach 1:

Exploring the

RESEARCH AREA

through studying a particular context</td><td>CORE THEORY
Networks and Weather
(Web 2.0 Weather)</td><td>CONTEXTUAL
New theory
("share weather")</td></tr>
<tr><td>Chapter 3 (3.2, 3.4, 3.5, 3.6.1, 3.7.1-3.7.2, 3.8.3); Table 3:
Networks (Web 2.0)</td><td>Chapter 3 (3.4.3, 3.6, 3.7, 3.8); Papers II – VII; Table 4:
"share weather" networks</td></tr>
<tr><td>Chapter 4 (4.1, 4.2, 4.3):
Motivation for online participation (Web 2.0)</td><td>Chapter 4 (4.4, 4.5); Paper VIII; Table 5:
Motivation to "share weather"</td></tr>
<tr><td>Chapter 2:
Meteorological applications and weather</td><td>Chapter 2 (2.1.2, Fig 1; summary in 5.2.1; Papers I and III:
Weather and media technologies</td></tr>
<tr><td rowspan="2">Chapter 5:
Methodology</td><td>Chapter 5 (5.3.2, 5.3.3); Papers II and VI:
New methodology ("Recent weather", "Scoring")</td></tr>
<tr><td>Papers I – VIII; summary in 1.5; Table 6:
Methods and empirical studies</td></tr>
<tr><td colspan="2">Chapter 6 (Table 9 and Table 10):
Results and discussion</td></tr>
<tr><td colspan="2">Chapter 7:
Conclusions</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="9">Approach 2:

DESIGN

and evaluation of a new concept</td><td>THEORY
Design of a new Web 2.0 concept</td><td>DESIGN
of a new artifact (Shareweather)</td></tr>
<tr><td>Design theory: Chapter 5 (5.4)</td><td>Chapter 1 (1.5.10, Table 2);
Chapter 5 (5.5.4, Fig 3):
The design process applied in the thesis</td></tr>
<tr><td>Problem identification (Step I)</td><td>Chapter 2, Paper I</td></tr>
<tr><td>Objectives of a solution (Step II)</td><td>Chapter 2 (2.4)
Chapter 3 (3.6.2, 3.7.4, 3.8)
Chapter 4 (4.2.2, 4.3, 4.5); Table 5
Chapter 5 (5.1, 5.2.1); Table 7
Chapter 6 (6.3); Table 9</td></tr>
<tr><td>Design and development (Step III)</td><td>Chapter 5 (5.4, Fig 3); Papers II - VI**</td></tr>
<tr><td>Demonstrations (Step IV)</td><td>Papers II –VIII**; Table 6</td></tr>
<tr><td>Evaluation (Step V)</td><td>Chapter 6; Table 10:
Evaluation of the concept of "share weather"</td></tr>
<tr><td>Documentation (Step VI)</td><td>Chapter 7:
Conclusions of the compilation thesis</td></tr>
</table>

* see Design theory in Chapter 5 (5.4); ** see Table 2

Positioning of the thesis within Media Technology research is discussed in Chapter 3 (3.2). Studying interactive media technologies based on empirical data collected within the context of transportation in daily life requires introduction of some peripheral theories necessary to study the contexts introduced in the thesis. The peripheral theories of the thesis are not necessarily typical of research on participation in networks; instead, these theories correspond to the multidisciplinary dimension of my research and multidisciplinarity, even cross-disciplinarity, of Media Technology as a research field. One such side discipline is Intelligent Transport Systems ITS (research on ICT applications for support of transport-related activities), mainly addressed in the methodology chapter (Chapter 5). Other areas are represented by studies of natural resource management and environmental monitoring, introduced in Chapter 3 and Chapter 4. Further, in order to provide deeper understanding of how the service content is produced (i.e., weather forecasts), meteorology, meteorological applications and environmental modeling are given a separate chapter (Chapter 2), also providing the opportunity for selection of background information due to different readers' preferences. The thesis also targets, along with academics within Media Technology, a broader audience, including researchers and practitioners within peripheral disciplines such as ITS, meteorological applications and natural resource management, and other disciplines in which the research findings of this thesis might be applied.

The thesis aims at designing and evaluating a new concept. However, it may in parallel be regarded from a design perspective. The theories presented can be organized according to their role when exploring the interactive Web 2.0, and design and evaluation of "share weather". This approach follows from Table 1 under *Design of a new Web 2.0 concept* (see *Approach 2*, Table 1, p.14). The first group of theories, then, constitutes Media Technology theory (design theory, networks and motivation) related to an existing phenomenon – the interactive Web 2.0. The second class of theories is used to expand the body of knowledge of Media Technology, by transferring the concept of Web 2.0 into a new context of "share weather", the domain of weather information. The latter may be regarded as related to a *design* problem corresponding to the research question of the thesis. However, in general, the primary aim of the thesis is not to expand the knowledge on design theory; instead, design theory is used as a methodology in order to reach the aims of the compilation thesis.

Ignoring my potential audiences' different backgrounds, the thesis aims to examine the output of its findings from a sustainability – sustainable development – point of view (see section 5.1). In this anthropogenic era, it might be considered valuable to regard environmental perspectives of academic research. Given the particular associations of the thesis' topic with environmental impacts (climate change and extreme weather), a "sustainability" perspective might feel natural, and the importance of this topic is fairly easy to defend. However, I do argue that scientific work in general should regard all its sustainability dimensions, since not only the method, but the products of scientific work, should be regarded. I therefore suggest one way of defining the research problem with the help of the three sustainability dimensions: social, economic and environmental. This chapter raises these questions when asking not only why weather matters to media technology research, but also why it might be in the interest of the society to study the weather information domain and "share weather" (see 1.1, Paper II and Paper VII). The three dimensions regarded (the social, the environmental and the economic) might potentially be thought of as corresponding to particular aspects of "share weather", although this approach was not chosen: the social Web 2.0 possesses strong social aspects, whereas the information domain (weather) might be associated with environment and climate change, but also the economic aspects of weather in society (e.g., traffic weather forecasts and warnings). With the intention of regarding this research topic's societal implications from social, economic, and environmental sustainability perspectives instantaneously and equally valued, one of the papers (Paper VI) explores some potential implications of "share weather" practices on sustainable development. Later in the discussions in Chapter 7, the three dimensions of sustainability are considered (see 7.2), the aim of which is to discuss the contribution of my research on "share weather" from the holistic perspective of sustainable development.

1.5 The papers

The eight papers providing the empirical basis for the research presented in this thesis are presented below (1.5.1-1.5-7). They are, thereafter, summarized in an overview of research questions and papers of the compilation thesis (Table 2, section 1.5.10). Finally, some additional research is presented (1.5.9).

1.5.1 Paper I

Elevant, K. (2010). Governmental Services and Social Media: When Weather Becomes Global. In *IADIS International Conference e-Society 2010* (pp. 103-114).

The paper was presented by the author at the IADIS e-society conference in Porto, March 18-21, 2010, and published in the proceedings of the same.

The paper describes current weather information services and the market for weather information data, including an analysis of the historical development of the market for weather information services, the transformation from the "industrial weather information market" to the "weather information market", with emphasis on market agents and roles, data availability, and data distribution policies. In addition, introducing Web 2.0 as a technology, the paper presents future scenarios of the weather information market, based on Benkler's (2006) previous reasoning on participatory culture, and implications of Web 2.0 on the society, including data availability and policies.

1.5.2 Paper II

Elevant, K. (2009). Customization by Sharing Weather Information: A Study on Winter Road Weather Warnings. In *The 5th International Conference on Mass Customization and Personalization.*

This paper was presented by the author and published at the proceedings of the (renamed) World Conference on Mass Customization, Personalization, and Co-Creation, in Helsinki October 4-8, 2009.

This paper investigates the nature of weather services in respect to media technology layers: content, design, and technology platforms, while designing and evaluating a personalized early-warning traffic weather service based on recent weather. The paper also discusses general customization and individualization of weather service content based on recent user weather observations. The method is drawn by merging theories originating in several disciplines, such as human cognition (psychology) and driver behavior that belong within the research area of Intelligent Transport Systems (ITS). In the paper, SMS technology was tested as a channel for distribution of weather service content within the chosen context, namely traffic weather alerts or notifications before the occurrence of severe weather events. In Paper II, two empirical studies were conducted on a group of traffic weather interested habitants of Stockholm (denoted group A in Paper IV, Paper V, and Paper VI). The first consisted of 17 interviews aiming at: establishing new knowledge and possible hypotheses regarding relationships between different variables, testing the feasibility of questions posed to the respondents and conducting a design iteration. The second part of the empirical study consisted of questionnaires provided to 71 respondents after their participation in tests of an SMS weather alert service during the winter season 2008/2009, providing evaluations of the personalized weather alert service from several perspectives. In addition, important personal information was collected from respondents in order to establish knowledge regarding possible relationships and in order to design the collection methods and tools later introduced in Paper IV and Paper V.

Findings of this paper confirm that the "recent weather" method achieved the desired effect on the behavior during severe weather. In addition, the results suggested that user-generated data on recent weather observations and personal-relevant data should be collected in order to personalize weather services.

1.5.3 Paper III

Elevant, K. (2010). Collaborative Observations of Weather: A Weather Information Sharers' Community of Practice. In *The 6th International Conference on Web Information Systems and Technologies, WEBIST 2010* (pp. 392-399).

The paper was presented at the WEBIST conference in Valencia, 7-10 April, 2010, by the author, and published in the conference proceedings.

Drawing from the theory presented in Paper I, the established practices within meteorological applications, and some findings from Paper II, this paper focuses on design of the interface of artifacts for collection of weather observations from individuals. The paper discusses suitable weather variables that can be reported by volunteers and suggests one feasible collection method based on text phrases and pictures taken with mobile phones, using web and mobile technology as a platform.

The paper focuses on the "objectives of a solution" part of a design process, that is, step II (see section 5.4.5) drawing from the problem definition presented in Paper I and Paper II. Based upon specification of desired properties of an artifact for collection of weather data from individuals who possess varying skills, conclusions are drawn regarding design of the interface of a Web 2.0 weather information tool for collection of weather and climate data from individuals.

1.5.4 Paper IV

Elevant, K., and Turpeinen, M. (2011). Improving weather and climatic information quality with user-generated observations. In *The 44th Hawaii International Conference on System Sciences (HICSS)*. IEEE.

The paper was presented at the conference, in January 4-7, 2011, by the first author, who also made the major contribution to the paper.

This paper presents an empirical study related to performance of "share weather" tools. The collection method introduced in Paper III was tested within a series of demonstrations in order to attain performances of three different groups: adults interested in traffic weather information (group A previously introduced in Paper II), children aged 7-9, and visitors to a dental clinic. Different user groups' needs and preferences were discussed by introduction of a "time-consumption model". The findings of this paper provided important empirical support for further work in developing theory and carrying on with the thesis' main task, i.e., addressing research questions Q1, Q2 and Q3. The thesis contains some additional theory that was omitted in Paper IV due to required paper length.

1.5.5 Paper V

Elevant, K., and Hrastinski, S. (2013). Web Weather 2.0: Improving Weather Information with User-generated Observations. *AIS Transactions on Human-Computer Interaction*, *5*(1), 28-41.

Elevant made the major contribution to this paper.

In this paper, the empirical material presented in Paper IV and Paper II was further developed, while applying design theory. Based on Design Science Research Methodology DSRM theory introduced by Peffers et al. (2007), and the empirical studies from Paper IV, Paper V presents and evaluates an artifact for collection of user-generated weather observations, including other components of a "share weather" system. The contribution of this paper is to apply and test DSRM theory (Peffers et al., 2007), presenting the components of artifacts for collection of weather data from individuals, i.e., "share weather" systems, and generalizes the concept of "share weather".

The summary of the compilation thesis further develops the discussion presented in Paper V regarding requirements and performance of "share weather" systems in respect to spatial and temporal distributions of user-generated input, i.e., where, and how often users should provide input in order to potentially improve the content of weather services issued by a "share weather" system. Additional contributions of the compilation thesis in relation to this paper are to provide further details regarding artifacts for collection of weather data, and generalizations of the design model of artifacts for sharing weather and environmental information, with emphasis on environmental data.

1.5.6 Paper VI

Elevant, K. (2013, in print). Trust-Networks for Changing Driver Behavior During Severe Weather. Accepted for publication in *IET Intelligent Transport Systems*.

An earlier version of the paper was presented at, and published in the proceedings of ITS World Congress 2011 in Orlando, 16-20 October 2011:
Elevant, K. (2011). Trust-Networks for Changing Drivers' Behavior during Severe Weather. In *The 18th World Congress on Intelligent Transport Systems*.

This paper, together with Paper II, constitutes a knowledge foundation for personalization of services generated by the "share weather" system. Based upon the same empirical studies described in Paper IV and Paper V, Paper VI provides additional empirical results and conclusions on "share weather" platform design and feasibility, here approached within the context of individuals' need for weather information during severe weather events. Paper VI presents new results achieved on the effects of the weather alert service used in the empirical studies presented in papers II, IV and V, focusing on behavior of the subjects that had participated in the tests. The impacts of the service, based on SMS technology, systematic personalization of content, and Web 2.0, were measured in a longitudinal study, with the purpose of evaluating the impacts of the service on respondents' behavior. In addition, the methodology applied in the empirical studies of Paper IV and Paper V, and now also in paper VI, was presented and analyzed in more detail in order to resolve questions regarding the reliability of the measurement method. The paper provides some important results on motivation and interactions; the results pointed out positive impacts of interactivity on user trust and probability of changed behavior during severe weather events.

The summary of the compilation thesis contributes motivational theory that is an expansion of the theory presented in Paper VI. While motivation is only presented in brief, this paper provides important input and support for the reasoning and discussions on motivation presented in the summary of the compilation thesis.

1.5.7 Paper VII

Elevant, K. (2011). Climate Information Crowdsourcing – A Bottom-up Practice for Sustainability and Growth. In *IADIS International Conference on e-society 2011*.

This paper was presented by the author on the IADIS 2011 conference, in Avila, 10-13 March, 2011, in addition to being published in the proceedings.

This paper reflects upon the impacts of "share weather" on sustainable development of the society in respect to all three dimensions: economy, social sustainability, and ecological sustainability. The paper bases its discussions on empirical results presented in Papers IV and V and additionally introduces new empirical results on farmers in Sudan sharing weather (precipitation) data in a collaborative project between volunteers and officials. The case study on volunteer weather observers from Sudan collecting precipitation data in remote places of Sudan, where such data sets were missing, provided some input regarding motivation, feasibility of "share weather" collection methods and their potential implications in the future.

1.5.8 Paper VIII

Elevant, K. (2013). Why Share Weather? Motivational Model for "share weather" Online Communities and Three Empirical Studies. In *The 46th Hawaii International Conference on System Sciences (HICSS),* 781-790. IEEE.

The paper was presented at the HICSS conference in January 7-10, 2013.

Because sources of motivations to contribute to "share weather" were yet unexplored, the last paper addresses motivation to participate and contribute to "share weather". The research questions were, first, what motivational theory is suitable for studying "share weather" and, second, what sources of motivation are imperative? Paper VIII develops a theoretical framework for "weatherwikis", based on several established theories and the concept of "social capital". Then, this framework is evaluated using three empirical studies: (I) 50 students' preferences regarding "weatherwikis", (II) self-reported interest to participate in sharing weather data provided by a group of 180 people interested in traffic information, and (III) user-generated data collected by the "share weather" artifact previously developed in Paper V. Paper VIII contributes important theory, further discussed and developed in the compilation thesis. Identification of different sources of motivations conducted in the paper provides important input to some of the central discussions and conclusions of the compilation thesis.

1.5.9 Related research

A short version of Paper II was presented at the ITS World Congress in Stockholm, 21-25 September, 2009:
Elevant, K. (2009). Customized Weather Warnings – A User-Centered Approach. In *The 16th World Congress on Intelligent Transport Systems*.

The following paper, adjusted to the audience of academics and practitioners within meteorology and meteorological applications, is an extension of Paper III, presented at WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation, in Helsinki, 30 August-1 September, 2010:
Elevant, K. (2010). Social Media and Weather Surface Observing Technologies and Systems: Expanding the Synoptic Network through Web 2.0. In *World Meteorological Organization Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TECO-2010).*

An earlier version of Paper VI was presented at the ITS World Congress in Orlando, October 16-20, 2011:
Elevant, K. (2011). Trust-Networks for Changing Drivers' Behavior during Severe Weather. In *The 18th World Congress on Intelligent Transport Systems*.

Some new empirical research is presented in empirical studies of user-generated contributions and "share weather". This work is based on the theory developed in the compilation thesis:
Elevant K. (2014, in print). Who wants to share weather? In *The 47th Hawaii International Conference on System Sciences (HICSS)*. IEEE.

1.5.10 Summary of papers, research questions and the design process

Individual papers are related to at least two research questions each. Also, individual papers correspond to particular design steps of the design process (later described in 5.4 and illustrated in Fig 3). In order to picture how the empirical research and research questions relate to the papers of this compilation thesis, the papers, research questions and design steps are displayed in Table 2. In this overview, I also add a schematic of the sustainability dimensions focused on in individual papers: social (S), environmental (N), and economic (E).

Table 2. Summary of papers, research questions, the design process, and sustainability dimension focus

PAPERS		Paper I	Paper II	Paper III	Paper IV	Paper V	Paper VI	Paper VII	Paper VIII
QUESTION	Q1	X		X		X	X	X	X
	Q2	X	X		X	X		X	X
	Q3		X	X	X	X	X		
	Sustain-ability	N S E	S E	N S	N S E	N S E	S E	N S E	S
DESIGN	Step	I	III (IV,V)	II-III	III-IV (V)	III-V	III	I-II	IV-V
	Iteration	*Problem identificat.*	*Iteration* 1	*Iteration* 2	*Iteration* 2	*Iteration* 2	*Iteration* 3	*Iteration* 3	*Iteration* 3

1.6 Delimitations

This compilation thesis explores the concept of Web 2.0 with delimitations associated with how Web 2.0 and "share weather" are defined. For instance, some definitions of Web 2.0 may include a wider range of applications that do not require a "social dialogue" or social interactions. The thesis narrows the "Web 2.0" landscape of possible "share weather" applications toward sharing weather between *individuals* within particular contexts. This approach implies that monitoring weather with sensor networks is not addressed. However, sensor networks cannot be ignored when regarding the possibilities of how "Web 2.0" might contribute to improving weather information. By narrowing the research inquiry toward networks of individuals, the general research question of the thesis is reshaped, as the concept of "share weather" is defined and further explored in the theory sections and the discussion.

It is also important to note that exploring user-generated weather observations is not equivalent to improving weather forecasts, although related questions are touched upon in the thesis, and this work may provide input for further studies that may address issues related to practical implementation of "share weather" data into operational activities. Identifying *motivation* to contribute user-generated weather observations as a key factor that may impact future methods in meteorological applications and focusing on related questions in this dissertation, however, help in moving toward an answer to how the interactive Web might contribute to improving weather services and weather forecasts.

Some delimitations of the thesis are contextual. Due to lack of previous empirical data on the subject, empirical evidence was required in order to confirm the theory. The thesis is based on empirical data achieved from several transport-related studies. It is here important to bear in mind that the research presented in the papers is based on empirical studies in which specific tools were utilized, within a limited geographical area, i.e., Stockholm, Sweden, and under special prevailing weather conditions. The results from these studies are subject to generalizations and discussion in the thesis, but, generalization may only be perused with certain restrictions associated with the context which is defined by: severe weather, winter and traffic-interested individuals. Also, it is of particular importance to thoroughly examine the methods used to collect the empirical data in order to determine their generalizability.

As far as a comparison with theory on networks and motivation is concerned, a set of issues also creates delimitations. The context of "sharing weather" as performed in the empirical studies of the thesis that is compared to studies presented in available literature on participation and motivation in online communities requires both new theory and comparison with existing contexts. Differences in community settings and interactions may generate essentially different results. Choice of theory is a delimitation in itself; the compilation thesis selects theory from extensive research material on networks and motivation. Here, I try to merge several theories into a framework representative of networks on a more general level than the context of "share weather"; this may be regarded as a summary and compromise of current theories. Current choice of theory in the thesis is explained in the theory section, while I also discuss and recommended other theories for future research.

Another delimitation of a more theoretical nature is a consequence of the choice of focusing on motivational theory, at the expense of quality issues, for instance possible deeper analysis on expected levels of quality of individual user inputs. Here, some results presented in the papers, for instance Paper VIII, provide material for further discussion and future investigation. Also, I defend my approach of prioritizing research questions on motivation because they are exposed to greater challenges. On the other hand, feasibility of the "share weather" concept strongly depends on potential levels of contribution.

Finally, selecting "weather information" as a research topic represents a delimitation to a particular domain. The Web 2.0 landscape of different services and information domains is narrowed to: information domains that represent a subject of personal interest to the individual who motivates participation in the activity of sharing information, and information domains that represent a value to the society as an information "commodity" that may be utilized by different agents on existing markets. The compilation thesis here introduces a concept of "User-Generated Observations", UGO introduced in 3.7.4, the delimitations of which I will return to later in 3.8.2.

During my work with this thesis, several researchers and practitioners have commenced related work toward inclusion of individuals as active producers of information describing the environment. Very recent initiatives have been made regarding the collection of weather and other spatial data through social media tools. With the course of the rapid development of communication and information technologies and new practices arising at a speed much greater than that of researchers producing results – some of which applies to this thesis – my intention is to try to look beyond the present practices while attempting to provide knowledge that can be used in future development, studies and research on the collection of environmental data. Although the rapid development of this research area imposes these limitations, it provides a great and satisfying challenge. The summary of the compilation thesis is intended to be shared with others within academia as well as within the larger community of practitioners.

Chapter 2
Weather data and meteorological applications

This chapter addresses readers who are particularly interested in weather and meteorology. Because the content is aimed at, and adjusted to, a broad audience, all readers are welcome to take in the content of this chapter. However, those who are more interested in other aspects of this thesis are recommended to read a short summary provided in Chapter 5. That summary, provided in 5.2.1 of Chapter 5, with references to Chapter 2, may provide sufficient understanding of the content of this compilation thesis.

In this chapter I commence the exploration of the domain of weather information. In addition, Chapter 2 may be regarded as the first step of a design process, namely, problem identification (see Table 1, p.14). This includes an overview of how weather data are managed, a little on meteorological applications, and challenges associated with predictions of weather and related fields. As I outline several problems facing researchers and practitioners within the meteorological community and its periphery, I bring the perspective of a media technology researcher. Analogous with the aims of this compilation thesis (previously defined in 1.2), my approach is to regard weather information through the lenses of media technology research, while exploring how weather information might be potentially improved.

I therefore start the exploration of "share weather" in 2.1 by regarding how media technologies were used in the past for assisting practitioners within meteorology and how weather services for the society and the public were designed. Thus, some material presented in Paper I is further developed, serving the purpose of problem definition. However, some of the contents of this thesis might also be relevant to researchers and practitioners within meteorology and related fields. Although meteorology and environmental research do not define the topic of this thesis, I hope to gain attention from the meteorology research community regarding the results of the thesis; this endeavor encourages inclusion of some meteorological aspects of "share weather". My background in natural science and extensive practical experience related to the topic of this thesis – meteorology, weather forecasting and weather services – represented the main source of ideas, and provided me with the multidisciplinarity required to view the problem from different perspectives, while approaching "share weather" networks as a new phenomenon that belongs under the broad area of network research. With this background knowledge presented in the second part of this chapter, I try to share some essential theory, reasoning, and conclusions, aiming to address readers who are particularly interested in weather and climate. The text includes a summary of climate data and environmental modeling, weather forecasting and collection of real-time data. Related sections (2.3-2.4) may, however, be excluded from reading, since the remaining parts of the compilation thesis are thought sufficient for understanding the research presented in the thesis. However, the compact outline of current solutions within weather forecasting presented in a short section 2.4 can be recommended for those interested in the technical aspects of "share weather". The same solutions are later also used to define the objectives of a "share weather" solution.

Section 2.2, containing definitions of concepts and the information domain studied in the thesis, represents some of the most important results of this chapter. It is frequently referred to later in the thesis, and strongly recommended for reading due to its general importance. Section 2.1 below takes the first steps of introducing the media technology perspective and is therefore recommended to researchers within that field. However, because the presented ideas and reasoning might be applicable to a number of other areas and applications, section 2.1 may serve as inspiration to researchers and practitioners within other fields.

2.1 Weather information services

This section serves as an introduction to what "share weather" may represent. As this section will illustrate, looking back in history points to some interesting developments regarding weather information management and scientific progresses, most of which is related to media technologies. This section will use some of the contents of Paper I, which describes human societies' concerns related to weather in the present and the past. This historical outlook of weather information aims to introduce the reader to the idea and concept of "share weather", as well as to point out some aspects of media technologies.

2.1.1. Weather and media technologies in the past

People talk about weather, and the most natural way of relating to weather is through "storytelling" (Benkler, 2006). Through storytelling, experiences of weather phenomena are transferred through conversation and passed on to friends or next generations, that is, stored and replicated without co-presence. In early civilizations, an important purpose of storytelling was sustaining the wellbeing and survival of a community (Paper I). Storage and replicability of weather information relied entirely on human memory, and, what may be regarded an even greater obstacle, information was not exchanged synchronously. By the 18th century, printed media, newspapers, magazines, books and logbooks had created opportunities for unrestricted weather-storytelling, storage and replication of weather information across large distances of space and time, with inclusion of larger audiences among the population. Synchronicity had not yet been achieved; for instance, marine logbooks could document heavy storms, but the audience was reached after their occurrence (Burton, 1986; Davis, 1984; Craft, 1999). In addition, interactivity was lost with the introduction of printed media, including social cues such as audio and essential elements of socializing, transforming "weather" from a piece of private sphere socializing to an asset of the public sphere; weather information established itself as a part of printed media news content and a "commodity" owned by organizations and media corporations (Simpson, 1987). However, keeping records of weather in printed form by enthusiasts, scientists and printed media (Pfister et al., 1999; Feldman, 1983; Frisinger, 1983) were imperative for the development of meteorology and weather information services. Today old records of weather observations, such as marine logbooks (Wilkinson et al., 2011), represent important sources of evidence of weather conditions in the past, utilized by climate researchers among others.

The actual breakthrough for weather information services came as the telegraph announced an imperative change by "allowing real-time communication across long distances" (Baym, 2010) corresponding to the same magnitude as the size of weather systems, i.e., the "synoptic" scale (Paper I). Because weather information could be sent instantaneously across large geographical distances, the information was co-located and synchronized. This marked the commencement of an era of rapid development of weather networks (Paper I), which were of the size ten (10^1) to hundred (10^2) weather observation stations (Craft, 1999; Davis, 1984). Based on information exchanged through telegraphic networks, the first early-warning systems were introduced: weather alerts or "storm warnings" were sent to other stations whenever observed at one station. Compared to contemporary weather information services, the content was not filtered in a systematic way and weather station networks of the "industrial information economy" (Benkler, 2006) concentrated all resources on a few agents in the market for weather information services (Paper I). Several other technological inventions of the 20th century created synergies with the media technologies used, increasing the number of nodes in meteorological observation networks: aviation, the computer, satellites (an important contribution to increased density of meteorological data from the 1970s and on, in particular over remote areas including the oceans), and Internet and mobile technology, as illustrated in Figure 1. The service content of weather services significantly improved with the first computational methods that ran Numerical Weather Prediction models (NWP), and through satellite remote sensing. Aviation was particularly important for establishing the WMO international exchange of weather data (Paper I) between 188 countries, today consisting of: 10^4 surface-based "SYNOP" weather stations, three thousand aircraft, a thousand upper air stations and more than a thousand ships (WMO, 2009a), sharing their updates every third or sixth hour (WMO, 2009a; WMO, 2010). While today we take weather forecasts for granted as a part of our expectations from the regular news feed, we should recall that weather forecasts first produced reasonable outputs by the mid-20th century.

2.1.2. Contemporary weather storytelling media technologies

As will be described in the coming sections on meteorological data, past preconditions set by the infrastructural basis of 20th century technology, inventions, and methods are still applied today. However, during the past century, a range of new media technologies with interactive properties or other implications for weather information services were invented. Some media technologies are highly interactive, and social, although they may seem old-fashioned: the telephone, radio, movie-pictures, and television. Namely, some first examples of user participation and collaboration within the weather information domain occurred through combining several of these media technologies: radio listeners were able to call in their weather observations, extreme weather filmed by storm-chasers and shown on television became popular and strongly mediated experiences of weather. Weather earned the position of an important part of the news feed, modified in order to suit specifically targeted television viewers, radio listeners, newspaper readers, and other passive receivers of weather information. Media technologies, such as radio and television (still the most popular source of weather information; see Paper IV), improved the service content design in terms of visualization, presentation, and increased accessibility, and individuals may now freely choose their own favorite source of weather information and even purchase customized weather services (see Paper II).

The point is that all weather services are based on the same set of weather data shared between world governments and organizations – the original SYNOP weather station observation network based on sharing weather information via WMO. Yet, a short historical review shows that several premises are now changing with the advent of new interactive technologies. New interactive media based on Internet and mobile technology undoubtedly modify the weather information market in many ways: improving weather service content design, providing tools for increased sharing and dissemination of weather data, and transforming the former role of gatekeepers (Paper I). Despite different policies, the course of the development implies not only increased data accessibility that incorporates both enterprises and individuals, but also lower prices and increased diversity of services and applications. Perhaps most important, weather observations may be synchronized, and the reach of the Internet and mobile networks is global; it involves anybody with a connection.

Let us experiment with the figures while regarding the *potential number of points that may interact*, that is, not only receive, but also supply, weather information. Weather forecasts build upon collection of observations from different locations. The approximate number of interactive points at a particular time in history may, according to 2.1.1, correspond to: the number of telegraphic stations in the first storm-warning service networks (Paper I), the number of SYNOP stations used as input to NWP (i.e., the WMO SYNOP network), the number of aircraft reporting to WMO on regular basis, the quantity of satellite data due to a satellite's pixel size, which is typically one kilometer (Warren and Hahn, 2002), the number of mobile phones, and the number of connected individuals through the Internet and Web 2.0. In Fig 1, the estimated number of interactive points are plotted (on a logarithmic scale) against the time of invention of corresponding communication technology: the telegraph, aviation, computational methods for both collection of data and numerical weather forecasting modeling, satellite technology, and, finally, the Internet and Web 2.0. Starting by the mid-19th century, telegraphic networks were based on hundreds of stations. On the other (rightmost) end of the timeline, Web 2.0 technologies based on Internet and mobile technology offer opportunities to distribute information recorded by anybody with a cell phone or Internet connection, a network reaching far beyond traditional collection and distribution of weather data; Web 2.0 involves billions of nodes.

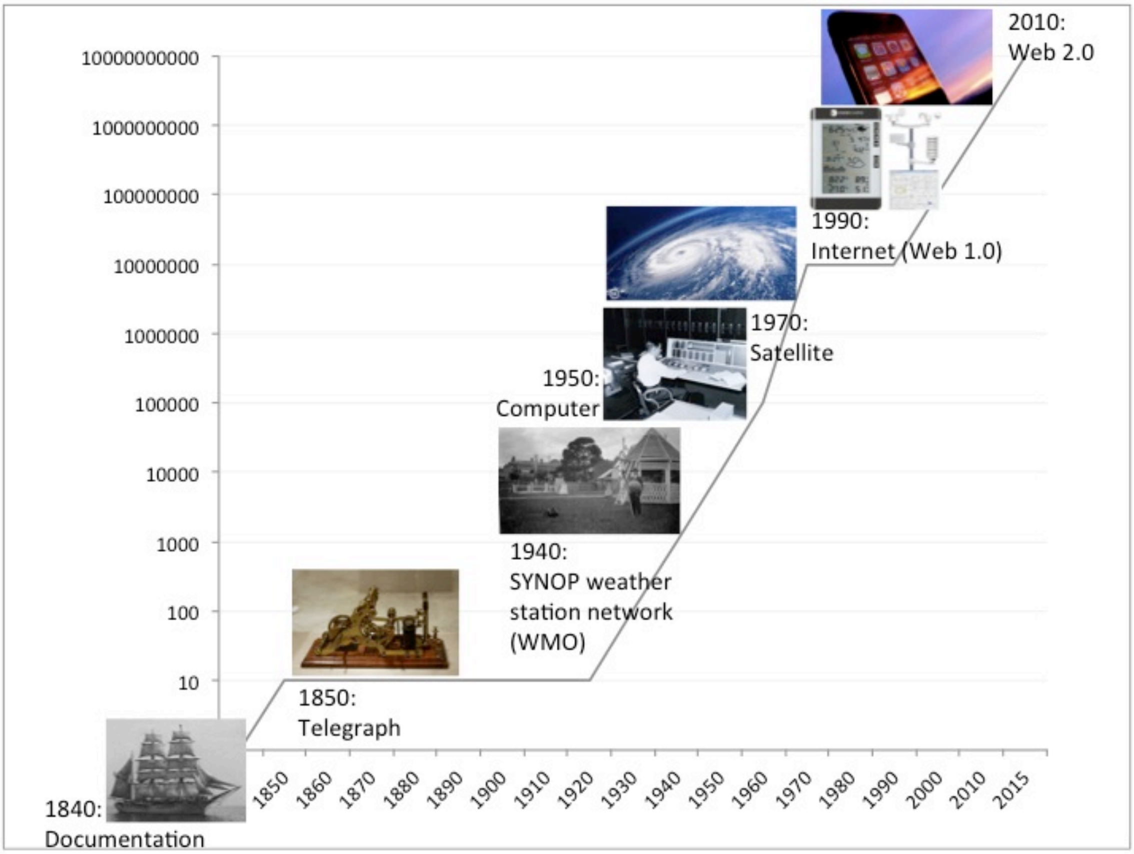

Fig 1. Weather information technology paradigms

2.2. Current weather observation networks

The global WMO SYNOP network constitutes a basis for current weather forecasts; they represent the main input to Numerical Weather Prediction models, NWP. The inspiration for the research presented in this compilation thesis was the idea that Web 2.0 may represent a part of a solution to a general problem related to the accuracy of weather information, in particular weather forecasts, and these are based on NWP. With at least 10 km, often several tens of km, between the observation points, meteorological observations and forecasts have a resolution far denser than the number of nodes constituting Web 2.0.

Fig 1 suggests that the number of nodes in weather observation networks may radically increase in the future, a prediction that suggests improvements due to larger quantities of weather data. However, the vast number of potential observation points does not reveal information on the quality of meteorological data they might supply. In addition, observations must also be integrated into useful applications if they are to contribute to improved information on weather forecasts for instance.

In the later sections of this chapter, I will describe how current researchers and practitioners utilize weather observations. The coming sections may be regarded as additional theory to the research relevant to the Media Technology research community. The reader will be introduced to some theory related to meteorology and environmental modeling relevant for the context and methods used in the empirical studies presented in the thesis. The results of these sections serve input to both methodologies and methods for comparison between UGO and current observations (Chapter 5) and discussions on results in Chapter 6, with final conclusions in Chapter 7.

But first, some definitions of the studied concept are required. Weather information is a very wide concept. There are spatial, and temporal, distinctions. Forecasting weather is conducted with different time perspectives, ranging from turbulence (i.e., wind power production within the next hours), to projections of future climate (that might predict future preconditions for food production or planning of infrastructure). Second, the atmosphere interacts with other parts of the environmental system: soil, biosphere and oceans. Observations for assessment of climate change thus include monitoring of several components of the environmental system.

2.2.1. What is weather? – Weather, climate and some basic concepts

Weather is defined by a set of variables observable in *space,* all of which may change over *time*: pressure, temperature, water content, wind direction and speed. Every day, hour, or second, these variables are differently defined over the Earth's surface, causing motions and sometimes spectacular phenomena, from the ground up to about ten kilometers (three hundred thousand feet) high. The whole system is driven by solar energy (Holton, 1992; Deaton and Winebrake, 2000; Peng et al., 2002). Because the Earth's surface is irregular, including oceans, land and mountains, their rotation around the Earths' axis occurs at different speed. All parts of the Earth are exposed to different amounts of solar radiation that, in addition, vary over the four seasons. Therefore, weather offers great temporal and spatial diversity.

While *weather* expresses snap-shots of the state of the atmosphere, *climate* represents average values of weather variables, which may be defined as the sum of previously observed weather for an area and a particular time of season.

Weather observations represent recordings of weather-related variables made by man or instruments. Observations are usually collected and further distributed within time intervals of 15 to 30 minutes, accessible to multiple agents shortly after they have been recorded. Since weather observations are shared between several parties such as countries, they form networks of weather observation spots, where the observer – whether a professional weather observer or an automatic weather station equipped with instruments and communication technology – represents a node. The largest weather observation network is the WMO SYNOP station network (WMO, 2009a), founded and based on standards established in the 1950s. Besides SYNOP observations collecting data every third or sixth hour, the WMO and other agents use additional data sets such as weather observations from over 10^4 aircraft, ships, and satellites (WMO, 2009a; WMO, 2010) (WMO, 2010), which under certain conditions can improve the resolution up to one kilometer (Warren and Hahn, 2002). Observations are collected with two main purposes: weather observations are used as *climate data*, and weather observations are used as input source to numerical *weather prediction models* NWP. Climate data are also used for running different models for *climate projections* and other models describing the *natural environment*.

It follows that the two main applications of weather observations are: (1) weather forecasts, and (2) climate data as a part of a larger set of data describing the natural environment. While section 2.4 will discuss weather observations and weather forecasting with shorter time perspectives, 2.3 focuses on climate change – gradual modification of climate conditions and weather (Milly et al., 2002), i.e., long-term changes on temporal scales of decades and centuries.

2.3. Weather observations and climate

This section presents some basic problems with measuring the natural environment. The natural environment is a complex system constructed of several components, one of which is represented by the atmosphere. Modeling the natural environment includes research on biodiversity, soil and land degradation, oceanography, hydrology, and many other disciplines. The weather (the atmosphere) is often an important input to modeling other environmental systems. Climate change therefore attracts the attention of many disciplines, practitioners within different areas, and policy-makers.

2.3.1. Anthropogenic climate change and weather observations

It is today considered that climate change may represent a potential catastrophe of great dimensions, including change of weather extremes and global circulation patterns (IPCC, 2007; Smil, 2008). Previously in history, climate change occurred on timescales corresponding to slow astronomic and geologic processes (Milankovitch, 1941). Today it is believed that humans have produced significant effects on climate through *anthropogenic* (human generated) climate change. However, as often correctly claimed by skeptics, many ecosystems of the past lived in symbioses with human societies; change of natural ecosystems by means of anthropogenic force has been present since ancient times, such as conversion of forests, grasslands and wetlands to crop fields and deforestation driven by the need for construction of cities, erosion and impacts on the water cycle (Smil, 2008). Consequently, environmental change is not necessarily equivalent to destruction.

However, one of the serious problems of modern time is the *rate* of change associated with anthropogenic impacts. The speed of release of greenhouse gases into the atmosphere causes a rapid change in the natural biogeochemical carbon cycle (including carbon dioxide CO_2) of much greater amplitudes per time interval (years and decades) than those that have happened in the past (millions of years). The concentration has tended within the range of 180-300 ppm during the last 650,000 years, while that figure was recently estimated to be over 394 ppm, according to NOAA (2013) ("Trends in atmospheric carbon dioxide"). However, the concentrations have been far larger in regard to the geological scale of millions of years (Warneck, 1998). The core of the climate change problem is that, even though the composition of the atmosphere has undergone many radical changes throughout history, the current rapid rate of change of substances present in the atmosphere is what creates both uncertainties and serious environmental concerns. Already in 1896, it was suggested that increases of atmospheric CO_2 may cause a rise in surface temperature (Arrhenius, 1896), and, more than hundred years later, there is a strong consensus regarding climate change and anthropogenic climate change (IPCC, 2007).

Several research needs are currently identified. According to the research community, major challenges include reduction of uncertainties in current projections describing future climate change and better understanding of the components and processes within the climate system (Peng et al., 2002; WMO, 2009b). The system is very complex, due to a number of factors and coupling effects (Holton, 1992; Park and Xu, 1999; Deaton and Winebrake, 2000; Peng et al., 2002). This specification of needs is provided in Paper IV, Paper V, and Elevant (2010) (see 1.5.9), justifying my exploration of the concept of "share weather".

In the coming sections, however, I provide additional background material that illustrates the difficulties in modeling environmental systems, including weather. These will manifest the potential benefits of contributions of new observation sets.

In brief, the problems with assessing climate change are associated with: uncertainties in climate models arising from simplifications ("parameterizations"; see Holton, 1992); uncertainties due to feed-back mechanisms, or "coupling", between different parts of the environmental system (see Deaton and Winebrake, 2000, or Peng et al., 2002); and finally, limitations in current observation sets, both spatially and temporally. These three inquiries will be addressed in the following sections 2.3.2-2.3.4, respectively. Some of them also concern weather forecasting addressed in the last section of this chapter (2.4). In addition, these issues are outlined and discussed in Elevant (2010) (see 1.5.9).

2.3.2. "Parameterization" illustrated through the example of clouds

Parameterization is a method of creating simple representations of complicated processes and feedbacks occurring between variables that describe the atmosphere or other components of the environmental system. It can be suggested that "share weather" data may contribute new knowledge regarding such processes, along with improved parameterizations.

In 1861, John Tyndal said that clouds are "a blanket, more necessary to the vegetable life of England than clothing is to man" (Tyndal, 1861). Although scientists of the 19th century were not familiar with the crucial impact of carbon dioxide on the properties of atmosphere, this actually summarizes the role of water vapor and carbon dioxide in the radiation budget of the atmosphere: water vapor and carbon dioxide keep the Earth at a relatively high temperature compared to its surroundings in space. As previously stated (2.2.1), the climate system is driven by solar energy: the sun emits energy towards the Earth. The "greenhouse gases", water vapor and carbon dioxide among others, "radiate back" some of the energy. The atmosphere is transparent to solar radiation but absorbent to thermal radiation (Fourier, 1827). In this way energy is "captured" at the Earth's surface and within the atmospheric layer where weather phenomena take place.

There are also other reasons to be interested in clouds. Paper III briefly describes why input such as "cloud type" and "cloud cover" may be useful in weather forecasting. This section will further explain the reasoning behind this statement. Here, I use the same example, clouds, in order to illustrate how improved information on cloud cover and cloud type may be used in climate and environmental research. Clouds are clusters of water in liquid (water) and solid (ice) form. Creation of clouds thus affects the concentration of water vapor, and, because water vapor is a greenhouse gas (even stronger than CO_2), clouds are an important variable in the climate system. Moreover, ice and snow reflect light better than liquid water, which might explain why clouds create "a blanket, more necessary to the vegetable life of England than clothing is to man" (Tyndal, 1861). This is why a change in cloud cover might affect the climate, and a changed climate might affect cloud cover. It has been established that changes in cloudiness are a key factor in the problem of climate change (e.g., Arakawa 1975; Charney et al., 1979). Also, morphological identification of different cloud types is necessary for describing cloud processes (e.g., Warren and Hahn, 2002). However, treatment of clouds in climate models is associated with the difficulty in obtaining quantitative agreement between atmospheric measurements and theoretical calculations (Cess et al., 1996; Held and Soden, 2000). The range of uncertainty in different scientific results is primarily due to different representation of complex, cloud-related processes (e.g., Stephens, 2005). Namely, the number of parameters of possible relevance to the cloud feedback problem is potentially considerably larger than was believed in early studies. Held and Soden (2000) say that this uncertainty is disturbing, due to large discrepancies in the range of predicted mean surface temperature response to a doubling of CO_2 concentrations (1.5ºC to 4.5ºC): If the Earth lies near the upper boundary of this sensitivity range, climate changes in the 21^{st} century will be profound.

2.3.3. Complexity of the climate system due to "coupling" between air, water and life

The problem of different feedback mechanisms was mentioned in the previous section on clouds; limited knowledge and simplified representation of cloud physics and chemistry generate uncertainties. A range of analogous problems are manifested at a higher level of the environmental system; namely, not only do different phenomena in the atmosphere occur on different time and spatial scales, but different *systems* of the environment – one of which is represented by the air – are in constant interaction. Unfortunately, our knowledge on the characteristics and magnitude of these interactions – *coupling* between different *reservoirs* of the environmental system (atmosphere, hydrosphere, biosphere, soil) – is limited (see Deaton and Winebrake, 2000, or Peng et al., 2002).

Apart from data collection and availability, uncertainty constitutes a uniquely common and key challenge in modeling of the Earth's surface and ecosystems (e.g., Paper III; Yue et al., 2009). Non-linearity of these systems may impose so-called "tipping points" (Scheffer et al., 2009) characterized by a major change of state of the system. In the climate system, which represents a coupled system of atmosphere-hydrosphere-biosphere, this phenomenon may be manifested in irreversible changes that are often the subject of controversy such as melting of the global sea level rise, which is associated with great uncertainty (IPCC, 2007). Some possible irreversible changes are: melting of the Greenland ice sheet, dieback of the Amazon rainforest and shift of the West African monsoon (Lenton, 2011).

2.3.4. User-generated observations of weather and the environment for improved climate change assessment?

One source of uncertainty is associated with limitations in the data sets; this problem is not related to the properties of the system, but the input provided into calculations on different changes and scenarios.

Observations represent input data to all modeling, and they are often based on a restricted set of data collected through field studies limited in time and space. Therefore, available models are based on interpolations of available data. In general, more dense and accurate measurements, and better linkage between field experiments and modeling are required. For instance, "soil carbon" contents are usually reported as a single number; in reality, soil carbon consists of many complex organic compounds with different chemical properties and turnover rates (Larocque et al., 2011). Field experimentation, used for collection of data for parameterization, is therefore very important. Moreover, climate researchers use substitute variables in order to measure climate in the past: the structure and patterns in ice cores, tree rings (these data do not, however, constitute input to climate scenarios presented by IPCC that are mainly considered here). In addition, climate researchers use man-made artifacts such as marine logbooks (Wilkinson, 2011).

I will, again, use the example of clouds to illustrate the potential contributions of new data sets. As most have witnessed, satellite pictures are used to visualize weather events in media. They are, however, also used to accurately describe atmospheric motions and analyze the current state (see 2.4.3). In Paper III, I introduce the idea that individuals may create complementary satellite pictures taken from below, based on pictures taken with ordinary integrated cell phone cameras. Furthermore, individuals might observe clouds from below, morphologically, and more accurately. The reason is that particular cloud types are difficult to detect from satellites, and individuals can identify clouds by a resolution smaller than a satellite's pixel size, which is typically at least one kilometer (Warren and Hahn, 2002). They may observe clouds by type, clouds during the night, over snow, and the low clouds (often hidden from the satellite's view by higher clouds) (see Warren and Hahn, 2002). For climate modeling, this fact means that satellite climatology defines cloud types by their radiative properties, unable to distinguish between different cloud types with different properties, whereas individuals might provide morphological classifications, the latter directly related to meteorology and cloud processes.

Sometimes even smaller observation sets might be sufficient for the purpose of quantifying climatologic fluctuations (e.g., Warren et al., 2007). However, with this compilation thesis, I encourage the research community to consider new technology for monitoring that may create opportunities for improvements not considered a few decades ago. The research community agrees on the importance of accurate measurements of the impacts of climate change for climate change *assessment*. In addition, when modeling the whole environmental system – assessing the *consequences* of climate change – the level of complexity is greater than in climate modeling, and the need for parameterizations more urgent due to unpredictable thresholds issued by coupling and feed-backs. For instance Lenton (2011) proposes methods for forecasting such threshold events, using a combination of models and empirical data. Monsoons are relatively "fast" systems from the perspective of climatic change, but anthropogenic forcing is slow relative to internal monsoon timescales; therefore, relatively short records of high-resolution data on monsoons are needed.

There is an additional incentive to encourage increased environmental monitoring, and it can be found on the psychological level. The uncertainties in climate projections represent a serious obstacle for policy-makers and public understanding of the potential magnitude of problems related to degradation of the natural environment. Motivation theory later presented in Chapter 4 unveils the importance of individuals' perceptions of threat through presentation of evidence (see summary in 4.6) and personal engagement in environmental issues (see 4.3 and 4.4) In order to address environmental problems on a societal level (see also the discussion in 5.1), uncertainties must be reduced, and research results presented in terms of perceivable changes and quantifiable impacts on the society and the natural environment.

2.4. Weather forecasting and observations

In this section, I focus on the time perspective of the coming days. I further explore the domain of weather information by regarding weather forecasting and numerical models, NWP, used to predict future states of the atmosphere. As will be shown, weather forecasting is faced with the same problems as climate modeling, although the dependence on "coupling" is somewhat limited. Weather conditions are, in contrast to complex environmental systems, not affected by de-coupling with the other components of the environment. A single butterfly cannot affect the weather (although this claim is sometimes expressed in the popular press); the impacts of rivers, soil and biosphere are limited on the time scale of days within which weather models operate. On the other hand, challenges of weather modeling are different; they are associated with time-critical information and inclusion of different sets of input data.

2.4.1. Numerical Weather Predictions (NWP) and observation input

Weather forecasts are created using Numerical Weather Prediction models (NWP), developed and run at many national meteorological centers, institutes and enterprises. NWP are based on a series of non-linear differential equations describing motions and energy transport of the atmosphere, or, in technical terms, interactions between "air parcels" of the size of about 10 km x 10 km. Their output is usually presented on a spatial scale of 10-50 km and in time steps of 1-3 hours. It is important to note that the equations in NWP represent an approximation of a complex reality, and modeling requires further simplification.

The input of these models consists of measurements of the current state, that is, weather observations (see 2.2 and 2.1). Naturally, the performance of NWP models in terms of accuracy of their outputs strongly depends on the spatial coverage of their input and the accuracy of the data describing the current state (Holton, 1992; Park and Xu, 1999; Solomon et al., 2007). Because an NWP represents a time integration of an initial state problem, the ability to make skillful forecasts requires that the model offers a realistic representation of the atmosphere, and that the initial conditions are known accurately (Peng et al., 2002). However, from the above overview of available observation networks (see 2.1 and 2.2), it is evident that weather observations of the current state are sparse: a network of the size of 10^4 nodes describes the initial conditions for the whole Earth.

2.4.2. Data assimilation

This problem is addressed by meteorologists through the process of *data assimilation*. Because the quantity of weather observations (10^4 SYNOP stations; see section 2.2) does not correspond to the large number of "air parcels" modeled in NWP (a greater part of initial input data are missing) in meteorological modeling, the method of *data-assimilation* estimates the input for all required cells, including those that do not have any real observations. Data assimilation creates new data for those points in which such information is missing, based on available observations (Park and Xu, 1999). One might think that this process increases the uncertainty to a large extent. However, considering other limitations of current models, data-assimilation improves the input significantly, and, since it has been applied for many decades, it is well-integrated into NWP processing.

2.4.3. Additional weather observation networks

The SYNOP observation network is obviously not sufficient to meet the needs of WMO. Opportunities for collection of additional weather data were already created decades ago, for instance with the development of aviation and space technology. The latter contributed largely to improvement of NWP in the 1970s through integration of weather data collected by satellites, with resolutions down to 1 km (Warren and Hahn, 2002). Also, observations from aircraft were incorporated into the WMO network at an early stage. Despite the numerous efforts to develop assimilation techniques, investments in additional data sets are also considered important. There are several additional sources of weather observations that are imported into the NWP processing. More recently, the Citizen Weather Observer Program (CWOP) became an additional input to NWP, and current ambitions are to integrate more sources. Another example is Volunteer Observations from Ships (VOS) (Kent and Berry, 2005), used for comparison in Paper V and Paper III.

It is evident that inclusion of several sources and greater coverage in both space and time is desirable. This is the main argument supplied in 5.1, in which I discuss the potential implications of "share weather" for meteorological applications, if it were introduced as practice.

2.4.4. Nowcasting

We may conclude that the number of SYNOP stations is rather modest (see 2.1 and 2.2), and, as previously indicated, not sufficient for the purposes of meteorological applications such as transport. Therefore, new observation networks have been introduced in order to manipulate and improve the outputs of NWP.

Most readers have probably heard of, or seen, weather radar pictures. Radar observations represent one category of observations that can be integrated into NWP. A set of observations often referred to in this thesis is related to the many road weather observation networks – Road Weather Information Systems RWIS – utilized to improve forecasts of road surface for instance. RWIS systems can have a resolution ranging between 1 and 100 km; namely, their purpose is to measure traffic weather related variables on larger roads and highways within short time intervals (0-15 min). In this thesis, an RWIS system is used for reference when defining the requirements of "share weather". The freely available RWIS covering Sweden, administered by the Swedish Transport Administration, was used in the empirical studies presented in Papers II-VI. These observations are, however, not integrated into NWP. Sections 5.1 and 5.2.1, complementing Chapter 2, point out the importance of RWIS data from the perspective of this thesis' results and its methodology.

Radar, RWIS and other types of additional observation sets, although not standardized, are commonly used to manipulate the outputs of NWP. Integration of new weather observations after the NWP has produced an output – a weather forecast for the coming days or two weeks – in order to correct the values calculated by NWP to better suit the observed reality is a process known as *nowcasting*. This process is particularly important for the compilation thesis, since it rather easily permits integration of real-time weather observations into NWP outputs.

2.4.5. Parameterization in NWP

A similar method of parameterization of different processes, as the one previously described in 2.3.2, is often necessary in order to describe interactions between different variables in the atmosphere. For instance, cloud microphysics processes must be parameterized due to their complexity, and because clouds are smaller than the size of the "air parcels" represented in NWP models (10 km). This fact also explains some of the limitations in predicting cloud cover and cloud type referred to in the thesis and the papers (Paper III).

Chapter 3
Research field: Networks and the concept of "share weather"

The thesis aims at contributing new knowledge regarding individuals' participation in networks. This chapter introduces the research area. I also position my contribution and the concept of "share weather" within the research field. The aim of this chapter is to assess: What are networks, and what is "share weather"? Answering this question naturally leads to some objectives of a "share weather" solution. While the previous sections provided problem identification in a long introduction of "weather" and launching the idea of the "share weather" concept, now I move forward towards addressing the research questions of the compilation thesis. Thus, some needs will arise during the research process, and therefore, I develop some necessary tools for further analyzing and discussing the concept of "share weather" in the coming chapters.

This chapter presents the theory on networks and collaborative production that sometimes occurs in networks, usually referred to as user-generated content (UGC). As the topic suggests, UGC is narrowed to the domain of "weather information" in this compilation thesis. In brief, two general issues are associated with UGC: quality, and quantity. Quantity corresponds to exploration of how individuals might be motivated to contribute UGC. Related theoretical issues are addressed through presentation of motivational theories in the next chapter (Chapter 4), although some theory on motivation will appear already in this chapter. Instead, here I focus on the concept of networks and how it is related to "share weather": what are networks (3.3), and what are the objectives of "share weather" (3.8)? In search for adequate answers, the question of "quality" becomes central. A model for interpreting phenomena occurring in networks and their characteristics, must be developed. One of the most important outcomes of this chapter is, therefore, a model of network features primarily aimed at describing "share weather", which is also, however, generalizable to other information domains (see Table 3). Thus, the contribution of this chapter is some new theory on networks and user-generated content (UGC), positioning my research within the research field of Media Technology, defining the concept of "share weather", and commencing the design process of "share weather".

I start with a definition of the concept constituting the main research inquiry of this thesis (3.1). Then, in 3.2, I take the challenge of describing the research discipline of Media Technology, a multidisciplinary field somewhat vaguely defined by the research community. As I explore "share weather", some new concepts are born. I explore how new interactive media technologies may be used for creation of information services as individuals take an active role in *observing* their environment while supplying expert systems and the society with *valuable data* using interactive tools. The concept of "user-generated observations", UGO, is hereby introduced and related to the body of theory in Media Technology (3.7). While the beginning sections (3.3-3.6) serve as an introduction to research on networks, UGO and "share weather" networks are explored in 3.6-3.7. General features of a network and some differences in research approaches are presented in section 3.4 (Table 3). Some of these features, the network environment and "online" status (3.5), Web 2.0 technologies (3.6.1), and components of networks including ties and nodes (3.4.3, 3.6.2), are used for further exploration of "share weather". Section 3.6 commences the exploration of design-related issues, narrowing the research scope towards the research questions (Q1, Q2, Q3). Sections 3.6 and 3.7 analyze the information domain (weather) through relating it to other media technology phenomena (3.6.1), summing up with the introduction of the wider concept of user-generated observations (UGO) in (3.7.4) and objectives of a solution (3.6.2 and 3.8). Section 3.8 aims at summarizing the results of this chapter in order to provide the reader with background theory before narrowing the research focus toward motivation theory in Chapter 4. This summary also provides some essential pieces for the design of "share weather".

Finally, I wish to emphasize that the central findings of this chapter are found in 3.7.4 and 3.8.

3.1 What is "share weather"?

In beginning to approach the research inquiry of evaluating a new concept, the basic question is how "share weather" should be defined. I start by regarding the key components constituting "share weather": Web 2.0 and weather.

Weather is a set of phenomena that everybody can relate to by perceiving the environment using human senses. More strictly, and as previously more thoroughly discussed in Chapter 2, weather may be defined as *a set of variables in the environment describing the current state of the atmosphere changing over time and varying in space.*

Considering the impacts of new technologies on weather information management, the thesis uses an assembly term "Web 2.0", coined by Tim O'Reilly and defined as a paradigm-like change of practices with the increasing use of interactive technologies in the society (O'Reilly, 2005). Starting with this definition of Web 2.0, sharing weather information does not necessarily require information exchange between individuals; "share weather" in a broad sense may be any tool that uses several sources in order to create new content, including hybrid applications, thus creating features from a composition of material collected from different sources. Interestingly, this definition would rightly apply to many existing meteorological applications, which usually merge several information sources (such as numerical weather prediction models, radar, satellite picture analysis, and other observation sources) in order to improve weather information. This compilation thesis, however, aims at exploring new potential advantages for "share weather" offered by the highly interactive, and social, "Web 2.0". According to Wikipedia (Wikipedia, "Web 2.0"), Web 2.0 represents the changes in the way software developers and end-users use the Web (1.0), i.e., web applications that facilitate participation, information-sharing, and collaboration, allowing users to *interact* and *collaborate* with each other in "a *social media dialogue* as *creators (prosumers)* of *user-generated content* in a *virtual community*, in contrast to websites where users (consumers) are limited to the passive viewing of content that was created for them". This definition, instead, suggests that "share weather" might be a social process, a product of a "social media dialogue". Second, since Web 2.0 allows "creation and sharing of user-generated content", individuals may be regarded as new sources of weather information, referring to "observations" (see 2.2.1) of the current state, whereas "forecasts" of future states might be excluded because they require expertise (see 2.3 and 2.4). The social nature of weather can be instinctively acknowledged by the fact that weather is a popular subject of conversation rooted in human desire to share daily experiences with others. This chapter explores how the new *online* status based on the interactive Web 2.0 can apply to weather information. The thesis' contribution to the research community consists of new knowledge regarding collaboration in networks, through regarding and studying the related phenomena occurring within the weather information domain.

Due to the considerably short time of existence of online settings, implications of the interactive Web on collection of information describing the environment are an unexplored area, in contrast to some other information domains. Much of the previous research has focused on domains considerably different from that studied here, subjecting information related to: the use of social media in crisis response (including extreme weather such as hurricanes), collective action (for instance environmental protests), citizen journalism (exemplified by Twitter), knowledge sharing (e.g., Wikipedia), open source software (e.g., Linux), socializing (e.g., Facebook), online games and Muds, solving puzzles (see Jenkins, 2006), citizen science (e.g., SETI@home). Areas that "share weather" might be close to are knowledge-sharing and "citizen science", In citizen science (see Irwin, 1995), volunteers contribute to the progress of scientific knowledge through personal efforts or by volunteer sharing of computational resources in computing-distributed projects (Nov et al., 2010; Hand, 2010). Since weather is a spatial variable, it can also be compared to collaborative collection of environmental data and spatial data, which can be found within ecology, geosciences and space exploration. Here, the term "volunteered geographical information" is sometimes applied (Goodchild, 2007; Heipke, 2010). Some past experiences in the history of applied meteorology are also relevant for "share weather"; collaborative work around observations of weather, traffic and the natural and built environment are not entirely a new phenomenon. "Share weather" may be associated with: traffic information networks practiced by many radio channels (e.g., Radio Stockholm; see Viktorsson, 2013), the "Hurricane Hunters", dating back to World War II (www.hurricanehunters.com), collaborations between weather institutes and volunteers such as "storm spotters" (NOAA "Skywarn"), the Citizen Weather Observer Program (CWOP) in the US, constituting a large network of private weather stations (www.wxqa.com; Nov et al., 2010), and verifications of weather radar observations with the help of volunteers (NOAA "PING").

All of the listed examples are highly relevant to the thesis, including environmental monitoring. Although the title implies a limitation to weather information, one objective of the thesis is to generalize the achieved results to other spatial data. I hope that the thesis might lay a first cornerstone to future work in the intersection of Media Technology and studies on different aspects of the interactive Web 2.0 within environmental sciences, in which the potential role of ordinary citizens and non-experts as major contributors of important information might receive increased attention.

3.2 The contribution of the thesis to Media Technology research

This thesis studies a particular subdomain of environmental information. Based on research findings on new media technologies, the thesis intends to explore the concept "share weather", while developing some theory, applying new methods, and conducting empirical studies within a new information domain that may be subject to collaborative production and networks (1.2). In addition, since there is still lack of profound definitions of the research area of Media Technology in literature, I will here take up the challenge of providing a short orientation, prior to positioning the thesis within the research field.

The multidisciplinary nature of Media Technology implies that the thesis brings a non-integrative mixture of disciplines in which each discipline retains its methodologies and assumptions (Wikipedia, "Multidisciplinary approach"). I hope, however, that the knowledge presented in the compilation thesis may contribute to evolving Media Technology research towards interdisciplinarity. Due to its considerably short history, most academics working within Media Technology are rooted in other disciplines and methodologies applied in this field are often adopted from other established research disciplines.

Media Technology may be defined as the research field studying "technologies and methods that support human communication over distance in time and space", here using a definition established in my home department at the Royal Institute of Technology, KTH (KTH, 2013; www.kth.se). Research areas within Media Technology may include, but are not limited to, the following areas: media production, e-learning, media content design, interactive design, media use, social media, virtual communities and collaboration, media culture, e-participation, and e-democracy. The research field of Media Technology is relatively new. Many of the topics correspond to phenomena that have arisen due to the development of "new media", in particular the Internet and mobile technology. However, because humans have communicated since the cradle of our civilization, long before modern technology inventions, Media Technology is rooted in several established research fields which study human behavior (behavioral sciences), human societies (sociology), culture (communication and linguistics), and different branches of technology. My research touches upon several of these areas. The main focus of the thesis is, however, studying interactive information services and participation in networks in which content is created by users (UGC), an approach which positions the thesis in the intersection of behavioral science (participation and collaboration) and technology (interactive weather services).

Multidisciplinary research often evolves toward interdisciplinarity (Lazar et al., 2010); such disciplines may not yet possess a universal methodology within the field, but employ "borrowed" methodologies from different established research areas. Collaboration in networks is often subject to studies using methodologies constructed through merging sociology, behavioral science and technology research. My contribution to the research field is to study these findings in the light of a new context, "share weather", to further test and develop the theory, and, in that respect, to contribute to the development of interdisciplinary methods and theories in Media Technology. As illustrated in Table 1 in the previous chapter, the new concept presented in the thesis, "share weather", implies studying human collaboration in networks within a new context. Such work is often multidisciplinary, and Table 1 reveals how the concepts "weather" and "Web 2.0" are first treated separately and eventually merged with the help of some new theory. It is hoped this work might help move Media Technology research toward interdisciplinarity.

In addition to exploring the "share weather" concept, this compilation thesis also aims at contributing to design theory (see Paper V and 5.4). As illustrated in Table 1, the thesis may be regarded as a design process (see also Fig 3). Other theoretical contributions to Media Technology research include testing new methods in the empirical work presented in the papers: integrating "recent weather" observations as a part of the personalization process of a (weather) information service (Paper II), and introducing user "scoring" of a (weather) information service (Paper VI).

As a part of positioning the compilation thesis in the Media Technology landscape, implications for society should also be highlighted. With the general research goals presented in the previous section, the topic of this compilation thesis, weather, relates to society in yet another way apart from constituting the information domain. Weather and climate information are highly relevant from the perspective of sustainable development. Sustainable development is, in this compilation thesis, reflected upon from two perspectives: climate information (4.4, 4.5, 5.1, 7.1 and Paper VII) and transportation in daily life (Paper II, Paper VI, and 5.1).

I conclude that the main contribution of this compilation thesis to Media Technology research is exploring participation in networks and collaborative production (Chapter 3 and Chapter 4) within the context of "the weather information domain" (3.7 and 4.5), which design theory and some new methods are subjected to (Chapter 5), while I also add a sustainability perspective (5.1, 4.4 and 7.1).

3.3 What are networks?

This section discusses the context of "share weather" in relation to online networks and communities. Since there might be some confusion regarding the miscellaneous definitions of "networks" and "communities", I intend to first discuss their meaning and appropriate definitions for the purpose of this compilation thesis.

Starting with the popular term "Web 2.0", the "original" definition provided by O'Reilly (2005) (see also 3.1) suggests that "Web 2.0" includes networks (connected nodes) without inclusion of "communities", of course unless networks and communities are not equivalent by nature. The concept of "identity" is often introduced when defining the "community" concept. According to Wenger (2011, December 28), "networks" are distinguished from "communities" based on *identity*: The network aspect refers to the set of *relationships*, personal interactions, and connections among participants viewed as a set of nodes and links, while the community aspect refers to "the development of a *shared identity* around a topic that represents a collective intention – however tacit and distributed – to steward a domain of knowledge and to sustain learning about it". Thus, some researchers distinguish "communities" from "networks". Regarding networks and communities as equivalent may not, however, be very controversial. According to Wikipedia (Wikipedia, "Web 2.0"), the "Web 2.0" involves interaction between different users who interact and collaborate in a *social media dialogue* as creators of UGC in a *virtual community* (Wikipedia, "Web 2.0"), although many scholars refer to the term "online" instead of "virtual". The terms "online community" and "virtual community" were introduced by Rheingold (2000). Here, a "community" is a group of interacting individuals, although "interactions" may be limited to or be defined by different sets of relationships (Tönnies 1887). Already in 1887, Tönnies posited that different *kinds* of *relationships* may tie the community members together, with *Gesellschaft*, defining impersonal and formal relationships, representing one. Prior to the rise of the Internet, communities were often associated with geographical proximity and face-to-face communication, which, naturally, includes large portions of socializing.

We may note that the term "social" is frequently attached when describing online settings. For instance, Preece (2000) defines online communities as a collective of individuals that interact socially with other individuals by using computer mediated communication, while adhering to a set of policies imposed by tacit assumptions and protocols that guide their interaction. As the next two chapters will show, there is plenty of evidence in contemporary research on online communities that socializing is also integrated into online interaction, although constituting a different type of interaction through muds, chats, newsgroups, conferencing systems, distribution/mailing lists, social media networking sites, and other new Web 2.0 applications.

Another classification can be added to "networks". Networks may be classified due to the technical platforms used for transactions: wikis, folksonomies, mashups and social networking sites (SNS). Mashups, hybrid applications creating a new feature from a composition of material collected from different sources, might suggests that a Web 2.0 tool may be any tool that uses several sources or features in order to create new content, and none of the sources has to be human. Interestingly, this definition may apply to many existing weather information systems and services commonly supplied by national weather services and enterprises that utilize different kinds of input data: several different weather forecasting models, radar observations and satellite picture analysis. These information sources are all used to improve the output of their services, such as weather forecasts. However, based on the delimitations of this compilation thesis (see 1.6), the research questions posed (1.3), and a first definition of the concept of "share weather" provided in the beginning (Chapter 1, p.1-2), "share weather" is associated with creation and sharing of user-generated content (UGC) between individuals. Because weather information consists of observations and forecasts (2.2.1), it can be posited that weather data describing the current state *observations* are the type of content most likely to be created by users who are not in possession of expert-knowledge, while it may be considered implausible that users will be able to *predict* future states (weather predictions) unless they possess special skills and tools. Therefore, Tönnies' earlier distinction of *Gesellschaft* (1887) provided defining impersonal and formal relationships as tying community members together and does not place constraints on a "community" of weather information sharers constituting a group of people whose relationship is to "share weather", even though the purpose of the interaction is not social. A network of weather observers may, therefore (according to Tönnies for instance), be defined as a "*share weather community"*. Weather is both a topic of social conversations, and, drawing from history, weather often captured the interest of explorers, scientists (for example FitzRoy and Darwin; see Burton, 1986, and Cerveny, 2005) and non-experts, who sometimes made records of weather for no particular practical reasons (Frisinger, 1983). Thus, it seems natural to explore the already existing settings of "sharing weather", using theories on networks and communities.

We may now return to the previous dilemma regarding the definition of Web 2.0 (3.1): what distinguishes networks from other Web 2.0 applications? The social dimension, "the social media dialogue" (see p.42), may be one answer; in that case, Web 2.0 is not always social, whereas networks are. For the purpose of this thesis, I will initially use the following generally broad definition of networks and Web 2.0, which allows inclusion of other technologies (e.g., mobile technology) beside the World Wide Web, drawing on O'Reilly's definition (see p.41-42): *Web 2.0 is a property associated with communication technologies and communication practices that enable users to interact as creators of user-generated content (UGC) in a network*. The next sections will, however, point out that a social component is always integrated in *online* networks, contradicting the current exclusion of "social" in this initial definition.

3.4 Overview of network theory

There are, of course, different approaches to studying human interaction in networks; these approaches originate in a range of different disciplines from psychology to information systems. However, online phenomena create a need to merge different theories that are used to explain more explored offline settings such as: individual cognition, organizations, social movements, information systems and communication among others. One important difference between offline and online constellations is that, in the latter, technology is introduced as a new agent changing the premises of interactions. In this section, I first discuss different approaches to studying networks. As a second assignment, some central features of networks are identified (Table 3) and will serve as a tool in further exploration of "share weather". This points to the next section's (3.5) discussion of why the online status is different from the offline status.

3.4.1. Different theoretical approaches to networks

If communities can be associated with both formal and informal relationships

(Tönnies, 1887), the definition may cover a wide range of topics and relationships: political systems and organizations (such as states, municipalities, official bodies, institutions), economic profitability (such as enterprises and corporations), individuals' personal interests (such as hobbies and other issues recognized as important to different groups of people), and plain social motives (such as social forums for connecting and socializing). It is possible to go as far as regarding the whole society as one entity (Castells, 1997), claiming that we are all connected through one large network. Some sociologists, such as Wellman and Berkowitz (1988), choose to define all social structures as networks constituted by nodes (social system members) and ties (defining their interconnections). In such large structures, individuals may be regarded as moving across different "social fields" (Bourdieu, 1986) in which certain activities are performed due to established rules, and individuals are continuously challenged to defend and strengthen their positions (Gripsrud 2002, p.95). In this approach, the concept of shared "identity" (Bourdieu, 1986) and "trust" (Putnam, 1995) are commonly used to describe the social dimension emerging in networks. In addition, the concept of "social capital" is sometimes introduced. As mentioned previously, Wenger (2011, December 28) uses "identity" to distinguish "communities" from "networks": networks refer to a set of *relationships*, while the community aspect refers to development of a *shared identity*. However, as will become evident in 3.5 and Chapter 4, when bringing communities online, the line between "online networks" and "online communities" becomes blurred, because online networks may also create a sense of identity.

There are some fundamental differences in research approaches, and I will try to outline them below. Table 3 distinguishes between three different theoretical and methodological approaches. First, research may regard individuals as central, or may focus on structures within which individuals interact; these approaches correspond to "micro-" and "macro-" levels respectively. Different research approaches are associated with different "relationship perspectives", as illustrated in Table 3. For instance Layder (1993) argues that research can use the approach of using micro- and macro-perspectives. In general, organization studies and information systems focus on structure, while communication studies and sociologists often emphasize individual properties and personal drives in which interactions and networks are regarded as products of social interactions and communication. In this compilation thesis, I try to regard both these perspectives.

The second important research issue involves the context of relationships and interactions altered within the network. Based on available literature, I propose a simple classification that identifies five different components that may distinguish relationships in networks further discussed in the next section.

3.4.2 Features of a network

A network may be described using some features and components that describe the context in which the network occurs: **nodes** (*who* participates in the network and the context of their participation), **domain** (the type of *information* that is exchanged, general *purpose* with the network, and the *tasks* performed), **ties** (initial *dyadic relationships* and how they evolve), **environment** (defined by transformation from offline to online) and **technology** (used to mediate and communicate) (see Table 3).

Table 3 suggests that networks may form around different goals or topics that define the relationship context in which individuals pursue through their engagement in networks or communities (see *domain* in Table 3). In Media Technology research, networks often refer to interactions issued through media channels. For instance, "mass media" may be regarded as one community, because mass media gathers individual media-consumers (*nodes*) around the activity of consuming media content (purpose, *domain*) while living identical experiences (e.g., Gripsrud, 2002; McQuail, 1987); "Wikipedians" (*nodes*) form a community of contributors of user-generated content to Wikipedia (purpose, *domain*); software developers (*nodes*) that participate in development of "Linux" or "Apache" (purpose, *domain*) for instance represent a community; natural resource management encourages public (*nodes*) participation in environmental issues (purpose, *domain*) (e.g., Olsson et al., 2004; Folke et al., 2003); civic actions (purpose, *domain*) are organized using new media technologies in order to mobilize individuals (*nodes*) (e.g., the Arab spring, environmental protests). In organization research, the goal may be represented by achieving higher performance and efficiency (e.g., an enterprise); therefore organizations today increasingly stress complementarity and informal relations based on trust (Powell, 1990). The *domain*, or contextual purpose of interaction, may entail some fundamental differences between networks. For instance, drawing parallels between large organizations such as national weather institutes and smaller social entities of people gathering around a subject that matters to them personally (for example a sailing club) is not plausible, due to their widely different origin, goals, performance and the motivation of their members to participate in different activities.

While motivation to participate (Q2) is the question focused on in the next chapter (Chapter 4), we may already conclude that the purpose of joining and participating in a network might not be equivalent to the community goals. For instance, different participants may have different motives for taking part in televoting in a television show or open source community. As will be later explored on a deeper level, different research approaches and methodologies are very useful; they are often specialized and can unveil behaviors of different origins. These different approaches are associated with a particular relationship perspective (see Table 3): whether individuals are regarded as agents in networks (micro), or interactions and structure in fact define the network (macro).

The next distinction between different contexts is exemplified by the character of *ties* or *dyadic relationships* between individual members of a community. These may be substantially different and are often described in terms of "strength" of the ties. Namely, ties are often classified as "weak" and "strong" (Granovetter, 1973). For example, a group of car drivers in a city area may consist of solely weak ties, with car-driving as the only property tying them together; a yacht sailing club may be a mixture of a weak and strong tie network diverse in its horizontal structure; while institutions managing weather data may be ruled by strong horizontal ties and homogeneity.

One of the most profound differences between different network settings is that between offline and online *environments*. New premises arising online such as synchronization and co-location are explored by Rheingold (2000). Networks may sometimes be classified according to the mode of interaction (personal/impersonal) and mode of engagement (entrepreneurial/organizational) (Flanagin, Stohl and Bimber, 2006). The logic of behavior and interactions when people gather around a subject online are further discussed in the next section on bringing communities online (3.4).

Finally, *technology* also provides a piece of the context. According to my earlier definition, Web 2.0 technologies include all technologies that enable interaction and are not only limited to "new media" (see p.47). Therefore, the technological options are many.

Table 3. Network features

RESEARCH APPROACH	**Macro (Structure)**		**Micro (Individual)**
Relationship perspective	Structure	Interactions	Individuals
Definition of networks and motivation to participate	Structures decide how networks are formed and evolve	Networks are products of interactions	Agents form networks as a result of personal decisions and desires
FEATURES (CONTEXT):			
Nodes	Co-workers, employees/members of an existing organization, etc.	People with different backgrounds, different geographical locations, etc., gather around a topic	
Domain (Purpose and Tasks)	Learning, Communities of practice, Civic action, Political organizations, Emergency management	Media consumption, Personal interest, Socializing, Civic action, News, Learning, Knowledge sharing, Citizen science, Computing, Crowdfunding, Emergency response	
Ties	Strong, weak	Weak	
Environment	On-line and offline, often Organizational/Impersonal	Online, often Entrepreneurial/Private	
Technology	Storytelling, SMS, Publishing tools	SMS, radio/telephone, Publishing tools, Mash-ups, Wikis, Folksonomies, Social Networking Sites (SNS), Crowdsourcing, Distributed resources	

3.4.3 What kind of network is "share weather"?

The question is how "share weather" networks may be suitably placed and categorized. If we regard the contextual purpose, "share weather" may potentially be defined as borrowing concepts of established research from several disciplines. First, sharing weather information may occur in both online and offline *environments,* while using different *technologies*. Second, weather might be associated with several *domains*: socializing, civic action, news, learning, knowledge sharing, citizen science and emergency response. So *who* are the participants, the *nodes*, of "share weather" networks? I previously suggested that nodes can be represented by individuals active in large organizations (co-workers, members of an existing organization) or nodes in assemblies formed more spontaneously (people with different backgrounds or geographical locations) (see Table 3). The first type of network usually corresponds to offline phenomena that are somewhat extensively explored. The latter is considered by research disciplines studying online phenomena. Both can be associated with the concept of "communities of practice", and I argue that both may be applied to the domain of "weather information". We can start with the notion that weather observations during most of the 20th century exclusively involved organizations. Observing weather was associated with a particular "worker group" of professional weather observers with special training to conduct the task. According to previous use of the "community of practice" concept, it can be fairly linked to "worker groups". Namely, a "community of practice" is a worker group defined by common disciplinary background, similar work activities and tools, and shared stories, contexts, and values (Millen et al., 2002). Another definition suggests that a "community of practice" is a group of people, sharing common practices, who develop their knowledge and expertise together through interactions and "situated learning" (Wenger, 1998; Lave and Wenger, 1991). Learning is regarded as a product of the activity and context in which it occurs (Lave and Wenger 1991), whereby it becomes "situated". Practice, interaction and performance of peripheral tasks leads new members toward learning about the community goals, organization, resources and principles, so that, in the following phase of their participation, they start building skills that enable them to move to more central tasks (Lave and Wenger 1991; Wenger 1998). This concept can be applied to "share weather" as follows: First, observing weather may be regarded as a peripheral task (provided that the community has other important goals). Drawing from Table 3, the official goal, converging with the personal intent, might therefore be to socialize or exchange useful weather information. Weather observations collected systematically may be regarded as "knowledge" (further discussed in section 3.6.1 on "share weather" networks and technologies and in a deeper discussion in 3.7.2). This means that "share weather" may have a primary goal of creating knowledge and other values, with peripheral tasks that include user participation and creation of UGO. While the concept of "communities of practice" originated from research on knowledge management and learning, the idea of linking learning with socializing is also established in sociology. An individual's general learning, cognition, and shaping of his/her identity occurs through "socialization" (Giddens, 2009), which means becoming acquainted, learning, and finally enhancing community norms, codes and customs (McQuail, 1987). Finally, Brown and Duguid (2001) provided an extension of communities of practice, through the introduction of "social networks". They posited that, when individuals share a common practice, knowledge flows across that practice in "social networks" that may be called *networks of practice*. While a community of practice consists of a tightly connected group meeting face-to-face (Lave and Wenger 1991; Wenger 1998), *networks* of practice may be a larger, loosely connected (through weak *ties*), and a geographically distributed (online) group; individuals connected through networks of practice may not know each other, nor do they unconditionally have to meet face-to-face (Brown and Duguid, 2001). The relationships are formal (as suggested by Tönnies), although they might develop towards less formal relationships (that is, stronger *ties*). Drawing from the above, "share weather" may thus be defined as a network of practice, in which geographically distributed, loosely-tied individuals can develop knowledge and expertise through performing peripheral tasks and central tasks, interacting in different ways while producing information that can be useful to others.

This short analysis of potential categorization of "share weather" networks and the features presented in Table 3 provide an overview of some established concepts, while striving to define "share weather". In parallel, it can also be concluded that some original definitions of a "community" – Tönnies' (1887) early definition (including "informal relationships"), Rheingold (2000) ("virtual communities") and Brown and Duguid (2001) ("networks of practice" and "social networks") – somehow seem to converge toward a mutual consistency as their ideas are being applied to *online* network *environments* (see Table 3). Under these conditions, the concept of "network" may be regarded as analogous with "online community". Thus, in some sense, online "networks" are online "communities", and weak *ties* seem quite important. My first conclusion is, therefore, that not only is it justifiable to use the term "network", but that the "community" concept might under certain circumstances be applied to "share weather". The second conclusion is that "share weather" may be related to some established theories associated with learning and knowledge-sharing. Further, "share weather" might occur both offline and online, and different "share weather" constellations can be studied using different existing theories.

3.5 Bringing networks online

Since this thesis aims at a more thorough exploration of *nodes* and *technologies* of "share weather", these features are addressed in more detail in 3.6 (technologies and nodes) and Chapter 4 (nodes and their ties). But first we need to understand the premises of sharing weather information: how do different *environments* shape networks, or communities, within the weather information domain? This section explores the nature of the online status by regarding the differences between online and offline *environments* (see Table 3). These are mutually distinguished by some basic differences: levels of anonymity, the social dimension, different status of organizations and individuals in the re-organized "collective action space" (Flanagin, Stohl and Bimber, 2006), the properties of the "goods" created through interactions, temporal and spatial perspectives, or co-location and synchronicity aspects (Rheingold, 2000).

First, it is relevant to acknowledge the existence of a social dimension even online, and that identities might be created within that social dimension. The discussion of the previous section pointed at a newly-born analogy between "communities" and "networks" as they are brought online. Rheingold (2000) described this in terms of "social presence" and the occurrence of several levels of social connections. In addition, the popular term "social networks" might potentially constitute a wider meaning, according to the findings of the previous section; namely, research implies that all online interactions through networks incorporate a social dimension. This observation might not be surprising due to the fact that communication through any media technology channel involves some range of social cues. Body-to-body interactions (pictures), audial interactions (sound), even plain textual conversations (books and printed media) add a social dimension to every conversation. Interaction online often contains several of these elements: we write, play sounds, share pictures, even physically touch our technical devises. Yet, the limited number of social cues compared to offline conversation, where social cues flourish in diversity and intensity, instinctively suggests that online communication may restrict social interaction in online settings. While the discourse regarding the Internet's negative effects on socializing received attention during the first decade of the Internet era, many researchers later claimed the opposite, highlighting that social relationships can also be created through the Internet (Wellman et al., 2001). Thus, social dimensions and identities might also be present in "share weather" networks; moreover, this can be supported by plain intuition due to the very personal nature of this subject.

Several differences between online and offline settings must, however, be considered. The first is associated with anonymity. The ability to interact anonymously may lead to a lack of responsibility and accountability (Krosnick, 1999) and, on the other hand, the threat of restricting or violating an individual's privacy. For "share weather", it must be considered that hidden identities can alter deliberate violations and inaccurate input. A related issue concerns privacy and new possibilities to track online behavior, activities and content. Both phenomena raise some ethical concerns, and these are addressed in Chapter 5 (5.3.9).

The next issue regards the new order of community hierarchy created by the Internet. The Internet causes re-distribution of power and re-organization of former hierarchal constructs. Research shows that online environments, by nature, counteract creation of hierarchical relationships, resulting in equalizing statuses. Membership in online communities requires only a network-connected computer with a web browser, while memberships in offline communities might require a set of other properties that may create obstacles to joining. Evidently, the negative side of connectivity is that it also increases the digital divide (Van Dijk and Hacker, 2003) between different groups. Nevertheless, in online communities, instead of social hierarchy (socio-demographic related offline status defined by: gender, age, economic condition, values and political orientation), an individual's reputation and power will form according to that individual's actions while participating in the network. In that sense, online environments equalize individuals' conventional statuses.

Online settings not only diminish the impressions of social cues that may create inequalities and hierarchies, but connectivity also overrides former physical boundaries to communicate. It can be said that online environments re-organize space and time. Rheingold (2000) identified several features that distinguish online communities from corresponding offline phenomena: "breakthrough" constraints allow co-location and synchronization beside social presence and the occurrence of several levels of social connections. Giddens (2009) expresses the idea that new technologies have created an environment in which time and space are compressed, events are disembodied from location, and geographic borders and personal boundaries are easily transcended. Thus, bringing networks online alter some dramatic modifications concerning temporal aspects and space-related parameters associated with a particular network. Since online communication may connect individuals separated by very large geographical distances, co-location has particularly important implications for this complementary thesis centered on a phenomenon that is space-dependent (see definition of "weather" in 2.2.1). Paper I illustrates the impacts of co-location on the development of weather services and meteorology as a science. The development was triggered by new opportunities for co-located and synchronous weather observations; in particular, the telegraph enabled instantaneous transfer of real-time weather observations measured at one geographical position to a telegraphic station with another geographical position (see 2.1 and Fig 1, p.29).

Interestingly, earlier research focused primarily on co-located communities in which the interactions rely on the geographic proximity of its members (Brown and Duguid, 2001; Lave and Wenger 1991). However, it was also evident that co-location does not entirely erase spatial constraints, because, even though each individual is only a few, to be more precise most probably "six clicks away" (Buchanan, 2003) from an arbitrarily chosen individual in the world, people are grouped in clusters according to certain principles. Studies on online networks show that there is a correlation between the geographical location and number of connections in online communities, although people who live in urban areas tend to have more dispersed friends (Backstrom et al., 2010). Individuals are clustered according to geography, cultural background, norms, and other personal properties. Despite unlimited possibilities to reach anybody also online on the Internet, individuals seem to prefer interactions with those they resemble. Therefore, they are clustered in hemophilic groups in which geographical position of their residence constitutes one variable. For instance, De Choudhury et al. (2010) conclude that users similar by location, type of content created, and other characteristics diffuse content throughout Twitter's network, while Java et al. (2007) suggest that the geographic distribution of users deduce user intentions on in their daily chatter, conversations, information-sharing and news-reporting. Easley and Kleinberg (2010) acknowledge the existence of certain individual clustering due to occupational structures and a marketplace of ideas similar to hierarchical media platforms. These findings suggest that online behavior will still follow some rules of corresponding offline environments. This may have implications for "share weather" networks, since sharing weather data mostly benefits individuals that are located within reasonable geographical distances. As previously explained in Chapter 2 (on meteorological data and applications), additional observations might improve the spatial resolution (for improved data assimilation and nowcasting; see 2.4). Thus, sharing a weather observation might, first of all, potentially improve a weather forecast provided to other individuals within the same geographical area.

Finally, the property of created goods resulting from online interactions may be different from those created offline. Prior to the rise of the Internet, Olson (1971) had already suggested that the logic of collective, or civic, action is based on the idea that no individuals take advantage of the effort of other individuals (i.e., free-riding); the result of their actions is, by contrast, referred to as a "public good". Civic action is a context in which free-riding is, generally, irrelevant, since individuals participate in actions that result in the public good; it therefore represents an interesting context that may be studied in order to explore the possibility of "share weather" networks' association with environmental protection. A network of environmentalists who create a social movement, for instance, may develop and operate under different premises online than offline. Several researchers studying the logic of behavior and interactions when people gather around a subject and perform collective actions such as protests, riots, social movements and political campaigns propose that the Internet changes the premises of collective action. This change occurs because the act of organizing may be "decoupled" from formal organizations and more easily accomplished than in the past (Flanagin, Stohl and Bimber, 2006). This finding may suggest that, with the Internet, activities such as "sharing weather" may experience a sudden take-off, because they are no longer coupled to formal organizations such as weather institutes. In fact, the online status changes the way many organizations operate

(Chadwick, 2007). In an era of grave environmental threats, it is possible that weather can be regarded as a "public good", thus "share weather" being organized by institutes might potentially engage many individuals. Parallels can, however, also be drawn to other types of networks where the "goods" created can be used for commercial purposes. Von Hippel and von Krogh (2003) argue that individuals might be willing to share information and ideas, despite the fact that they can be commercially exploited by others. The basic drive in these constellations is that individuals realize the benefits of sharing. And, the Internet makes sharing easier to achieve.

The extensive information-sharing occurring online is, in fact, often explained by the new unique opportunities to merge individuals' interests and issues of the private sphere on the one hand, and discourses of the public sphere and the interests of large organizations (institutes, enterprises), on the other. For instance, Flanagin, Stohl and Bimber (2006) classify networks into four categories due to interaction (personal/impersonal) and engagement (entrepreneurial/organizational) (see also Table 3). They explain that online settings allow easy and sometimes "unintentional transitions" from private to public domains (Flanagin, Stohl and Bimber, 2006) that offer a broader range of possibilities beyond situations where there are "solid, well-demarcated boundaries between private and public". This lack of demarcation may have some important implications for "share weather". In a larger perspective, regarding the role of the United Nations (UN) in the international climate change negotiations, there is a societal interest to both collect climate data and to encourage individual participation, because urgent environmental issues need to be addressed on several levels (WMO, 2010). Also, studies on how climate change protests are conveyed online (Segerberg and Bennett, 2011) show that web 2.0 applications are efficient tools. What we might see in the future is many examples of how online settings allow easy and sometimes "unintentional transitions" from private to public domains (Flanagin, Stohl and Bimber, 2006), trespassing the "solid, well-demarcated boundaries between private and public". These implications – the potential contribution of "share weather" to the society – will be further discussed in section 5.1 and Chapter 6. So far, it can be concluded that "share weather" is of general interest from the perspective of sustainable development and that institutes currently responsible for collection of weather data may be looking for new methods and ways of conducting their tasks and undertaking their responsibilities, of which some will be based on new media technologies and tools. Paper I discusses possible consequences of adaptability of organizations, for instance weather institutes, to the premises of online communication, weather data management and policies and weather information services. Paper I argues that de-coupling from former stakeholders, i.e., weather institutes, eventually might result in the rise of new information flows that change the roles of former institutes and require novel approaches for them to sustain their current role. Papers IV and V refer to possible associations between environmentalist civic actions and the activity of observing weather in "share weather" networks. The summary of the compilation thesis, however, aims at clarifying these statements, using a theoretical framework derived in Chapter 4 and further exploring different motivations in Chapter 6.

3.6 "Share weather" and Web 2.0 technologies

Because this thesis endeavors to design and evaluate the concept of "share weather", I will take the first steps required for the design of a "share weather" solution here. Issues regarding its *technology* features (see Table 3) are strongly related to a design problem. In the attempt to map current practices and contexts that involve sharing of weather information supported by digital applications and tools, in 3.6.1, I provide a short overview of Web 2.0 technologies followed by different areas of application in which online networks have manifested their power and parallels can be drawn to the weather information domain. Some central design features of "share weather" are then derived from these findings in 3.6.2.

3.6.1 "Share weather" and network technologies

Web 2.0 technologies include a range of different technologies, such as publishing tools, folksonomies, mashups, social networking sites (SNS) and wikis. Media corporations are increasingly utilizing these interactive technologies. There is also a widespread use of some more conventional technologies such as cellular phones and SMS that, according to the definition provided in section 3.1, should be classified under the list of Web 2.0 technologies. For instance, the television audience is increasingly characterized by shared common practices, activities, tools, and shared stories; television-watching may resemble participation in a community (Gripsrud, 2002). On the other hand, the same content that was previously delivered through television, radio, and print media may now be distributed via the Internet and mobile devices. As media technologies converge (Jenkins, 2006), it is justifiable to assume that, in the future, the majority of available tools will belong under interactive technologies. Consequently, constituting a part of the regular news feed, weather information is becoming increasingly integrated with Web 2.0 technologies.

The interactive properties of media are, however, not an entirely new phenomenon, and weather information services are no exception. For instance, networks consisting of a stationary traffic radio reporter at a radio station and volunteers calling in their local observations of road conditions, traffic situation and weather, through their mobile phones, represents a network in which individuals interact, and information is transferred. Nevertheless, many media productions, such as television entertainment shows (with tele-voting), contain elements of interaction based on technologies like SMS. Even before the rapid progress of tools based on

Web 2.0, particularly those created for massive interaction between individuals, media consumers have been able to provide news tips and multimedia content such as photos and videos that could be integrated with regular media news productions. With interactive publishing tools, however, users now become more than just active producers of media content; ordinary citizens can also challenge the role of professionals such as journalists. The content created by consumers can be competitive due to convenience, presence and availability. "Citizen journalism" is a manifestation of the "expert paradigm" (Levy, 1997; Benkler, 2006); publishing tools designed for "ordinary people" enable participation on an equal basis, independent of resources and power. The microblog Twitter is perhaps the most well-known tool for publishing short texts that may contain news material. Other publishing tools such as blogs – digital diaries that can be written and read by everybody – are accessible at low cost, enabling publishing of content created by creative commoners.

Putting "share weather" into the context of publishing tools means that users are able to publish content, making it visible to everyone else on the Web. This may, first of all, refer to established sites for sharing weather data collected through privately-owned weather observation stations, today acquired at a reasonable cost. For instance, initially established by amateur radio operators, a network of over ten thousand weather-observation stations incorporated in the Citizen Weather Observer Program (CWOP) in the US expanded with the opportunity to share weather data via the Internet (www.wxqa.com). There are several examples of "share weather" networks, such as networks of private weather stations (www.awekas.at) "storm spotters" (NOAA "Skywarn"), and verifications of weather radar observations with the help of volunteers (NOAA "PING"). In addition, media corporations exploit new opportunities to "share weather" through publishing tools: for instance videos taken by eyewitnesses to storms. Weather information today constitutes at least as relevant a news topic as reports since their first publication in newspapers in the 19th century (Simpson, 1987).

Today, publishing may be executed far more smoothly and speedily in the shape of written text messages, on-site reports and warnings produced by users sharing their stories with other citizens. Thus, "share weather" may, in theory, be organized using microblogs or other applications designed for the purpose of publishing UGC. Recent experiences from crisis response and disaster management during severe weather, for instance the hurricanes Sandy in October 2012 and Katrina in 2006, provide such evidence of the increased role of interactive media during weather-related events (Hughes and Palen, 2009). During Hurricane Sandy, twenty million tweets were issued within just a few days (Techcrunch, 2012, November 2). Crisis response is yet another area in which citizens and users, by analogy with "citizen journalism" above, can provide important information and even compete with official sources, a topic addressed by Paper I.

Folksonomies, highly based on content tagging, i.e., metadata enabling linking of content shared by different users into entities, may play a similar role in the collection of weather data. Flickr and YouTube enable sharing of photos and videos, respectively, while Twitter uses "hash tags" for organization of conversations. Because folksonomies organize data using metadata, this technology may potentially be useful for collection and distribution of data associated with an information domain that is easily defined with the help of specific metadata.

Mashups, hybrid applications creating new features from a composition of material collected from different sources (Maness, 2006), are based on principles similar to many existing weather information systems. In order to improve their outputs, weather forecasts and weather information systems utilize different kinds of input data: several different weather forecasting models (NWP; see 2.4), radar observations and remote sensing and satellite picture analysis. However, in weather information systems, the data are manipulated before being presented (see 2.4).

On Social Networking Sites (SNS), users not only publish their profiles including backgrounds, photos, work and other personal information but also connect with friends with whom they may interact and exchange different information. In contrast to real-life (face-to-face) friendships, SNS enable distant and geographically proximate friendships, i.e., the relationships may be either real or virtual. The increased use of SNS, currently with Facebook representing the largest SNS with over one billion users worldwide, largely impacts current media use and practices. Applied in "share weather", it may be suggested that the social dimension may alter useful synergies. Therefore, SNS may be considered relevant as potential "share weather" platforms, a marketplace in which "weather" represents a fraction of the information content.

Wikis enable users to edit different content. Users can collaboratively create different features, including knowledge and other useful information. "Peer production", in which many users contribute to improving content previously created by other users, sometimes manifests considerable levels of accuracy. Wikis are relevant for "share weather" since they can be used for the creation of valuable and high-quality information. The question is how "share weather" can be designed (Q3) to meet the quality issues. Drawing from research on Wikipedia – representing the most famous and considerably successful wiki – it is evident that meaningful, even highly reliable, information can be created by the editing of many users (Luyt and Tan, 2010). Applied to the weather information domain, while aiming at improving weather information (Q1), weather data from different sources should be merged according to a similar process. This merger would suggest a design feature that can handle content editing performed collectively by many users. Since Wikipedia is open for editing by anybody, it is potentially exposed to issues such as accuracy, standards, information sources and deliberate and inadvertent errors. Although there has been discourse within the research community regarding the accuracy of Wikipedia content, most researchers agree on the high level of content quality (Chesney, 2006; Giles, 2005; Luyt and Tan, 2010) nonetheless. These results suggest that a "share weather" wiki might engage participation and that UGC can be relatively reliable. The latter, however, partly depends on the number of contributors, a quantity issue. Therefore, motivational factors, one of the key questions (Q2) of this compilation thesis, further addressed in the next chapter (Chapter 4), are imperative for the level of reliability of the products of a "share weather" wiki (addressed in Paper VIII).

Finally, the terms "crowdsourcing" and "distributed computing" should be introduced in order to cover the terminology of the landscape of Web 2.0. While the previously outlined web technologies are distinguished by their particular technological properties, crowdsourcing is a phenomenon of communication practice. Crowdsourcing can be defined as the act of a larger organization outsourcing a task usually performed by employees, to an undefined, and generally large, network of people in the form of an open call or contest (Howe, 2009). Crowdsourcing often takes the form of peer-production, collaborative production performed by "working consumers". The act of crowdsourcing may create substantial value, and this may distinguish crowdsourcing from UGC created in many other Web 2.0 applications. One example indirectly related to collection of weather information, but directly evaluating social networks as a tool for collection of time-critical data, is the "2009 DARPA Network Challenge". During this challenge, ten red weather balloons were launched at ten previously undisclosed fixed locations, and a $40,000 challenge award was announced to the first team to detect the locations of all balloons. The winning team completed the task within nine hours by using Facebook, Twitter and other social media to share clues, coordinate their search, and double-check their findings (Tang et al., 2011). This example obviously demonstrated that crowdsourcing can potentially be used as a method for collecting and sharing information associated with weather.

Perhaps a more advanced method of participating in crowdsourcing activities is lending one's own resources for the purpose of achieving collective production or collective funding. In volunteer distributed computing, advanced operations that require great computing capacities are performed by distributing computers owned by individuals. Here, computers are lent for performance of tasks, instead of individuals themselves. In "citizen science" (see Irwin, 1995), volunteers sometimes share computational resources in computing-distributed projects (e.g., Nov et al., 2010; Hand, 2010).

A summary of media *technologies* and their areas of application associated with the information *domain* or purpose is presented in Table 4. The upper part of Table 4 and the previous outline of network technologies suggest that "share weather" may take several different forms, and that the strongest parallels can be drawn to technologies: *publishing tools* (also associated with: news, discussion forums, crisis management, civic action), *wikis* (used in: open source software development and knowledge creation), *crowdsourcing* and *distributed computing* (applied within knowledge creation, for instance citizen science).

Table 4. Interactive media technologies and their applications, including User-Generated Observations with the subcategory "Share weather" under the Knowledge creation domain

Web 2.0 applications	**Web 2.0 technologies**				
	Publishing tools	*SNS and SMS*	*Wikis*	*Crowd-sourcing*	*Distributed resources*
News	X				
Crisis management	X	X		X	
Civic action	X	X		X	
Socializing	X	X			
Discussion forums	X	X			
Knowledge creation	X	X	X	X	X
Communities of practice	X	X	X		
Encyclopedias (e.g., Wikipedia)	X		X		
Open source software (e.g., Linux)			X		
Citizen science (e.g., NASA)	X			X	X
User-Generated Observations UGO:	X		X	X	
Built environment (e.g., GIS)					
Natural environment (e.g., biosphere)					
"Share weather"	**X**		**X**	**(X)**	

3.6.2 Nodes and "share weather" technologies

The third question of the complementary thesis (Q3) will focus on how "share weather" might be designed. Design of "share weather" platforms is specifically addressed in Paper V, which describes some iterations of the design process including evaluation. As a part of the design process (see 5.4.2), key properties (design objectives, see 5.4.5) must be identified, and this section provides some relevant theory for that task later addressed in 5.4.5.

Previous experiences of collective production and peer production suggest that the design should address integration of smaller entities of user contributions (UGC) into one larger entity. In order to facilitate task performance and increase motivation to contribute (research question Q2), Benkler (2006) introduces "task granularity" as a key property. This term refers to the tasks being divided into smaller tasks or sets of tasks, meeting the needs of different users with different levels of motivation. While studying citizen science, Nov et al. (2011) proposed that task granularity is highly important when engaging citizens in projects that aim at creating scientific knowledge in which the results themselves represent complex information (see also 4.1.2).

I will here add another two issues that may be relevant for the context "share weather", namely, convenience and attention/awareness. Since weather is a part of our environment, it is almost always "present", and it can be constantly observed; that is, theoretically, everyone might observe the weather all the time. Naturally, this is not the case, according to convenience to observe weather and actively recording and forwarding that information. Paper IV exemplifies this issue with the presence of other, relatively more important, activities that compete with the activity of observing weather and sharing weather observations. Three different groups are introduced in Paper IV (children, adults with long travel-times to work, and an average person) in a "time-consumption model" in order to illustrate the broad range of individual task-performance in everyday life. This "time-consumption" model illustrates how "share weather" might be suited among competitive tasks: transportation, work or spare-time. Due to competition between tasks, individuals frequently may not even be aware of the weather, a situation which reduces their attention. In addition, observing weather may not be convenient, depending on parallel tasks performed. However, it can be suggested that individuals may intentionally focus their attention toward the sky, if they are requested to observe the weather. This compilation thesis suggests that awareness rises naturally, if individuals perceive that weather impacts their lives, either through a sense of solidarity with others within a community of (mass)media consumers, or due to direct consequences of weather on their lives, including safety, property and health. These issues related to motivation are further discussed in the next chapter (Chapter 4, section 4.5) on contexts of human interest in weather.

3.7 "Weather" as the network information domain

This section deepens the analysis of features of networks that belong to the weather information domain. I explore existing "share weather" networks from a media technology perspective, referring to previous findings in 3.6, in order to extract relevant objectives for design of a "share weather" solution. Table 4 suggests that "share weather" networks may be compared with the following existing network categories: publishing tools (used for publishing news, in crisis management, and civic action), wikis (applied in open source software development and knowledge creation), and crowdsourcing (also contributing new knowledge). The domain itself may be regarded as a subcategory of a larger domain:

environmental information. Weather is, practically, present everywhere, and it can be observed by most individuals. As we have previously seen (see Chapter 2), weather is a set of spatial variables that change over time (see 3.1). This definition is also valid for many other variables describing the natural and built environment; they can be observed, measured and documented, sometimes without using any equipment, and they vary in both space and time. Drawing from the theory presented in this section, I introduce the concept of "User-Generated Observations" that may be applied to weather or any other spatial variable that can be observed by individuals and shared within a network.

3.7.1. "Share weather" and publishing tools

Among all technologies and practices that have arisen with the Web 2.0, some have particularly contributed with useful weather information, even to saving lives and property. Section 3.6 previously identified several weather-related networks using publishing tools: media news (daily weather), crisis response (e.g., storms), infrastructure (e.g., traffic) and collaborative action (e.g., climate protests).

As most readers know, weather usually constitutes an important news topic. The mutual identity created by the media (Gripsrud, 2002) is probably one explanation why natural disasters usually attract great attention on the part of media consumers. Additional factors related to preferences on a personal level and individual perception may, however, be equally important, and, since weather varies in space, motivation to take part in weather information is related to geographical position. This fact is supported by research confirming online clustering of individuals, including geographical proximity (Backstrom et al., 2010; De Choudhury et al., 2010). Particularly severe weather events reaching proportions of natural disasters, however, may create a sense of mutual identity and collective belonging that occasionally spans large geographical distances. It can therefore be argued that weather news becomes more relevant due to spatial correlation and the magnitude of the event. Some existing "share weather" networks are examples of communities of practice forming around weather-news production. Because severe weather events may unexpectedly create a need to collect information from remote places or locations inaccessible to regular news teams, "storm chasers" collect information on-site and forecast future developments, although the majority of storm chasers are not professional meteorologists. The products of this collaborative work are used in news production, and they sometimes evolve towards online communities (e.g., stormtrackers.org). While the first technology used was the radio, storm chasers today use rich media and sophisticated instruments and technology available at low cost.

Emergency response is another context in which Web 2.0 publishing tools are used for sharing information related to weather. Extreme weather events account for 90% of natural disasters (WMO, 2009b). During such events associated with disasters and crisis, the public becomes an agent while taking an active part in the developments (Hughes and Palen, 2009). Web 2.0 technologies facilitate such participation, and media news is created by individuals in terms of: pictures, blogs, microblogs (tweets), and documentaries (see www.ushahidi.com). For instance, the microblogging tool Twitter is used to mobilize and organize crowds during emergencies (Vieweg et al., 2010). In fact, during Hurricane Sandy in 2012 over twenty million Tweets were sent between October 27 and November 1 (Techcrunch, 2012, November 2).

Web 2.0 publishing tools are also interesting from another point of view; they are used in civic action, affecting the public sphere, politics and societal structures in new ways. One example is environmental protests organized by using the popular microblog Twitter (Segerberg and Bennett, 2011). Thus, the information domain studied in this compilation represents a topic of public discourse, societal and moral concern, and sometimes controversy, associated with climate and environmental change. "Share weather" tools may potentially become platforms for public participation in environmental issues (Paper III, Paper IV, and Paper V).

This matter might at first appear simple; as previously concluded, publishing weather news is associated with the magnitude and type of weather event. However, some weather events may cause impacts far less serious than the effects of occasional natural disasters of large magnitudes (which are less frequent). Events of smaller magnitudes, however, are common in everyday life. Their consequences may be limited to a local geographical area, but the effects may be perceived as serious to some individuals. Here, the need for weather information is created in order to facilitate human activities and reduce loss of property and efficiency (Basher, 2006; Paper I and Paper II). Transportation is an activity evidently affected by weather (see Paper II). One of the first networks ever established was transport-related, namely traffic information systems managed by traffic reporters from radio studios who collected data on road conditions, traffic flow and incidents, based on information supplied by the public. Today Intelligent Transport Systems (ITS) offer centralized systems for monitoring, surveillance and traffic management for officials. While their requirements on accuracy and reliability of the sources (own systems of observation network) are often very high, traffic radio information systems are informal, yet very efficient networks, based on joint efforts by journalists and volunteer citizens (see Paper I).

From this outline, it can be concluded that "share weather" networks may exist in both organized forms and looser networks based on information supplied by volunteers. "Share weather" may be positioned within both types of domains in respect to the properties of the nodes and their ties: organized and volunteer networks (see Table 3, p.50). But what shapes might "share weather" take according to the definition provided in this thesis? This question can be answered if we regard the nature of the content.

3.7.2. "Share weather" networks and knowledge creation

"Share weather" is, first of all, aimed at improving weather information, by analogy with the definition of "share weather", the aim and research questions of the thesis (see Chapter 1, p.8-9). Improving information means contributing better information or new knowledge. So, "share weather" might belong under the major domain of "knowledge creation".

Knowledge creation can be associated with wikis (for instance used in open source software development and online encyclopedias) and crowdsourcing (e.g., public participation in scientific projects). Several examples can be identified within the domain of weather information, and they usually occur when volunteers collaborate with officials. The rise of the Internet enabled sharing of weather data collected by small private weather stations, some of which were organized by officials and others constituting smaller, private, initiatives. The most prominent example of "share weather" networks is represented by the public-private collaboration project Citizen Weather Observer Program (CWOP) (www.wxqa.com) initiated by the US national weather service. This service has been subject of studies of collaboration in online communities, according to Nov et al. (2011), who termed the phenomenon "scisourcing", synonymous with "citizen science" (Irwin, 1995; Hand, 2010).

Such "share weather" networks may also be regarded as communities of practice. If individuals gather around "sharing weather" as a topic, they may also interact, gain new knowledge, and create mutual identities (see 3.4.3). For instance, the US "storm spotters" collaboration established in 1948 are volunteers that receive special training by the National Weather Service in order to conduct their own observations of weather phenomena. The "storm spotter" program thus resembles a community of practice in which a large organization collaborates with volunteers. More precisely, people with different backgrounds, different geographical locations, etc., gather around a topic (see Table 3, p.50), while learning and creating valuable knowledge. Thus, for "storm spotters", collecting weather information represents a community goal, i.e., the information domain or purpose (see Table 3).

If individuals are, instead, requested to provide information or complete a task by an agent who might benefit from that information, the "share weather" network is associated with crowdsourcing (Howe, 2009; see 3.6.1, p.60). This type of collaborative project between officials and non-experts is similar to "citizen science".

From this outline, I conclude that wikis seem the most appropriate alternative for achieving the goal proposed by the compilation thesis. In many ways, wikis are distinguished from publishing tools and, for instance, SNS, because wikis are aimed at creating meaningful content that can be stored and still keep its original value. Here, it should also be noted that weather information is of a twofold nature: weather may be news (and instantly consumed) or climate data (that are stored). While publishing tools can be used for some collaborative operations associated with weather, "share weather" networks aimed at improving weather information must address the requirements of data that are stored and classified as knowledge. It can also be concluded that examples of "share weather" networks based on new interactive technologies are very few. Current interactive technologies are usually associated with severe weather crisis management rather than improving weather forecasts on a regular basis.

Knowledge creation, for instance online encyclopedias (e.g., Wikipedia) and crowdsourcing, use wiki technology and "peering", a method that produces relatively reliable results (Chesney, 2006; Giles, 2005; Luyt and Tan, 2010). According to the reasoning in section 3.6.1 on "share weather" and different network technologies (see Table 4, p.61), "share weather" needs a design feature that can handle content editing performed collectively by many users. In addition, it should address issues associated with user editing: accuracy, standards, information sources and deliberate and inadvertent errors. Of course, situations are different depending on the nodes and the context of their participation, whether they are workers who belong to an organization or arbitrary users who voluntarily contribute content. Considering the possibility that the nodes might be organized, another relevant subdomain is represented by open source software (see Table 4). Interestingly, open source software collaboration platforms often arise according to a specified need to develop new tools that are not available on the market. According to von Hippel and von Krogh (2003) and Powell (1990), online networks for knowledge sharing frequently emerge in fields in which the pace of technological change requires access to knowledge unavailable within any single organization. What does this mean? In the case of open source, already in the 1960s, while using computers in their work, researchers started to share software code because commercial software was not available (Stewart and Gosain, 2006). Today, an industry is organized around the sharing of open source code in which professionals with different interests gather in collective problem solving and software design. As applied to "share weather", it can be suggested that the introduction of Web 2.0 technologies creates an opportunity for the advent of new "share weather" applications and practices that may offer innovative solutions and serve needs and opportunities that were not foreseen at the time of raising the fundament of current share weather practices. As previously mentioned in Chapter 1 and Chapter 2, these are still based on technologies available in the 1950s, for instance the WMO SYNOP observation network (see 2.2.1) and the principles behind NWP data assimilation (see 2.4). Now, contemporary technologies offer many alternatives with a vast number of potential new observation points (see 2.1.2).

3.7.3. Sharing environmental information

Exploration of the information domain, weather, leads further towards closer examination of its content. We previously concluded that "share weather" is aimed at creating knowledge. But what knowledge category of information is here addressed? Weather is obviously a part of the environment. While the previous two sections focused on existing networks within the "weather information" domain, here, I examine domains that might be similar, not by their exact characteristics but through their similar *purpose* (see Table 3), applications, and the way the content is created. Some of them are associated with meteorology sister sciences.

Namely, parallels can be drawn to related work on collaborations centered on other types of environmental data. The term "citizen science" is often applied (Irwin, 1995) when referring to research collaboration or data gathering, knowledge creation, based on wikis or crowdsourcing performed by untrained "non-expert" members of the public. Citizen science appears within: ecology, biology, geology and space exploration.

Current volunteer programs may be divided into three different categories: supporting projects through lending one's own resources (such as one's own computer power), actively observing the natural environment (for instance species populations), categorization of geological features and providing input to Geographical Information Systems (GIS) (see Connors et al., 2012). For instance, NASA recruits volunteers for creation of new scientific knowledge through classification of pictures of celestial bodies, such as the Moon and Mars, in order to perhaps improve Martian maps (see "clickworkers" in Benkler, 2006). Other NASA projects offer volunteers the opportunity to discover new celestial bodies including the privilege of "naming a star". Another example of collection of spatial and environmental data from volunteers that not only confirms the efficiency of crowdsourcing operations, but also suggests that results of citizen science projects may be exploited by organizations and enterprises is presented by Tapscott and Williams (2006). They point out that geological data were collected for the mining industry by volunteering individuals who manifested proof of extensive local knowledge, and these operations proved very successful for the gold-mining company. I regard contributions to the knowledge corpus on living beings and ecosystems as a second category, not without similarities to GIS, although it focuses on the biosphere in particular. A third category of projects comprises contributions in computing-distributed projects, that is, providing computational power to scientific projects and discoveries, such as SETI@home that uses Internet-connected computers in the Search for Extraterrestrial Intelligence (SETI) (Benkler, 2006; Hand, 2010, Nov et al., 2010). While the third category refers to lending one's own resources such as computational power, I conclude that there are two application areas in which volunteers can offer their help in monitoring the current state of their immediate environment, and these are the built environment, and the natural environment. I will return to this finding later in this compilation thesis, as the perspectives of human interest in weather are explored in section 4.5 and also presented in Table 5.

It is obvious that the research areas related to environmental monitoring are in the midst of robust and rapid progress and that new results will be acquired within the near future. Capabilities of Web 2.0 increasingly attract researchers within disciplines such as ecology, biodiversity, and natural resource management. The general collection of data is encouraged by Kowal (2002). Some researchers suggest future webcrawlers digitally monitoring ecological flips (Galaz et al., 2009). Some research already provides interesting results, in particular the domain of birds is being explored, for instance the online community for birders to report observations, eBird (Sullivan et al., 2009). Further, Irvine et al. (2009) integrated local knowledge to greatly increase accuracy of deer habitat models. Ground-level crowdsourced imaging (photographs taken by individuals) is suggested by Newsam (2010) for land use/land cover determination. Kearns et al. (2003) describe how web tools are used in sustainable natural resource management, while Kelly et al. (2004) suggest web tools for detection of forest disease. The classic examples are related to observations of bird populations (Greenwood, 2007), significantly associated with pioneering environmentalist work such as *Silent Spring* (Carson, 1962).

In accordance with different weather observation collaboration projects such as the Citizen Weather Observer Program (CWOP), (see 3.7), the majority of these projects assemble human resources in terms of volunteering individuals that help to create new “knowledge” that can be used for scientific purposes as does CWOP (see 2.4.3). Individuals are asked to contribute information or resources that result in the creation of new knowledge. There are relatively few “crowdsourcing” operations orchestrated by a third-party in the form of a competition, for instance the DARPA project (see 3.6.1), and these rarely occur within the weather information domain. One example is the online Encyclopedia of Life (EOL), an idea dating back to the 1990s. EOL is a partnership between the scientific community and the general public, collecting and providing knowledge about any of the world’s organisms known to date. UGC is handled in a similar way as Wikipedia allows publishing of user-generated contributions in which anyone can register as a member and add: text, images, videos, comments or tags to EOL pages (Preece et al., 2011). In this respect, “share weather” has many similarities with other subdomains mapped under the natural environment.

Environmental information is interesting in particular if regarded from a historical perspective. History points to important parallels and synergies between weather information and other environmental data sets. In the 19^{th} century, Charles Darwin, the founder of modern evolutionary theory, took an interest in both meteorological conditions and local biological knowledge of people he encountered during his voyage on the Beagle (Cerveny, 2005). The captain of the Beagle, Robert FitzRoy, later became the head of the Meteorological Department of the British Board of Trade, founder of their first weather-warning service (Burton, 1986) and established one of the first theories of movements of weather systems (FitzRoy, 1863). Synergies between explorations within biology and meteorology had already emerged in ancient Greece, as Theophrastus, the pupil of Plato and Aristotle, wrote on both signs of coming weather events and signs in nature (Theophrastus, 2007). This may seem natural, since both biology and weather are features of the environment visible to and classifiable (in some ways) by most individuals. Just as weather information attracted particular individuals to record weather variables (Paper I; Burton, 1986) contributing to development of modern meteorology, pioneers within biology recorded biological data that were used for the development of biology (Taylor, 2008). The German botanist Georg Rumphius produced a catalogue of local biological knowledge, *Herbarium Amboinense*, including the plant's name, illustrations, description for nomenclature, place, discussion of the plant's use to the local inhabitants, stories, folklore and religious practices. During the 18th century, one of the fathers of modern ecology, Carl Linnaeus, referenced Rumphius's work and, in addition, corresponded with other observers throughout the world while developing the biological classification scheme with binary nomenclature in his *Philosophia Botanica* (Taylor, 2008). Linnaeus emphasized that both learned and lay people could participate in the methodical classification of plants. He therefore reached out to new audiences and collaborators (Koerner, 1999).

It is interesting to note that the pioneer "experts" were largely self-taught, their knowledge being based on empirical evidence and systematic collection of data, along with consulting others, and greatly emphasizing evidence collected by eyewitnesses. Some examples are Darwin's collection of evidence from the people he met on his voyages and Linnaeus's collaboration with other observers. Experts taking on the role of explorers and first-time collectors of evidence on classification systems in biology or trying to systemize occurrences of meteorological phenomena suggest that the limit between experts and non-experts sometimes may be blurred. This phenomenon can be described using the concept of "collective intelligence", later addressed in 3.8.

The importance of local knowledge possessed by non-experts is illustrated by yet another example based on "storytelling". Today, the research area of "traditional ecological knowledge" is introduced in order to preserve empirical evidence stored and replicated in traditional societies. The most interesting implication of ecological knowledge is that observations made by non-experts sometimes provide evidence of events that provide useful data if placed in a larger context, although per se they represent indices. Changes, such as shifts in storm tracks and intensification in the evaporation and precipitation cycles due to climate change that alter the frequency and intensity of floods and droughts (Milly et al., 2002; Paper III; see also 2.3), may be rejected as indices, or not even noticed, if observed as single events. Kelling et al. (2009) explain that in biodiversity the massive volumes of scientific data may, with appropriate methods, identify interesting, truly novel and surprising patterns that are "born from the data;" a "data-driven" approach is necessary because of the complexity of ecological systems, particularly when viewed on large spatial and temporal scales. Patterns that are otherwise not apparent may now provide valuable insight for hypotheses about the underlying ecological processes. Researchers within natural resource management also emphasize that traditional knowledge from individuals and communities can be systematically combined to produce accurate regional pictures of change, based on indicators rarely monitored by science (Fenge, 1997). Ecologists cannot measure the impacts of climate change everywhere; neither can they go back in time and conduct measurements of past conditions. What is, however, possible, is to collect stored data (e.g., decades or centuries) created through "storytelling" of "traditional ecological knowledge".

For instance, researchers have found data supporting that "traditional ecological knowledge" may supply information on the impacts of climate change. A reference may, again, be made to Darwin's work. He began by observing phenomena typical of La Niña episodes from a rather small data set and recorded indices that systematically pointed to the existence of El Niño (Cerveny, 2005). In modern times, the valuable knowledge possessed by non-experts is increasingly highlighted. For example, when assessing land degradation, experts tend to underestimate "the abilities of local farmers, many of whom have been able to modify their land management" (Stroosnijder, 2007; Paper III). Mackinson (2001) suggests a method for complementary use of science and traditional knowledge. It is claimed that ecological knowledge may be suitable for identifying environmental changes attributable to climate change at the local and regional level (Kofinas, 2002). Reidlinger and Berkes (2001) studied a case in which useful environmental monitoring was performed by non-experts in the Alaska Yukon River subsistence, used for identification of a suite of environmental changes that impacted fish, fish habitats and fishing activities, with observations of drying-up of wetland areas, lakes, and waterways, as well as changes in weather patterns. Kitson (2004), and Lyver and Moller (1999), studied prolonged, recorded observations of populations of titi birds in New Zeeland, introduced by locals before the scientific community, as a part of systematic collection of data forming the basis for knowledge necessary for daily planning, nourishing and survival. In particular, people of Rakiura Maori, who travel to thirty-three Pacific islands to harvest "titi" birds, observed the populations and well-being of the birds, for instance the "rate of catch" (Kitson 2004). Interestingly, many "titi" harvesters kept written records of weather or moon conditions during each hunt, in many instances going back for decades. Kitson (2004) claims that the observations have manifested a correlation with climatic perturbations known as El Niño. Another case from Newfoundland cod fisheries demonstrated how coastal fishers registered changes in the ecosystem long before the collapse of the fisheries occurred (Finlayson and McCay, 1998).

These examples provide some empirical evidence that environmental monitoring can be useful to the scientific community and society as a whole. In environmental politics and natural resource management, collection of data is necessary in order to prove existence of a problem, prior to taking measures of collective action or natural resource management. Researchers also highlight the importance of collaboration between different actors in order to realize natural resource management in practice (Alcorn 1993, Hackel 1999, Berkes et al., 2003). In an example from Lake Racken, Sweden, local residents played a key role in developing indigenous ecological knowledge and reshaping management practices (Berkes et al., 2000).

So far, I have examined existing networks for sharing environmental information, which are later referred to when analyzing "share weather" networks and studying the "share weather" concept. It can be concluded that the work of many scientific explorers relied on empirical evidence collected from individuals who were non-experts. Additional theory associated with environmental information is further developed in Chapter 4 focusing on motivation (section 4.5).

3.7.4. User-Generated Observations (UGO) of weather

The previous outline of theory, discussions and drawing some conclusions now allows further scope for reference to the concept of User-Generated Observations. So far, this chapter has provided material that may help one understand some relatively recent phenomena occurring online *associated with communication technologies and communication practices that enable users to interact as creators of user-generated content (UGC) in a network* (see definition of "Web 2.0" in 3.3, p.47). Since "share weather" was defined as a concept with the aim of improving weather information, it naturally suggests that user-generated content (UGC) should contain weather observations, because they might potentially improve weather forecasts and climate information (see 2.3 and 2.4).

Features of a network presented in Table 3 (p.50) suggested that the concept of "share weather" can be related to the following information domains: news and knowledge creation (corresponding to publishing tools, wikis, and crowdsourcing; see Table 4, p.61). Further exploration of related information domains unveiled some common forms of participation: lending one's own resources (e.g., citizen science computer-distributed projects) (see Hand, 2010), occasional participation in competitions (crowdsourcing), and volunteer participation on a regular basis. All these forms of collaboration may include user-generated content that describes the environment and its current state (observations). This concept also includes the "built environment", while weather may be situated within the category of the "natural environment" suggested by the definition provided earlier. To be precise, weather is *a set of variables in the environment describing the current state of the atmosphere changing over time and varying in space* (see 3.1, p.41, or 2.2.1). The atmosphere constitutes only a part of the environmental system. Other components of the natural environment are (Peng et al., 2002; see also 2.3): the biosphere (living things, or ecosystems), the hydrosphere (water such as rivers and oceans), and the cryosphere (including soil).

Most variables describing the natural and built environment vary in space and time, and many can be observed by humans. If we then consider Web 2.0 applications in which users create content (UGC) describing the current state of the environment, including weather, I suggest that these can be put into a new category of Web 2.0 applications centered on "User-Generated Observations". The concept of "User-Generated Observations" (UGO) may include both the built environment and the natural environment. This means inclusion of various phenomena different by nature and areas of application, such as traffic conditions and road surface observations along with observations of the sky, soil and ecosystems.

The purpose of introducing UGO is to include as many different types of information domains as possible in order to detect and make use of potential synergies. As will be explored later in the papers and the summary of the compilation thesis, the context of transportation in daily life is associated with several sets of environmental variables that, from the perspective of research disciplines that study these variables separately, have very little in common with studying the natural environment. However, if put into the context of an action performed by users, for instance transportation, several different sets of variables may be observed simultaneously. Encouraging people's interest in sharing weather information requires a user-centered approach; we must examine how people relate to weather on a personal level. In user-centered services that adopt the perspective of the user (Paper II; 5.3.2; 5.4.1), different sets of variables must sometimes be brought together, spanning disciplinary boundaries. I will here provide an example relevant to this thesis: Atmospheric models such as NWP (see 2.4) aim at predicting meteorological conditions; they calculate future states of the atmosphere in terms of air temperature, pressure, wind, and humidity. A user might, however, be interested to know the *consequences* of weather in the future, i.e., *predictions* of how the weather *feels, how* and *how* quickly to get to work/activities, *whether* it may be *hazardous* to perform an activity, and *if* and *when* spare-time activities such as outdoor-hobbies might be most *enjoyable*. These are the kinds of observations users make. Another example is measuring the impacts of climate change. While decision-makers really want to measure the *impacts of climate change*, available measurements usually consist of CO_2 concentration levels in the atmosphere.

Foreseeing weather might indeed represent a challenge, but predicting the consequences of weather is far more complicated, since these predictions must involve several sets of variables that describe the environment. For instance, in order to predict how fast the user might arrive at work, all of the following are required: forecast of meteorological conditions, observations and forecast of road surface conditions (e.g., ice, water), prediction of traffic flows, and accurate city maps. Calculations of future impacts of climate change, such as those used for climate change mitigation (IPCC, 2007) also require many different sets of variables that involve both the natural and built environment.

I conclude that variables describing both the built and natural environment are relevant to users in everyday life. Synchronicity and co-location of Web 2.0 creates a number of opportunities to facilitate collection of useful observations of the environment created by users, User-Generated Observations (UGO). Users that participate in creating UGO may contribute useful information, knowledge that can be utilized by others such as other users, and systems that further process UGO into useful services adjusted to the context within which the user requests information services.

3.8. Summary: What is "share weather"?

The general question of the compilation thesis is how sharing of weather information involving individuals can make a contribution in terms of useful information and how such systems might be designed. The concept of User-Generated Observations (UGO) may, now, provide a closer definition of "share weather" as, guided by previous findings of this chapter, I narrow the concept to a particular subdomain:

"Share weather" *is associated with communication technologies and communication practices that enable users to interact as creators of User-Generated Observations (UGO) in a network, particularly focusing on, but not limited to, the subdomain of "weather information"* (a set of variables in the environment that describe the current state of the atmosphere changing over time and varying in space).

This section presents relevant research on user-generated content (UGC) and filtering processes necessary in order to proceed with understanding the concepts of UGO and "share weather" and addressing the research questions of this compilation thesis. This section also summarizes some findings of Chapter 3.

3.8.1. Network features associated with "share weather"

We are finally ready to draw the objectives of a "share weather" solution. First, we conclude that in online networks aimed at observation of the environment and exchange of related information, i.e., User-Generated Observations (UGO), the *context,* including the information *domain*, (see Table 3, p.50), defines premises under which individuals will decide to contribute content. Some features that describe the context were presented in Table 3: network *nodes* (who), *purpose* and information *domain* ("what" information is exchanged or "what" actions and tasks are performed, and "why"), *ties* (the nature of dyadic relationships between nodes), the *environment* (including online or offline) and the *technology* used (how).

Some first arguments that suggest a strong user-centered approach and design were presented (see 3.7.4). According to Table 3, "share weather" networks may be associated with personal interest such as hobbies, socializing, and civic action or learning and emergency response. Concepts that might be associated with "share weather" are therefore: communities of practice (see 3.4.3), crowdsourcing, citizen science, collective action and microblogging. Based on the previous discussion in section 3.7.4 that introduced weather observations as a subdomain of UGO, we may now add several subcategories to the head category "knowledge creation": the built environment (including GIS), and the natural environment (including "weather"). Terms such as "citizen science" (Irwin, 1995; Hand, 2010) and "scisourcing" (Nov et al., 2011) (see also 3.7.2) may refer to the *purpose* under which collaboration was established between the nodes (e.g., citizens participating in scientific projects initiated by the scientific community). "Share weather" might potentially take the form of "citizen science". However, several other collaboration forms may arise, such as those between an enterprise and individuals, organizations, professionals, or a network consisting of only individual citizens exchanging weather information.

Depending on the goal of a particular "share weather" network, I also concluded that wiki technology might be appropriate, although crowdsourcing might be applied as well. The definition of "share weather" networks implies that they collect, and possibly process, UGO. Thus "share weather" technology features include interfaces for collection of UGC. It might also be desirable to display different activities taking place in the "share weather" network to other users, or publish the content or even share the collected data with others. Publication tools are therefore also an important feature.

The dual nature of weather information, weather and climate, adds another aspect regarding potential application areas for "share weather" outputs. Just as "knowledge" and "news" represent different types of values, "climate" and "weather" are two separate things. While news and weather forecasts may generate values during crisis management for instance, the value of weather forecasts in news declines rapidly after consumption. The value of knowledge will, in contrast, persist; knowledge can be used for a long time after its creation and consumption, and climate information data series will be most useful in the future. Furthermore, it is highly credible that individuals will pay attention to weather and become engaged and motivated during extraordinary events (3.7.1), especially if related to activities that concern them personally. Including features presenting weather forecasts is, therefore, highly desirable. From a societal point of view, weather forecasts are relevant for the safety and protection of lives and property, although the societal interest goes beyond the present into assessing future climate and projections of future climate (see 2.3). "Share weather" thus aims at serving some of the goals of sustainable development.

3.8.2. Delimitations of the concept of "share weather" used in the thesis

The strong interest in weather in everyday life may potentially imply that "share weather" should use several technologies for collection of data: publishing tools, wikis, folksonomies and SNS. However, this compilation thesis makes a delimitation regarding the context under which weather data are collected. As will be discussed in Chapter 7 (7.1.3), there are several ways of accessing weather data. Take, for instance, weather information provided in SNS. Facebook (currently the largest SNS) and Twitter (a hybrid of SNS and a publishing tool) sometimes contain weather information that individuals share with others. This type of sharing occurs more or less randomly and can only be accessed through the introduction of methods that may localize and identify relevant messages and interpret the content of free text messages. I conclude that it would be more convenient to interpret and integrate weather information provided through publishing tools that consist of different types of modules of low task granularity (e.g., smaller entities of user contributions into one larger entity; see 3.6.2) instead of self-composed text.

Furthermore, the use of computing-distributed resources (e.g., volunteer distributed computing), i.e., physical resources supplied by individuals is not specifically addressed in this compilation thesis. It is, for instance, possible that "share weather" may use networks of distributed computers owned by individuals to perform weather data collection, weather data processing and even weather forecasting. I suggest that future research should address these other approaches to sharing weather information.

3.8.3 "Share weather" intelligence

I previously suggested that "share weather" might use wiki and crowdsourcing technologies, and filtering methods based on "peering" (see for instance 3.7.2). We must here consider the accuracy of outputs of "peering" technologies. Jenkins (2006), Benkler (2006) and Chesbrough (2003) use the term "collective intelligence" to label products of collaborative work that are useful, that is information, design and artifacts that may be utilized or further processed by others for a meaningful purpose. This phenomenon may refer to problem solving; Jenkins (2006), for instance, provides examples on how the audiences of TV-shows reveal the truth or create stories of their own through detective work of scrutinizing coming events, based on stories, rumors and observations. The starting point is that collective intelligence has been proven quite efficient. For instance, although authored by “amateurs”, Wikipedia articles are actually quite accurate and reliable (Chesney 2006; Giles 2005). Open source has proven quite efficient (e.g., Linux). “Peering” through many users' editing of a text (as in Wikipedia) or classification of pictures (for instance NASA clickworkers) can produce meaningful and highly reliable content, thus contributing to “knowledge”.

The power of “collective intelligence” (Jenkins, 2006; Levy, 1997) is redefining our traditional assumptions about expertise and encouraging changes in the “knowledge hegemony” of a number of fields (Walsh, 1999) (Paper III)., This may not be as surprising as is might appear at first, however. Nor is collective intelligence an entirely new phenomenon. Namely, traces of collective intelligence have remained throughout history. As I previously described in 3.7.3, pioneer “experts” were often self-taught, and had to build their knowledge on empirical evidence and systematic collection of data. Moreover, they often consulted others and used empirical evidence collected by others. Some examples are Darwin’s collection of evidence from the people he met on his voyages and Linnaeus’s collaboration with other observers (see p.69). Exploration implies collaborative work and collective intelligence, and the line between experts and non-experts is blurred. Knowledge sharing frequently emerges in fields in which the pace of technological change requires access to knowledge unavailable within any single organization (von Hippel and von Krogh, 2003; Powell, 1990) (see also 3.7.2).

Consequently, calling related terms “citizen *science”,* “collective *intelligence”,* and “scisourcing” (Nov et al., 2010), in which “scientific” and “intelligence” might appear provocative to some, is far from unjustified and not only figuratively; the striking level of quality manifested in outcomes of crowdsourcing and collective intelligence confirm the crowd’s capability of reaching the levels of scientific work which indeed may justify the word “intelligence”. Drawing from such experiences, it is justified to assume that the output of “share weather” knowledge-sharing might be comparable to equivalent data collected with methods developed by professionals. As appealing as it might sound, this can, unfortunately, only be possible under certain conditions. The quality of the outputs of “share weather” depends on the volumes of contributions. This can, first of all, be compared to the meaning of “scientific”, and “intelligence” might also be near at hand when thinking about great human achievements.

“Scientific” usually requires an area of study corresponding to an academic discipline, for instance meteorology. Scientific work is, by analogy with the outline later presented in Chapter 5 (5.1), provided with two claims. Namely, scientific means that scientific methodology (further addressed in Chapter 5) must be applied, and one of its properties is that it is systematic. Second, science should produce relevant knowledge. In this chapter, I have manifested how “share weather" can be related to sustainable development; "share weather" can therefore be regarded as relevant knowledge. Moreover, the outputs of "share weather" might also contribute important and relevant data that can be utilized by the scientific community. Finally, "share weather" can be designed to collect data in a systematic way.

Nonetheless, as in scientific work, the size of the sample is of critical importance. In science, validity of a result is partially dependent on the size of the sample (see also 5.2.3 and 5.3.4). For instance, a satisfactory level of significance means that the number of individual participants (of the sample) should be sufficiently large to provide the same result, independent of the individuals who are participating (i.e., the sample) (Herzog, 1996). This is also valid for citizen science and other forms of collective intelligence.

At this point it becomes evident that *quantities* of information, i.e., the number of nodes supplying useful information, will determine the future potential successes of "share weather". In order to understand how "share weather" might contribute to improved weather information, motivational drives to participate and contribute UGO should be investigated. In the next chapter, Chapter 4, motivation to participate in "share weather" is explored based on available research on online networks.

Chapter 4
Motivations for online sharing and "share weather"

The key question is: can "share weather" be realized in practice? In the previous two chapters (Chapter 2 and Chapter 3), the occurrence of phenomena in which individuals share weather information was confirmed (see 3.7). In fact, people have shared weather information since ancient times (2.1) and have developed sophisticated methods to predict weather (2.4). In this thesis, I introduce the concept of "Web 2.0" (see 3.1) within the context of weather information. So, what happens when "share weather" is brought online, what happens in general when relationships and interactions are brought online? Chapter 3 discussed the concept of Web 2.0 and networks in general, and "share weather" networks in particular. Some features of "share weather" were also elaborated. One of the main conclusions of Chapter 3 was that volumes of contribution are imperative (3.8.3). The question is how participation in "share weather" networks might be encouraged. This chapter explores motivation for participation and online sharing regarded through the lens of "share weather" and develops some new theory.

I start with an overview of available motivation theories, with the final aim of presenting theory on the contexts of human interest in weather by the end of this chapter and tools to further develop a theoretical framework for "share weather" in Chapter 6. After the overview of different research approaches presented in Chapter 3 (Table 3, p.50), I go more deeply into their treatments of motivation in this chapter. To begin with, tools that "support human communication over time and space" (see the definition of Media Technology research provided in 3.2, p.44) radically modify the nature of interactions between individuals. This fact is reflected in transfer from face-to-face synchronous communication with a larger number of social cues (audial, body-to-body, shared physical environment, etc.) to technology-based tools and features erasing borders in space (see 3.1 and 3.5). Technology thus becomes an essential component and feature of online interaction. Web 2.0 radically changes premises for communication (3.5), and the motivation to interact and take part in different activities. Research confirms that classic theory cannot fully explain phenomena and behavior arising in online networks. For instance, individuals manifest (with classic theory) an inexplicable desire to share content based solely on inner satisfaction (this desire is termed "intrinsic" motivation, later addressed in 4.1.2 and 4.2.3): emotions like altruism, sense of enjoyment, and other motivations are created on a highly personal and individual level.

Here, theory offers some different explanations. Section 4.1 outlines different theoretical approaches and theories (also displayed in Table 3, Chapter 3, p.50). One may approach motivational issues from either a micro-, or macro-level. The macro-perspective studies network structure or interactions taking place within the network, sometimes with different initial hypotheses. Despite different approaches, researchers agree on the prominent impact of prior social interactions on future behavior (Coleman, 1994; Putnam, 1995; Goffman, 1959; White, 2008; see also Paper VIII); if we have previous relationships, or *ties* to others, we feel responsibility (Coleman, 1994), trust (Putnam, 1995), commitment and even shared identities (Bourdieu, 1986). I note that these concepts that describe *relationships* between humans are what truly make us "social" beings. So how do trust, commitment, and mutual identities form? It is evident that they evolve as results of previous events, or *interactions*. Somewhere in the early course of development of relationships, we interact and interactions create ties and encourage future interactions. In this chapter, I explore what theoretical approaches might be appropriate for studying motivation and behavior in "share weather" networks. I examine their relevance for "share weather", and how the theories may complement each other. I will particularly focus on regarding the sociological processes, such as learning, that arise through interactions in addition to the previously recognized psychological parameters, utility and needs, often studied in Media Technology research. In addition, I will regard "share weather" as a piece of a larger network/community in which environmental policies and general attitudes are shaped. To be precise, defining the "need" for weather information calls for deeper understanding of attitudes and drives that may create a perception of a need. The first issue is to identify, or develop a new, suitable motivational theory model for "share weather", using existing relevant theories. The uses' and gratifications' approach is treated in particular, according to frequent use in Media Technology studies. In this thesis, I try, however, to consider other approaches in order to identify the contexts of human interest in weather. Some of the theory was previously developed in Paper VIII. However, Chapter 4 presents some new ideas and further development.

Narrowing the scope of the information domain studied in the thesis, key issues in motivation research on networks within related areas are discussed in 4.2. These can be analyzed using network features previously defined in Chapter 3 (see Table 3, p.50). Here I consider radical changes in the network *environment* issued by a shift from offline to online, *purpose* and the role of *tasks* performed, network *nodes* and potential motivation sources including their instrumentality. Section 4.2, in addition, provides some input for the design of "share weather" (Q3).

By analogy with the theoretical outline in 4.1, the discussions in 4.2, and the research questions of the thesis (e.g., Q2), I adopt some new concepts. Particular emphasis is placed on uses and gratifications corresponding to the individual dimension (4.1.2), adding, however, a "social capital" perspective in order to capture influences attached to the structural dimension. Also, the concept of "trust" is introduced (see 4.1.3).

What does previous research tell us about motivation to share information? Weather information may be associated with the information domains "news", and, most important, "knowledge creation" (see 3.7.1 and 3.7.2). In current research, "knowledge creation" has been studied within the following contexts: open source software, creation of user-generated content in encyclopedias (e.g., Wikipedia), participation in scientific projects (Hand, 2010.), collection of data on the built and natural environment (see 3.7.3). In 4.3, the theory is narrowed to existing research on relevant domains: wikis, open source, and the environment. The domain of environmental data or user-generated observations (UGO) of the environment (see 3.7.4) receives particular attention. Through a discussion in 4.4 of the sustainability aspects of motivation to supply UGO of weather and the natural environment, I draw some important, new conclusions regarding individuals' potential sources of motivation to contribute to "share weather". These are then compared to research findings about knowledge creation addressed in 4.3. This comparison is particularly important for some key conclusions and to highlight the sustainability aspects, which is undertaken in 4.4. Section 4.4 provides input for development of a motivation theory around "share weather" networks from the perspective of environmental concern and contexts of human interest in weather.

Drawing from the findings of this chapter, including motivation to participate in networks within related domains, I develop a framework describing what contexts might motivate people to share weather information, in 4.5. The results of 4.5 contain an illustration of the framework (Table 5). A summary of findings of Chapter 4 is presented in 4.6 as the basis for further discussions and development conducted in Chapter 6, in which, finally, all three research questions of the thesis (Q1, Q2, and Q3) are addressed.

4.1 Uses and gratifications and "social capital"

Theories most commonly used for describing behavior in networks merge methods and theory from various research disciplines (see also Table 3, p.50, and Paper VIII): communication studies, sociology, psychology, collective action, organizational research and information systems. This compilation thesis is therefore balancing in the intersection of these research disciplines. Three different approaches can be distinguished, and these are centered around individual nodes, network structure and network interactions. Thus, networks manifest two dimensions: the individual dimension and a network dimension with variables describing relationships between nodes and interactions between nodes. In section 4.1.1, I will introduce the concept of "social capital" in order to discuss the structural dimension of networks. However, the individual dimension might be at least equally important. It suggests that not all individuals will participate in a particular network, and, if they do participate under given premises, they will behave differently. Related issues are treated in section 4.1.2 centered on potential personal drives and instrumentality. A set of general network features previously served to identify context-related features of a network (see Table 3, section 3.4.2.). We may, here, recognize several features that can describe the context from an individuals' point-of-view; these include the information exchanged (domain), ties and environment (offline/online, private/entrepreneurial). Here, it is possible to add a psychological dimension that explains the behavior of different individuals within the same environments and contexts. These ideas are specifically developed within research approaches that regard networks as a result of individuals' personal decisions and desires. Media Technology research often focuses on these individual properties, in terms of "uses" and "gratifications". We can say that behavior is governed by a series of needs and potential rewards that an individual will receive or benefit from. However, other approaches that consider the structural dimension are often useful. Modeling relationships and interactions may contribute important aspects of online communication in addition to the established theories based on uses and gratification perspectives that only account for the individual dimension.

When considering networks, a concept often touched upon is "social capital". The concept of "social capital" appears in substantially different contexts with different definitions (Paper VIII; Farr, 2004). Paper VIII presents an outline of these (see Paper VIII). Most scholars use "social capital" in order to describe structural and relational properties of a network. However, it can also be regarded as "owned" by individuals. The role of *trust* is envisioned by most researchers, who sometimes disregard substantially different approaches in defining and analyzing the characteristics of "social capital". Despite many reasons to question its classic definition (Coleman, 1994), the concept of "social capital" deserves some attention. The concept of *trust* is also particularly relevant to the compilation thesis and the context of its empirical studies (Papers II, IV, V, VI and VIII). Because "trust" is used as a key concept in the papers, I intend to use related concepts here to describe "share weather" networks.

4.1.1. The structural dimension, ties and "social capital"

As the word "capital" might imply, social capital is a resource that can be transformed into other forms of capital. For Bourdieu (1986), this means inclusion of cultural capital while focusing on "identity", which implies that "social capital" might be a property owned by individuals who position themselves according to their economic, cultural and social capitals. Putnam (1995) and Coleman (1994) posit that social capital is a resource that helps to establish expectations between actors who build relationships and trustworthiness. It seems that social capital is integrated into structure, in particular according to Coleman's (1994) rational view: greater stocks of social capital contribute to better efficiency and capability of societies and communities to solve collective problems, since social capital is synonymous with trust and reciprocity (Coleman, 1994; Putnam, 1995). However, Coleman applied his model to social structures and constructed forms, and these were very different from online interactions. Coleman (1994) explains the power of "social capital" as a product of "bonds" or strong *ties* in the society. A top-down model that regards structures as determinant is synonymous with the first research approach listed in Table 3 (p.50); in this approach, structures decide how networks are formed and evolve. Different types of ties between the nodes are attributed different importance, and strong ties or "bonds" both support structure and contribute to building "social capital". Coleman (1994), then, argues that these "bonds" are equivalent to "trust", and the concept of "trust" is thereby integrated into "social capital".

Here I will provide an example of a classic approach relying on structures and strong ties and how the concept of "trust" may be explained with this theoretical approach. The Technology Acceptance Model (TAM) (Davis, 1989), later developed by Venkatesh et al. (2003) towards the Unified Theory of Acceptance and Use of Technology (UTAUT), suggests that individuals' ICT adoption in organizations can be predicted based on *social influence* (Davis, 1989; Hsu and Lu, 2004), in addition to quality measures such as performance expectancy (perceived usefulness) and effort expectancy. Social influence occurs when individuals perceive that a new tool is mandatory in their work or recommended by their organization. For instance, a governmental institute may decide to test a new tool in their organization. Through the evaluation process, employees will be affected by social influence, which can be described in three processes (Kelman, 1961): compliance (influence according to expectations to receiving rewards or avoiding punishments), identification (accepting a behavior in order to maintain a relationship that forms one's self-image), and internalization (accepting an opinion or action because the induced behavior is congruent with one's value system). This process is equivalent to acceptance of induced behavior on rational grounds, often called "credibility" (Kelman, 1961), and credibility and trust are synonymous concepts. Some content might be considered "credible" (i.e., trustworthy) according to the expert status of the provider, or the trustworthiness of the content (Kelman, 1961, p.65); If an enterprise or institute introduces a new technology within its organization, users will first go through compliance and eventually identification and then accept the technology as trustworthy. Finally, repeated use of a tool that manifests a reasonable degree of performance and effort will create acceptance, because the user finds the technology trustworthy and credible. In this approach, individuals do have influence on each other, but strong ties are imperative for how identities and acceptance of technologies are being transferred through a top-down structure.

In contrast to these examples of how strong ties are attributed great importance, Putnam (1995) and Granovetter (1973) recognized the importance of "weak ties". In a similar vein as Coleman (1994), Putnam (1995) defines social capital as features of social organization and networks. They are trust and norms that can improve the efficiency of society by facilitating coordinated actions or pursuing shared objectives. These social connections, in turn, affect the productivity of individuals and groups (Putnam, 1995). In Social Network Theory (see Easley and Kleinberg, 2010; White, 2008; Paper VIII), as in most contemporary theories, it is well-established that weak ties may be very powerful (Granovetter, 1973), and that individuals interact despite absence of strong ties cultivated in established structures. While classic theories often projected organizations and systems with established structures, rules, and individual statuses, online networks often consist of networks of nodes with weak ties. In other words, people gather voluntarily around different topics, while their statuses are being equalized (see 3.5), boundaries in space and time are diminished with the Internet's co-location and synchronicity (Rheingold, 2000; see 3.5), and they are no longer limited to only communicate face-to-face in a shared physical environment. Online conditions seem to change the premises of human interaction fundamentally. Flanagin, Stohl and Bimber (2006) illustrate this change by dividing the collective action space, in which individuals meet online to perform actions, into four quadrants according to mode of interaction (personal/impersonal) and mode of engagement (entrepreneurial/organizational) (see 3.5). Both modes, engagement and interaction type, are associated with structural links between the nodes or ties. For instance, two individuals working at a weather institute have ties defined by their professional roles and the hierarchy of the institute. They may also have a relationship that could be defined as "personal". These relationships are considered carriers of strong ties and encompass classic network structure of organizations; strong ties may be associated with a personal-organizational setting. In online "share weather" networks, a person with any background whatsoever may participate. This list includes: professionals that do not know each other, weather enthusiasts, individuals with particular needs for weather information, enterprises. The majority will thus be linked by weak ties. Moreover, the new structure will equalize their statuses and alter a different agenda. In fact, the Internet cultivates a much larger range of topics as well as impersonal and personal interactions. In the collective action space this setting corresponds to the "entrepreneurial. It can be noted that impersonal-organizational corresponds to neither weak nor strong ties, which Flanagin, Stohl and Bimber (2006) denote "affiliative" ties, a zone in which network members may never see or interact with one another and have essentially no opportunities for exploiting their common affiliation in strategic or intentional ways (Flanagin, Stohl and Bimber, 2006). Two members of a network may thus feel the same sense of affiliation with the group but have neither strong ties to them nor weak-tie networks that they can employ. Therefore, Flanagin, Stohl and Bimber (2006) conclude that organizational commitment and homogeneity is no longer necessarily associated with organizational location in the collective action space. Their conclusion is essential for the previous discussion on networks and communities in sections 3.3 and 3.4; it shows that new identities, in terms of "affiliative" ties, might emerge in networks, a possibilty which might explain the analogy between the concepts of "community" and online networks previously questioned in 3.3.

However, in the cyberworld, nodes will also still have different interpersonal dyadic relationships, and their effects will be integrated into the context. Research implies that they will be manifested in how the whole network is shaped and evolves. In short, Social Network Theory, often referred to as Social Network Analysis (SNA), attempts to model the effects of ties and other integrated phenomena, in order to study the whole network; relationships define the properties of the individual, and personal variables are assumed to interact with patterns of relationships (White, 2008). Paper VIII notes that this interaction emphasizes detection and interpretation of patterns of structural ties in terms of relations that transmit information, behaviors and attitudes ("sharing weather" engenders new identities and relations), rather than focusing on the properties of the subjects (an individual participates in "share weather" activities because he/she feels obliged, a well-defined need in daily life, or a sense of enjoyment). Patterns of relationships are thus transformed into "identities", representing a basic concept in Social Network Theory. Identities, which are formed in the attempt to gain control (White, 2008), are only stable if they are recognized by others. A person can be defined in terms of a set of identities corresponding to different contexts, which can be thought of as attributing individuals new roles and performance in everyday life (Goffman, 1959) (see Paper VIII). As a result of these effects of relations on network structure, networks can be analyzed and modeled. Social Network Theory and Social Network Analysis (SNA) provide a structural perspective on a network, while still taking into account the consequences of an interpersonal friendship being weak or strong. Besides "identity", the concept of "trust" is also introduced. An interpersonal relationship might create a trust-relationship between nodes that were previously not directly connected (Paper VI). Research has found that network structures obey certain rules. Due to a mixture of weak and strong ties, in which "bridges" between different clusters of people occur randomly, there is usually a six-degree of separation between two arbitrary nodes in a network (Easley and Kleinberg, 2010; Buchanan, 2003).

It seems that "social capital" in Social Network Theory and Social Network Analysis (SNA) is manifested as a property of a particular network; it is embedded within the network structure; however, it is dependent on interpersonal relationships and interactions. Moreover, interactions in networks can create new identities and build trust. Paper VIII suggests that SNA may describe how "share weather" networks evolve over time and how the nodes are expected to behave. This view is analogous with "networks that are products of interactions" (see Table 3, p. 50).

4.1.2 The individual dimension of uses and gratifications

In contrast to the two former approaches, Uses and Gratification Theory (UGT) regards individuals as agents that perform different actions, driven by their own judgments, needs and desires. Strongly focusing on properties of individuals, this approach posits that networks are the results of personal needs and decisions (see Table 3, p. 50). It represents a common way of treating motivational drives in Media Technology research, anchored in traditional research on human behavior and psychological needs. According to Maslow (1943), individuals are driven by five levels of physiological needs associated with their goal of self-actualization: psychological, safety, love/belonging, esteem, self-actualization. Later, Deci (1975), Ryan and Deci (2000), and Hars and Ou (2001) distinguish between two different categories of motivations driven by personal psychological needs: "intrinsic" and "extrinsic" motivation. Extrinsic motivation includes direct or indirect compensation (e.g., monetary) and others' recognition; in other words, it is formed due to factors present in the environment. UGT is widely applied in Media Technology research (Sangwan, 2005), for instance the motivation behind the consumption of mass media (Stafford et al., 2004). It posits that media consumers make deliberate choices regarding selection and consumption of media in order to accomplish personal goals (Rubin, 1986). Other approaches regard cultural aspects of media and communication, introducing terminology such as "participatory culture" (Jenkins, 2006), and they regard creativity as an essential function of humanity; users are driven by mostly intrinsic needs to express their creativity through sharing products of their creativity (Jenkins, 2006).

Some important distinctions within different theories that should be mentioned are instrumentality and the general assumptions behind human motivation. The utilitarian tradition, inspired by economic theory, regards social actions in terms of rational, self-interested behavior, suggesting that individuals contribute (e.g., weather observations) only if their expected benefits overweigh the efforts, for instance Theory of Reasoned Action (TRA) (Ajzen and Fishbein, 1980). Uses and Gratifications Theory (UGT) does focus on individuals alone, but the motives are not purely self-interested; they include determination of ideas, technology and material conditions (e.g., interest in weather may arise both according to a need for safety and self-actualization) (Paper VIII). While TRA promotes strong instrumentality, UGT provides a more multi-faceted picture of individual drives. As described in the previous section, SNA focuses on identities and growing relations such as trust. There is no pure individual perspective; personal variables are assumed to interact with patterns of relationships that define the structure.

Uses and Gratification Theory (UGT) assumes the opposite: individuals' behavior in networks is explained by six different categories of individual needs as possible sources of motivation (Ruggiero, 2000), with varying degrees of instrumentality: information and learning (cognitive needs); pleasure; entertainment and aesthetics (affective needs); strengthening of self-image and self-confidence (personal integrative needs); affiliation and social relationships (social integrative needs); escape and diversion (tension release needs).

Drawing from the list of rewards studied in UGT, most of them can be considered *intrinsic* (see 4.2.3). Intrinsic motivations are associated with the experience of challenge, enjoyment and internal satisfaction experienced while performing tasks (Deci, 1975; Ryan and Deci, 2000), without expectations of obtaining rewards for one's performances. The satisfaction and enjoyment is not associated with particular separable consequences, and, according to Media Technology scholars, most of them are non-self-interested.

Does this mean that "share weather" might operate based on the same set of motivations? Although research on online sharing is extensive, it is important to consider that sharing weather information may be associated with different motivations than suggested by the contexts of current research. Paper VIII concludes that all of the listed approaches may be directly applied to the domain of weather information, but with the risk of overlooking important elements of motivation, as previously suggested by Nov et al. (2010). They studied the Citizen Weather Observer Program (CWOP) (Nov et al., 2011) and noted that there are several important differences between citizen science (here denoted by "scisourcing") and other online networks. In particular, the following issues can be manifested: small benefits from aggregated contributions (and scientists benefit more than the volunteers), each contribution constitutes a small, unidentifiable part of the project, a delay from when the contribution is made to the time when the output of the project is made public, and the challenge of task granularity.

4.1.3 Social capital and trust-networks: Integrating the structural and individual dimensions

In this section, I turn to the proposed model for studying networks, based on a two-dimensional plane of "social capital". Why use "social capital" at all in order to describe networks within the context of this compilation thesis? There are several reasons for this. I will point to some analogies between "social capital", networks and communities and the concept of "trust". When referred to in Media Technology research, social capital is often associated with "communities of practice" (Wasko and Faraj, 2005), a concept previously introduced in 3.4.3 potentially associated with "share weather" (3.8.1). Communities can be described in terms of "social capital"; knowledge and other values, acquired in a community of practice, can be transferred into other contexts (see 3.4.3 and Bourdieu, 1986).

Second, in approaches studying network structures (macro-approaches), "social capital" is synonymous with the concept of "trust", and "trust" is particularly salient in the papers of the compilation thesis. A third reason is that some parallels regarding "social capital" in communities of practice may be drawn to research on the domain of environmental data, which is relevant in the context of "share weather". Finally, available research is often limited to a particular perspective, either individual, or structural. The point is that "social capital" can be applied independently of the chosen research approach. Some thrilling discoveries (those described in Buchanan, 2003) of methods that, drawing from their structure, can relatively accurately describe interactions in networks might help us understand how a whole network evolves. I will use one common example to illustrate how structures in networks affect individual behavior, in which, at the same time, the concept of "trust" might reflect motivations to interact. If two individuals, A and B, are friends and one of them, B, also is a friend of C, then it is more likely that A and C will become friends. The probability that A and C will become friends can even be quantified (using Social Network Analysis SNA; see 4.1.1). The chances that A and C will become friends arise from: (1) the opportunity to meet or get connected, (2) A's trust in C's judgment because A believes that B's friends are trustworthy, and (3) latent stress is created if the parties A and C are not introduced to each other (see Easley and Kleinberg, 2010). Yet, a new range of complexity arises if we intend to study the motives behind each individual's decisions and the nature of their incentives. Uses and Gratifications Theory UGT (4.1.2) might want to address the question: How will A actually behave, based on his/her personal properties and premises?

As the overview of theories illustrates, individual properties and network structure represent two different dimensions (measured with different units, not directly comparable). They must be separately studied if we are to understand personal drives on an individual level. This approach was suggested in Paper VIII, which developed a motivational framework for the empirical studies addressed in the paper. Paper VIII drew on some properties of the context associated with "share weather", and developed a framework that included variables associated with the context.

In order to include both perspectives, the individual and the structural, merging the outlined theories is required. I will here, further develop the reasoning in Paper VIII. I introduce the concept of "social capital", while accepting the challenge of regarding both dimensions, as was previously carried out by other researchers.

One approach is presented by Ren et al. (2007), who combine common "identity" theory and common "bond" theory. The former theory makes predictions about the causes and consequences of people's attachment to the group as a whole, whereas the latter makes predictions about the causes and consequences of people's attachment to individual group members. Ren et al. (2007) argue that individuals participate in communities or networks due to either of these two reasons, bonds, or identity. In "share weather" networks, this may be applied as follows: an individual participates because he/she has a strong common "identity" with car drivers or weather enthusiasts, or, the individual participates because he/she has relatives or friends that already participate. Ren et al. (2007) found that identity-based relationships sometimes evolve towards bond-based relationships, a finding which suggests that the social relationships are transformed from one form to another. This is analogous to the concept of "capital", a value that can be transformed into different forms. Therefore, it seems logical to suggest that the two assets associated with different dimensions, bonds (structure) and identity (individual), can both be converted into "social capital".

Nahapiet and Ghoshal (1998) solve this question in a different way: they propose three forms of "social capital": structural, relational and cognitive. Paper VIII draws upon their findings. Cognitive capital refers to resources that enable shared language and understanding. It develops over time with experience and increased expertise, and individuals are likely to contribute the more they feel their expertise to be adequate. While structural capital refers to structural links or connections between individuals, relational capital is regarded as a set of variables of affective nature associated with relationship-positive characteristics, such as identification with the community, perception of obligation to participate in the collective, trust toward others within the collective and obedience of cooperative norms (Wasko and Faraj, 2005). What might be regarded as different in this approach from theories often applied in Media Technology is that a utility perspective is predominant, which means that instrumentality is a driving force. For instance, relational capital refers to both "commitment" and "reciprocity". Commitment is associated with duty or obligation to engage in future action - a sense of responsibility to help others within the network - arising from frequent interaction. I conclude that there is a certain analogy between the previously introduced concept of "social influence" (Kelman, 1961; 4.1.1, p.82) and "commitment", and potentially also the "latent stress" associated with weak links in Social Network Theory. "Trust" is considered to reflect reciprocity; a history of favorable past interactions leads to expectations about positive future interactions by Wasko and Faraj (2005), a situation which is analogous to a classic definition of trust as synonymous with "credibility" (Kelman, 1961) (see also "social influence", 4.1.1).

The problem here is that empirical research in Media Technology reveals that "trust" may be associated with emotions, identity and enjoyment, although "giving information" may also be attributed to expectations of gaining something in return. It seems that commitment may be of two kinds, namely, obligation or trust, a point which was concluded in Paper VIII.

However, this approach creates an opportunity to account for motivations of different origins reflected in the same behavior. Motivations can be "translated" between the two different dimensions using "social capital". For instance, it follows that "trust" can be associated with either expectations of gaining something in terms of useful information or other beneficial outcomes of interactions, or, expectations of future interactions that will provide inner satisfactions in terms of enjoyment and social acceptance. Trust can thus be defined in two ways, and both agree on the positive role of interactions. I summarize as follows:

Trust is created as an individual, based on a history of favorable past interactions, has expectations of future positive interactions. In the individual dimension, the history of positive past interactions is based on experience of benefits of particular instrumentality. In the structural dimension, the trust-building role of the *interactions* themselves is emphasized, provided that these interactions generate benefits (e.g., satisfaction).

Wasko and Faraj (2005), like Putnam and Coleman, use "trust" as a concept synonymous with "social capital". As I will show later, this concept is also suitable for the context studied in the compilation thesis, despite other limitations. It is, however, important to note that there are several ways of approaching "share weather" networks. For instance, Social Network Theory is an elegant way of describing interactions. Second, the nature of ties may be further explored, although this compilation thesis will not proceed with analyzing ties, due to the context of the empirical research. Researchers studying the logic of collective action present models that can be used to explain the difference between online and offline environments in which conventional theory (such as Coleman's) cannot explain new phenomena that arise online. For instance, Flanagin, Stohl and Bimber (2006) suggest existence of "affiliative" ties that are "weaker than weak ties, but powerful enough to reshape the collective action space once it is brought online (see 4.1.1). Lin (2001) also suggests that social capital may emerge from impersonal, online interactions.

Paper VIII concludes that the concept of "social capital" might be useful when studying "share weather". Drawing on an analysis of the context of "share weather", Paper VIII presented a series of sources of motivation in a two-dimensional plane (see Table 1, Paper VIII). One may focus on one dimension, individual or structural, at a time. One contribution of Paper VIII was that context-related variables were added to other variables that describe the structural dimension (see Wasko and Faraj, 2005); these include structural, relational and cognitive. Motivations were classified into four categories (including the context-related) and arranged according to the level of instrumentality.

The context was highlighted based on previous research that emphasized its importance. For instance Foley and Edwards (1999) claim that social structures, norms, and trust, i.e., variables associated with "social capital", are highly context-dependent and therefore cannot be simply generalized. This view was also confirmed by Nov et al. (2011), who suggest that the context is imperative for motivational factors that affect participation in citizen science. It should be stressed that "social capital" is a concept embraced by researchers within considerably different research approaches; in fact, it is embraced within all the three research approaches presented in Table 3 (see Chapter 3, p. 50). Nov et al. (2011), who looked into individuals' motivation to participate in sharing of weather data issued by privately owned weather stations, the Citizen Weather Observer Program CWOP, first applied uses and gratification theory (UGT; see 4.1.2) but recently introduced a model based on social capital while analyzing citizen science projects (Nov et al., 2011).

Therefore, despite potential inconsistencies due to the merger of two separate dimensions (resulting in issues associated with variable separation later addressed in Chapter 5), it is justifiable to examine how the concept of "social capital" can also be used within the context of weather information and for the purposes defined by the thesis. In many respects, exploration of a new field, such as exploring "share weather" in this thesis, favors isolating the individual dimension. We must, simply, start somewhere in order to explore why people might want to share weather (see Paper VIII). The empirical studies and the design process described in this compilation thesis required investigation of individuals' behavior based on certain premises, rather than exploring structures. In addition, I used the concept of "trust". Therefore, my theoretical approach in this compilation thesis is to merge the concepts "trust" and "social capital" with the individual-centered perspective of uses and gratifications.

4.2. Key issues in motivation research on networks for knowledge creation

The basic questions are why individuals might be interested in participating in "share weather" (Q2), and how "share weather" should be designed in order to address motivations that might be present (Q3). Earlier in Chapter 3, I concluded that "share weather" can be compared to networks within a larger domain of knowledge creation (7.2), while "share weather" is a subcategory of User-Generated Observation (UGO) that is classified as knowledge creation. This comparison is displayed in detail in Table 4 (p.61). Drawing from motivational theory presented in the previous section, 4.1, it seems justified to present some central issues that are found in motivation literature on similar domains. "Share weather" interactions include collection of useful data that are perceived, recorded, processed, and transferred between agents. These activities can be related to interactions in other communities of practice, citizen science, or microbloging (3.8.1; see also Table 4, p.61). I will first try to highlight some major differences between the various sharing contexts that can be associated with "share weather". Therefore, this section provides some central findings regarding the design of "share weather". Another important purpose with the coming outline is to shed some light onto the relationships that might constitute the structural dimension. I use the network features drawn in 3.4.2 and displayed in Table 3 (see p.50) in order to explore key issues in motivation research on knowledge creation and "share weather".

4.2.1 Online and offline environments

Sharing weather information may occur both online and in offline environments. Results on motivation studies on online and offline networks, respectively, diverge in several respects. This should not be as surprising as it sounds if we regard the differences between online and offline *environments* previously described in 3.5. For instance, earlier research studying offline environments suggests that giving away knowledge eventually causes the possessor to lose his or her unique value relative to what others know (Thibaut and Kelley, 1959), and that knowledge-sharing will benefit all others except the contributor (Thorn and Connolly, 1987). "Trust" and "social capital" were thought of as being difficult to transfer to online networks, because "social capital" is more likely to develop in collectives characterized by a shared history, high interdependence, frequent interaction, and closed structures (see Nahapiet and Ghoshal, 1998). Studies on offline networks imply that knowledge-sharing is positively related to strong ties (Wellman and Wortley, 1990; Krackhardt, 1992), co-location (Allen, 1977), demographic similarity (Pelled, 1996), status similarity (Cohen and Zhou, 1991) and a history of prior relationship (Krackhardt, 1992; Allen, 1977). Drawing from the major differences between offline and on-line settings presented in section 3.5 (equalized status, co-location and synchronization, and anonymity), it is justifiable to expect some discrepancy between offline and face-to-face acquaintances. In fact, much of the utilitarian-oriented literature dating back prior to the Internet era would suggest that online sharing is difficult to motivate. In contrast, as will be shown in the coming sections, people do share, even though they do not know each other, never meet face-to-face, and are geographically dispersed. Moreover, utility is not the only drive.

It seems that these differences between expected outcomes of online settings, and observed behavior and motivations online, are due to different assumptions concerning how "social capital" and human relationships and interactions are regarded, and that the classic approach (Coleman, see 4.1.1) deserves some critique. Online settings cannot be modeled if one regards only structures with the assumption that strong ties are predominant. Researchers in Media Technology and related disciplines have addressed these issues, suggesting that new theoretical approaches listed in the previous section (UGT, SNA; see 4.1.2 and 4.1.1, respectively) or amendments and extensions of "social capital" theory are necessary. For instance, drawing on Coleman's and Putnam's findings, Hsu and Lu

(2004), Lin (2001), and Wasko and Faraj (2005) further extend "social capital" theory for online settings. They base their theories on Deci (1975), who proposed a distinction between "intrinsic motivation" and "external rewards. Leonard et al. (1999) introduced "self-concept-based" motivation. Peddibhotla and Subramani (2007) suggest differentiating "other-oriented" (social affiliation and altruism) and "self-oriented" motives (self-expression, personal development, utilitarian motives and enjoyment).

4.2.2 Network purpose and tasks

Contexts may differ by a range of variables associated with the network nodes and the tasks performed as a result of its purpose. This section addresses several context-related features that are determinant for the drive to participate: information *domain*, *nodes*, and *purpose*, including *tasks* (see 3.4.2 and Table 3, p.50). This analysis provides some results on the design of "share weather".

First, we have the information *domain* (see Table 4, p.61). The domain studied in the thesis is a subcategory of knowledge creation and a subdomain of user-generated observations (UGO) (see 3.7.4). Other properties of the network domain can be described in terms of its *purpose* (see Table 3, p.50), and the *purpose* reveals more on the nature of a particular network, for instance what technology and design might be most appropriate. According to certain conclusions in the previous chapter (see 3.8.1), contexts in which users voluntarily share weather information can be associated with communities of practice (see 3.4.3), knowledge creation (e.g., online encyclopedias and open source), citizen science, collective action, and microblogging (news) (see Table 4, p.61). Awareness and attention as well as convenience to observe also decide the levels of contribution (3.6.2). Other issues that can be addressed with appropriate and attractive designs are collection methods based on publishing tools that consist of different types of modules of low task granularity (e.g., smaller entities of user contributions into one larger entity) (3.6.2). I concluded that wiki technology might be appropriate, although crowdsourcing also represents a potential complementary activity (see 3.8.1).

All this emphasizes the importance of strong personal engagement, which is stronger than that found in crowdsourcing. We are, then, looking for individuals (representing the network nodes) that are sufficiently motivated to contribute on a regular basis, through wiki technologies and "peering" (see 3.8.3). This search suggests a major individual focus, in which motivation driven by personal properties and drives should be explored. Again, this approach implies that particular focus should be kept on the individual dimension. On the other hand, studying particularities of the context can unveil different relationships associated with the structural dimension.

4.2.3. Instrumentality and motivation of individual nodes

When looking at individual drives, a first classification can be performed by different motivation categories' *instrumentality*. These can be divided into two categories of motivations that are substantially different from the perspective of the type of reward received: intrinsic, and extrinsic.

Extrinsic motivation is associated with expectations of receiving particular rewards that may be either in terms of direct compensation, or on a personal level. Extrinsic rewards on a personal level are, for instance, learning and gaining a fine reputation (synonymous with approval, status, and respect; Blau, 1964). Research shows that performing an action that may help an individual advance in his/her career or gain an excellent reputation enhances participation in networks and that building a good reputation is a strong motivator for active participation (Donath, 1999). The opportunity to improve one's standing may increase general participation and volume of contributions (Lakhani and von Hippel, 2003). However, an individual's reputation may also enhance career advancement, which may explain why developers still share open source code with others despite potential competition. An important effect of reputation systems is that they enhance establishment of "trust".

Intrinsic motivation refers to internal satisfactions that do not have to be associated with any external awards or separable consequences. Research on online networks implies that individuals may gain satisfaction from sharing knowledge due to the enjoyment of not only learning but also helping others (Wasko and Faraj, 2005; Lin, 2001). "Feeling good" about helping other people falls into the category of pure intrinsic motivation. However, sometimes the line between intrinsic and extrinsic motivations can be slightly blurred. "Helping others" may be regarded as intrinsic motivation, but it can also be associated with instrumentality. For instance, Nahapiet and Ghoshal (1998) claim that, in order to contribute knowledge, individuals must believe that their contribution to others will be worth the effort and that some new value will be created, with expectations of receiving some of that value for themselves; that is, helping others increases the likelihood of receiving help from others (von Hippel and von Krogh, 2003). Other extrinsic motivations that, at first, may seem to be expressions of altruism are related to exposure; individuals may feel inner satisfaction as their content is being published or just enjoy manifestations of their status.

Given these examples of sources of motivation, it becomes evident that measurements of behaviors and motivations often manifest themselves in a mixture of intrinsic and extrinsic motivations, while achieving several goals through single actions. For instance, one action may result in all of the following: recognition, self-efficacy (see Bandura, 1997), and altruism.

Another context in which intrinsic and extrinsic rewards may be merged is when people participate in volunteer organizations and actions. According to Clary et al. (1998), motivations may be driven by many factors. These include values (altruistic and humanitarian concerns for others), social status (engaging in activities viewed favorably by important others), opportunity to learn and improve skills and abilities, opportunity to achieve career-related benefits, protection of the ego (negative features of the self, reduce guilt or address one's own personal problems), and enhancement (involving positive strivings of the ego). These variables have equivalent descriptions in identity-based concepts. For instance, Goffman's (1959) theory of presentation of self in everyday life claims that people may engage in, let's say environmental matters, according to prevailing norms, provided that particular environmental issues are accepted by the group (Paper VIII).

These examples on the complex nature of human motivation and behavior justify some caution when interpreting empirical results regarding what seems to motivate people to do certain things, such as sharing weather information. This issue is addressed in Paper VIII through some examples acquired in three empirical studies on "share weather".

Sometimes users are directly compensated, including monetary compensation. Crowdsourcing is, for instance, often rewarded with a payment. However, some studies indicate that extrinsic rewards might actually decrease intrinsic motivation (Deci et al., 1999). Nevertheless, research shows that compensation can be relevant (Antikainen and Vaataja, 2010). The effect of receiving rewards must be considered in "share weather" networks, since weather information can be useful, and users might have considerable benefits from acquiring weather information. Because one purpose of "share weather" is improving weather information, we may, therefore, at least acknowledge a possible interest in different products of "share weather" potentially expressed by consumers, provided that the quality is satisfactory (Q1). It can also be assumed that a "share weather" community might potentially create values of interest beyond the "share weather" network, for instance services based on high-quality data produced by "share weather". What happens if the results are commercialized? Equivalent commitments are usually rewarded or compensated, as is the case with employees at weather service institutes that observe weather on a regular basis (see Paper I and Paper VII). This fact may support the hypothesis that members of a "share weather" network might wish to receive compensation for their work, including monetary compensation. From this point of view, using certain chosen elements from utilitarian approaches is relevant. It may, however, be pointed out that Lakhani and Wolf (2005) found that, although financial incentives are important to contributors, enjoyment, creativity and development of skills are imperative (see also Antikainen and Vaataja, 2010).

Also related to compensation and instrumentality are the different types of motivations that may arise due to different roles in the market, such as sharing of weather data between agents, data access and pricing. Although the thesis focuses on individuals' motivation, organizations may play an important role in not only managing and practicing "share weather" activities, but also defining some premises for individuals' motivation to share weather. Currently, organizations may control the price on weather information (see Paper I), indirectly affecting the expected compensation level for weather data sharing.

This final observation clearly indicates that structures are important for motivation to contribute to "share weather". This section shows that, although individual properties are paramount to the context of this thesis, both the individual and the structural dimension must be regarded.

4.3. Findings on motivation within related areas

In this section some key results from related research are presented. Although I limit my outline to some well-explored communities (e.g., Wikipedia, open source and environmental information), it should be stressed that research results on other domains in which knowledge is exchanged between parties are consistent with the findings presented below. The examples are chosen according to their wide range of exploration and because they are not only networks for exchanging information, but also for *creating new knowledge* that can be utilized by others. Naturally, environmental and geographical information are addressed because they belong under the same domain of observable phenomena in the environment (the category of user-generated observations UGO, previously introduced in 3.7.4).

4.3.1. Contexts, samples, and volumes of contribution

I would first like to point out the importance of understanding the context of different studies of networks prior to applying these results on "share weather". The issues include not only features describing the context (see Table 3, p.50), but also the context of different studies, their methods and methodology. Specifically, most studies focus on established communities and networks in which people are already engaged in a particular topic. For several reasons, such as anonymity, it might be difficult to study individual behavior in networks. For instance, on Wikipedia, many users are anonymous, a detail which has aftereffects on our general knowledge regarding the Wikipedia content-producer population. Users may choose whether to register formally on the site or keep semi-anonymous identities. Due to this functionality in Wikipedia (and many other Web 2.0 platforms), the opportunities to study the population in detail, such as identifying individuals who only contribute occasionally or are "free-riders", is limited.

Moreover, a great majority are free-riders (lurkers) who benefit from the efforts performed by a small minority (see Preece et al., 2011). The volume of contributions (Peddibhotla and Subramani, 2007) including their distribution over different groups might be an important variable, and the observed power law distributions imply that volumes of contribution are unevenly distributed. Participation figures suggest that only a couple of percent of all users are active: four percent of the members of open-source development communities provide 50 percent of answers on a user-to-user help site (Lakhani and Hippel, 2003); on Gnutella (a peer-to-peer service) 10 percent of users supply 87 percent of all content (Adar and Huberman, 2000); and results on Wikipedia show that 2.5 percent of the users contribute 80 percent of all the content and that 50 percent of the content is generated by one percent of the users (Tapscott and Williams, 2007; Benkler, 2006).

4.3.2. Open source

In the previous chapter, it was concluded that weather information may be compared to knowledge-sharing and knowledge-creation (see 3.7.2 and Table 4, p.61). One related area is represented by open source development communities in which software developers collectively develop software under the creative common's license, a situation which means that the products of their volunteer work are accessible to anybody and can be useful to others (see von Hippel and von Krogh, 2003). Obviously, there is an analogy between open source and improving weather information by sharing weather information.

Previous research on open source development identified both intrinsic and extrinsic sources of motivation. Extrinsic motivation is related to expected benefits of contributing, that is improvement of programming skills and enhancement of professional status (von Hippel and von Krogh, 2003; Oreg and Nov, 2008). Intrinsic motivation, in contrast, issues inherent satisfactions such as altruism, fun, reciprocity (Wasko and Faraj, 2005), intellectual stimulations, and a sense of obligation to contribute (Oreg and Nov, 2008). Three types of motivations that drive open source contributions may be identified (von Hippel and von Krogh, 2003; Oreg and Nov, 2008), and they are ordered according to decreasing instrumentality: desire to establish reputation and gain approval from others in the field (high degree of instrumentality, i.e., purely extrinsic), desire for self-development through learning from others in the field and improving one's skills (mid-range instrumental, either extrinsic or intrinsic also known as "flow;" Csikszentmihalyi, 1996), altruism or the desire to help others in the community and lastly the internal sense of obligation (low degree of instrumentality). However, many studies also point to ideology as a very strong drive in the open source "movement" (Stewart and Gosain, 2006; Chesbrough et al., 2008; Bergquist and Ljungberg, 2001).

Since recognition seems most important, it has been further explored. Oreg and Nov (2008) suggest that the filtering process may create or reduce barriers. In particular, open software developers undergo a formal peer-review process (Bergquist and Ljungberg, 2001) whereby they, after acceptance, receive credit for their work. In contrast, creations of content contributors on Wikipedia may pass unfiltered before being published, whereby the user receives immediate exposure and recognition for his/her work.

Findings on open source development thus suggest that reputation should be attributed highest importance. Also, exposure and feed-back are key elements. The need for learning and sharing knowledge is a strong driving force, although it is difficult to distinguish between motives related to potential career advancement and the inner satisfaction due to learning and sharing information with others. Finally, occurrence of incentives associated with ideology is particularly interesting from the perspective of this thesis.

4.3.3. What motivates knowledge sharing?

Wasko and Faraj (2005) posit that altruism, generalized reciprocity, and community interest created by ongoing interaction of the members of online groups are important motivations. This result should apply to Wikipedia, for instance as confirmed by Nov (2007). Second, the social processes are considered highly important. In an overview, Rafaeli and Ariel (2008) advance the idea how motivations to contribute are manifested in a hierarchal system in Wikipedia. New (regular) users gain small but satisfying rewards for basic participation, and "fanatics" (administrators and rigorous contributors) get the larger rewards through special status (see also Butler et al., 2008). Motivations can also be issued as a person gains "power" over the page. The power to influence – contributors can have immediate influence on article content and can take part in editorial decisions – is consistent with Chavis and Pretty (1999), who add the following elements that constitute a persons' "sense of community": membership, influence, integration, fulfillment of needs, shared emotional connection, community boundaries (who belongs and who does not), shared history and emotional connection, including the quality of interactions, intensity and the amount of time. Further, Joyce and Kraut (2006) point to the fact that group interactions might increase newcomers' commitment to the community; for instance, in the case of positive feedback, users are more likely to continue their participation. They also propose that interactions create an unspoken obligation towards the group.

I conclude that several factors that enhance online knowledge sharing and knowledge creation are associated with recognition. Additionally, exposing the content, i.e., products of one's work, is also perceived as highly rewarding. Second, interactions within the network/community seem to create a sense of belonging, which may be associated with "identity", whereas the hierarchy of the network/community, in addition, encourages competition (which may be associated with desire for recognition).

4.3.4. Findings on environmental and geographical data

Findings on Wikipedia and open source can be compared to motivations proposed for citizen science. Studying different domains of environmental and geographical data within "citizen science" projects, Nov et al. (2011) postulate that the challenge consists of making the results of one's efforts perceivable and recognizable (in addition to low task granularity).

In general, findings on motivation for participation in networks for sharing environmental and spatial data are scarce, but empirical evidence points to the existence of such networks/communities and increased interest from the research community to utilize Web 2.0 based tools, for instance, in ecosystem modeling (Larocque et al., 2011). Public participation in environmental monitoring is noted by Danielsen et al. (2010), who found that the speed of public policy changes may be three to nine times quicker when local people participate in the monitoring process. Protection or enhancement of a personal investment may strongly motivate people to contribute according to Coleman et al. (2009), who studied photos of erosion problems or silted streams, while others may be motivated by the ability to learn from the website through the submission process and through the website's training and educational content (Budhathoki et al., 2010). Monetary compensation has also been suggested as a potential drive (Budhathoki, 2010).

These findings confirm occurrence of some similar drives in the domain of environmental information-sharing as previously observed in research on knowledge-sharing in open source development and Wikipedia; namely, users want the results of their work to be perceivable. Moreover, elements of both intrinsic and extrinsic drives were detected. It is particularly interesting to note that motivations seem to increase with personal gain, such as protection of personal investments. Parallels can be drawn to research on natural resource management. It is well-documented how the motivation to support wind power (a sustainable energy source) depends on personal savings or gains that can be made. People support wind power plants if they are co-owners, whereas they tend to oppose such projects if the outcome is associated with a personal loss (e.g., disturbing noise).

It is interesting but not surprising to note that in sharing environmental data feedback in terms of perceivable results is also important. This need is partly analogous to the desire for recognition, according to related literature, one of the strongest drives for participation in networks for knowledge creation (see 4.3.2 and 4.3.3). However, motivations associated with environmental concern are highly complicated and therefore further discussed in section 4.4 below.

4.4. Motivation and environmental concern

This and the following section (4.5) aim at developing a framework for contexts of human interest in weather, complemented by a general discussion in section 5.1 for more profound understanding of the sustainability aspects of "share weather". The question is whether some particularities might be associated with motivation to share weather information, in respect to its association with environmental issues such as climate change.

From 4.3.4, it can be concluded that sharing environmental information may be confronted with particular challenges, namely, due to the difficulty of perceiving the positive effects of individual contributions. On the other hand, sustainable development demands active participation and also involvement from individuals. Knowledge owned by the scientific community is not enough in order to accomplish the goals of sustainable development. Earlier in Chapter 3 (section 3.7.3), some empirical findings on the important role of non-experts collecting environmental data were addressed. Research findings on management of natural resources point to the importance of collaboration between different agents; in order to conduct successful natural resource management, participation and inclusion of the public is necessary (Alcorn, 1993; Hackel, 1999; Reidlinger and Berkes, 2001). For instance, collaboration between different actors in the case of Lake Racken in Sweden resulted in considerable social response to acidification from local residents and illustrated how an environmental crisis can trigger a social response, including a platform for collective action and social learning (Olsson et al., 2004). In 3.7.3, I also provided some examples in which the local population was highly engaged on a strictly volunteer basis. In these examples, such as the Rakiura Maori people's observations of titi birds in New Zeeland (Kitson, 2004; Lyver and Moller, 1999) and the Newfoundland cod fisheries (Finlayson and McCay, 1998), observations were necessary for daily planning, nourishing and survival of the volunteers; the members of these networks sharing environmental data had great benefits from acquiring that information.

Because the extent of public engagement and active participation in environmental issues is limited in general, although proven successful in some cases that were referred to, I intend to further explore potential sources of motivation for individuals to engage in environmental problems such as climate change.

4.4.1. Why most do not act against climate change: The tragedy of the commons

Studying an environmental issue-related topic demands understanding of pro-environmental behavior and human relationships with nature. In general, *belief* is determinant when it comes to what an individual will observe; that is, we base our observations on hypotheses. Errors may be issued due to the difficulty of revising hypothesis probabilities on the basis of evidence (Einhorn and Hogarth, 1985; Paper II), a phenomenon also confirmed in studies of perceptions of climate change (Weber, 2010). Studies on environmental policies and attitudes show that environmental problems are difficult to manage due to their complexity and lack of defined responsibility that could enhance mutual efforts to approach the problem. Practically, environmental politics meet the challenge of reducing the conflict between common environmental interests and interests of individuals (Connelly and Smith, 2003), which is often explained as "the tragedy of the commons" (Hardin, 1968). "Tragedy of the commons" suggests that no one will feel motivated to address a problem if the problem is owned by someone else (Hardin, 1968). For instance, it is most logical that all countries will benefit from a stable climate and decreased CO_2 emissions. However, the current impasse concerning climate change shows that most countries are hesitant to decrease their CO_2 emissions. According to the "tragedy of the commons" perspective, this attitude stems from the immediate benefit of maintaining current behavior, which is perceived to be greater than the eventual benefit to all countries if the behavior were changed.

The same would apply to individuals; individuals may feel that their personal benefits from maintaining their current behavior is greater than the eventual benefits to the collective that may arise as a consequence of their changed behavior. The tragedy of the commons is, therefore, reflected in (lack of) actions, such as behaviors related to energy use and consumption. Paper III and Paper IV exemplify the challenge of motivating citizens to participate in climate-related issues, using a study on the film "The day after tomorrow" conducted by Lowe et al. (2006). This study shows, among other results, that very few would act, although many are aware of the threats of climate change; moreover, watching a movie about a climate change disaster raised their awareness only temporarily. Some respondents claimed that they do not have information on *what action* they can take to mitigate climate change (Lowe et al., 2006), a claim which might justify their lack of action. We may, therefore, conclude that not only individuals' belief but also their lack of knowledge of how to address the problem might represent a challenge. However, the "tragedy of the commons" indicates that the greatest challenge is that the immediate benefit of maintaining current behavior is perceived to be greater than the eventual benefit if the behavior were changed. I therefore conclude that general obstacles are: knowledge, and perception of feedbacks of one' actions.

4.4.2 Motives enhancing pro-environmental behavior

Once we have identified issues that represent obstacles, it might also be useful to know what factors may lead to increased awareness and pro-environmental behavior. From the perspective of this compilation thesis, some findings regarding the social interaction aspects of this problem are highly relevant. In research on public perception of climate change, it is found that sociodemographic characteristics, residence, and political ideology are inadequate in explaining the variance in perceptions of environmental problems or pro-ecological behavior (Jaeger et al., 1993). Perhaps more interestingly, pro-environmental behavior can be attributed to social learning and behavior, and these depend on interactions within one's social network. Some researchers even suggest that pro-environmental behavior can be understood as processes of rule evolution in social networks. Jaeger et al. (1993) claim that the probability of climate-related environmental action is significantly increased if individuals are exposed to interpersonal rules favoring such action, a situation which depends on the existence of such rules and on the density of social networks in which these rules are considered relevant.

It can be noted that findings on Wikipedia and open source presented in this chapter, although providing evidence of the existence of altruistic motives, show that perception of receiving personal benefits alters participation in networks for sharing information, knowledge, and creating new knowledge. One of the strongest drives in networks for knowledge-creation is recognition, like that manifested in the desire for exposure of one's work. There might be an obstacle in applying this finding to user-generated observations of the environment. Environmental issues might be facing a unique problem: the benefits of contributing to the cause of improving the environment must be perceivable in order to reward users in terms of recognition.

Jaeger et al. (1993) also draw a parallel to benefits experienced on perceivable time-scales; according to them, pro-environmental behavior is enhanced by social learning in the social networks in which people carry on their *everyday lives* (Jaeger et al., 1993). The everyday life perspective is supported by other findings unveiling the fact that people in general are more concerned about the weather than climate change (Stern and Easterling, 1999). Other researchers have drawn similar conclusions regarding natural resource management and social networks and additionally provide evidence of "situated learning" (see section 3.4.3). According to Berkes et al. (2003), the knowledge collection system in natural resource management (see section 3.7.3) becomes part of the processes of social learning how to deal with changes in ecosystems. Berkes et al. (2003) identify a collective learning process coming from experience with the ecosystem change which evolves as a part of the social memory and further embeds practices that nurture ecological memory. Olsson et al. (2004) conclude that the knowledge of ecosystem management applied by members of the fishing association for instance (see 3.7.3 and Finlayson and McCay, 1998) is stored in the social memory of the group, all of which implies that participation in natural resource management may be described as a social process. Blaikie and Brookfield (1987) explain that some individuals may have special skills that depend on a person's background and social status, while Folke et al. (2003) call them "key stewards". The ecosystem knowledge that stewards possess may even be imperative for which trajectory is chosen in response to change (Olsson et al., 2004; Berkes et al., 2003).

Guided by these findings, Olsson et al. (2004) propose that local resource users should be involved in monitoring the environment for two reasons. Namely, participation may enhance incentives to learn about local ecosystem dynamics increasing the general understanding of ecosystem functioning and the probability of local management of complex systems. Second, local residents can provide early warnings of environmental change and help create feedback loops for improved management on other levels, e.g., avoiding critical thresholds in ecosystems. Some researchers recommend general networking and interactions. Westley et al. (2002) argue that the capacity to deal with the interactive dynamics of social and ecological systems requires the entire network of interacting individuals and organizations at different levels. Vertical linkages (between the community and governmental agencies) are, however, more difficult to establish than horizontal (municipality-municipality) ones. This fact further supports the importance of social networks, as will be discussed later in section 7.1. Blaikie and Brookfield (1987), and Berkes et al. (2003) claim that "social network building" is achieved with the help of particular stewards, as they establish functional links within and between organizational levels, facilitating the flow of information and knowledge from multiple sources.

All of the above suggests that the "tragedy of the commons" can potentially be addressed with some of the social processes taking place in networks. Due to this interesting finding on potential linkages between sustainable development and networks, a longer discussion will be provided on this subject in 7.1.

4.4.3 Ideology and environmentalism

Based on the previous findings, sustainable development is challenged by the fact that most people do not act against climate change (4.4.1); some, however, will act. For instance, there are activists who care enough about an issue that they are prepared to incur significant cost and effort. The context studied may be assumed to be correlated with personal values and ideology because the topic can be associated with climate change. There are different levels of activism and engagement. Research indicates that fostering processes of social learning in the social networks in which people interact in their everyday lives may enhance awareness of environmental problems (4.4.2). That is, individuals who are already concerned about the environment or behave pro-environmentally will continue to do so and even increase their concern and pro-environmental behavior through interactions with others. The question is how individuals may become part of networks that enhance sustainable development in the first place. This is addressed in the coming discussions in Chapter 6 and Chapter 7.

But what lies behind the motives of individuals that are already practicing pro-environmental behavior? Research provides different opinions on whether self-efficacy (Tabernero and Hernandez, 2011) or intrinsic motivations (De Young,

2000) may best explain individuals' pro-environmental behavior. However, the general conclusion is that emotions, regardless of their origin, seem to be a stronger drive than extrinsic motivations. In addition, in pro-environmental behavior, it may sometimes be difficult to draw the line between intrinsic and extrinsic motivation. I will here apply some additional theory. In search for adequate theory that might describe the context (see 4.1.3), in Paper VIII, I added variables that may be associated with volunteer work and ideology based on Clary et al. (1998) (see also section 4.2.3); these variables included values (altruistic and humanitarian concerns for others), social status, learning and improving skills, career-related benefits, protecting the ego and enhancement.

It is interesting to note that these motivations have their equivalent in other motivations defined in networks: learning, recognition and altruism. Also, in many open source communities, ideology is recognized as a strong drive (4.3.2; Stewart and Gosain, 2006), and for some individuals "ideology" may correspond to intrinsic motivation such as altruism. Now, findings supporting that intrinsic motivations are determinant for pro-environmental actions may be compared to the motives discovered behind the most active Wikipedia contributors (see 4.3.1). In Wikipedia, active participation is often associated with intrinsic motivation (e.g. Nov, 2007).

However, active wikipedians and environmentalists constitute very small fractions of their entire networks. The question is how the context might also encourage participation among the larger portion of the population. In the next section, I develop some theory on the contexts of human interest in weather that may lead the way towards design of the "share weather" concept.

4.5. The contexts of human interest in weather

The question is what might attract individuals to join a network for sharing of environmental information, or participate in "share weather"?. Based on the theory presented in the previous section, I develop a framework for contexts of human interest in weather, aimed at reflecting the level of motivations that can be associated with different contexts and thereby trigger sharing of weather information.

I start with the notion of Jaeger et al. (1993) that, for influential but small elites to which scientific communities belong (e.g. the Intergovernmental Panel on Climate Change, IPCC), these networks have a strong international dimension. In contrast, however, for most people, the relevant networks have a regional scale, also implied by the examples of successful natural resource management provided in section 3.7.3. In general, networks for knowledge-sharing are positively related to: strong ties, co-location, demographic similarity, status similarity, a history of prior relationship, and, most important, co-location (4.2.1). Even online, there are such tendencies; people connect with and disperse content to others with similar cultural background, norms, and other personal properties (3.5).

The relationship between geographical proximity and personal engagement might explain some of the obstacles for individuals to relate to climate change; the problem is perceivable on a global scale, while the individual perceives changes that can be observed on a regional level. This situation is serious, because, not only in knowledge-sharing (4.3.2 and 4.3.3), but also when sharing environmental data, individuals manifest a desire to perceive the results of their actions (cf. 4.3.4); feedback in terms of perceivable results of one's work, or one's pro-environmental behavior (see 4.4.1), is a strong motivational factor.

The other dimension of the problem is time. Weather is the state of the atmosphere changing over time and varying in space (section 2.2.1), and climate change is manifested as gradual modifications of average weather conditions (see 2.2.1 and 2.3). Therefore, the process of climate change is very slow relative to human life. This observation can be contrasted with the time perspective of pro-environmental behavior. Namely, according to 4.4.2, pro-environmental behavior is enhanced by social learning in the social networks in which people carry on their *everyday lives* (Jaeger et al., 1993).

The contexts of human interest in weather are summarized in Table 5, including corresponding time and spatial scales. Transportation corresponds to the shortest time scale, days, hours, or minutes, over small areas corresponding to kilometers (miles), and even meters. Climate change is, by contrast, found in the other end of time-space dimensions, with time scales of centuries or millennia, and spatial scales of many thousands of kilometers.

According to human determinant dependence on the natural environment, i.e., there is no alternative Earth, and humans are a part of the Earth's ecosystem, and its forces (weather dynamics and forces on astronomic scales; see 2.3), Table 5 suggests that climate change is persistent and more serious than extreme weather. This fact, however, may not be directly obvious to individuals. To us, such changes are not perceivable in daily life in modern societies, due to the many tools, facilities and inventions that make our lives easier, compared to the reality of our ancestors. Empirical evidence, instead, points out that people in general are more concerned about the weather than climate change (Jaeger et al., 1993; Stern and Easterling, 1999) (see also 4.4.1).

Transportation represents one activity in which weather dependence is perhaps most obvious in everyday life, according to the fact that transport-related behaviors occur at time-scales highly relevant from an everyday life perspective, namely:

minutes, hours and days. The context of transportation was chosen for most of the empirical studies conducted in the papers (Papers II-VI and Paper VIII). Agriculture, on the other hand, is not particularly focused on in the industrialized countries, since food supply may be taken for granted. In countries in which the economy and production relies on agriculture, motivational drives may, however, be present. That context was chosen in Paper VII, which studied farmers in Sudan observing weather in order to supply the local officials with precipitation data.

Table 5. *The contexts of human interest in weather*

RESOURCES /SYSTEMS	**Built environment (roads, buildings)**		**Natural environment (atmosphere, oceans, lithosphere, biosphere)**	
Impacts	Temporary		Persistent, durable (serious)	
Context	Transport, Energy	Agriculture (food supply)	Ecosystems	Climate change
Time scales in which changes/anomalies can be observed (in days)	10^{-3}-10^{0} (hours, days)	10^{1}-10^{2} (weeks, months)	10^{2}-10^{3} (months, years)	10^{4}-10^{7} (centuries) $>10^{7}$ (geologic)
Spatial scales (in km)	10^{-3}-10^{0} (meters, kilometers)	10^{-3}-10^{0} (meters, kilometers)	10^{0}-10^{4} (thousand kilometers)	10^{2}-10^{5} (hundred thousand kilometers)
Research methods and modeling*	Numerical Weather Prediction models (NWP) Meteorological applications Environmental modeling			Climate scenarios Geological models

* see Chapter 2

If we instead regard climate data alone, the picture is somewhat different and more complicated. Climate is not an everyday-life issue. Previous experience regarding environmental politics and motivation of individuals to engage in difficult environmental issues suggest that engaging the public might be a challenging task due to the "tragedy of the commons" (Hardin, 1968) (4.4.1). While networks and organizations related to environmental concern exist, they hardly engage the major population. This fact of the "tragedy of the commons" would suggest that the logical coupling between climate change and events in our daily life is very vague.

Table 5, however, suggests that the temporal perspective of "weather-related" problems may offer a window of opportunity in that extreme weather, a change experienced in daily life on timescales of days and hours, may be considered important. People in general may feel more engaged in preventing hazards that concern them personally and are likely to occur within a short time than they feel by the amplitude of future events. This is for instance reflected in weather "news" often focused on events of large amplitudes (see 3.7.1). It can be implied that the context of "extreme weather" may enhance participation in "share weather" networks and that interactions and the social learning process within the network may create awareness about change beyond the reality of our daily lives experienced on time scales of days and hours.

4.6 Conclusions on motivation in “share weather” networks

This chapter presented motivation research on networks for knowledge creation and discussed possible drives in “share weather” networks. Theory suggests that recognition is one of the strongest drives, besides the positive effects of learning and the pleasure of sharing with others (4.3.2, 4.3.3 and 4.3.4). Most researchers agree on the prominent impact of intrinsic motivation on online participation and knowledge creation (4.2.3), and sometimes ideology is the primary driving force (4.3.2). These drives on a personal level, entirely decoupled from self-interest, are often observed online. My discussion addressed some theoretical explanations (see 4.1.3): the classical structural approach (see 4.1.1) and the utilities and gratifications individual-centered approach (4.1.2). First, research on online environments provides increasing volumes of evidence of the importance of weak ties (4.1.1). The Internet spans, not only spatial and temporal distances, but it also shrinks distances between individuals, thus creating a sense of belonging issued by “affiliative” ties (4.1.1) that may explain the analogy between communities (of practice) and online networks (see 3.3). This approach might reject the validity of classic theories.

However, can contexts studied in previous research within Media Technology (e.g., uses and gratifications; see 4.1.2) really be applied to “share weather”? Would individuals generously share weather information, driven by intrinsic rewards? Some utilitarian approaches might suggest the opposite (e.g., reasoned action; see 4.1.2), and, with the background of the context, producing a “good” that can be further processed and exploited by others. It can be proposed that reciprocity and different compensations should be taken into account. Moreover, theory and practice often reveal an inseparable blend between intrinsic and extrinsic rewards (4.2.3) indicating that the expected benefits, whether intrinsic or extrinsic, should overweigh the effort (4.1.2). The challenge might be even greater with weather information. In one respect, the domain of environmental information is different from the previously analyzed contexts. Individuals also seem encouraged by motives associated with, sometimes strong, instrumentality. This discovery may be related to the phenomenon of the “tragedy of the commons” (4.4.1). Therefore, the level of interest in acquiring weather information and actual benefits may represent one threshold for participation in “share weather” networks. This observation is supported by earlier findings on the Citizen Weather Observer Program (CWOP) (see 4.1.2). Nov et al. (2011) discovered a difference between citizen science and other online networks, namely the small benefits from aggregated contributions and the fact that scientists benefit more than the volunteers. However, there are several other challenges. Research on Wikipedia and open source highlights the importance of recognition and exposure of the outcomes of users' efforts (4.3.3). In citizen science and observation of the environment, this factor might entail limitations, because there is usually a delay from when the contribution is made to the time when the output of the project is made public (4.3.4). In addition, each contribution constitutes a small, unidentifiable, part of the project, making acknowledgments and recognitions difficult (4.3.4; Nov et al., 2011). For this purpose, this chapter (see 4.2.2) also drew some conclusions regarding the design of "share weather" (based on 3.6.2). It should address awareness and attention as well as convenience to observe and be based on collection methods adjusted to processing through "peering" (see 3.8.3), and publishing tools that consist of different types of modules of low task granularity (e.g., smaller entities of user contributions into one larger entity), in order to increase the opportunity for each individual to choose to perform suitable tasks. Tasks should be designed to provide a good balance between investments associated with contribution of content and the experienced benefits, whether those generate intrinsic or extrinsic awards. According to key findings in related areas, the importance of immediate feedback, exposure of one's work, and recognition were highlighted. These issues represented one of the central findings of this chapter. In addition, in order to motivate participation in "share weather", personal properties and drives should be explored within the individual dimension, for instance users' personal interest in weather.

The previous outline indicates that "share weather" should reward users with useful weather forecasts for instance. Environmental data in general may be confronted with a unique problem, which is that the benefits of contributing to the cause of improving the environment must be perceivable. Drawing from these findings, contexts of human interest in weather information are presented in Table 5. The contexts of human interest in weather, frequently referred to later in the thesis, show that time and space are variables of central importance. However, Table 5 also suggests that demands for weather information manifested among individuals may offer a window of opportunity. Because individuals are often most attentive to events that affect their personal everyday lives, particular weather events may increase awareness about weather in general. As displayed in Table 5, events of the amplitude of severe weather events are perceived as highly relevant (see also Paper II). In contrast, possible future events of considerably larger amplitudes may not receive the attention they deserve.

Since the context of "extreme weather" in daily life (e.g., traffic) may enhance participation in "share weather" networks, this was chosen for the studies subjected in the papers and will be more deeply analyzed in the next chapter on methodology, Chapter 5. Further, I hypothesize that interactions and the social learning process within the network may play a role in connecting different contexts, spanning discrepancies introduced by different time perspectives. This constitutes an important topic in the coming discussions (e.g., Chapter 7), not the least due to its relevance for sustainable development. This chapter provided the theory and key issues necessary for the development of a theoretical motivation framework for studying "share weather", later developed and presented in Chapter 6 (6.3). In this chapter and Paper VIII, I shed some light on the social cues that trigger social behavior online, the context of the research domain, and possible theoretical approaches. Interactions have evident impacts on creation of mutual "identities" associated with the concept of "trust" and "social capital" (4.1.3). Here, guided by results of Paper VIII, I proposed an approach based on "social capital" expressed in two dimensions: individual and structural. Chapter 6 continues the theoretical discourse initiated in this chapter through detailed discussion of different theoretical approaches for studying motivation in networks (6.3.8) and drawing specific directions towards exploring "share weather" (6.3.9). These are studied as I commence the evaluation of the "share weather" concept, based on theoretical findings related to the contents of this chapter (Chapter 4), and empirical studies presented in the papers. The methods behind this work are discussed in the next chapter.

Chapter 5
Methodology

After the theoretical outline in the previous two chapters, I will now focus on the empirical investigations, tools and methods aimed for evaluation of the "share weather" concept. This chapter provides methodology, methods, and some theory used in the empirical studies of the compilation thesis. The purpose is to provide the final tools in order to address the research questions of the thesis (Q1-Q3) in the next chapter.

In this chapter I address four main issues: the scientific method, specific methodology and methods used in the empirical studies, design theory, and methodology underlying the analysis conducted in the discussions of Chapter 6.

I start by highlighting what "scientific research" really means and defend why this compilation thesis should qualify as a scientific piece of work. Products of scientific research are provided with two claims in order to be classified as science. First, the problem should be analyzed in accordance with good scientific tradition using *scientific methodology* (e.g., Lazar et al., 2010), and, as a second precondition, products of scientific work ought to be approved as *relevant* systematic knowledge. It is, however, not the area of study, but the type of knowledge and the methodology used, that determine whether a field of knowledge should be regarded as scientific (Hansson, 2007). In order to show why my exploration of "share weather" can be regarded as science, first, I analyze the characteristics of the research presented in the thesis, and the type of knowledge that is created. The remaining parts of this chapter illustrate how this compilation thesis applies "scientific methodology", through an overview of methods and methodological issues, in the papers, and the summary of the compilation thesis, respectively.

The first part (5.1) of this chapter addresses the information domain and the context of information sharing in the empirical studies presented in the papers, while regarding the thesis from a sustainability perspective. Next, I explore scientific methodology in Media Technology research and methodology for analyzing "share weather" in 5.2, including a short overview of methods in meteorological applications in 5.2.1. Section 5.3 explains and discusses different methods used in the empirical studies, including reflections upon the ethical issues of my research (5.3.9). The following section (5.4) is entirely devoted to design theory used for construction of a "share weather" artifact, which both facilitated the empirical studies and provided an opportunity for evaluation of the "share weather" concept. Finally, methods used in the summary of the compilation thesis are discussed in 5.5, providing the necessary tools to begin the evaluation of "share weather" in the coming chapter.

5.1. Valuable systematic knowledge: Why interested in "share weather"?

This section evaluates whether this compilation thesis is relevant systematic knowledge. It will also clarify some statements previously made in the papers regarding the expected benefits of the concept of "share weather", and highlight the sustainability perspective.

At the same time, I also address some particularities of the context. In the empirical studies used in this work, the context of sharing is extensively associated with transportation in daily life. The reader will need some short background on how meteorological data are treated in the thesis, in particular the methods used while studying individuals' participation and user-generated observations (UGO). This chapter is aimed to provide sufficient background. For more thorough background regarding meteorological data, I refer to Chapter 2 that covers this area in more detail for interested readers.

Why does this compilation thesis contribute relevant systematic knowledge? We may intuitively conclude, in analogy with the arguments presented in the introduction chapter (Chapter 1), that predicting weather is valuable. Weather has strong impact on the local environment where human societies have developed and grown (Paper I). Basic needs such as food and water supply depend on weather, and, with economic development, industrialization, and growth of complex societies, the impacts are both different and more pronounced, due to increased frequency of severe weather events (Deaton and Winebrake, 2000; Parry et al., 2007) associated with climate change (Milly et al., 2002). In accordance with Table 5 (p.105), displaying human interest in weather, transportation, exploitation of energy resources, and energy power supply, are all weather dependent. Paper VII explores the context of agriculture. Paper II and Paper VI deal with some impacts of weather on the transportation system and individuals' daily lives. Beside the impacts issued on road conditions and traffic flows in everyday life, modern societies are occasionally stroked by extreme weather events and natural disasters such as storms, floods, landslides and blizzards (see European Environmental Agency, 2012). Threats of the future include direct impacts of climate change on the natural environment, and indirect effects arisen from insufficient resilience of the infrastructure (Changnon et al., 2000; European Environmental Agency, 2012; Smil, 2008). It is therefore possible to regard human dependence on weather in terms of two different sets of variables that might involve several contexts (Table 5, section 4.5): the natural environment, and the built environment. In order to define and position "share weather" within the research landscape, I introduce the concept of User-Generated Observations UGO (3.7.4; see Table 4, p.61). The most evident weather-related potential catastrophes are represented by climate change, including change of weather extremes and global circulation patterns (IPCC, 2007). Broad participation from different stakeholders in the society, including the public, is widely encouraged as the United Nations state that:

"In sustainable development, everyone is a user and provider of information considered in the broad sense. That includes data, information, appropriately packaged experience and knowledge. The need for information arises at all levels, from that of senior decision makers at the national and international levels to the grass-roots and individual levels. ... " (UN, 1992, Agenda 21, United Nations, Rio de Janeiro)

The research questions of this compilation thesis explore how "everyone" could be included in sharing weather information, suggesting the concept of "share weather" based on interactive media technologies (see 3.1 and 3.8.1). The thesis suggests the idea that "share weather" might improve weather information. Research question Q1 aims at theoretically testing the feasibility of the "share weather" concept. Q2 and Q3 are aimed to increase knowledge on designs and potential outputs of "share weather". These questions are expected to contribute new knowledge on development of tools and methods that might contribute to, for instance: reduction of uncertainties in projections of future climate, and improved knowledge on processes that cannot be modeled with current methods in environmental science. (Further details are provided in Chapter 2 for interested readers; see 2.3). The question is: how will we know what will happen with the climate? Currently, we do not know. It is evident that lack of data regarding components such as "clouds" in changing climate and the lack of profound knowledge on their properties (2.3.2) create uncertainties in predictions of future climate change (IPCC, 2007; 2.3). These, and other, uncertainties need to be reduced in order to provide more accurate estimations on the effects of climate change on the natural environment and human societies exploiting its resources. Sustainable development requires extensive data sets and systematic knowledge on weather and climate. Meteorology and other environmental sciences are, of course, active within this research domain, addressing the challenge of improving environmental data.

One step in the process, is studying how new media technologies might progress this area, and this compilation thesis addresses some related questions. Uncertainty, beside data collection and availability, represents a key challenge in modeling of the Earth surface and ecosystems (e.g., Paper III; Yue et al., 2009), and it can be associated with three different origins (section 2.3): (1) representation of processes in the atmosphere (e.g., how clouds are formed and how they affect the climate; see 2.3.2), (2) interaction and feed-backs between the atmosphere, hydrosphere and biosphere that may be manifested in undesirable "tipping points" (e.g., Scheffer et al., 2009; Lenton, 2011; see 2.3.3), finally, (3) limitations in current observation sets. In the introduction of this thesis, I pointed out that current methods of integration of weather observations into models are based on methods introduced in the 1950's (see also 2.2-2.4). Paper III and Paper IV suggest that "share weather" may possibly address the expansion of current meteorological observation networks in order to produce better weather forecasts (issues presented in 2.4), and to better estimate climate change and other changes in the environment (issues presented in 2.3) with the help of better or more complete observation sets of the environment. There is support, in both literature and practice, that using a combination of models and empirical data can improve weather information. Some examples are: integration of data from citizen programs such as CWOP (www.wxqa.com) (3.6.1), volunteering observation ships VOS (Paper III), prediction of tipping points and monsoon patterns (2.3.4), detection of shifts in storm tracks and precipitation cycles (see traditional ecological knowledge, 3.7.3, p.70), and, not the least, evidence of El Niño in Darwin's data (3.7.3, p.70). Feasibility of the "share weather" concept regarding collection of high-resolution data is further evaluated in the discussions of Chapter 6 and Chapter 7, including some generalizations that are relevant from a sustainable development perspective (7.1).

The empirical research of this compilation thesis, however, focuses on the context of transportation. In some papers, other contexts were explored, including a study on African farmers (Paper VII). Paper VII studied volunteers that provided precipitation data for the climate data records and agricultural forecasts, over an area with very poor weather data coverage. In this paper a cohesion between climate data, weather forecasts, and environmental impacts (related to property and survival) enabled collection of important data. The methodological approach in the empirical studies of Papers II–VI was, instead, to study the context of traffic in everyday life. Referring to the beginning of this section where the impacts of local weather on the built environment were highlighted, we may discover some interesting synergies between exploration of the built environment and the natural environment. If an individual is observing the road surface (the built environment), he/she may simultaneously observe several domains or sets of data associated with both the built environment, and the natural environment. It is possible that some of the obtained data contain information that might be used for environmental monitoring purposes. This means that "share weather" might potentially improve a traffic weather forecasting for tomorrow, while the same information might also be useful to researchers modeling the Earth surface. This inspired the previous introduction of the concept of User-Generated Observations (UGO) in 3.7.4.

The United Nations state that the need for information arises at all levels, from that of senior decision-makers at international levels to "the grass-roots and individual levels" (UN, 1992). "Share weather" is the concept of sharing weather data between individuals (see 3.1). Therefore, I will here also propose that "share weather" might take an important role in shaping awareness about environmental problems and increased public participation in complex environmental issues (see 4.6). These issues are further explored in the discussions and generalizations on "share weather" findings in Chapter 7. In order to address the sustainability aspects, in Paper VII, I explore how all three dimensions of sustainability might develop within the context of "share weather". The findings of Paper VII suggest that, under certain premises (e.g., rural areas in developing countries), the concept might be supportive of sustainability through the connections it might establish at several levels: linking the economic dimension (pricing of "share weather", "goods" and improving forecasts for agriculture) with climate assessment and the positive social aspects of participation in networks (see Paper VII).

Based on the outline above, I conclude that exploring "share weather" can contribute relevant and valuable systematic knowledge, provided that the methods used are scientific, which is addressed in the coming sections.

5.2 Scientific methods and methodology in Media Technology and "share weather"

Prior to Auguste Comte (1798-1857), the "founder of sociology" (Giddens, 2009, p.12) introduced the word "sociology", researchers called this area of research "social physics". Most scientists of the time tried to explain the social world in terms of universal laws just as natural science explained the behavior of atoms and the general functioning of the physical world. A positivist approach, proposing that even social beings and their interactions, i.e., society, can be studied by applying rigorous scientific methods of physics and chemistry, prevailed at the time.

The empirical work presented in this compilation thesis represents a series of studies on how individuals behave while interacting and using media technologies. As we all know, technology takes many forms, and human beings are not monolithic; therefore, a pure positivist approach cannot be applied. Meteorology, the information domain defining the context of the empirical studies of the papers, however, belongs under natural sciences. Weather forecasts are creations of computer technology (2.4.1) based on laws of physics (e.g., conservation of energy) (2.2.1). In theory, physics may provide a full description on how natural elements are predicted to behave. In that sense, the compilation thesis investigates how social beings may replace or complement outputs of systems based on physics and accurate mathematical descriptions. Namely, the compilation thesis explores how a new concept that must account for human behavior, might improve systems whose operations are based on natural science. The question is why this would be possible, why should we believe that humans can improve the work of advanced machines? We will find an explanation in the methods and methodologies. Meteorology and other disciplines in environmental science can be chosen, because methodologies applied within Meteorology and the environmental sciences are not deterministic. In fact, Meteorology is slightly more "similar" to social science methodology than the conventional disciplines of natural science (such as physics). Interestingly, environmental sciences use system science approaches, and this might provide some advantages while attempting to integrate meteorological applications with social science methodologies.

This section will discuss methodology applied in Media Technology research and provide some first results on how meteorological data might be introduced in Media Technology, with the aim of designing "share weather" – a fusion of the two.

5.2.1 Measuring weather: An overview of meteorological applications

Merging the two areas "weather" and "Web 2.0" (3.1) and investigating whether "share weather" might improve weather information requires methods for assessing quality of weather data. This section provides tools for comparison between measurements conducted on "share weather" and current weather information, for instance used to address Q1.

The results of this section also reflect some central questions regarding the potential importance of research on "share weather". In the beginning of this chapter, a sustainability perspective unveiled that accessing new weather data might be important to society (see 5.1).

Chapter 2 outlines the complex nature of environmental systems. These have urged a range of simplifications of the equations describing atmospheric and environmental processes (e.g., 2.4.1). This is why weather can be predicted only two weeks in advance, and with great uncertainty. This section briefly describes how meteorology works and current methods used for improving weather information. To begin with, natural science is not enough, and forecasting weather with Numerical Weather Prediction (NWP) models is solved by compromising between physics and empiricism. Physics – studying the basic components of matter governed by fundamental laws of nature on atomic level – provides a very important basis for meteorology in terms of equations describing the motions, and energy transport, in the atmosphere. The number of atoms exposed to different conditions is, however, extremely large in the atmosphere, and the physical descriptions are simplified in order to be useful and applied in practice.

A common application, of which we all have some experience, is the many weather forecasts presented through media technologies. Another application is the "climate scenarios", simulations of future climate used by the Intergovernmental Panel on Climate Change IPCC (www.ipcc.ch) for assessment of climate change. A third group of applications is addressed in this thesis; it is represented by the many applications for assessing the *consequences* of weather on different human activities such as transportation and agriculture.

In these simplified models of a complex reality, the atmosphere is described as a large grid of "air parcels" of the size of about 10 kilometers (2.4.1), or more. Their standard input consists of the 10^4 observations collected by the WMO SYNOP observation network (see 2.2 and 2.1) every third or sixth hour. Mutual interaction, processes within "air parcels" and interactions with other parts of the environmental system (e.g., the Earth's surface covered by oceans, rivers, woods, fields, mountains, snow) are represented by "parameterizations" in both environmental modeling (2.3.2) and weather forecasting (2.4.5). Additional data sets (2.4.3) can be integrated through "nowcasting" (2.4.4) or the more advanced method of "data assimilation" (2.4.2).

While interested readers are advised to look for details in Chapter 2, this section will proceed with an outline of how these methods affect the methodology of this compilation thesis. Data assimilation (2.4.2.) creates interpolations over points with missing observation data prior to running NWP. These are necessary in order to adjust the available observation set consisting of only ten thousand (10^4) observations to "air parcels" of the size of ten kilometers ($10km^3$) covering 510 million square kilometers ($5.1\ 10^8\ km^2$) of the Earth's surface. Another method is applied after running an NWP for improving the outputs, nowcasting (2.4.4), where the weather forecasting systems is "fed" with new real-time observations, or the outputs are improved by comparison with real-time observations, subsequent processing and modifications. It is important to note that the origin of these methods is contextual and defined by technological premises prevailing at the time of their introduction. Data-assimilation was introduced due to lack of sufficient input in the 1950s, while some new sets, for instance satellites, improved the input in respect to some variables. Nowcasting, on the other hand, may be based on many different sources of weather data, including non-standardized data sets.

One aim with this thesis is to explore new sources of additional data that might improve weather information. The methodology of the compilation thesis, in particular Q1, therefore involves comparison of "share weather" with the processes of data assimilation, nowcasting and parameterization.

Parameterization is imperative in both environmental modeling (2.3.2) and weather prediction (2.4.5). Parameterizations aim at describing complex processes in a simple and generalized form using substitute variables that can simplify the temporal and spatial dependence and the processes themselves. Because weather (pressure, temperature, humidity, wind) affects the environment (e.g., biodiversity, soil and land degradation, run-off of rivers, ocean currents, ice cover), climate researchers use substitute variables, and environmental research has a long tradition within field studies. In weather forecasting, parameterizations compensate for lack of methods to accurately predict weather which, ideally, would require pure physics and additional computational power to reduce the size of the “air parcels” from their current size of 10 kilometers, to smaller entities. Environmental processes are, in general, described in terms of substitute variables; parameterizations therefore constitute an essential input to climate simulations. In this way, NWP and climate models may simplify a complex reality: each air parcel is attributed a certain value of different substitute variables. Naturally, modeling the whole environmental system, including interactions between air, water, soil and living things, requires even more extensive parameterizations, such as long-range (months and years) interaction between air and ocean temperature in climate models. In environmental studies, the large number of unknown variables implies that results acquired in one study (for instance one geographical area) are not universal and valid for other contexts.

Models describing the built environment, such as modeling road conditions, can be compared to environmental modeling, because they must also integrate several different systems. Modeling road surface represents a real challenge for infrastructure administrators of temperate climate zones such as Scandinavia. An area of road surface in a modern city is exposed to different weather conditions and the environment in terms of road type and microclimate: neighboring vegetation, woods and buildings, open water surfaces, vegetation or fallen objects and liquids on the road, warmth (energy) radiated from houses and by vehicle (tires) friction (e.g., Wallman et al., 2005). Drawing on the above, it is evident that the needs identified by road officials and citizens in everyday life – accurate forecasts on a very local level (meters/miles) (see Table 5) – are beyond the reach of the spatial resolution of the SYNOP weather station network (see 2.2) and weather forecasts (see 2.4) that operate on a spatial scale of ten kilometers and a time scale of hours. Moreover, modern cities require forecasts of variables describing the *consequences* of weather (e.g., slipperiness) rather than forecasts of meteorological variables (e.g., temperature), and the relationships between these sets of variables are highly complex (as in environmental modeling). Therefore, transport administrators in many countries have introduced additional data sets (2.4.3), Road Weather Information Systems (RWIS), particularly well-dispersed over areas with dense road infrastructure (e.g., large cities). RWIS can have spatial resolutions down to 1 km, supplying expert systems with real-time data (0-15 minutes).

Drawing from this overview, “share weather” system properties should be compared to current technologies and methods: parameterizations, data assimilation, and nowcasting. User-generated observations (UGO) of weather should be compared to SYNOP and RWIS.

5.2.2 Measurements in Media Technology research

From the previous outline it follows that addressing the goals of this thesis requires empirical measurements of different variables associated with weather and human perception. The empirical studies presented in this thesis were, therefore, challenged by methodological concerns issued by the complex nature of weather, and humans, respectively.

Independent variables are defined as the "cause" of the change in the independent variable. They are usually the conditions that the researcher can control, while dependent variables mostly refer to the outcomes that are measured (e.g., Oehlert, 2000). In Media Technology, and closely related disciplines, such as Human-Computer Interaction, independent variables are represented by: different technologies, users, or the context in which the technology is being used, while dependent variables often are: efficiency, accuracy, subjective satisfaction, ease of learning and retention rate, physical or cognitive demand (Lazar et al., 2010). Typical independent technology-related variables are: devices, different types of technologies, and different designs.

In Paper II, SMS technology is an independent variable, as is the early-warning service based on the "recent weather" method (5.3.2) delivered to the respondents. User-related independent variables may be: age, gender, experience, motivation. Paper VI and Paper VIII used the user-related independent variable "time of participation". Independent variables may also be associated with the context of use of a technology covering both physical factors (environmental noise, vibration, temperature), and users' status (seated, walking, driving a car) (Lazar et al., 2010). The context of transportation (Papers II–VI), agriculture (Paper VII), Group D in the patients' waiting room at a dental clinic (Paper V), and Study I (Paper VIII) on 50 students all represent different contexts; this is an independent variable in the studies presented in the compilation thesis. Another set of variables related to the physical context was the weather type. For example, user-generated weather observations of group A were studied under uniform (particularly severe) weather conditions (Paper IV and Paper V); temperature, precipitation, snow cover, and other variables associated with the weather, were therefore considered independent variables. A summary of dependent and independent variables is available in Table 6 (p.129).

In the empirical studies of this thesis, several variables were measured on several different occasions; the papers therefore form a longitudinal study (Paper II, Paper IV, Paper V, Paper VI, Paper VIII). One variable measured in most surveys was "scoring" (5.3.3) reflecting subjective satisfaction (experienced quality) (see 5.3.2) of the service. Other dependent variables were: the type, and quantity, of changed decisions (Paper II, Paper VI, Paper VIII), the quantity of user-generated weather observations (UGO) (Paper IV, Paper V, Paper VIII), and the weather type in UGO (Paper VIII).

5.2.3 Scientific studies

Empirical studies on different media technologies, including the empirical studies of this thesis, are often relational. Other possible methods are descriptive investigations, and experiments (e.g., Rosenthal and Rosnow, 2008; Lazar et al., 2010). For comparison, natural science strives at using the experimental method; this is facilitated because the relationships are universal and subjects behave according to particular laws. In a true experiment, the investigator can fully control the experimental conditions so that a direct comparison can be made between dependent variables and an independent variable (Lazar et al., 2010). An experiment can identify causal relationships and provide statistical evidence to refute or nullify the null hypothesis in order to support the alternative hypothesis (Rosenthal and Rosnow, 2008).

The design of an experiment consists of: treatments, units, and assignment method (Oehlert, 2000). In Media Technology research, units are usually represented by humans (e.g., individuals that volunteer to participate in a research project studying traffic weather services), whereas treatments represent different conditions applied to the test persons (e.g., receiving weather alerts, or interacting, or perceiving different types of weather). Because the units are incoherent, randomization of assignments is necessary. In the empirical studies of this thesis, first of all, the weather could not be controlled. The weather alerts were issued based on the weather type, of which many have widely different characteristics. Finally, the respondents represented an incoherent group, and their actions and perception were not only governed by the treatments. However, I identified a quasi-experiment. A *quasi-experiment* involves multiple groups or multiple measurements, and thus resembles a true experiment in some respects (Lazar et al., 2010). When an experiment or a quasi-experiment is not conductible, research may be based on relational investigations. Relational investigations are characterized by only one observation or observing only one non-randomized group, and conclusions can only be drawn on how different variables relate to each other.

Due to the different limitations in relational studies, one naturally seeks to address them with new approaches. If evidence is found on a phenomenon in one study, it is desirable to conduct a new study confirming the "scientific truth" of the results (Lazar et al., 2010). A combination of several methods regarding several sources of evidence is desirable and is called *triangulation*. In the papers of this thesis, several measurements were often performed (e.g., on Group A, see Papers II, V, VI, and VIII), and the same measurements performed on several groups (e.g., Group A, C and D; see Paper V). However, the studies were challenged by variable separation and the large number of variables that could potentially intervene. Doing research based on relational investigations means that one can describe connections between multiple events or variables or *identify relations between multiple factors*. Causal relationships cannot be established, but *evidence* of correlations between different variables is presented.

In the first, explorative phase, there might be situations where conclusions on relations between different variables cannot be drawn; then the researcher may accurately describe what was observed in a *descriptive investigation*. For instance, I applied this method when conducting some pre-studies. On these occasions, data were collected in order to design the set-up of the relational studies and one quasi-experiment.

It can be concluded that studying how weather (a variable changing over space and time) influences the behavior of individuals (incoherent subjects with different perception and properties) might be difficult. I will here illustrate this with some statements made by Theophrastus (373-286 B.C.) on "weather signs":

It is a sign of rain or storm when birds which are not aquatic take a bath. It is a sign of rain when a toad takes a bath, and still more so when frogs are vocal. So too is the appearance of the lizard known as "salamander", and still more the chirruping of the green frog in a tree. It is a sign of rain when swallows hit the water of the lakes with their belly. It is a sign of storm or rain when the ox licks his fore-hoof; if he puts his head up towards the sky and snuffs the air, it is a sign of rain.
A dog rolling on the ground is a sign of violent wind.

Theophrastus (2007) (373-286 B.C.)

Theophrastus provides a series of "signs of rain" and "violent wind" related to behavior of animals such as frogs, the salamander, the ox, birds, and dogs. What Theophrastus discovered was a possible relationship between weather and some particular behaviors of animals. Anyone knows, however, that a dog may roll on the ground on a calm day. This means that different causes of a dog's behavior cannot be separated from each other, because they can be several: the dog might be showing its affection, or expressing his feelings because of the storm, or just be a lazy dog. In addition, the dog may be rolling because it is raining, and not due to the "violent wind", although the observer may not be aware of that fact unless measuring precipitation (the real cause of the behavior). In these examples, a causal relationship between multiple factors is not established; Theophrastus only presents *evidence* of correlations between different variables. He probably based his conclusions on multiple observations, but he could not control the independent variables. Treatments, i.e., different conditions (breeze, storm, rain, sunny weather) applied on the test dogs, must be assigned randomly (to both happy dogs and lazy dogs), and on a sufficiently large and randomized group of dogs, in order to achieve statistical validity.

The same reasoning applies to behavior of respondents in the empirical studies of this thesis. What causes their behavior after receiving a weather alert for instance (e.g., Paper II and Paper VI)? Do they change decisions based on some additional factors, and are there other variables associated with the weather alert service that can issue changed behavior? In Paper VI, it is proposed that there is an additional variable affecting decision-making. Namely, I assume that interactions issued through participation in the test of weather alerts creates "trust" (see 4.1.3 and Paper VIII). It is, however, possible that the subjects change behavior due to a series of other unknown factors: holiday, illness, work, appointments. Or, lack of randomization resulted in selection of a population sample of individuals that were exceptionally trustful. Conclusions made in both Paper VI and Theophrastus' "signs" are results of relational studies; they present evidence of correlations between different variables and create arguments for formulating hypotheses. In the worst case, the original hypothesis – that trust grows with interactions – might be based on wrong assumptions. For instance, Coleman's classic theory (see for instance 4.1.1) is based on observations conducted within contexts characterized by strong established structures, strong ties, and little networking with the outside world. When networks go online, the structure that is *studied* might be radically modified by a new context: in networks where many weak ties are present, researchers might discover new relations.

Sometimes, when it is not possible to draw conclusions regarding correlations, one can describe what has been observed. For instance ethnography applies in-depth descriptive investigations of different group cultures, where the aim of the investigator is to become more or less integrated with the group in order to truly understand the group culture (Lazar et al., 2010). Although ethnography was rooted in particular research on non-western cultures, it has developed into a general methodology describing a human group: its institutions, interpersonal behaviors, material production, and beliefs (Angrosino, 2007). Due to the particular role of myself ("the meteorologist") as an "involved researcher" (see Walsham, 2006), it may be recommended to apply ethnography as methodology. One argument is that I utilized my particular knowledge within weather forecasting and meteorology in order to create a service and the study set-up attributed me the position of a central node in the network. The service, and interactions, impacted the respondents' behavior (e.g., Paper VI). In another study, some exploratory steps were taken prior to designing the empirical studies: studying school children (Group C in Paper IV and Paper V), I had to become integrated with the subjects and their environment under the pre-study, collecting data and preparing the subjects for coming activities (weather observations) and eventually observing the activities on one occasion. Integration into the schoolchildren's environment provided opportunities to collect data regarding children's vocabulary and their understanding of weather phenomena, or: describing a human group with its interpersonal behaviors and beliefs (Angrosino, 2007).

It follows that, in Media Technology research, it is particularly important to explore the context, identify issues and to design relevant questions, prior to designing and conducting studies. The reason, also representing one issue in this compilation thesis, is the rapid change of the context in terms of technological development. A novel phenomenon studied over a short period of time might result in erroneous conclusions. For instance, questions designed in 1990 (prior to development of smartphones) investigating navigational equipment while driving, may jeopardize the validity of the results. If only alternatives represented by early and quite expensive GPS installations are regarded in research studies, their validity is limited in time. Therefore, research on "share weather" must consider that new technologies may become available in the future, changing the premises and contexts of sharing weather information. For instance, in Chesbrough et al. (2008) it is argued that, because open source (see 4.3.2) is an emergent phenomenon, there might be issues regarding the sustainability of its current shape. Results on "share weather" presented in this thesis must therefore be analyzed in respect to the studied context and a potentially rapid change of premises.

The issues presented in this section reflected how reliability and validity can be challenged in Media Technology research. Reliability means that research can be replicated if repeated and still yield results that are consistent and stable (e.g., Lazar et al., 2010). Here, reliability is challenged by fluctuations in human behavior, interactions, and weather. In addition, particular requirements are placed on the analysis; it should reach the same conclusions if performed by other researchers. Validity requires, besides reliable measurements, also valid methods or establishing correct operational measures for the concepts that are studied (construct validity; e.g., Yin, 2003), and that particular conditions are shown to lead to other conditions (internal validity e.g., Yin, 2003). The empirical research in this thesis is therefore confronted with the difficulty of generalizing the results to new contexts, whereas the validity and the reliability issues can be partially addressed through appropriate research design, methods, and suitable methodology. In 5.3, I proceed with the specific methodology used in this compilation thesis, in order to address these issues.

5.3. Methodology used in the papers

In this section, I describe the methods used in the empirical work conducted in this compilation thesis and show why they should be regarded as based on scientific methodology. This section provides complementary material to the papers and conducts a more thorough discussion of methods and methodologies excluded from papers due to convenience and available space.

5.3.1 Introduction to methods

The papers describe a series of studies mixing quantitative and qualitative analysis, aimed at studying user-generated observations (UGO), design and evaluation of a "share weather" artifact, and a weather service as a feature of that artifact. Examples of weather alerts are provided in English in Paper VI, and in the original language (Swedish) at www.shareweather.org. Fig 2 displays studies on respondents in Group A, who were divided into groups based on time of participation. An overview of all the empirical studies and the papers is also presented (see Fig 2).

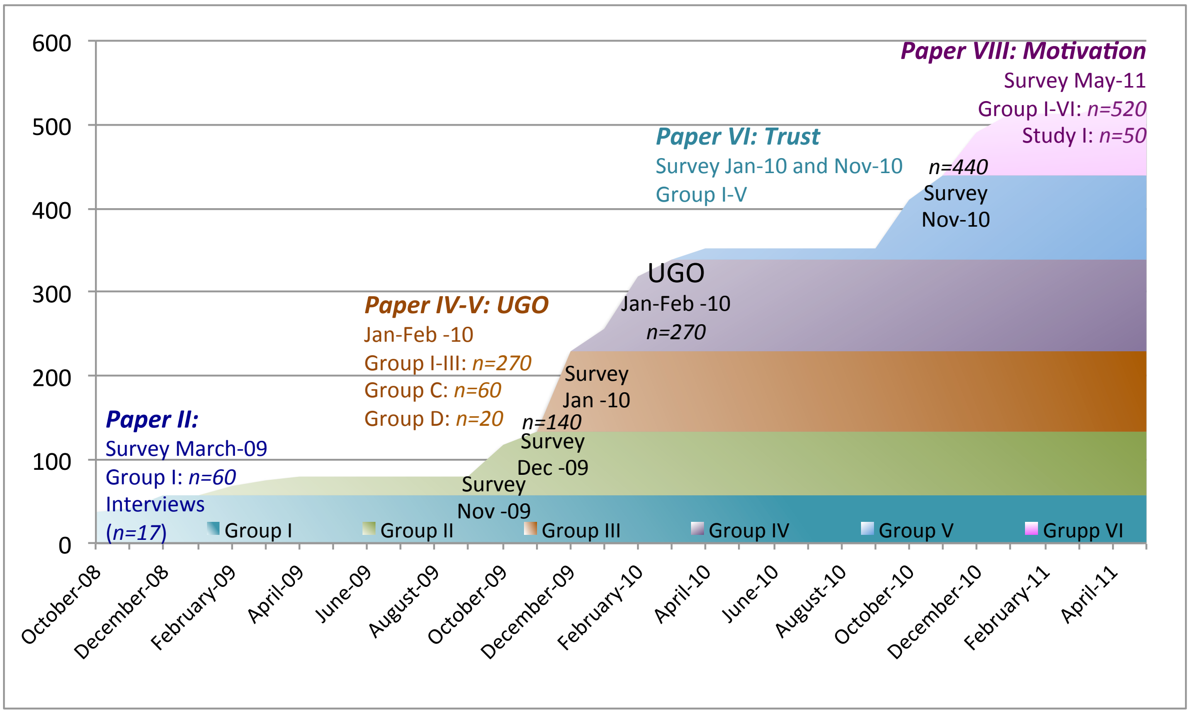

Fig 2. Overview of empirical studies and respondent groups

The method applied in this thesis consisted of a longitudinal study conducted during 2008-2011. Respondents assigned to participate in a research project and received weather alerts via SMS and e-mail and were addressed with questionnaires (Paper II, Paper IV, Paper V, Paper VI, Paper VIII). Seventeen respondents participated in interviews conducted at the time of the commencement of the study. About 90 alerts were sent during the three winter seasons. During the course of the studies on this group (Group A, see Paper V), new respondents signed up expressing their interest in participating, resulting in a growing number of respondents. Questionnaires supplied data on self-reported behaviors and personal information. A parallel study was conducted on UGO in 2010 collecting data via: SMS, a web form, and a printed form (Paper IV-V). Here, two new groups were added: 60 schoolchildren (Group C, Paper IV-V) and visitors at a dental clinic (Group D, Paper IV-V). In addition, a study of UGO of weather within a different context, African farmers (Paper VII), was based on one interview and an official report. A new study on UGO in 2011 focused on self-reported behavior (Group A, Paper VIII) and data collected from www.shareweather.com (Paper VIII). Finally, a qualitative study on 50 students' written descriptions was conducted (Paper VIII).

The compilation thesis applies a set of different measurement methods that enabled triangulation, and a combination of qualitative and quantitative approach. The overview discusses the different approaches and some new methodology introduced through "scoring" and "recent weather".

5.3.2 "Recent weather"

The "recent weather" method was applied in Paper II, Paper IV, Paper V, Paper VI and Paper VIII. The method is anchored in a user-centered approach regarding the user perspective and user needs. This is relevant for Q2 and motivational theory studying individuals' needs. The method was introduced when designing the traffic weather service (Paper II) necessary to conduct some of the empirical studies. It also constitutes a part of the design of a specific "*Shareweather*" artifact (Paper V). Consequently, it was an important step in the design process, addressed in Q3. Moreover, applying the "recent weather" method provides insight into customization and personalization of weather services and some variables associated with the *quality* concept, constructed from several variables including meteorological quality and the experienced quality.

The "recent weather" method draws on the limitations in individuals' memory of past events. It is well-established that individuals recall recent events to a greater extent than events that occurred in the past. Therefore, it was assumed that the size of change in weather characteristics is reflected in user perception of weather. If the temporal structure of the service is adjusted to "recent weather" (during the past week), the service will manifest a greater effect on user behavior (see Paper II), and a weather alert is only relevant if the change in weather characteristics might issue concerns that are real or perceivable by the user. Exploration of perception of weather required input from other disciplines associated with Intelligent Transport Systems (ITS) that studies application of information and communication technology to the planning and operation of transportation systems (e.g., Juhlin, 2010). The following ITS topics are relevant: traffic psychology and perception of risks in traffic, factors that impact perception of weather information, and behavior issued by such information. "Recent weather" was introduced in order to address the limitations in current (road weather information) services through bringing a user perspective and introducing "Web 2.0" as a solution (see Paper II). Based on the weather conditions during the past two weeks that could be observed by the user, a weather alert is sent only if a certain threshold is reached compared to "recent weather".

Some other important issues are associated with "recent weather". Based on a "user-centered" design perspective (later addressed in section 5.4), a user perceives a service including all its components, and the effects of a weather forecast cannot be separated from other features: service design, the content (including meteorological accuracy), and context-related variables. The concept of *quality*, then, becomes the sum of user perception of weather, user perception of quality of the service content, and user perception of service design (see also 5.5.4), and, possibly, it reflects local variability of weather. Most important, it does not measure meteorological quality. This was relevant when comparing measurements of user-satisfaction with "share weather" outputs, and when comparing the weather alerts service (a part of the "*Shareweather*" artifact) to other services. Namely, high user-satisfaction associated with the service designed in Paper II, compared to other services, pointed out that "recent weather" was relevant.

5.3.3 Interactions and "scoring"

The empirical studies of this thesis were highly based on measurement methods involving user-satisfaction, and the researcher was involved in terms of different interactions with the respondents, understanding and assessing the effects of interactions was of particular importance. Moreover, one of the measured variables in the papers was "time of participation", a substitute variable for "trust", which issued questions on how "trust" can be measured. While this was treated in Paper VI and Paper VIII, I will here provide a summary pointing at the methodological issues that were raised as a result of different interactions. I also describe the methodological approach behind "scoring", a method introduced in Paper VI.

The concept of "trust" was previously defined (4.1.3) as a consequence of past interactions and a consensus was reached, disregarding the motivation theory approach, on that: a history of favorable past interactions leads to expectations of positive future interactions. In Paper VI and Paper VIII, the quantity of interactions was measured using a substitute variable "time of participation" (see also Table 6). Respondents were divided into groups based on time of joining the network (see Fig 2). This was possible because the weather alerts were dispersed over time and respondents tended to join after occurrence of events of larger magnitude or after broadcasting on radio, resulting in "sudden jumps". Because the amount of received weather alerts was almost constant within a group, it might be regarded as an independent variable. Fig 2, which displays the number of participants on a timeline, however, shows that, in reality, there are some differences within the different groups. Namely, the groups were registered on a weekly basis and thereafter divided into 5 (Paper VI) or 6 (Paper VIII) groups. However, considering the size of the groups (n=57 to n=110), it might be justifiable to associate experienced equivalent benefits in terms of receiving a service (positive experiences in the past), with time of participation within the network. However, a more serious concern should be raised because the alerts were not the only type of interactions. Several respondents also interacted via UGO, spontaneous e-mail-conversation, SMS, open-ended questions, telephone conversations. In addition, 17 respondents were interviewed. The definition of "trust" (see 4.1.3) implies that it is not possible to separate credibility – the effects of a potentially useful and trustworthy service (the individual dimension) – from the possible impacts of personal interactions (structural dimension). This means that the respondents were influenced by different interactions with the researcher, reflecting the problem of "involved researcher". One methodological approach was introducing the method of "scoring".

"Scoring" was aimed for separation between the effects of interactions on different measurements. There were three different sources of interactions that could issue measurable effects: the effects of the service, the effect of interactions with the service provider (central node), the effects of online participation. The researcher had a role of a service provider. It was, therefore, highly probable that the subjects were affected which might have created convenient responses. Therefore, in parallel to other measurements, the respondents were asked to compare weather events with the forecasts provided in the service in a closed-ended question with ordered response. This methodology provided information on the impact of interactions on the objectiveness of respondents' evaluation of the service. The analysis (see Papers V–VI) rejected a correlation between "scoring" and time of participation. Based on this result, measurements of "subjective satisfaction" (evaluation of the service in Papers II, V, VI and VIII), and measurements associated with decision-making and behavior (Paper VI) were considered reliable.

5.3.4 Validity

Because the studied subjects are human, the studies had to account for individual differences within a sample and the properties of the sample compared to other populations. The respondents were asked to provide personal information on a regular basis (every questionnaire). This section provides some examples on how validity was treated through introduction of several measurements and variable separation. In most cases, it was a question of assessing the effect of different individual properties, that is, the variance of different measurements. Here, I discuss personal properties and perception of weather, personal properties and local variability of weather.

Personal properties may differ due to experience, psychological profiles, socio-demographics. While it is possible to assess socio-demographics and experience, the psychological effects are more difficult to account for. Such differences, naturally, impacted respondents' decisions. Moreover, they can also affect perception of weather. For instance, an individual with high-risk awareness may report that "the weather is as (bad as) forecasted" while a person with high-confidence in personal driving-skills may be of the opinion that the weather is "better that forecasted". This potential issue associated with internal validity (see 5.2) was addressed in Paper II: The respondents were asked to provide their opinion on the frequency of weather alerts (whether they would have preferred more warnings, or fewer warnings). This variable reflected risk awareness. However, Paper II showed that other dependent variables were more important (and consequently biased this result), among which trust and the weather type represented some.

Due to 5.2.1, it is difficult to compare observations of weather within an area of a size smaller than 10 km^2. Namely, the weather, in particular traffic weather, may vary within that area. This issues concerns associated with construct validity (see 5.2). I used the following approach: In the study on UGO in Paper IV-V, the problem of separating variability of local weather, from differences issued by individual properties was addressed by choosing extreme weather events that resulted in uniform weather conditions over large areas. Therefore, local weather was constant for the studied area (Stockholm county). In other weather cases, in particular during early winter season, a significant discrepancy was manifested. Namely, Paper IV and Paper VI noted a dispersion of respondents' "scoring" during early winter season. However, the sum of scores "as forecasted" and "slightly better than predicted" was comparable. This shift toward "slightly better than predicted" may, theoretically, be attributed either "denial of consequences" (Forward, 2008) before revising a hypothesis (Einhorn and Hogarth, 1985) or local variability of weather. Previous research shows that local variability of weather is pronounced during early season, in particular in icy situations, which may explain the larger variance.

These findings point to the importance of studying the properties of the sample, and they underline that context-specific limitations must be considered when analyzing the results. In the empirical studies of this compilation thesis, some particularities of the context might restrict further generalizations. Concerns associated with validity were addressed by triangulation, conducting several measurements on the sample under the same or similar (weather conditions are difficult to repeat) conditions.

5.3.5 Reliability

Because the methodology used in the papers is based on surveys consisting of subjective opinions provided by individuals, the reliability of the results should be questioned; self-reported motivations and behaviors do not necessarily reflect actual behavior.

First, respondents might be affected by how questions are presented. Krosnick (1999) suggests that the level of effort a respondent devotes to completing a questionnaire depends on the individual level of motivation to invest time in interpreting its meaning, searching memory for relevant information, and expressing judgment by selecting one of the response options. When motivation declines, people shortcut this process by, for instance, selecting the first response alternative or selecting an offered “don't know” response option. In the questionnaires applied in the papers, the most positive scoring (“the weather was as forecasted”) was provided in the middle, while the first option was “the weather was much worse than predicted” (see Question 4 in the Appendix in Paper VI); both “don’t know” and “don’t remember” options were offered, and these alternatives corresponded to 0 % up to a few percent.

One source of errors is a result of interactions (see also 5.3.3). This phenomenon can be explained with “impression management”: the respondents are presenting themselves in the “role” of, for instance, an excellent car driver or a responsible participant in a scientific project, due to identities issued by the context (e.g., Goffman, 1959). The results may also be biased if participants are under social influence (4.1.1.), for instance employed by an organization that enhances their participation in the project (professionals were estimated to account for 10% of all respondents, e.g., Paper V and Paper VI), or they may try to avoid the risk of receiving punishments (the student group in Study I, Paper VIII). Since 20 of 70 students rejected the question, and thereby avoided being confronted, Paper VIII argues that compliance is partly avoided. In the case of the larger group of individuals interested in traffic information (group A, Paper V); the respondents were told that their contributions were anonymous; therefore, the effects of potential compliance are reduced. Also, the method of “scoring” implied that compliance was not significant for some specific results, confirming the reliability of the chosen measurement method.

An additional methodological approach was to measure several variables that reflect the same phenomenon. For instance, decision-making may be reflected in type of changed decisions, frequency of changed decisions and change of equipment. These variables were also measured on several occasions, for instance different weather cases, different seasons (early and mid-season respectively, see Paper VI), and years (2008/2009: Paper II; 2009/2010: Papers IV-VI; 2011: Paper VIII). To some extent, it was even possible to choose an appropriate variable that can be measured with higher reliability. For instance, several variables might reflect “trust”, such as different types of changed behavior in multiple choice close-ended questions. However, one specific behavior that might be considered to be a more accurate measurement method is the “change to winter tires”, because change of tires requires more planning. In general, I assumed that it is more reliable to ask what types of behaviors were manifested instead of requesting subjective opinions. While answers describing decision-making potentially might be biased by factors such as recall, misunderstanding of questions, or violations, perception of the service is additionally influenced by subjective opinion.

It can be concluded that the risk of issuing errors related to recall of events and misinterpretation of questions may be reduced by carefully designing the surveys, including testing questions on a few respondents prior to conducting the survey, and by sending the surveys with no longer than a two weeks' delay (e.g., Lazar et al., 2010) after the occurrence of the studied events. Seventeen interviews were conducted (Paper II) in order to test survey questions, and the questionnaires were sent not later than two weeks after occurrence of severe weather events that were subjected in the survey. (Naturally, this was not possible when the questions referred to a longer time period such as the previous month; surveys were, however, sent not later than two weeks after the occurrence of the latest event.)

Respondents can also be affected by the environment (e.g., Lazar et al., 2010). In this thesis, the potential impacts of the weather type on respondents' answers and how their satisfaction influenced evaluation of the service was highly relevant. This was investigated in a separate test through sending the same questionnaire to two different groups, at different points in time. The first group (half of the respondents) received a questionnaire after a severe weather event had occurred (see Fig 2 in Paper II); the other half took the same survey a couple of weeks later shortly after the winter season's last event, when the weather had suddenly turned very sunny and the first signs of spring were announced. The results indicated that the prevailing weather conditions might have impacted the survey results: the second group had more optimistic judgments of the service. The effects of weather on human perception are confirmed in literature by, for instance, the effects of weather on the stock exchange (Hirshleifer and Shumway, 2003). Impacts of weather on survey outcomes was particularly addressed by Forgas et al. (2009) and Williams et al. (1997) who found a relationship between the prevailing weather conditions on the day of the survey and attribute satisfaction ratings at winter resorts. In fact, the "recent weather" method (5.3.2.) was also based on the assumption that recent weather experiences affect perception of road conditions and weather. However, the difference between the two surveys conducted during different weather conditions can also be attributed the first group's disappointment due to a "missing" alert, and the satisfaction of the other group as they had recently received an alert. This result therefore also reveals not only the effects of environment such as the (sunny) weather, but also possible systematic errors due to satisfaction/disappointment related to the service. It can be assumed that the results presented in the compilation thesis potentially might manifest more optimistic judgments of the service due to the benefits and gratitude related to the service, based on the fact that there were very few drop-outs (about 4).

5.3.6 Summary of methodological issues

A list of methodological issues is provided in Table 6 along with variables and measurements conducted in the empirical studies presented in the papers. Most studies were relational. A quasi-experiment is described in 5.3.7, while qualitative approaches are addressed in 5.3.8.

Table 6. Overview of relational studies and one quasi-experiment

	Independent variable	Respondents	Methodological issues	Hypotheses and analyses	Measurement method	Dependent variables
Trust Quasi-experiment Papers VI, VIII	Time of participation T (substitute for Awards/Interaction)	User groups with different time of participation (see Fig 2)	-Reliability of self-reported behavior* -Variable sep: Interaction/Awards	Confirmed: Increased T results in increased Trust	Quasi-experiment Closed-ended questions with ordered response	Changed: 1. decisions 2. equipment (reflect Trust)
Scoring Relational study Papers VI, VIII	1. Time of participation T 2. Evaluation of a service W	User groups: 1. with different time of participation 2. comparing services	Variable separation: -local weather -interactions -perception	1. Rejected that increased T results in more optimistic evaluations. 2. Users prefer service W1	Subjective satisfaction Several weather cases	Scoring of: 1. the weather service W1 2. other weather forecasts W2
Motivation Relational studies Papers V, VI, VIII	1.&2. Time T Interactions I 3. UGO collection 4. Students	Group I (personal communication) compared to Group II-V (limited personal communication) Students	Rewards and reciprocity enhance participation; intrinsic/extrinsic non-separable	1. Trust related to T/I 2. T not related to UGO vol. 3. Bad or sunny increases UGO 4. Sources of motivation	1. Survey participation 2. Self-reported 3. UGO volumes 4. Content analysis	1. Survey part. 2. Freq. UGO 3. UGO vol. for different weather types 4. Motivation categories
Sample Relational studies Papers II, IV-VI	Different user groups with different properties (e.g. level of interest in weather)	Group A (volunteered to participate) compared to Group D (dental clinic)	Variable separation: -weather -user personal properties and perception	Volunteers frequent users of weather info modern technology and transportation	Closed-ended multiple-choice (socio-demographics, transportation, media use)	1. Media technology use, 2. Transport 3. User properties
Evaluation of the weather service Papers II, IV-VI	"*Shareweather*" interface, "recent weather", other channels and providers	Group A (volunteers interested in traffic weather information)	Variable separation: -evaluation of SMS -evaluation of "recent weather"	Users believe that the weather service provided better information than other services	"Scoring" of the weather service vs. other sources	Evaluation/ Subjective satisfaction
Evaluation of UGO and "*Shareweather*" Papers V, VII, VIII	1. Users provide UGO in the "share weather" text format (SMS open-ended questions) 2. Scoring	Group A Observer B (trusted member of A) Group C (children) Group D (dental clinic, no prior notice)	Variable separation: -perception -local variability of weather -limitations in WMO/RWIS -compliance*	UGO of A, B and C reliable, D not reliable (Qualitative analysis, DSRM)	Comparison between UGO and WMO/RWIS (external sources of evidence)	Consistency between UGO: -Group A vs WMO/RWIS -B vs C/D

5.3.7 A quasi-experiment

The papers of this compilation thesis provide a relatively strong empirical basis enabling several measurements of different variables under different conditions. In this way, variable separation in the papers could be addressed through studying the variance and by controlling different variables at a time. The papers enabled drawing conclusions on probable correlations presenting evidence of correlations between different variables (i.e., relational study). For instance: ordinary untrained individuals can perform accurate weather observations, under the given premises (collection methods, weather situation, etc.), was concluded by Paper V, after a series of studies and two winter seasons of studies.

While the studies presented in Paper II, Paper IV Paper V are relational, one study in Paper VI can be classified as an experiment (see Table 6, Paper VI, "Trust"), namely behavior change. An experimental study aims at identifying causes of a situation or a set of events: X is responsible for Y (Lazar et al., 2010). In Paper VI, X is represented by the "effects of the service", and Y corresponds to measurements of dependent variables: quantity and type of changed decisions, and change of equipment: control of the independent variable "effects of the service" with division into groups depending on the time of participation (between groups). However, as previously discussed in section 5.3.3, exposure to the service was also associated with several types of interactions, therefore it is difficult to separate the "effects of the service" and the "effects of interactions". Therefore, a more accurate description of the independent variable X is "time of participation", although it is related to "the amount of received awards", and it might reflect "the amount of interactions". In this case, we have an experiment, although the context of X – the service – must be taken into consideration, because sole "interactions", or only exposure to the service with no interactivity, might not have produced the same result.

The findings suggested that "time of participation" is responsible for increased amounts of changed decisions during severe weather events (see Fig 4 in Paper VI and Fig 2 in Paper VIII) and increased number of respondents basing their change of equipment on the service (see Fig 5 in Paper VI). However, in order to determine a causal relationship, the results must also be statistically valid. In addition, the sample should be randomized, or the study would be classified as a quasi-experiment. It is difficult to randomize the sample since different respondents participated on volunteer basis and were divided into groups according to their time of joining the network. As discussed in, for instance, Paper VI, some respondents were under impression of other interactions (with for instance traffic radio reporters) and the sample was in that respect not randomized.

5.3.8 Qualitative analysis

The studies described in the papers applied a combination of qualitative analysis and quantitative analysis.

For instance, the questionnaires were analyzed quantitatively providing: the number of scores "as forecasted" (e.g., Paper II), the number of cancelled trips etc. However, some variables such as the set of variables describing the observed weather (e.g., Paper V) were compared using a qualitative approach, due to the large number of variables (over thirty) that described the weather. In Paper VIII, the quantity of UGO was sufficiently large (>3000), and only a few variables were relevant after the qualitative analysis was finalized, which enabled a quantitative approach.

The content of SMS (Paper IV and Paper V) and student responses (Study I, Paper VIII) were analyzed according to the following stages of qualitative research (Corbin and Strauss, 2008): analysis and identification of interesting phenomena; grouping of codes describing similar contents (time of observation, place, weather, road conditions, change of state, expressions of emotions, personal greetings, personal information); grouping concepts in categories, (i.e., grouping descriptions of wind into the category "weather"); forming a theory (i.e., possible correlations between concepts and categories). (See also Paper VIII regarding Study I.) Since a collection method was developed for "share weather" parallel to these studies, priori coding was applied on research-denoted concepts, that is, assumptions on what concepts are expected, and the latter were identified during the design of the collection method.

The evaluation of the "share weather" artifact required a combination of qualitative and quantitative analysis. For example, weather observation forms provided by group C in Paper IV and Paper V were first quantitatively evaluated in terms of "how many" groups provided identical answers, mode of their answers, and "how often". Then, the same weather observation forms were qualitatively analyzed as studied individually in respect to: "who" (which individuals) had participated, the prevailing weather conditions, and the measured variables.

Another qualitative study was conducted prior to proceeding with the other empirical studies: 17 respondents participated in semi-structured interviews (Paper II). The material collected under the interviews was used, through an iterative process, to, create and modify questionnaires used in Paper II–Paper VI; in addition, the input provided information for Iteration 1 in the design process, further described in 5.4. Finally, an unstructured interview was also conducted (a representative from the Sudan Meteorological Authority, see Paper VII).

5.3.9 Ethical concerns

Online contexts are associated with anonymity (see 3.5). While anonymity may create quality concerns, it also raises questions associated with user integrity. In the empirical studies of the papers of the compilation thesis, including the "share weather" system that resulted from the research presented in the thesis, volunteers provided data related to their private sphere, on their social demographics, habits, geolocation, preferences, media use, and opinions. Digital media, including the results of the empirical studies presented in the thesis, included different ways of efficiently collecting, storing, and exploiting, large data volumes of individuals' behavior and personal data, with potentially unfavorable outcomes. While the researcher should strive at protecting anonymity of users that participate in empirical studies, "share weather" may, if taken into practice, raise concerns. Different agents' interest in monitoring of certain behavior and opinions, for commercial, research, or other purposes, include serous concerns related to integrity, safety and democracy. "Share weather" applications may, therefore, include elements of monitoring and cause privacy violations; the threat of misuse of collected personal data, such as geographical position and activities, to name a few, is always present with digitalization and the Internet providing fast access and dissemination of data. Ethics is therefore important when researching "share weather" networks and related applications.

Another very important aspect of this research was manifested in the effects on respondents' behavior and trust. With time and increased confidence in the research project, interactions and built trust, also came a responsibility to not only avoid providing inaccurate information, but also a responsibility to provide highly accurate information. This ethical issue, for instance, limited the opportunities to experiment with false messages provided to individuals during severe weather, due to the potentially serious consequences. In the empirical studies, only one such test could take place and it was conducted early in the project (a "missing warning" during the first season, see Paper II). Although the respondents were frequently reminded of that the weather alerts were a part of scientific project, it can still be assumed that increased trust regarding the provider of weather alerts created expectations. As a researcher, I could not pursue any tests without fist regarding the ethical and practical consequences.

5.4 Design theory

"Whereas natural sciences and social sciences try to understand reality, design science attempts to create things that serve human purposes" (Simon, 1969, p.55, cited by Peffers et al., 2007). Design is a research area sometimes accused of not corresponding to the requirements of scientific methodology. This is due to the common view of scientific knowledge being characterized by statements formulated as testable hypotheses, i.e., deductive reasoning, whereas design processes build on inductive methods.

The scientific method is built on a base of testability and reproducibility: an experiment done in one place when replicated with the same set of conditions in another place with other scientists will yield the same results (e.g., Lazar et al., 2010). However, design science may be defined as a research area that focuses on developing *methods* that can use past ideas while developing – designing – new features in various contexts. The contribution of this compilation thesis to design theory is: applying design theory and extending knowledge regarding use of methods developed in design theory.

5.4.1 How the topic of the thesis relates to existing design theories

The empirical studies of the papers, including design and evaluation of a "share weather" artifact, are based on extensive participation of volunteers. Not only do they respond to questionnaires; they are also requested to provide user-generated weather observations. The process of creating information or artifacts in activities that take place in online communities is often referred to as "open innovation" (Chesbrough, 2003), a process where both internal and *external* sources of ideas are taken into consideration during the design process. Other possible approaches to design of "share weather" artifact are participatory design (Muller, 2003) (with a strong tradition in my home department at KTH), open innovation and the lead-user methodology (von Hippel, 1986) (where individuals particularly devoted to a subject have strong needs that are not met by current services).

I, however, chose a conventional, "user-centered" design approach, where the users do not specifically innovate. I argue that, in this compilation thesis, the needs are not only specified by users (who need attractive weather services), but also tightly coupled to premises set by stakeholders: institutes, officials, organizations, and other users of environmental data. In participatory design, the user is regarded as the system owner, and is presumed to equally benefit from the design and take the role of researchers and developers. In this thesis, this is not the case. Instead, user-centered design was convenient, because user-centered design places emphasis on user needs but does not allow users to make the decisions, nor does it provide the users with all accessible tools that the experts have access to. A parallel can be drawn between "share weather" and Wikipedia that applies user-centered design. Wikipedia content is entirely based on user contribution, although the produced content is *filtered* by a system designed by experts. While users are allowed to propose changes or have input on the design, a smaller and more specialized group decide about features and system design (see 4.3.2). In the design of "share weather", a solution is thought to "replace" or complement current methods, i.e., the WMO network, by applying new technology, rather than inventing entirely new solutions. Problem identification and objectives of a solution (see 5.4.5) were imperative for the choice of design method and methodology.

5.4.2 Design science research methodology

Peffers et al. (2007) developed a Design Science Research Methodology (DSRM) based on six steps, or activities, and the assumption that the result of DSRM is creation of an artifact addressing an identified problem: **I. Problem identification and motivation**, **II. Objectives of a solution**, **III. Design and development**, **IV. Demonstration**, **V. Evaluation**, and **VI. Communication**. The six steps are associated with different activities. *Problem identification* implies identification of a relevant problem that needs to be solved (justifying the value of a solution). Presenting *Objectives of a solution* may be conducted through presentation of a list of arguments supporting how a suggested solution is expected to support a solution of the problem, for instance presenting terms in which a desirable solution would be better than current ones. *Design and development* implies identification of properties of the artifact, including practical steps to embody the suggested solution. Then, *Demonstration*, e.g., in the form of experiments or case studies, and *Evaluation*, i.e., analysis of demonstrations, provide knowledge on the feasibility of the solution. Finally, the acquired knowledge, including presentation of all previous steps (I-V) is communicated to researchers and other relevant audiences.

The process can be driven by either (Peffers et al., 2007):

- Problem-centered initiation (showing importance of the I. problem identification);
- Objective-centered solution (responding to: what are the accomplishments of a better artifact, i.e., II. Objectives of a solution?);
- Design and development centered initiation (suggesting an artifact based on a particular III. Design and development); or,
- Client/Context Initiated (using the artifact to solve the problem).

With these four possible research entry points, Peffers et al. (2007) maintain that there is no expectation that research is always conducted in sequential order (from I to VI). A research entry starting with identification of a problem, i.e., *problem-centered*, corresponds to previous observations of a problem which justifies solution of the same, while an *objective-centered* approach is issued by a research or industrial need. A *design-centered* process would start with suggesting an existing artifact as a solution to an explicit problem belonging under another research domain.

DSRM (Peffers et al., 2007) was used in the thesis in order to create tools that enable empirical testing of the concept of "share weather". Second, DSRM is used for evaluation of "share weather" as a solution to an identified problem within meteorology and current weather information services (Q1).

5.4.3 The design methodology used for designing "share weather"

The general approach in Q1 is presenting arguments that may support that "share weather" is a solution to a problem. Thus, Q1 alone has an objective-centered approach. The papers mostly apply a problem-centered initiation. The problem is identified as a series of issues referred to in the papers. For instance, Paper III defines the problem as limitations in current observational techniques due to: (1) human perception (e.g., Kent and Berry, 2005); (2) "surrogate" variables (e.g., spectral radiance and radar reflectivity) (Park and Xu, 1999), rain gauge precipitation measurements (Robinson et al., 2004); (3) physical environmental preconditions (e.g., topography, vegetation); (4) spatial extrapolations non-representative of extreme values and meso- or microscale phenomena (Wallman et al., 2005); and (5) introducing different standards (Paper III). Paper IV, instead, uses a list of critical issues defined by the World Meteorological Organization (WMO) (WMO, 2009b): (1) climatic information with higher spatial and temporal resolutions; (2) improvements of forecasting seasonal, interannual to decadal variability; (3) increased investments in National Meteorological and Hydrological Services for strengthening observing networks; (4) active participation by civil society; (5) data quality, availability and data sharing.

Here, "share weather" may either be immediately compared to other methods, that is: what can "share weather" accomplish compared to other solutions used for organization of meteorological data (*objective-centered*). Or, one may, first, present evidence that "show the importance of the problem identification" (*problem-centered*). In the first approach, Q1 is analogous with defining the objectives of a solution, starting with activity II of DSRM (Peffers et al., 2007). The latter approach requires an outline of the problem area such as the overview presented in Chapter 2 (with a summary in 5.2.1), or a list of specified needs provided in this section.

There is, however, also an additional, third, alternative. It is possible to regard the design process as a result of new research needs on Web 2.0 – an existing artifact – as a potentially feasible solution to improving weather information services – a new research problem domain. In that respect, the problem may be defined as *design-centered*. This is in accordance with the Introduction chapter of this thesis: suggesting an existing artifact (Web 2.0) as a solution to a defined problem (a need for better weather services) (see Table 1, p.14). This approach will be further discussed in section 5.5.4 (*Approach 1*).

A *design-centered* approach can be found in Paper IV where the general focus is drawn towards a first evaluation of the concept (Q1) by exploring some empirical results on user motivation to participate. Namely, Paper IV needs a design solution in order to study "time-consumption". A *design-centered* approach is also adopted in the design of the weather alert service based on "recent weather", although objectives of a solution are presented in Paper II.

In general, the choice of design approach depends on what expectations one might have on the summary of the compilation thesis: Is the purpose to design a (whole) "share weather" solution (which may be related to Q3), or use a particular tool to prove a concept (which may be related to Q1)? As declared in the theory chapters of this compilation thesis, the theoretical approach is to make a contribution to participation in networks and Media Technology research, rather than making extensions of design theory. Although I hope that the knowledge gained through the thesis can make a contribution to design theory, the main theoretical approach is to study interactive media technologies within the domain of weather information. I therefore regard Q3 as *objective-centered* within the context of the summary of the compilation thesis (see Approach 1, Table 1, p.14, and 5.4.2).

5.4.4 Iterations of the design process

Q3 is divided into a series of iterative steps of the design process where Paper I defines the problem (I), and Papers II-VI correspond to different steps of the design process as displayed in Fig 3.

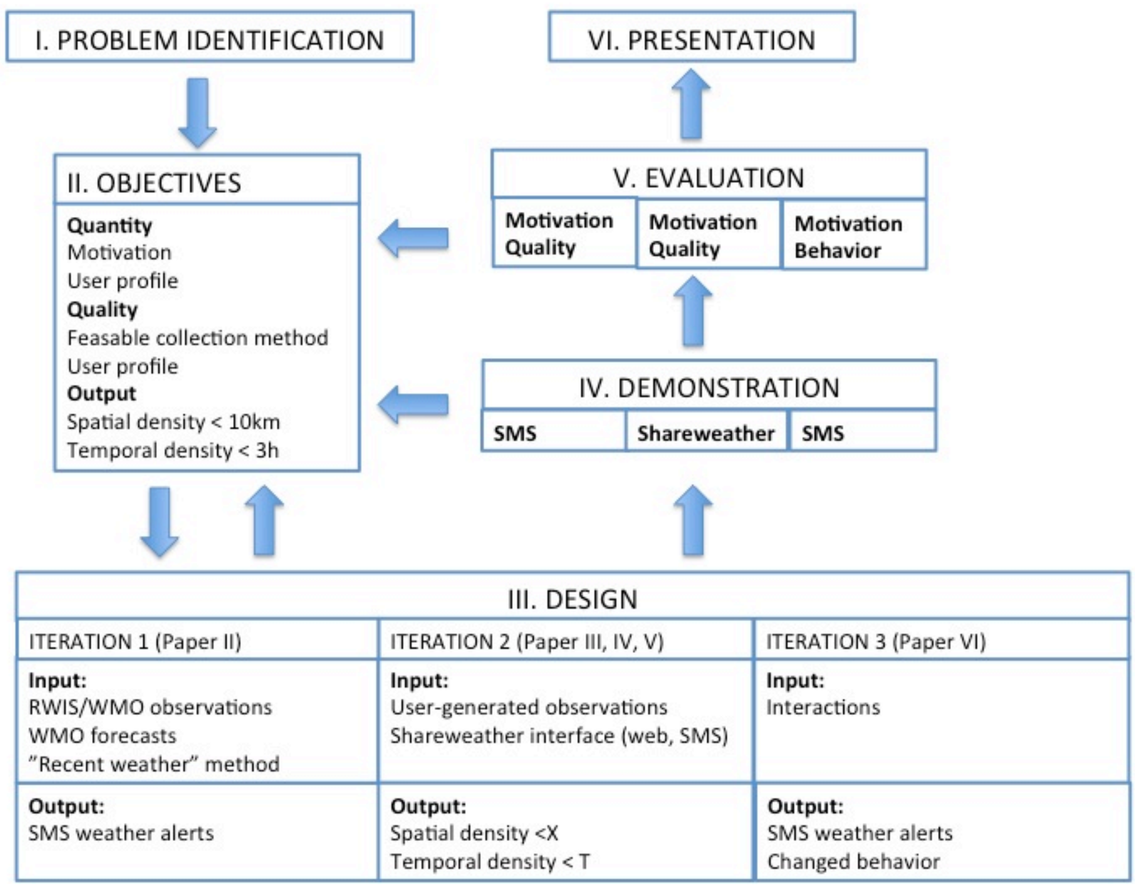

Fig 3. The design process of the "share weather" artifact

Paper V particularly describes the design process, while focusing of demonstrations and evaluation. Problem definition is presented in terms of critical issues identified by the World Meteorological Organization (WMO) (WMO, 2009b). Paper IV starts with a similar identification of a problem, i.e., *problem-centered*, while Paper II has an *objective-centered* approach issued by a research need: creating a tool (personalized weather alerts) that enable empirical tests.

It is important to note that a different approach could have generated different results in terms of, for instance motivation to contribute UGO of weather (Paper IV, V and VIII). The choice of testing a service on a user group – initiating a series of interactions that affected the outcome of the empirical studies – are determinant; these interactions were shaped by the set-up of empirical studies and the design process. The empirical studies would therefore most probably provide different results if, for instance, the subjects were not receivers of the weather alert service. This exemplifies how products of design do not necessarily represent universal, scientifically established, relationships, although the research methodology applied is scientific. As stated in the beginning of this section, design represents scientific knowledge characterized by inductive methods that cannot grant that a replicated design process will yield the same results. Peffers et al. (2007) provide an inductive scientific *method* that can use past ideas while designing new features in various contexts, such as "share weather". I conclude that a design process, in fact, never stops, but is subject to new iterations due to exposure to new contexts, whereby the design process never reaches a silent "equilibrium".

5.4.5 Objectives of a solution

In order to "present terms in which a desirable solution would be better than current ones (see 5.4.2) and explain what the accomplishments of a better artifact might be, I use comparison with current methods applied in meteorology (see Chapter 2 or a summary in 5.2.1): data assimilation (2.4.2), nowcasting (2.4.4), and parameterizations (2.4.5). The objectives include two different perspectives: user-oriented, and technology problem-oriented (Paper V), because the "share weather" artifact is a synthesis of human and Web 2.0 technology properties/abilities. Table 7 displays problem definition, objectives of a solution and research questions of the compilation thesis based on the design process methodology presented in section 5.4.4. In sum, problem identification is limitations in current technology (Chapter 2, see summary in 5.2.1), and *"share weather"* is presented as a solution based on UGO, producing a list of objectives: motivation, quality of UGO, system properties (see Table 7).

Table 7. The design process related to research questions of the compilation thesis

	INPUT		PROCESSING	OUTPUT
	INPUT Quantity	**INPUT Quality**	**System PROCESSING properties**	Spatial density (D_S) = 10km (1km) Temporal density (D_T) = 3h (0,25h)
Current TECHNOLOGY		How accurate are WMO observations?	Parameterizations Data assimilation Nowcasting	
"Share weather" and UGO	Motivation to contribute UGO	Quality of User-Generated Observations (UGO)	Collection method & Filtering	
PROBLEM identification Design step I	**DESIGN of "share weather" Design step II - IV**			**EVALUATION Design step V**
RESEARCH QUESTIONS	How many users within a spatial area will be motivated to contribute, and how often?	How accurate are UGOs? What is the bias of UGO?	How are UGO collected, filtered and integrated?	Spatial density (D_S) < 10 km (1km) Temporal density (D_T) < 3h (0,25h)
	Q2 & Q1	**Q1**	**Q3 & Q1**	**Q3 & Q1**
DESIGN iteration	*Iterations* 2 and 3	*Iteration* 2	*Iteration* 2	

5.4.6 Design

Three components of the "share weather" artifact are identified, in accordance with Table 7: Input, Processing, and Output. Input consists of user-generated content, but data from other available sources (NWP, WMO, RWIS) can also improve the output. The requirements of the "share weather" Output are defined by the output produced by current methods, that is, NWP (see 2.4.1): D_S < 10km, D_T < 3h. The requirements of the Input are based on WMO (SYNOP), which are sometimes equivalent, or, at times, more dispersed than: D_S < 10km, D_T < 3h. I will here use that requirement on "share weather", although the current input it significantly less resolved in many areas (for instance in developing countries, see Paper VII). Or, if comparison is made regarding traffic weather applications, these can be defined by RWIS (see 5.2.1 or 2.4.5): D_S < 1km, D_T < 0.25h. Processing includes conventional system components that may manage weather data, and, additionally, a set of new features that should be designed in order to maximize quantities of user-participation, and appropriate filtering processes and integration of UGC with other existing weather data, that altogether produce improved output. Three aspects of the design objectives of a solution are:

- Motivation: How many users within a spatial area will be motivated to contribute, and how often? (associated with Q2 and Q1)
- Quality of user input: How accurate are UGO? (associated with Q1)
- System properties: How is user-generated information collected, filtered and integrated? (associated with Q3 and Q1)

When evaluating the design, quality of UGO (Input) and system properties (Processing) may be evaluated simultaneously. Because Processing might improve the Input, the final Output will depend on both the quality of user Input, and the methods used for Processing.

One important conclusion is drawn from Table 7. In a "share weather" solution, the content format must be designed with respect to both acquiring real-time data from *users* (UGO) and performing computational modeling or acquiring equivalent data, i.e., current technology (see also Paper V). The point is that a "share weather" system must use collection methods adjusted to some existing formats and standards defined by officials (Paper I), particular time, and spatial scales defined in 2.2.1 (WMO), or 2.4.4 (e.g., RWIS). At the same time, the design must meet additional requirements, for instance explored in 3.6.2 and 4.2.2. A summary of design requirements is presented in 4.6.

5.5 Methodology used in the summary of the compilation thesis

Issues related to "share weather" are explored in the empirical studies presented in the papers. This included design of a "*Shareweather*" artifact (Paper V), and qualitative and quantitative results on: the quality of UGO (e.g., Paper III and IV), and user motivation to contribute UGO. This compilation thesis, then, evaluates the concept of "share weather" (defined in 3.1 and 3.8.1) in respect to its ability to improve weather information. Table 7 (p.138) illustrates a methodological framework used in the next chapter, Chapter 6, addressing the research questions of the thesis. This section provides some input to Chapter 6 on methods that can be used for evaluating "share weather". I also comment on the methodological approach pictured in the introduction of the thesis presenting two different alternatives for the research methodology (see Table 1, p.14).

5.5.1 Motivation

First, motivational aspects are particularly highlighted in the summary of the compilation thesis. Motivation was chosen as a separate topic because it represents one of the key issues in order to make the concept of "share weather" functional. Since volumes of contribution were not accurately assessed in the papers, motivation did not receive the attention it deserves. In the summary of the compilation thesis, I address relevant theory (Chapter 4) and further develop a motivational framework (6.3.9) based on Paper VIII (Table 1 in Paper VIII). Through this process, I am guided by theory previously developed in Chapter 3. Namely, network features derived in Table 3 (p.50) are valued towards theoretical findings of Chapter 4 (individual and structural dimension and condensed in Table 8. Finally, I discuss different theoretical approaches on the basis of empirical results, and previous research and theory derived from Chapter 4 (6.3.8).

5.5.2 Design

The second important contribution of the summary of the compilation thesis is the details provided on the design process based on Peffers et al. (2007) Design Science Research Methodology (DSRM). The summary of the compilation thesis aims at providing a complete picture of the design process of the "share weather" artifact, with the iterative steps corresponding to different papers. The previous section, 5.4, was particularly devoted to that achievement. In addition some other relevant methodological issues are presented below (see 5.5.3).

5.5.3 The question of improving weather information: Two different research approaches

The basic question posed in the summary of the compilation thesis is how "share weather" might address limitations in current weather information systems and thereby improve weather information services. This topic is explored by comparison of "share weather" features with existing weather information systems (Q1), by discussing potential quantities of contribution and motivation (Q2), and by developing and designing a "share weather" artifact (Q3).

My approach can be regarded from two perspectives, and this was also previously documented in the introduction of this thesis (see Table 1 and 1.4).

Approach 1 (see Table 1):
I define questions associated with two aspects of a new concept "share weather"; these are "weather" and "Web 2.0". Web 2.0 corresponds to different technologies (see *Technologies* in Table 3, p.50), and weather is an information domain (see *Domain* in Table 3). The thesis presents some core theory associated with Web 2.0, a media technology (Chapter 3 and Chapter 4), and weather, the new information domain studied in the thesis (Chapter 2). The new domain is introduced, analyzed (see Table 4, p.61), and studied using a framework of network features (Table 3). Here, I introduce features that should be studied: the type of information, the purpose, the nodes, their ties, the environment, and the technology used. Based on theoretical findings on the new domain, I draw conclusions on the particularities of this new domain and new directions for further empirical and theoretical exploration in the papers. Here, the approach is to, in Chapter 6, address previously defined questions, based on research conducted in Chapter 1– Chapter 5.

I summarize that, this approach uses design in order to construct the methods necessary to test my different hypotheses. For instance, I hypothesize that users can accurately observe the weather using a collection method based on cloud pictures (Paper III) and text phrases. Therefore, a collection method is designed (see "*Shareweather*", see www.shareweather.com) in order to test this hypothesis (e.g., see Paper IV). I assume that participation in a network where individuals receive weather alerts (Paper II) results in increased trust (Paper VI), and potentially also increased levels of motivation to provide UGO (Paper VIII). Therefore, a weather service (based on the recent weather method, 5.3.2) is designed and tested. As previously concluded in 5.4.3, the first represents a design-oriented approach to DSRM where the entry point is "suggesting an artifact based on a particular design" (see 5.4.2), including the artifact "*Shareweather*" as a collection method. The second is client/context initiated, because, here, the service is introduced to solve the problem of studying the effects of participation in a network where individuals receive rewards.

I conclude that the first approach, Approach 1, uses DSRM for a limited part of this work and task conveyed within a larger research context, namely addressing Q1-Q3. I use design science research methodology to achieve the primary goal of responding to a set of pre-defined research questions.

Approach 2 (see Table 1):
The second approach is a design approach, and it follows Design Science Research Methodology (DSRM) presented in 5.4. Here, the methodology includes all activities defined in the design process, I-V including some iterations. The summary of the compilation thesis realizes activity VI (documentation). I define the need from the aspect of a design problem, through applying an objective-centered initiation. In Chapter 6, I ask what the accomplishments of a better artifact are. This is analogous with comparing the Output of a current solution, and the Output of a better solution. Each chapter of this thesis corresponds to a design step. First, design-centered initiation is practiced in the introduction (see also 5.4.). Then, an overview of the problem area is presented in Chapter 2 (step I). A summary in 5.1 presents the research needs: better solutions based on increased Input and better Processing, which might contribute better Output. These are some possible Objectives of a solution addressing the problems described in Chapter 2. In Chapter 3 and Chapter 4, theory (addressing Approach 1) is developed. In each chapter I outline my conclusions regarding design features that were drawn from the theory (see 3.6.2, 4.2.2, 4.5). Together they represent a set of features associated with Design and Development (step III). Paper V designs an artifact "*Shareweather*" associated with "share weather". While feasibility of this particular artifact is evaluated in Paper V, the summary of the compilation thesis adds a new dimension through putting three questions and evaluating the whole "share weather" concept. In this, larger, design process, papers correspond to different iteration steps of the design and development (see Table 7), whereas demonstrations were performed in the papers. Chapter 6 constitutes the final evaluation of the concept of "share

weather" and I use this summary of the compilation thesis to document the "share weather" concept.

It can be concluded that the summary of the compilation thesis can be regarded either as a design process, preferably as problem-centered, although exclusion of Chapter 2 would lead to an objective-centered design initiation (with 5.1 and 5.2.1 presenting objectives of a solution). Or, the methodology of the thesis applies design theory only to peruse some minor goals that required tools for conducting empirical research, for instance the weather service, and the collection method.

5.5.4 Conclusions on the research methodology of the summary of the compilation thesis

With this discussion on the design process of the summary of the compilation thesis, we are approaching the final evaluation of the "share weather" concept, and the research questions associated with this evaluation (Q1-Q3). I finalize this chapter with some notions of importance for the coming evaluation of the "share weather" concept in Chapter 6.

When evaluating a new concept, it is compared with existing solutions. Weather services today primarily consist of different presentations and visualizations of meteorological data that are of two different kinds: observations of current, and predictions of future, states. The suggested solution, however, reflects a fusion of technology and human behavior (see 5.2.1). "Share weather" participation is a product of technology and social processes developing around its features and the interactions taking place.

From this it can be understood that comparison with existing tools is difficult. Design is integrated with the research problem addressed in this thesis. Individuals using a service perceive the service differently, and behave differently; social behavior is guided by roles and norms and expectations, and individuals perceive the reality differently according to their backgrounds, interests and motivations (Giddens, 2009, p.251). Because the compilation thesis holds a user-centered perspective, I evaluate the whole *design* of "share weather" and associated features. In addition, my personal role as an involved researcher (e.g., Walsham, 2006) must be questioned, scrutinized, and evaluated (see also 5.3.9), because it impacts the subjects evaluating "share weather". In addition, evaluating a "self-developed" concept requires particular cautiousness and openness. Building personal relationships with the respondents that participate in evaluations inevitably issues some undesirable effects. I addressed them through the methodology of the compilation thesis (e.g., 5.3.3).

In any case, the products of "share weather" are not comparable with available data. "Share weather", or any artifact or concept supplying weather information, has an appearance resulting from methods for information processing, visualization of the output and other potential features related to service content presentation. This definition thus distinguishes between meteorological quality and experienced quality (e.g., user satisfaction), where the latter is a product of all design features including meteorological quality (see also 5.3.2). Design theory is therefore necessary.

5.6 Summary: "Share weather" and science

This chapter was centered on methodology, the foundation of scientific work. One of the greatest challenges in this thesis is plowing unexplored research fields. I positioned my research in the gray zone between Meteorology and Media Technology. Interestingly, environmental sciences use system science approaches, and this might provide some advantages when addressing methodological issues.

I found that a design approach will help resolving the many difficulties in assessing the outputs of "share weather". Comparing a non-deterministic system describing complex processes evolving over time and space with the perception and behavior of incoherent subjects requires great precaution. In this thesis, I searched for appropriate methods to compare Meteorological applications with "share weather", a system based on human input and behavior. I found that, when addressing Q1–Q3, elements of design science research methodology might address some issues. Despite the relatively large data volumes produced through the empirical studies of the papers, I questioned the validity of the different results due to the large number of variables associated with weather and human nature respectively. Applying scientific methodology, such as conducting several measurements (e.g., the longitudinal study on Group A), using several sources of evidence (e.g., observer B and RWIS compared to Groups C and D; observed behavior compared to self-reported behavior), and conducting the same relational study on several samples, might capture some correlations. However, validity should always be questioned, due to the fact that the resolution of available weather information is restricted in time and space. We may draw a parallel to Geographic Information Systems (GIS) that are a subdomain under User-Generated Observations UGO that include the built and natural environment. Similar challenges are recognized in GIS, with a "tension between natural variation in the real world and the data models used" (Brimicombe, 2003).

Finally, I would like to comment on the purpose of this work in relation to sustainability and scientific knowledge. The empirical studies involved a group of individuals that volunteered to participate in a research project, including individuals in modern cities' transportation systems and volunteers collecting precipitation data on request of a research institute. This may provide an interesting reflection on previous comparison between "share weather" networks and knowledge creation and citizen science (see Table 4, p.61), and the meaning of "scientific" in this thesis. The general goals of the thesis are in line with some important societal issues associated with the environment and sustainable development (5.1). First, studying "share weather" in this thesis provides knowledge that can be used to facilitate transportation in the society (5.2.1). Most important, "share weather" is regarded and valued from a sustainability perspective. The data and knowledge created while studying "share weather" might serve some purposes defined by the international community and research addressing climate and environmental change (5.1). This thesis may thus produce valuable knowledge in respect to sustainable development.

Chapter 6
Discussion

Improving weather information probably represents an area of important future discoveries. Learning more on the numerous and complex processes governing the natural environment (2.3) in which we reside, represents one of the many pieces necessary for sustainable development (5.1). The theory presented in the previous chapters suggests that some of the solutions could be found in the intersection of Media Technology and Meteorology. My sustainability approach (see 5.1) pointed at the importance of this problem for humanity, while Chapter 3 and Chapter 4 provided theory for potentially addressing these challenges. I suggested a new concept “share weather”, derived from a Media Technology perspective, as a potential solution. Can Web 2.0 help solving some sustainability challenges of the future; is there a way of improving weather information through online participation? The eight papers (Papers I-VIII) might, theoretically or intuitively, suggest that Web 2.0 offers solutions that can address the problems defined in Chapter 2. However, theoretical reasoning and empirical evidence is not yet provided to fully address the key question of this thesis: How might “share weather” improve weather information?

By introducing the concept “share weather” (3.1), I suggested that individuals, while connected and interacting via networks, can contribute something as meaningful as meteorological data created by expert systems based on scientific methods. I started this challenge by narrowing the problem towards the “knowledge creation” domain and defining a subcategory “user-generated observations” (3.7.4; see Table 4, p.61). This idea was drawn from reasoning on findings in Media Technology research on networks and the interactive Web 2.0 (Chapter 3) and behavior manifested in new online environments (Chapter 4). Research on online networks shows that individuals participate actively within different online contexts, and at surprising levels and sometimes peculiar sources of motivation (Chapter 4). Individuals' participation and collaboration online sometimes results in knowledge creation. Based on evidence collected from related research areas (e.g., 3.7 and 4.3), I suggest that the abilities of Web 2.0 may be applied on useful applications within one new area – Meteorological applications. I stipulated that the work of former experts can be challenged by the created commons observing their natural environment and sharing their observations through online networks (3.8). These phenomena, or expert paradigms, are observed within other domains (e.g., citizen science, journalism, emergency management, programming, encyclopedias; see Table 4). My main argument in the beginning chapters of the thesis was that the number of connected individuals is approaching the vast figure of residents on Earth (2.1, 1.1). The exceptionally large number of individuals that may potentially record local weather observations was put in the light of past inventions that revolutionized the weather business (see Fig 1, p.29). The considerably large populations and population densities in cities compared to the current network used in meteorological applications (WMO SYNOP; see 5.2.1 or 2.1 and 2.2) urges for some exploration of this topic. If for a moment we regard what an individual can observe just by stepping outside his or her house, the weather will be a part of what he/she sees. Because we live and depend on our built environment including the transportation system, we are, sometimes, unintentionally and sometimes curiously, observing things occurring around us, within a range of a small "weather box" much smaller than the size of "air parcels" treated in weather forecasting models (2.4.1, 5.2.1). This is an opportunity that may address the needs behind the research questions of this thesis.

In this chapter, I address the research questions posed in the introductory chapter (see p.8-9):

Q1. Is "share weather" a solution that can be used in order to improve weather information?

Q2. Why might individuals be motivated to make contributions in terms of user-generated weather observations (UGO)?

Q3. How can a "share weather" solution be designed?

6.1 The methodological approach

The first question is: how can we address these three questions? As concluded in Chapter 5, the research questions of this compilation thesis (Q1-Q3) are all associated with properties of "share weather" – a synthesis of human behavior, and Web 2.0 technology (5.4.6). Web 2.0 offers the opportunity for individuals to interact, create, share information, and access knowledge. Given that Web 2.0 is a great cyber-space and a large network connecting people worldwide, within which many small networks operate, the concept of "network" and "community" was explored (3.3). It provided some insight regarding the nature of online environments (3.5) that radically change premises for interactions and knowledge creation. At the same time, networks are shaped by their contexts that can vary greatly. Previously, in Chapter 3 (3.4.2; Table 3, p.50), I developed a general model that can be applied in networks including "share weather". Its features are the information domain, nodes, their ties, the environment, and technology used. These features may be associated with different design options.

In 5.5.3, it was explained how the methodology of this thesis can be regarded from two perspectives. The first one (Approach 1, see Table 1, p.14, and 5.5.3) draws from network theory and fuses these findings with reasoning on the properties of the "weather" information domain (3.6 and 3.7) including chosen delimitations (3.8.2). It explores what happens when the abilities of Web 2.0 are applied to "weather". "Share weather" was composed of an information *domain*, weather, and a *technology*, Web 2.0. Clearly, the domain is associated with some particular *design* requirements that also involve technological aspects. In this chapter, I will apply the model of network features presented in Table 3 (p.50) while addressing the research questions.

As illustrated in Table 1, the second approach (Approach 2) is a design approach. In this chapter I will use some findings developed through this perspective, when regarding how the research questions are related to each other. From 5.4.5 and Table 7 (p.138), presenting the objectives of a solution, we see that the research questions are associated with different "share weather" components: Input (Q2), Processing (Q3), and Output (Q1). The problem definition in this objective-centered solution (see 5.4.2) is associated with limitations in current solutions. There are several limitations in the current methods: observational Input (see 5.1 and 5.2.1, or: 2.1, 2.2, 2.4.1, 2.4.2, 2.4.3, 2.4.5), methods for Processing (see 5.2.1, or 2.3, 2.4.1-2.4.5), and presentation of their Output (see 5.2.1). Drawing from 5.4.6 and Table 7, I conclude that the Output can be used for direct evaluation provided that we develop "share weather" artifacts and test them in real environments.

The latter – design and evaluation of "share weather" – is aimed to be materialized through this thesis that designs and evaluates the new concept "share weather". According to 3.6.2 and 3.8.3, the design should enhance motivation to participate, address issues associated with user-experience and design, and, through simple tasks, enable collection of user-generated observations (UGO) of weather. I regard these features as related to the human aspects of "share weather": *nodes*, and their *ties*. The technological aspects, on the other hand, unveil new features of "share weather" as "weather" is integrated with "Web 2.0" (e.g., 4.2.2). These can be associated with *environments* and *technologies* that define the context (see Table 3).

Accordingly, I have to address several aspects of "share weather" while studying its potential role in improving weather information. Q1 conducts an inventory of objectives of a solution (Step I in the DSRM design process; see 5.4.2) determined by either Output, or Input. Q2 and Q3 are associated with the design process and properties of user Input and system Processing (see 5.4.6 and Table 7, p.138). In my outline in this chapter, Q1 explores what spatial and temporal densities might be achieved with "share weather" systems, including a discussion of the quality of their Input, i.e., UGO. Q2 studies potential sources of individual motivation to contribute UGO and explores how to assess the volumes of their contribution. Q3 is associated with objectives of a solution, the desired design features that might provide some final conclusions regarding the performance of "share weather". Q3 designs an artifact ("*Shareweather*"). Second, Q3 is used for generalizations towards other information domains and final conclusions presented in Chapter 7.

6.2 Is "share weather" a solution that can be used in order to improve weather information? (Q1)

As previously argued in Chapter 5, we need to regard both sides of the interactive Web: technology, and human nature. While technology shapes the communicative space, human behavior and perception of weather must be accounted for in order to determine whether individuals can contribute meaningful content to "share weather". How accurate are UGO? Second, what happens when "weather" and "Web 2.0" are integrated?

My first question, treated in 6.1.1, is: can "share weather" – a fusion of "Web 2.0" and "weather" – improve weather information? I start with an overview of the differences between "share weather" technology and other available technologies for sharing. They are viewed through the components: Input, Processing, and Output (see Table 7, p.138). Then, in 6.1.2, a comparison is made between current methods and practices used in weather information services, and "share weather" systems. Most important, I investigate how the potential number of nodes within a "share weather" network can be assessed (see Table 7); this is necessary in order to later estimate the potential volumes of contribution in Q2 (7.1). Section 6.1.3 scrutinizes the reliability of UGO of weather. Drawing from Table 7 and 5.4.6 this can be addressed by evaluating "share weather's" Input. Chapter 5 (see 5.4.6) and Paper V concluded that both the "share weather" Input and Output could be compared to spatial density D_S < 10km and temporal density D_T < 3h, and discussed in relation to (see 5.4.4): "data assimilation" (2.4.2), "nowcasting" (2.4.4), "parameterizations" (2.4.5). Or, if comparison is made towards traffic weather applications, UGO should instead be compared to (see 5.2.1 or 2.4.5): D_S < 1km, D_T < 0.25h.

In 6.1.4, finally, I try to answer the research question Q1, that is, whether it is correct to assume that "share weather" can be used to improve weather information. Because the Output is determined by network features associated with "share weather" context and designs, some new questions will arise (Q2 and Q3).

6.2.1 Key concepts of "share weather"

How is "share weather" different from other solutions? Exploring how media technology might change premises for sharing weather requires a set of tools. I define *interactivity* as the property *enabling messages being sent back to the provider of weather information*. The spatial density can be expressed in units of receivers per geographical area unit. Since weather is a set of variables that vary in both time and space (see 2.2.1), this creates a spatial dependence between individuals. I add the variables "time" and "space" to the set of variables describing the network *environment*. Does this mean that only geographically proximate individuals will benefit from "share weather"?

Fortunately, weather represents a global system that can be forecasted if input from many different observation points dispersed in space can be collected and used to predict future states, which lies behind the idea that new observations might improve weather information. Weather systems stretch over hundreds of kilometers (or miles). A more accurate description of levels of interaction would, therefore, include usefulness, real capabilities and performance. In order to capture all these requirements, I introduce a new variable: *temporal structure* represents the number of interactions between different points in space, within a time window of allowed asynchronicity due to time lags issued by the supply-chain. Temporal structure is a key variable because it reflects interactivity and theoretical chances of improving content through collaborative production. It refers to how fast expert systems creating weather forecasts (Output) are supplied with new weather observations (Input), in order to improve weather information and send it back to the site where the observation was made.

Q1 is then rephrased as: can increased interactivity be applied to weather information and weather forecasting? If we recall storytelling by speech (from Chapter 2), it is highly interactive (and social) by itself. However, it cannot always be stored and replicated, or transfer real-time weather information over geographical distances of the size of weather systems (Paper I) within a time window defined by the supply-chain. Citing Paper III, in the 17th century, two centuries before the invention of the telegraph, Robert Plot, Secretary to the Royal Society in England, collected weather observations and noted that, if the same observations were made "in many foreign and remote parts at the same time", we would "probably in time thereby learn to be forewarn certainly of diverse emergencies (such as heats, colds, dearth's, plagues, and other epidemical distempers)" (Paper III). With the telegraph, weather information could be exchanged, but it could not be *predicted*. Interactivity, as defined in this compilation thesis, in addition requires some feed-back integrated into the temporal structure.

The telegraph could disseminate weather observations and warn others about occurred storms; due to lack of appropriate methods for weather forecasting, however, telegraphs could not create forecasts (Output) back to the nodes. For weather forecasts, reasonable temporal structure was first achieved a hundred years later with the first NWP based on computer technology (see 2.1.2 and Fig 1, p.29). Considering climate information, its temporal structure is not time-critical. For instance, climate data from marine logbooks dating back to the 17th century (Wilkinson et al., 2011) and records of precipitation data collected by the network of farmers in Sudan in Paper VII are still useful to the global community.

The context in which different media technologies are being used may also provide different temporal structures and levels of interactivity. For instance, a satellite picture is here defined as non-interactive if it cannot be used immediately in an NWP or for other practical purpose within a required time interval. A network of telegraphs is interactive only if it is used to send weather observations to an expert system and the nodes also *receive* information from the expert system. For instance, a traffic radio journalist can represent an expert system, collecting Input from volunteers and creating an Output of traffic weather alerts. The service is interactive because information provided by a network of listeners and traffic weather observers can receive improved information based on a high number of listeners and short time required for the radio reporter to process the data and send updated reports back to the network. A similar network was studied in Papers II-VI. From Paper I, it can be seen that paradigms within weather business and meteorology as a science occurred according to appearance of new media and communication technologies or other technologies that facilitated the way data is transferred across large distances (see 2.1.2 and Fig 1). Satellite technology improved the Input by providing information from remote areas with increased spatial density (2.1); whereas computers drastically improved weather forecasting through fast Processing (e.g., 2.4). These, at the time novel, technologies have one important property in common: they reduced the time lag between the point in time when a weather observation (Input) is recorded and the time when a useful service (Output) is delivered. With the Internet, offering instant communication across large distances, the temporal structure improved, because time lags issued by communication barriers are, practically, erased.

There is yet another property associated with the Output, and it touches upon design issues later addressed in Q3. Design may be restricted by the type of technology used through audience reach, storage, replicability, social cues. For instance, television weather shows may use spectacular visualizations; their limitation is that they can only explain large scale movements. Radio can provide more local weather, however, based on simple audio messages. Telegraphic messages are even simpler, the messages contain concise impersonal text, or international codes (see for instance Paper V or WMO, 2010). How does Web 2.0 fit into this? First of all, Web 2.0 is *social* (see 3.3): millions of stories are shared through Web 2.0 as you are reading this. Storytelling involves a strong component of socializing, with *social cues* created from (see Baym, 2010): physical context, shared language and meaning, and shared environment. However, useful knowledge and useful services such as weather forecasts cannot be created based on storytelling of spatially distributed individuals, if sharing weather data is not put into a context where the data can be utilized. For instance, sharing weather observations on Facebook does not provide information on coming weather events; neither does a weather observation for Stockholm provide the current weather in Tokyo. With lack of a system that processes weather information, individuals can only exchange wild guesses based on personal experience. However, storytelling might become useful if it is put into a context that enables synchronous collection of weather observations. Moreover, if the interactivity requirements are reached according to the claims of the thesis, weather forecasts can be created based on the Input from many nodes. This highlights the advantages of Web 2.0 as a communication environment filled with social cues. On the interactive Web 2.0, where spatial distances are erased and everyone can communicate with anyone, the social properties of storytelling are of particular interest. Namely, social dialogues may contain weather information, and socializing may encourage sharing weather information. It can, for instance, be assumed that people who "trust" each other may not only spontaneously share weather information (as people occasionally do on Facebook), but they might also introduce "share weather" practices to each other based on previous interactions and trust. These issues are, therefore, further explored in 6.3, addressing the motivational aspects of "share weather".

Based on the reasoning above, the following conclusions can be drawn: the most prominent effects of media technologies on weather services' Input and design are issued through an *increased number of points that may interact* due to the temporal structure (see also 2.1.2 and Fig 1, p.29). For instance, telegraphic networks were of the size of 10^2 nodes, whereas the interactive Web 2.0 potentially might correspond to billions of nodes (10^9). Issues such as time delays due to supply-chain (temporal structure), social cues, storage, replicability, and audience reach may all be addressed with "share weather". In addition, "share weather" nodes are mobile. They can move across space, modifying the temporal structure. Technologies used in the past contained some, but not all, of these features and key concepts. Finally, through Web 2.0, "share weather" might combine *social cues* with a very high *quantity* of nodes.

6.2.2 Expected quantities

However**,** assessing the number of interactive points, or nodes *n*, is not enough. In the end, we want to assess "how many users within a spatial area (D_S) will be motivated to contribute, and how often" (D_T) (see Table 7, p. 138). First, spatial density (D_S) is the number of nodes per area unit (see 6.2.1), so *n* is the integral of D_S. This means that spatial density D_S may vary with geographical position. D_S is considerably larger in urban areas than, for instance, mountains and oceans. D_S is a *function* of user motivation, geographical position, and, based on theory presented in 4.2.2 and 4.6, possibly other user properties, their ties, and interactions. Interactive technologies just create an opportunity, but human behavior decides the outcomes: not everyone will agree to participate nor will their volumes of contribution be constant over time. Namely, if we add "how often", the figure is further reduced as a result of, not only motivation, but habits (see Paper II) and convenience (time-consumption, see Paper IV) that enable and encourage participation over time. Thus, the concept of temporal structure is associated with yet another important variable essential for assessing the performance and Output of "share weather", namely the temporal density (D_T) (see Table 7). Temporal density is a function of several unknown variables related to user properties and motivation. "How many and how often" is, therefore, only a fraction of n, and the actual number of interactive points is x, where $x<<n$. According to research findings, interactions within a network encourage future participation (see 4.1.1). This is modeled, or understood, in terms of "social capital" of structural links in social network theory, or the concept of "trust" conceptualized in most theories (4.1.3). Individuals are influenced by interactions, where "trust" or "social capital" increases as they interact. I conclude that D_S and D_T depend on a series of variables that depend on network features describing the context, and which can be associated with the structural dimension. This motivates the following framework:

Motivation is associated with the individual properties (nodes). Interactions and ties are associated with the structural dimension (see Table 3, p.50). Further, motivation is space- and time-dependent (see Table 5, p.105). If we adopt a user-centered approach, where the user remains in the center of all happenings, space and time can be associated with the network *environment*. For instance, it can be assumed that motivation decreases with increased geographical distance, whereas motivation to disperse content increases with geographical proximity (see 3.5 and 4.5). Technology (Web 2.0) and the information domain (weather) are particular for "share weather", which is herein designed.

What can we expect, based on research within Media Technology and related disciplines? Network research suggests that usually a small group of users provide a considerable fraction of the total content (4.3.1.); the fraction of free-riders is considerably larger than the number of active contributors, and only about 2-4% of these active users contribute content on a regular basis (e.g., Lakhani and Hippel, 2003; Adar and Huberman, 2000; Peddibhotla and Subramani, 2007; Butler, 2001; Tapscott and Williams, 2007). It may, here, be of some comfort to regard that the number of human beings on Earth is in the magnitude of billions, and we are spread all over its surface except the large ocean areas. The concentration of humans is largest in big cities, where the need for weather and ITS services is greatest. In that sense, there is a consensus between "share weather" and the density of potential observation points. The contexts of human interest in weather

(4.5 and Table 5, p.105) suggest that motivation is maximized if setting the timescale to minutes, hours, or days, which corresponds to everyday life activities. We note that these timescales are in fair resonance with the need defined by the compilation thesis (i.e., existing weather applications): D_S < 10km and D_T < 3h. Nevertheless, it is not possible to suggest any figures before conducting empirical investigations valid for the context. Guided by the empirical findings in the papers, motivation is addressed in section 6.3.

Finally, an encouraging observation is that the first "share weather" networks (telegraphic and synoptic) relied on human observers. In fact, many of the official 10^4 WMO SYNOP weather stations are still operated by human observers (WMO, 2009a; WMO, 2010). The question is, though, how individuals with no training might contribute. Are their observations reliable enough?

6.2.3 Are user-generated weather observations reliable?

In order to create *knowledge* and useful data, not only is particular temporal structure determinant. The Input must reach a certain level of *quality* (see Table 7). There are two ways of assessing the accuracy of user-generated observations (UGO) of weather. First, we might study Processing methods and other functionalities that might improve the design (see Table 7, section 5.4.6). The second approach is a system approach: the Output of the "share weather" system may be compared to current expert systems' Outputs. The latter (comparison with outputs of other systems) is the method suggested for addressing Q1 in this compilation thesis. However, the papers did apply the method of comparison between UGO and external sources of evidence. These evaluations faced some challenges associated with lack of data of sufficient spatial density (see for instance Paper IV). Considering the major scope of investigation in this thesis ("share weather" as a potential solution for improving weather information), it might be wise to chose the first method comparing the Outputs. While the idea with "share weather" is to improve the Output of weather information systems according to the *limitations* in their *current Input* (i.e., SYNOP), from some point of view it might also seem contradictory to try to evaluate "share weather's" Input by comparison with conventional sources of evidence that are already characterized by limitations. The problem is then: what should we compare with, since the current observations are not accurate enough to meet the requirements of meteorological applications? Second, what does *quality* mean, and how should it be measured?

In Paper IV, two different approaches were presented. One was based on RWIS (see 2.4 or 5.2.1) as an external source of evidence (RWIS has higher spatial density than SYNOP). The other method consisted of users' "scoring" (see 5.3.3 and Paper IV-VI) of a service. However, this is also confronted with some challenges. "Scoring" is based on recent UGO and measurements of subjective satisfaction (see 5.3.3 and Table 6, p.129); it reflects user experience, that is, *experienced quality* of the "share weather" Output. As previously discussed in 5.5.4 and 5.3.2, *experienced quality* is highly subjective; it not only reflects user perception, it is a product of Input and different design features used in Processing (5.4.5). The relevance of experienced quality was addressed in Paper II (on Group A) and previously discussed in 5.3.3 and 5.4.5. Fortunately, here, subjectivity might not represent an obstacle. Namely, in *user-centered* services (see 5.3.2), meteorological quality is not synonymous with user experiences (see "experienced quality" in 5.5.4). In contrast, measuring subjective opinions is desirable in the evaluation process. However, evaluating the Output of "share weather" meets some other challenges. User satisfaction might be affected by interaction (see 4.1.3). My role as a researcher was also challenged by a parallel role of a service provider (see 5.3.9 and 5.5.4). The method of "scoring" (5.3.3) was introduced (see Paper VI) in order to assess such influences (see Paper II, Paper VI). A parallel study presented in Paper IV additionally applied comparison with other sources of evidence (RWIS); it therefore represented an important complement.

Since this thesis studies user-generated content, it was most justifiable to conduct some measurements that would compare user contributions with contributions of other users, or user groups. Not the least, it explored how "peering" might be conducted. Therefore, Paper IV and Paper V applied the following approach to facilitate comparison between different users' contributions: Based on a history of reliable observations, *trusted individuals* can be identified (e.g., in Paper V, observer B provided reliable observations in a pre-study) used to evaluate Input provided by other users or user groups. Different levels of accuracy can also be attributed different *user groups,* for instance based on pre-study, recordings, reasoning around the time-consumption model (Paper IV). In Paper V, Input from a group (D) of patients at a dental clinic and schoolchildren (C) was compared with nearly synchronous and co-located observations conducted by observer B. The advantages of using trusted users are several, as we can draw the following conclusions: UGO supplied by unknown, or new, users can be attributed an accuracy level based on a "default" user (e.g., Paper II, Paper V). Second, because users can change their geographical location, i.e., they are mobile, the same user can provide UGO from a set of different places and times (Paper III). Occasionally, observations may come from positions with proximate external sources of evidence, creating opportunities for evaluation against official measurements. However, this may, sometimes, be difficult in practice. In remote areas, the spatial density of SYNOP and other official measurements can be very low. Paper VII describes how the Sudan Meteorological Authority SMA engaged farmers in collection of precipitation data. In this case, very few external sources of evidence were available, but SMA considered that farmers' UGO manifested sufficient consistency with values that might be realistic. However, SMA had to rely on farmers' perception and skills based on the training they received prior to commencement of the project (Paper VII).

In the previous outline, I provided some examples supporting that the method chosen for the compilation thesis – comparison of Outputs – can be considered more convenient compared to evaluation of the Input or individual UGO. Namely, after the Input (UGO) is supplied, it is further Processed by the system, and *processing* represents a set of unknowns before a *design* is developed, demonstrated, and evaluated. For instance, the UGO collection method is a feature associated with potential modifications of the Input, due to interpretation of what the user actually perceives. Further, the Input is subject to some systematic Processing. As previously suggested in Chapter 3, during the exploration of networks and the concept of "share weather", "share weather" can apply "peering", a method associated with applications within related areas (see for instance 3.7.2, 3.8.3 and Table 4, p.61). Filtering by "peering" has been evaluated for Wikipedia (see 3.7.2), while open source software proves that trained professionals can create knowledge by "peering" (e.g., Linux). Perhaps more interesting, many "citizen science" projects, where individuals contribute to scientific projects (see 3.7.3 and 3.8.3) apply "peering" through surprisingly simple tasks, for instance based on photographs and classifications. Simple tasks performed by many have, in this way, replaced very advanced computer programs that would require substantial resource capacity to achieve the same performance; for Instance NASA clickworkers' classification of geological features on celestial bodies (NASA, see http://www.nasa.gov/open/plan/peo). Parallels can be drawn to "share weather". It can be assumed that morphological classification of clouds and other weather phenomena may be realized with adequate results (e.g., Paper III).

Some of the most interesting paper findings pointed to the importance of training. The African farmers were provided training (Paper VII), while for instance Group D, who were requested to provide UGO without prior notice, manifested low level of quality (Paper V). The children in Group C notably improved their skills with time, and adults in traffic that traveled long distances performed well (Paper V). Training and experience are, therefore, variables that should be taken into consideration. I conclude that more research should be conducted on UGO on the individual level, with the hypothesis that UGO of returning users are more reliable than those of new users. Learning might also point at synergies with the concept of "communities of practice", later addressed in Q3.

There is yet another aspect of the quality and potential benefits of UGO. Namely, UGO may contribute new weather variables that were previously non-recordable or measured with difficulty or errors. High accuracy, sometimes beyond expectation, has been achieved in projects collecting geographical data based on Web 2.0 applications (see 3.7.3). Paper III proposes that, in some cases, human observers are even better equipped than instruments: some variables may be more accurately observed by humans, and entirely new variables, previously not recorded, can be added. For instance, pictures taken with a mobile phone are an entirely new type of information that may correspond to "a satellite picture taken from below" complementing the current contributions from satellite technology (Paper III and Paper V). As previously discussed in Chapter 2 (see 2.3.2, 2.3.4 and 2.4.5), changes of cloud cover and cloud type represent extremely important input to atmospheric modeling, but they are not easily measured with instruments. Morphological classification of clouds ("cloud type") or numerical values describing cloud cover (for instance in "percent" unit) are variables that individuals can classify with ease and high accuracy (e.g., Paper III, Paper V), while instrumental measurements are not reliable enough, too expensive, or geographically dispersed.

I finalize this section with a short summary and remarks: It seems that evaluating the system Output – a design approach – is preferable for UGO of weather, before evaluations of the Input (UGO). The primary underlying cause is that the purpose of "share weather" is to address limitations associated with the current Input. If a user provides an observation that diverges from other sources of evidence that are proximate in time and space, the difference may be issued by either errors in user perception, local variability of weather, or both (see 5.3.3 and Table 6, p.129). As Table 5 might suggest, individuals conduct their everyday life activities within frames of spatial scales usually less than 3 hours and 10 km. In other words, individuals might be motivated to observe the weather within a "weather box" smaller than the "air parcels" modeled by NWP (see 2.4.1 or 5.2.1). Because the Output must be evaluated, this issues new research needs. "Share weather" should be evaluated based on a specific design. This is addressed by research question Q3, asking how "share weather" systems should be designed. In order to detect systematic errors created by user perception (even other errors due to, for instance, violations), the papers recommend division of users into different groups (e.g., Paper V) according to their expected level of performance.

6.2.4 Can "share weather" improve weather information?

Q1 touches upon the general research enquiry – can "share weather improve weather information – by an overview of the research questions of the thesis. The product of this inventory is a confirmation of some assumptions made in the papers. Analysis of key concepts (Baym, 2010) of "Web 2.0" pointed at several advantages compared to other technologies used for improving weather information (6.2.1). The potential number of nodes is exceptionally large compared to other weather information networks (6.2.2), while reliability of UGO of weather was proven sufficient (6.2.3). Here, I discuss why these findings suggest that "share weather" can be used to improve weather information.

Chapter 3 provided several examples of how individuals contribute new knowledge and valuable information (e.g., Encyclopedia of Life, NASA clickworkers, Wikipedia, open source; see 3.7), all of which are manifestations of "collective intelligence" and the "expert paradigm" (Benkler, 2006; Jenkins, 2006; Levy, 1997;

see 3.8.3). The Internet enables synchronous observations of the environment, realizing an ancient vision of "synoptikos" – seeing together (see Chapter 1, p.4). While the concept of "seeing the weather together" was suggested by both Greek philosophers and famous explorers and scientists (e.g., FitzRoy and Darwin), it could not be realized before the advent of Web 2.0. Guided by the large impacts of media technologies on meteorological applications through the course of history, a new "share weather" expert paradigm might be suggested.

The expert paradigm might even lie at the heart of science: In the beginning, everyone is a novice; the pioneer "experts" in biology, geography and meteorology were largely self-taught (3.7.3), their knowledge being based on empirical evidence and systematic collection of data, along with consulting others including evidence collected from eyewitnesses, such as Darwin's collection of evidence from the people he met on his voyages and Linnaeus's collaboration with other observers (3.7.3; Taylor, 2008; Koerner, 1999; see p.69). This notion suggests that the role of the expert may be non-trivial; the definition of "the expert" is being modified in a changing society, with new technology, knowledge, and communication practices. In section 3.7.3, it was shown how traditional ecological knowledge may take the lead or be conducted parallel to scientific work; how experts develop methods for complementary use of science and traditional knowledge (e.g., Mackinson, 2001; Reidlinger and Berkes, 2001) and collaborate with citizens in natural resource management (e.g., Berkes et al., 2003). It might here also be important to regard the general development in the level of openness regarding data policies (Paper I). Through the "structural dimension" of individuals' spectra of motivational drives, these might affect opportunities, even willingness, to share (4.2.3). However, theory suggests that entrepreneurial, rather than organizational, forms are likely to develop, and flourish online. In the entrepreneurial/impersonal collective action space (Flanagin, Stohl and Bimber, 2006; see 3.5 and 4.1.1), Web 2.0 is a resource that connects individuals through a cyberspace of "affiliative ties", not only erasing spatial and temporal distances, but crossing the borders of social relationships and the "solid, well-demarcated boundaries between private and public" (Flanagin, Stohl and Bimber, 2006).

WMO and national weather institutes might strive at improving their operations, for instance "data assimilation" (2.4.2), through introduction of new data sources (2.4.3) (e.g., VOS, see also Paper III). After all, weather observations during most of the 20th century were based on a "worker group" of professional weather observers with special training, a "worker group" that might resemble a community of practice (Millen et al., 2002; 3.4.3).

Finally, Web 2.0 is social, and weather is a popular topic of social conversations. The line between "networks" and "communities" based on strong ties is blurred (3.3) as networks are brought online (3.5). Therefore, "share weather" activities may be amplified by social cues associated with weather – a topic that may seem more natural, familiar, and personal than many other phenomena. In addition, all observers have previous experience of weather and might even improve their skills due to experience (see Paper V). Citizen science (see p.42 and p.60) faces challenges regarding complexity of tasks, feed-back, task granularity (e.g., Nov et al., 2011), convenience and awareness (Paper IV) (see also 4.2.2 and 4.6). For instance, asking an individual to observe chemical reactions through a microscope without any prior training does not appear very natural or tempting. Peering of cloud pictures and their morphological classification online may, by contrast, feel meaningful and an easy task demanding low effort (cf. NASA clickworkers).

Finally, the concept of "share weather" explores new hidden corners of space and time. Current networks are not capable of documenting all variables everywhere (e.g., input to cloud parameterization, 2.4.5 and 2.3; road surface temperature, 2.4.4). As mentioned in the beginning of this chapter, we all observe "weather boxes" of a size smaller than the "air parcels" of the size of 10 km or larger, represented in NWP models (see 2.4 or summary in 5.2.1). What do we find beyond these coarse resolutions in space? The papers manifested examples of how individuals observed phenomena such as ice on the road (see Paper II, Paper IV, Paper V, Paper VIII). This cannot be predicted by NWP and other meteorological applications (see 5.2.1 and 2.4.4). A large number of individuals can potentially provide UGO at the spatial scales where they occur (e.g., road slipperiness occurring within meters and minutes), in contrast to expert systems that operate on kilometers/miles and hours.

I conclude that it is possible that individuals can contribute information that cannot be achieved with any other current methods, with an increasing number of Internet users and mobile phone subscribers soon to reach the number of residents on Earth (e.g., BBC, 2012, October 12; ITU, 2013) (see also Fig 1, p.29).

Based on sustainability arguments (5.1), it is evident that UGO of weather could be of considerable value to the society if sufficient volumes of UGO were created and processed. The question is: how can people be motivated to provide such information and how many would contribute? In addition: what would such "share weather" activities look like, what variables can be reported, and what are the properties of tools necessary for organized collection of weather observations? Can business models enable this idea becoming a practice? Would it work at all? This leads to the next research questions of the thesis, Q2 and Q3.

6.3 Why might individuals be motivated to make contributions in terms of user-generated weather observations (UGO)? (Q2)

In this section, I address Q2 and the motivational aspects of "share weather". Motivation is determinant for potential *quantities* of future contributions of UGO of weather. Chapter 4 developed some new theory on the aspects of human interest in weather information (see Table 5, p.105, section 4.5), whereas Paper VIII drew a framework for studying motivation in some "share weather"-related settings. This section will further develop some of these ideas, as a basis for the coming discussions. As a final step of this section, the theory is applied on the empirical results of the papers.

While addressing the question why individuals might be interested in sharing weather information, I focus on the two key issues: exploration of the context and potential sources of motivation. My first move is to integrate variables describing the context with the structural dimension. Drawing from Chapter 3 (Table 3, p.50, and section 3.3.2) features of a network are *nodes*, their *ties*, the information *domain*, *environment* (e.g., online/offline, and entrepreneurial/personal), and *technology*. In 6.2 I concluded that "Web 2.0" is a *technology* shaping the *environment*, whereas *nodes* and *ties* are properties associated with the social aspects of "share weather". In addition, 6.2.2 proposed that, in a user-centric approach, variables "time" and "space" can be associated with the environment.

Following the same methodology in the coming discussion and applying findings of Chapter 4, I continue the exploration of "share weather" and under what conditions individuals might be motivated to share weather information.

6.3.1 The theoretical approach

Motivation theory offers several approaches, summarized and displayed in Table 3 (p.50): a classic approach that prioritizes network structures and strong ties (e.g., Coleman, see 4.1.1), a more recent structural approach studying interactions and recognizing the importance of weak ties (e.g., social network theory, see 4.1.1), and, finally, the perspective of individual utilities and gratifications often applied in Media Technology research (see 4.1.2). I identified two dimensions associated with the structural and individual approach respectively (4.2) and concepts linking them together: the concept of "trust" (see 4.1.3), and "social capital". Then, I argued that the individual and structural dimensions can be merged using these concepts (4.1.3) in order to capture motivations arising on both an individual level and the influence reflected from a higher structural plane. With both dimensions generating motivation, what might trigger the need, or desire, to share weather information? Independent of the theoretical approach, research suggests that an individual should perceive some kind of benefit. However, theories diverge in respect to modeling these drives and sometimes even in the interpretations on the sources of motivation. Uses and gratifications suggest that personal, primarily *intrinsic*, rewards experienced on the personal and psychological level can create desire to participate in networks and, contribute user-generated content (see for instance 4.2.3). Social network theory, on the other hand, suggests that behaviors are a result of previous interactions enhancing expectations of future positive benefits of new interactions. Because this thesis explores how Web 2.0 technologies might improve weather information, for instance weather forecasts, receiving a weather forecast might be regarded as a reward or benefit. Here, we also need a rationalist perspective often excluded from other work on online networks. I reason that individuals might be encouraged to share weather information if they can benefit from the results of their work in terms of accurate forecasts. On the other hand, intrinsic rewards should be present because prior research in Media Technology and related areas emphasized their importance in online networks. Theoretically, several models could be merged.

What theories should then be regarded? For "share weather", uses and gratifications theory is probably most interesting considering the explorative phase conducted in this compilation thesis and in respect to the research area (within which this theory is often applied). My strategy is, however, to examine the whole context prior to choosing a framework. Earlier research findings were acquired studying particular contexts. How is "share weather" distinguished from the studied contexts? Some propose that the context is always imperative (Foley and Edwards, 1999). Others point at the lack of opportunity to study sustainability of a particular behavior due to an entirely novel phenomenon and projections into the unknown future (Chesbrough et al., 2008; see 4.3.2). It has been suggested that citizen science might face barriers based on the context defined by the domain (Nov et al., 2011). After all, online phenomena are very recent, and "share weather" is a yet-unborn phenomenon. Drawing from, for instance 5.2.2 and 5.3.4, which exposed some of the methodological challenges of research on "share weather" and the question of validity, studying the context should be prioritized. Some first steps were taken in Chapter 4 (4.3-4.5), with 4.4 particularly focusing on the sustainability dimension, accounting for the strong association of "weather" with climate change. The theoretical outline eventually resulted in presentation of the contexts of human interest in weather (4.5), displayed in Table 5 (p.105), and applied here below.

It follows that, theorizing on motivation should be based on discussion of the context of "share weather" and rewards that participants may experience on different levels: intrinsic, extrinsic, and, potentially, rational. The previously introduced network features describing a context can here be applied (Table 3): information domain, nodes, ties, technology, and environment. The characteristics of the information domain are defined by activities (tasks) and their purpose.

Nodes, obviously, describe who the participating individuals are. It can then be assumed that the individual dimension is associated with nodes and their personal interest in fulfilling the goals of the network purpose, whereas all other features define the structural dimension: ties, tasks, technology and environment. The individual dimension is analogous with motivation on the individual level associated with intrinsic rewards that might drive an individual to perform actions. The structural dimension refers to ties and design, where design is defined by tasks, technology and environment.

I start with exploration of the individual dimension by regarding personal rewards (6.3.2), their instrumentality (6.3.3) and possible sources of motivation (6.3.4). Then, I proceed with analyzing the contextual particularities of "share weather" networks. Here, we will leave tasks and technology aside; they are associated with design and accordingly will be addressed by Q3 (see 6.4). Instead, I proceed with exploration of the structural dimension, including ties and "share weather" network environments. I study ties in respect to the online communicative space (6.3.5), and social learning processes evolving in communities of practice (6.3.6), whereas time and space define other relationships to the environment (6.3.7). I apply related research areas (see Table 4) in 6.3.2 (knowledge creation) and 6.3.6 (communities of practice). Based on this analysis, I summarize a list of relevant variables and organize them into the motivational framework for studying "share weather" presented in (6.3.9), including a discussion of the approach to theory (6.3.8). Finally, a summary of findings is provided in 6.3.10.

Table 8. *Motivation aspects of the individual and structural dimensions (based on Table 3)*

Individual	**Individual dimension**	Nodes (6.3.2, 6.3.3) Purpose (6.3.4)
Context	**Structural dimension**	Ties (6.3.5, 6.3.6) Environment (6.3.7)
	Design (Q3)	Technology (6.4) Tasks (6.4)

6.3.2 Motives behind knowledge sharing

Previous research on related information domains suggested that *recognition* and *learning* are important drives in networks for knowledge creation (4.3.2-4.3.4).

Let us, however, not be limited to the context of related information domains, but include other possible motives. The Internet is believed to radically change the premises of communication; it carries a number of "social" cues, and prior research identifies strong "intrinsic" motivation (e.g., Wasko and Faraj, 2005; Benkler, 2006) based on emotions, identity, strengthening of one's self-image, sense of enjoyment, altruism and benevolence (4.3.2, 4.3.3, 4.3.4 and Paper VIII). In addition, sharing weather information might be associated with different motivations than suggested by the contexts of knowledge sharing used in the thesis for reference, not the least due to the extensive volumes of research. Participation in scientific projects may generate different drives.

For instance, Nov et al. (2011) point at some major differences between "scisourcing", synonymous with citizen science (see 4.1.2 and 4.6) and other sharing contexts, one of which related to the postponed effects of participation in terms of exposure. Namely, in citizen science, there is a time delay between performing a task and the time when the results of a collaborative (science) project are displayed and acknowledged by the masses and perceived by the contributor (see 4.6 and 4.1.2). This changed the premises for recognition, and recognition was acknowledged as one of the most important drives.

I would also like to point to some differences associated with the information domain and the contextual purpose, and they should be kept in mind when generalizing from prior research on related domains. For instance, findings on open source development (see 4.3.2) suggest that desire to help others in the community and the internal sense of obligation are strong drives. This finding might be applied to "share weather" because it can be associated with many contexts. However, other findings on open source can be strongly associated with a network of professionals, such as reputation and approval from others in the field, and self-development through learning and improving skills. While it is possible that many individuals would want to be recognized as good "weather observers", only a minority of users of a "share weather" system are likely to be driven by learning or to improve the career, simply because the fraction of users that might be active as professional meteorologists or traffic managers is small. This should be compared to open source where everyone is a professional software developer or at least possesses adequate skills. It may be difficult here to draw direct parallels to "share weather" since "share weather" might want to address the general public. Another finding on open source was of particular interest: in some networks, ideology was recognized as a very strong drive. The question is, can such occurrences of motivation observed within one context be applied to "share weather"?

Section 4.5 (including Table 5) concluded that the temporal structure of "weather-related" problems offers a window of opportunity that might raise the personal interest in weather information: individuals may consider *changes* experienced in daily life on timescales of days and hours both perceivable and important, satisfying a reciprocal need in everyday life (e.g., preventing hazards, avoiding traffic jams, conducting daily planning, enjoying one's hobbies, etc.), whereas those of climate change might pass unnoticed. A second important conclusion was drawn from previous research on management of natural resources, and it was associated with communities of practice (see section 4.5) and the social learning process evolving in communities of practice (see 4.4.2). In research on natural resource management, "stewards" may play a key role. They are individuals in possession of special knowledge and skills. Further, ideology might be associated with the topic according to strong association with climate change. Thus, based on 4.5, it might be suggested that *knowledge* and *ideology* are potential drives.

Based on research findings presented in Chapter 4 (see for instance 4.6 and the outline in Paper VIII, it can be suggested that the following sources of motivation potentially might be associated with "share weather": recognition, learning, the sense of performing meaningful tasks that produced perceivable results, and task granularity.

6.3.3 Rewards and scale of instrumentality

When studying sources of motivation, it is inevitable to involve the structural dimension. Namely, rewards can have different origins although be reflected in the same type of behavior. For instance, recognition can be manifested on several levels: inner satisfaction, exposure of one's work or status within a community (4.3.2-4.3.4). This also applies to learning; learning can provide inner satisfaction in terms of "flow", or be reciprocal, or even improve one's career (see 4.3.2, see also 4.4.3).

In this section, I address the scale of instrumentality that may govern individuals' behavior. Some rewards are experienced on an individual level, while some are issued by relationships that define the structure, for instance ties and social influence (see 4.1.1 and 4.1.3).

Instrumentality is important because it may represent a bridge between different sources of motivation. Namely, I reason that "social capital" can be transferred between different types of motivations, through interactions and ties created within a network. The second reason to look closer at instrumentality is my critique regarding uses and gratification theory in terms of overrepresentation of intrinsic motivations.

Due to conclusions drawn in the previous section and earlier discussed in section 4.2.3, sharing weather information may be associated with extrinsic motivations. These must be taken into consideration since weather information may provide benefits, both to individuals and organizations operating within weather-dependent businesses. Paper I started with this assumption and suggested a relationship between concern about losing property and lives and motivation to improve weather services. For instance, it is known that individual motivation increases if participation might result in protection of personal investments (see 4.3.4, for instance in windpower and land degradation). Through the course of history, the occurrence of heavy storms that destroyed property was shown to encourage development of weather services (e.g., Paper I). One concern is that, in Paper I, motives were studied on the societal, and therefore economic, level, rather than personal interest, that is, the individual level.

The summary of the compilation thesis, however, attempts to put the problem in the larger perspective of the global community and sustainable development (sections 4.4 and 5.1), which clearly indicates the urge to improve currently-available weather information, not the least associated with threats of climate change (see also 2.3). Here, an extrinsic need should be recognized although modified by the long time perspectives, according to Table 5 (see p.105). Environmental motives will, however, vary individually, depending on factors such as knowledge, awareness and ideology (e.g., environmentalism, see 4.4.3). This suggests the presence of individual rewards on several levels, but, intrinsic and extrinsic rewards are not always separable, not even in the noblest of motives such as ideology (see 4.2.3). In addition, learning may provide inner satisfaction or be associated with gain in terms of career-advancement and positioning of oneself as an expert (4.2.3 and 4.3.2). In order to capture several sources of information that can be associated with ideology and environmental concern, I use some theory on motivation to participate in volunteer work (e.g., Paper VIII). I conclude that all of the following motives might be present (based on Clary et al., 1998; see also 4.2.3): altruism (an individual cares for others' safety and wellness, or future generations' environment), social acceptance, learning (opportunity to learn or to achieve career-related benefits).

Due to the previous reasoning on economic savings and protection of property and lives (Paper I), there might be a drive corresponding to the "opposite" of ideology which is often associated with altruism (4.4.3), namely, weather information services may be regarded as one form of compensation. This is based in the "need" for weather services (see for instance Craft, 1999), and that weather information services can be attributed a monetary value.

However, it can be noted that, the risk of losing property due to weather events should, logically, be higher in traditional societies based on agriculture and harvesting, as argued in 4.5 and supported by research findings on observation of titi birds (3.7.3; 4.4) and farmers observing rain in Sudan (Paper VII). In modern societies, knowledge and perception of own-weather-dependence, for instance incentives to protect the natural environment, may have gone "lost" due to perception of diminished dependence on the natural environment in daily life. This can be contrasted with the need for traffic weather forecasts describing the traffic conditions. In large cities, dependence on infrastructure is already high (see Paper II) and gradually increasing (5.1; see also Changnon et al., 2000). Receiving weather alerts from an expert may, therefore, be associated with reciprocity, not, however, excluding possible existence of intrinsic drives. Paper II, Paper V, and Paper VIII, draw the conclusion that shared weather information may be regarded as a part of a service; UGO are small "rewards" to others within the network. Paper V proposes that one way of designing attractive "share weather" systems and services is implementing services that create values and a sense of reciprocity, which may increase motivation to share local weather information.

Based on the reasoning above, we may now classify rewards according to their instrumentality, including three categories:

- Intrinsic (purely altruistic, social acceptance, flow, environmental care, or care for others' safety);
- Extrinsic (learning, recognition, gaining status within the community, for instance an "excellent weather observer");
- Compensation (monetary, weather forecasts, protecting investments and property, preventing losses associated with climate change, learning associated with career advancement).

6.3.4 Who will participate?

It is obvious that not everyone will contribute content to "share weather"; individuals are different and their relationship to weather is different. The question is which individuals are most likely to become active contributors in "share weather" networks, and what are their drives? This section explores the *nodes* (see Table 3, p.50) of "share weather" networks. Some categories of motivations may be general disregarding the context, and closely attached to the individual, while others might be special for the context of "share weather". According to the results of the previous section and Chapter 4 (e.g., 4.6), some possible motivation categories are recognition, learning, compensation, ideology, and pure intrinsic rewards, such as social acceptance, altruism and flow. These should be matched to the *purpose* of a domain. Using the network feature *domain* in Table 3, it can be suggested that sources of motivation behind network participation might be (drawn from the *purpose*): professional, issued by a personal interest, personal ideology, a need in daily life, personality, or plain curiosity.

I start with the intrinsic motivations and personality. Previous research presents evidence of sometimes remarkable levels of contributions manifested by a few nodes, while the large masses often are passive free-riders (4.3.1). We can assume that similar behavior patterns might apply to "share weather" networks. This suggests that some individuals might particularly enjoy contributing to "share weather" while providing large quantities of information, whereas others may remain more a passive role, resulting in none, modest, or occasional contributions. Paper VIII found evidence suggesting that this might be the case. Namely, based on self-reported motivation to contribute to "share weather" in terms of "how often" an individual would send UGO, Paper VIII found that there was no correlation between "trust" and "frequent observers", whereas a correlation could not be rejected between "trust" and "moderate contributors" (see Paper VIII).

It is true, however, that “frequent observers” would contribute a larger fraction of the content, but the difference between moderate and frequent contributors did not reach the same proportions previously observed in other online contexts. The findings of Paper VIII, therefore, suggest the existence of similar incentives on a psychological level; personality probably accounts for some behaviors, potentially resulting in large volumes of contribution. Thus, some users’ behavior appears to be independent on benefits and trust-building. However, in Paper VIII, the figures supplied by moderate contributors might suggest stronger motivations by “ordinary” members than presented by other research. The second conclusion is, therefore, that rewards in terms of weather forecasts probably explain this difference and increases moderate contributors’ willingness to invest some effort. About 20% reported that they would contribute on a weekly basis, and another 10% answered that they would provide UGO on daily basis (see Paper VIII). The high survey participation figures (36-95%; Papers II-VIII), and participation in terms of UGO contributions (Paper IV and Paper V) also confirmed that not only a few users were active. In contrast, there was a broad assembly manifesting sustained participation, also over time (see Paper VI).

Users’ high participation rate can be explained by adding a portion of “social capital” in terms of “trust” through previous interactions (social network theory) or increased credibility (a utility perspective) (see Paper VIII and 4.1.3). In this case, the service constituted a part of the design and should be accounted for in the motivational framework.

What other motives might vary within a sample? We must consider that different individuals may be driven by far different sources of motivation (although they sometimes may lead to similar behavior). According to the list of potential purposes associated with networks provided in the beginning (personal interest, personal ideology, a need in daily life, personality, or plain curiosity), participation can be altered by an individual’s professional background or knowledge due to personal interest in the subject. Paper II found that several respondents were particularly interested in new technology and/or weather. Research in natural resource management (4.4.2) describes “stewards” who know more than others according to prior experience and knowledge (e.g., Olsson et al., 2004; Folke et al., 2003; Scheffer et al., 2009). Another possible parallel can be drawn to “lead-users” (von Hippel, 1986): individuals with particular awareness, knowledge and skills, that create solutions for problems not yet expressed by “market needs” (if transferring this strongly market-oriented concept on natural resources). In Paper IV and V, it was mentioned that users sometimes provided very detailed descriptions of road weather including technical explanations behind different phenomena. This implies that some users possessed particular interest and knowledge in the subject and were potential “stewards”. Moreover, they also wanted to manifest their knowledge, which may imply both the importance of conducting something meaningful corresponding to one’s individual skills and a need to receive recognition. Some were professionals, who, accordingly, possess more knowledge of road weather: road maintenance, car manufacturers, traffic radio reporters, and emergency response personnel. In the interviews conducted in Paper II, survey results, and e-mail conversation, some users provided specific suggestions regarding weather information services, which might suggest that some users were "lead-users" that possessed special skills and requested more than an average user.

Ideology can also be associated with specific individuals. In 4.4.3, it was suggested that ideology should be considered a potential driving force in "share weather" settings; when environmentalism is purely altruistic, it may be independent on time perspectives (Table 5) suggesting that this might be imperative for some particular minorities in the society. In environmental issues, activists and ideologists represent a minority that can have strong points of view, expressions, often associated with lifestyles (Segerberg and Bennett, 2011). Their role may be described similarly to that of "stewards" (or suggesting "lead-users" of environmental services). Paper VIII presents a qualitative study on motivation categories based on input from about 50 students. The results suggest that ideology might be important, at least drawing on responses supplied by a group with particular socio-demographic properties (see Study I, Paper VIII). Supported by research on open source (4.3.2), ideology should be considered in a framework for "share weather".

The motives derived so far correspond to the individual dimension. The individual dimension, first of all, accounted for "needs" experienced on personal level and possibly equivalent with uses and gratifications (4.1.2). However, some ideas based on reasoned action (4.1.2) established in, for instance, Von Hippel's work that also accounts for a utility perspective, should be added. I conclude that the empirical findings of the papers of this compilation thesis suggest that "needs" refer to different levels of motivation associated with habits (such as transportation in daily life), professional background, personal interest in a subject (weather/technology), personality, socio-demographic properties, strong need for weather information not yet met through services present on the market, and ideology/environmentalism.

This outline narrowed the scope towards the individual dimension. It provided a set of potential motivation categories: social acceptance, recognition, learning, compensation, interest in weather, and ideology/environmentalism. In the coming sections, I attempt to expand the horizon towards a two-dimensional perspective, where structural components are regarded as well.

6.3.5 "Share weather" relationships and the online communicative space

The coming sections highlight some structural aspects of "share weather" networks. Structure can be associated with *ties* (dyadic relationships between nodes) (see 4.1.1) and the *environment* (for instance reflected in the differences between online and offline). This section treats dyadic relationships between individuals, i.e., ties, and modification of the communicative space issued by ties when networks go online.

Ties are imperative in many community settings. They may, for instance, develop between coworkers. In the light of the Citizen Weather Observer Program (CWOP) (e.g., 3.6.1), nodes can have strong ties or be employed by or collaborate with an organization that approves the community/network goal. Networks can also be organized by, for instance, national weather institutes or a professional. Such ties were created within the context of the empirical studies of the compilation thesis (Paper II-Paper VIII), where the subjects are interacting with an "involved researcher" (see 5.5.4) for the benefit of developing future weather services and contribute to better traffic weather information. The concept of "social capital" (see 4.1.3) allows some dynamics in the transfer between the individual and the structural dimension. For instance, individuals may have ties prior to joining a network. Eventually, they may also develop new relationships within the network, based on interactions. For instance, identity-based relationships sometimes evolve towards bond-based relationships (e.g., Ren et al., 2007). Occasionally, this raised methodological issues in the empirical studies of the thesis because of the difficulties associated with distinguishing the effect of interactions from other measurements (Paper VIII and 5.3.3). This is always a concern in research, but becomes evident with an "involved researcher". The question is, how involved is a researcher when all communication occurs online, as with 95% of the subjects, and communication mainly consists of exchanging impersonal information about weather, adjusted to specific formats and with limited social conversation? The paper findings suggests that interactions did affect the respondents.

There might possibly be a more general explanation to this. If we recall the discussion on the network concept presented in Chapter 3, it can be difficult to distinguish between networks and online communities. Online environments (see 4.1.1 and 3.5) apparently encourage a range of behaviors characterized by social cues. The structural dimension offers one potential explanation to these abilities of online environments, namely "affiliative ties" (Flanagin, Stohl and Bimber, 2006). "Affiliative" ties also justify why the respondents in the empirical studies can be regarded as nodes in a network, even a "community". I use Flanagin, Stohl and Bimber's (2006) quadrants in the collective action space (see 3.4 and 4.1.1). According to their theory, Web 2.0 creates the opportunity to interact within the entrepreneurial-impersonal collective action space. This can be contrasted with the "decay" of social capital in the personal-organizational quadrant described by Putnam (1995). As an example, this may refer to conventional weather services, where individuals receive weather information from large institutions. In Paper II, later confirmed by several measurements during the longitudinal study on Group A

(Paper V), the respondents systematically "scored" the service to be more accurate than other weather services. Many other services are based on large institutions (in this case: the Swedish Meteorological and Hydrological Institute, SMHI), or large media corporations (for instance, television was the most common source of weather information, although Internet services are progressing, see Paper IV). For some reason, the respondents perceived the service to be more trustworthy than other sources of weather information (although, when measuring subjective satisfaction, the effects of interactions cannot be separated from the effects of the design; see 5.5.4 and 5.3.2).

But why does this impersonal/entrepreneurial environment create trust? Flanagin, Stohl and Bimber's (2006) explain that "affiliative ties" may lead to socially productive networks with norms and shared values and some bases for social trust, even in the absence of traditional personal ties (see 4.1.1). Based on this reasoning, social trust can be established between people interested in traffic weather through participation in "share weather" activities, although interactions are restricted to impersonal exchange of weather information (see also 3.3). Behaviors that might support the existence of affiliative ties were manifested in small spontaneous contacts initiated by the respondents, namely, participation in the research project resulted in interactions of several different kinds, and some were realized on volunteer, even self-initiated, basis: providing UGO (Paper IV, Paper V, Paper VIII), participation in surveys (including satisfaction rates with the service), sending personal messages (e-mail), providing UGO via www.shareweather.com (Paper VIII). From this, it can be seen that some activities happened on a volunteer basis although respondents might have perceived a sense of obligation to participate (e.g., responding to surveys), or they were purely self-initiated (e.g., providing UGO). Moreover, survey participation rates did not change notably over time. The only variables that changed over time were associated with changed decisions, which increased with time of participation (Paper VI). I concluded that the latter reflected the effects of interactions associated with the service (Paper VI). Interestingly, the group of 71 users that had participated since the first season, including 17 users that were interviewed, manifested higher figures, which points to the possibility that the offline interactions resulting from participation in interviews created ties. This was, however, not investigated in the papers.

One key question, which resulted from exploring Q1, is "How many will contribute, and how often?" Theoretically, we may quantify potential motivation to participate and contribute content in "share weather" by studying distribution of UGO and personal messages. Paper IV and Paper V provide some key results on what levels of participation might be expected from a "share weather" network: Survey figures pointed at relatively high participation rates. While it is generally considered that 20-50% participation rate in surveys is fair and usually less than 20% for external surveys (Krosnick, 1999), here they were in general between 50 and 70% depending on group and survey. However, the study in Paper V identified a small group of respondents that made significantly larger contributions in terms of multiple reports provided through both SMS and a web interface. Paper VIII also pointed out that a small fraction of respondents might be more active.

The content of SMS and open-ended survey questions were particularly interesting: they contained long, often emotional, descriptions of weather, or manifested that respondents were interested in the subject and/or wanted to share their knowledge (Paper II, Paper V). These findings suggest that components of social interaction are present, and that intrinsic and extrinsic rewards on personal level (uses and gratifications), for instance social acceptance and recognition, are possible sources of motivation. This supports the choice of uses and gratifications theory (4.1.2) and that it should be included in the motivational framework for studying "share weather".

I conclude that, with theoretical arguments (e.g., 4.6) and some empirical evidence, this compilation thesis supports general findings in research on online networks, where it has been repeatedly revealed that online impersonal interactions contain components of social interaction and that intrinsic and extrinsic rewards on personal level are important drives. As previously discussed in Chapter 4, some behaviors may contain elements of both intrinsic and extrinsic motivations. For instance, the temporal distribution of UGO (Paper V) indicated that respondents tend to provide more information if the weather is "bad" (although not when "too bad" as might have been indicated by Demonstration 1b, see Paper V), or when sudden shifts occur. Paper VIII confirmed that the weather type impacted the distribution of UGO (Study III in Paper VIII), but there was a discussion associated with interpretation of the origin of this behavior (see Paper VIII). It may depend on an altruistic need to help, but it may also be an expression of need for recognition and self-efficacy (Paper V and Paper VIII). Moreover, it may also be reciprocal and issued from a need to acquire a weather forecast (Paper VIII).

The papers may be used to elaborate with the suggested motivational theory based on theoretical findings of Chapter 4 (4.3.1). It can be shown that both individual and structural dimensions are present. Here is an example manifesting the structural dimension. For instance, although the empirical evidence provided in the papers should be further tested and confirmed, there was a manifestation of slightly higher criticism (through "scoring", see Paper VI) among groups that had participated the longest (although not confirmed statistically valid). Group I (n=60), of which 17 respondents had previously participated in interviews (Paper II), manifested constant participation rates in a series of surveys (68%), while other groups tended to start from over 70% in their first survey, and thereafter decline toward 50-60% participation rates. If this manifestation of increased honesty was strictly individually-related and associated with personal perception and "needs" (the individual dimension), "scoring" should be relatively constant with time. This might be a slight indication of that ties (the structural dimension) impacted behavior (in this case manifested in desire to contribute an accurate evaluation of the service), although other explanations are possible and the empirical evidence was vague. This act of commitment potentially expressed by Group I can be interpreted as a result of interactions (see Easley and Kleinberg, 2010): after interacting for some time: A feels both confidence in C's trustworthiness and other extrinsic and intrinsic needs to participate and interact within the network; these previous interactions encourage A to interact more than, for instance, a new member D (dental clinic, see Paper V).

However, several other differences between the treatments of the groups unveiled interesting data. A rather clear example was manifested in the behavior of new members of the network that already had weak or affiliative ties with radio reporters (of the Sveriges Radio local channel Radio Stockholm P4). The effect of existing connections might here have been manifested in their survey participation rates and scoring which were exceptionally high (e.g., 65% scored the weather "as forecasted", and 95% were of the opinion that it was "as forecasted" or "slightly better"; see Table 1 in Paper VI). The existing connections were based on either ties with the traffic radio that recommended the service or the expert (researcher) who participated in two radio shows. This points to an interesting finding: it manifests how "social capital" can be transformed from one domain to another (from Sveriges Radio, to "share weather" network structure), adding a portion of social capital that might generate higher trust and higher participation levels.

The relatively high confidence and engagement despite a short time of participation in this case, illustrates the power of recommendations and weak ties. According to Easley and Kleinberg (2010), the influence of weak ties for interactions between network nodes occurs if: two parties, A and B, have a trust-relationship (car drivers' relationship with the traffic radio reporters), and one of them, B (the traffic radio reporter/s), acknowledges C's expertness (by inviting C to participate in a radio show). A will assume, already prior to finding own-evidence of C's expertness (receiving weather alerts for a year), that C is trustworthy. Existing ties (between A and B) create an added amount of trust (in C) through B's acknowledgement/ recommendation of C.

Classic theory (e.g., Coleman) might have difficulties explaining related phenomena. If only strong ties prevail in the structural dimension, this corresponds to the respondents believing in the service entirely based on the credibility of its content (see 4.1.3). This model will have difficulties in explaining the discrepancy manifested in the behavior of groups that were recruited from the radio (Paper VIII), unless we assume that a relationship between en individual and the radio represents a bond, which is indeed possible but not probable.

In this way, affiliative ties of the online communicative space issue behaviors that cannot be explained with classic theory and strong ties; in the connected world, weak and affiliative ties make people commit to and participate in activities they perhaps would not have undertaken otherwise. It is easier to join an online "share weather" network than engage in a community of interest gathering individuals with particular interest in the subject "weather".

6.3.6 Social learning processes in "share weather" online communities

Because of the proposed similarity between networks and communities, I take the opportunity to use the concept of "community of practice" (3.4.3; see also Lave and Wenger, 1991), which is particularly useful. The "community" studied in the papers of the compilation thesis is organized around developing a weather alert service (e.g., Paper II and Paper VI). "Observing weather" is an action performed by the individual despite absence of particular intention of contributing important information (I will here use the example of climate change). The individual may, instead be attracted by other benefits, such as accessing attractive and useful traffic weather services facilitating planning in daily life. According to Lave and Wenger (1991), new members first participate in peripheral tasks that are less important to the group, for instance observing the traffic situation and road conditions (UGO of the built environment; see 5.1 and 3.7.4). Then, new members are given opportunities to access community resources and interact with other members: find out what others do, think, and observe. This could be, for example: getting access to user-generated observations of other variables describing the natural environment, such as flowers, insects, birds. The theory suggests that, finally, through practice and interaction, new members gradually learn about the community's goals and organization. Here, it may be suggested that the goals of the "share weather" network are to both increase the accuracy of weather forecasts and also encourage public participation in difficult environmental issues (e.g., 5.1); thus, users of "share weather" may gradually become aware of climate change, adaptation and alternative choices in daily life, which is analogous with building skills and experiences.

This reasoning may indeed be supported by findings on networks for sharing environmental information (3.7.3 and 4.4.2). Interestingly, the processes taking place in natural resource management communities are also described in terms of a "social learning" process (Olsson et al., 2004; Reidlinger and Berkes, 2001; Blaikie and Brookfield, 1987), which can be compared to *situated learning* in "communities of practice" (Lave and Wenger, 1991) (see 3.4.3). This might be used as a piece of evidence supporting that social learning might occur in "share weather". Theoretically, it is possible that, through a community of practice for sharing traffic information, new tasks and agendas may arise, potentially increasing pro-environmental behavior and awareness about environmental problems such as climate change, active inclusion in the public discourse and perhaps even changed consumption patterns. The idea that traffic information might contribute to a better environment might seem impossible, or even ironic. Table 5 (p.105), however, shows that, based on social learning and a user-centered perspective, small weather issues experienced in daily life might serve a shortcut toward increased participation in difficult issues involving weather events of large magnitudes (e.g., climate change). Although these are merely speculations, similar processes occur in communities of practice. My theory offers a way to a possible solution that might address obstacles created by space and time. Non-perceivable changes on long time scales (possible long-term climate and environmental disasters within a hundred years, see Table 5) may be addressed through active engagement in communities formed around relevant issues perceivable in everyday life (e.g., traffic weather).

I aimed to picture how structures and interactions can lead to entirely new tasks and interactions and, potentially, more drastic change in values and other personal properties. It can be said that the "social capital" is transferred between the structural and individual dimension and that this might create opportunities to address some environmental problems.

6.3.7 "Share weather" in time and space

Finally, some contextual variables might shape the motivational framework. "Share weather" aims at improving weather information, and weather information is time-critical (see 2.4 and Paper II). The fact that "share weather" solutions require sampling of real-time data and fast processing in order to make the data (e.g., forecasts) useful, "share weather" is distinguished from knowledge creation in citizen science, encyclopedias, open source communities, even other user-generated observations of the (built) environment. For instance, GIS information may be collected during a long period of time; it does not change over minutes or days. However, observing the natural environment, in particular the most dynamic parts of its system – the atmosphere, hydrosphere, and biosphere – may be associated with very short time scales.

This was addressed in Q1 (see 6.2.2) as I introduced "time" and "space" as contextual variables associated with the environment. While in 6.2 properties of space and time were discussed in relation to quality of UGO, here, I regard the motivational aspects of this finding. Sharing a weather observation might, first of all, potentially improve a weather forecast provided to other individuals within the same geographical area (see 2.4 and 3.5). Geographical proximity is a property that often defines offline communities, and some findings suggest that even online communities are geographically organized (3.5). This can be attributed to individuals' tendency to cluster themselves in hemophilic groups and connect with others with similar cultural background, norms, and other personal properties (Backstrom et al., 2010). Content is shared and more quickly distributed between users that are geographically proximate according to studies on diffusion of content through Facebook and Twitter (De Choudhury et al., 2010; Java et al., 2007) (see 3.5). Thus, there is an analogy between "share weather" and "social media" behavior. "Share weather" networks require certain geographical proximity in order to utilize weather observations provided by an individual to improve weather observations and forecasts provided to other individuals (see for instance 2.4.4). If users that are similar by location diffuse content to a greater extent than those that are geographically distant, the social drives behind "share weather" might follow the same patterns, which might improve the chances of providing useful outputs.

6.3.8 Reflections on motivation theory approaches

Finally, before presenting a motivational framework, I will discuss some issues associated with the choice of theoretical approach. In this section, I analyze how the individual and structural dimensions of "social capital" are projected on the empirical findings of this thesis, and how this relates to the theory previously developed in Chapter 4.

The aim of the papers of the compilation thesis was to study how "trust" is created within a "share weather" network. The network was formed in the beginning of a longitudinal study (2008), and trust and related variables were measured occasionally during 2008-2011. As suggested by Table 3 (p.50) and Chapter 4 (see 4.1), there are different approaches in motivation theory concerning the role of agents, and their interactions. Uses and gratifications theory diminishes the importance of structures and sees individuals on a micro-level as quasi-rational beings performing actions, whereas the structural approaches interpret how structures shape individuals' behavior on the macro-level (see Table 3).

The individual dimension may be associated with different approaches, and they diverge in their view of instrumentality. The strictly utilitarian (and older) tradition regards social actions in terms of rational, purely self-interested behavior, suggesting that individuals contribute (e.g., weather observations) only if their expected measurable consequences outweigh the efforts (for instance receiving a weather forecast). It can therefore be difficult to address motivations such as ideology and altruism. Here and in research on media technologies, proof was found that individuals gladly share due to inner satisfactions. Uses and Gratification Theory UGT (4.1.2) models these inner drives very well. It even accounts for a degree of higher instrumentality, however with no accurate representation of external rewards that might treat the value of receiving a weather forecast. I, therefore, suggest that a stronger degree of instrumentality should be considered when studying "share weather". Utility can be captured with this approach, which is confirmed by that organization theory oriented research (e.g., von Hippel and von Krogh, 2003; Chesbrough, 2003) has conducted many studies on, for instance, open source, resulting in extensive knowledge, whereas Human-Computer Interaction also applies models that consider stronger influences from the structural dimension (see TAM and UTAUT, 4.1.1). In this thesis I, therefore, compromise between uses and gratifications, and rationality. Paper VIII introduced a model that includes both determination of ideas and material conditions. The benefits of receiving better weather information can thus, besides a list of intrinsic and extrinsic rewards (see 4.2.3), be represented in this model (see Paper VIII).

In the light of the outlined theory on online networks presented in Chapter 4, which contradicts much of the classic approach (e.g., Coleman), this structural approach can be excluded from the framework developed in this thesis. Instead, Social Network Theory might be used to explain identities that arise through interactions. This theory is particularly interesting from the perspective of the longitudinal approach in this compilation thesis, because it may model the *progress* of a "share weather" network in terms of ties and creation of new identities, for instance environmental concern highlighted in one of the previous sections. Social Network Theory can be used to interpret patterns of structural ties in terms of dyadic relationships between nodes, transmit information, behaviors and attitudes, for instance: observing weather through "share weather" engenders new identities and relations. Because I focus on the concept of "trust", however, all approaches may in fact apply to the context studied in this compilation thesis, including the strictly rational-based theories.

The compilation thesis further develops the framework presented in Paper VIII and suggests a blend of existing theories. The concept of social capital was used to describe development of "trust" on the one hand, and the individual perspective (needs) on the other hand. The concept of "social capital" can be used to transform values from the individual to the structural dimension, potentially even between different domains, as implied by the social processes associated with communities of practice (6.3.6). The strength of the concept of "social capital" is that it can be applied even if taking substantially different positions regarding the properties of the structural and individual dimensions: agents are social capital owners, but they may also transfer social capital through their ties. Regardless of the approach – uses and gratifications, utilities, or social network theory – all support that interactions (for example posting and responding to messages), create social ties and influence individuals' willingness to contribute knowledge to others. Paper II, Paper IV, Paper V, Paper VI, Paper VII and Paper VIII all examined "trust" in different studies and slightly different perspectives. The papers adopt a user-centered perspective (see 5.3.2) and user-centered design (5.4.1, see also 5.5.3 on design approaches) of the traffic weather service (e.g., Paper II). In Paper VI and Study II in Paper VIII, however, the quantity of interactions (through a substitute variable "time of participation, see 5.3.3 and Paper VI) are the subject, and the effects of these interactions measured in relation to how the respondents changed their decision-making (such as re-planning a route or teleworking; see

Paper VI) and behavior (changing one's equipment to winter tires due to weather predictions provided in the weather alerts). Here, interactions are given a central role: interactions create trust. It can therefore be suggested that Social Network Theory may be applied in future work.

Based on the discussion above and previous findings of this Chapter (6.3.3, see p.165), I suggest a theoretical framework based on three dimensions: structural, individual, and contextual. The contextual dimension contains "space", "time", and the design features previously drawn in 4.2.2, 4.6, 3.6.2, and 3.8.1.

6.3.9 Motivation framework for "share weather"

We can introduce a model that allows a mix of variables of different instrumentality. Interactions and ties (network structure) are, then, reflected in some of these variables. For instance, "identification" and "obedience" can be regarded as the same phenomenon manifested at different levels on a scale of instrumentality (see Table 1 in Paper VIII). As a result of this section, I present a motivational framework in Table 9. Drawing from uses and gratifications alone, individual motivation is explained with the following, mostly intrinsic, categories of needs: information, pleasure, entertainment and aesthetics, strengthening of self-image and self-confidence, affiliation and social relationships, escape and diversion (see 4.1.2). This theory is extended with ideology (based on Clary et al., 1998; 4.2.3) (see 6.3.3), due to the context of weather/climate (see 4.4 and 4.5) and findings on open source research (4.3.2). In addition, I add compensation based on both the theoretical findings (see 4.2.3) and the results on empirical research (Paper VIII), not the least supported by studies on environmental and geographical data (4.3.4). In this way, the framework may represent three different levels of instrumentality. These three different levels of instrumentality are assumed to capture influences from the structural dimension (see for instance "social influence", 4.1.1): individuals' relationships with others within the network and outside the network. The second source of influence issued by the context is design-related. Drawing on 4.6, these are: task granularity, convenience, attention. They will be treated in the next section.

Table 9 summarizes the findings of this section and provides a framework as a result of network features (Table 3, p.50), based on features of a network (Table 3), contexts of human interest in weather (Table 5), individual and structural dimension (Table 8), and Paper VIII. Design (addressed in the next section) is associated with technology (Web 2.0), whereas space and time are a part of the environment. Drawing on the findings of this section, motives for participation induced on personal level can be described in terms of three different levels of instrumentality representing the individual dimension: Intrinsic, Extrinsic, Rational. Different sources of motivation are, finally, positioned on this scale of instrumentality.

Table 9. "Share weather" motivation framework, based on Features of a network (Table 3), Contexts of human interest in weather (Table 5), Individual and structural dimension (Table 8), and Paper VIII.

<table>
<tr><th colspan="3">Motivation framework</th><th>Intrinsic</th><th>Extrinsic</th><th>Rational</th></tr>
<tr><td rowspan="2">INDIVIDUAL</td><td>Individual dimension</td><td>Nodes</td><td>Social acceptance
Feed-back
Environmental care
Altruism (and social care)
Ideology
UGT</td><td>Recognition
Learning
Ideology
(UGT)</td><td>Monetary compensation
Career
Protection of investments
Preventing losses associated with climate change</td></tr>
<tr><td rowspan="2">Structural dimension</td><td>Ties</td><td>Identity</td><td>Interactions
Trust
Social influence</td><td>Obedience</td></tr>
<tr><td rowspan="2">CONTEXT</td><td>Environment: Space
Time</td><td>Global
Geological time scales</td><td>Geographical proximity
Time associated with the social world</td><td>Geographical proximity
Everyday life</td></tr>
<tr><td>Design</td><td>Technology</td><td>Attention</td><td>Task granularity
Convenience</td><td>Technology acceptance (TAM)</td></tr>
</table>

Now we can compare with some key results from the empirical studies. Findings of the empirical studies presented in Paper VIII confirmed prior research on common motivations to contribute: social acceptance and recognition (see Study I, Paper VIII). A set of other variables was also discovered, namely: ideology, and compensation. Recognition was also suggested by Paper VII, although the empirical evidence is vague. Finally, the results of Paper VIII (Study II) point at that reciprocity or compensation is relevant.

In addition,, information supplied by the respondents in UGO (open-ended questions and SMS), surveys (open-ended question), and other communication, unveiled existence of some of these motives. Personal conversation suggests that components of social interaction are present and that, for instance, social acceptance and recognition might be possible sources of motivation. School children's patience and completion of tasks, even improved skills, might indicate the importance of learning, possibly also supported by the occurrence of open-ended questions with information explaining weather phenomena (Paper IV, Paper V).

6.3.10 Conclusions: Why would individuals "share weather"?

Based on the outline above, we can draw several conclusions. They confirm that "share weather" networks may contain elements of social interactions, despite the simple conversational format and absence of direct links or socializing. Moreover, participation in "share weather" networks might create new ties and trust.

The "share weather" network studied in the papers was a network of affiliative ties, where nodes could share weather information. Previous findings were confirmed: the network developed elements of social networks, including intrinsic and extrinsic rewards, although they were not separable in the empirical studies.

Analyzing "share weather" from the individual dimension perspective resulted in several important findings. It follows that respondents' motivations were of several origins and that there is no simple answer to research question Q2; members of a "share weather" network may be motivated by a range of possible factors including intrinsic and extrinsic rewards and even compensation. As suggested by previous research, it was indicated that recognition is an important drive (for instance manifested among farmers in Sudan, Paper VII). However, studies on motivation (see Study I and Fig 1 in Paper VIII) showed that intrinsic motivation might be the strongest drive. It can be suggested that, displaying the results of individuals' work (e.g., weather observations) and acknowledging particularly interesting or important UGO, can also encourage people to share. Second, the aspect of learning (based on for instance school children's improved skills and responses, and open-ended questions in Paper IV and Paper V) suggests that "share weather" should contain features with interesting content that can satisfy intrinsic drives such as learning and self-development.

The impact of the structural dimension, primarily governed by ties, was discussed based on evidence that offline interactions might influence future commitment and interactions. Further attempts to draw conclusions upon these empirical results would, however, result in uncertain assumptions. While the papers provided only indications, a new study, however, collected new evidence supporting some first observations (Elevant, 2014, accepted for publication; see 1.5.9). It is evident that participation was sustained over a couple of years with steady participation figures pointing at a committed assembly. The results manifested how social capital, or trust, was created, through interactions, resulting in changed behavior. While this might be valid within the studied context (based on the high satisfaction figures in Paper II, Paper IV, Paper V and Paper VI, changed behavior in Paper VI, and generally high participation rates), these conclusions cannot be generalized to other settings. It is important to bear in mind that the results presented in this thesis may not be valid for a different context where weather forecasts are not supplied.

Based on the empirical evidence, I suggest that a "share weather" system should provide personal rewards addressing user needs. User needs are manifested at several levels: intrinsic, extrinsic, and rational. "Share weather" should provide weather forecasts as rewards in order to maximize user contributions.

Before designing a “share weather” artifact, some other variables should be taken into consideration. In addition to the individual and structural dimensions, a third set of variables relevant for “share weather” networks is derived from the particularities of the “share weather” domain and identified as: space, time, and task granularity. The third dimension is thus associated with design features. These are separately addressed in the third research question Q3 of the compilation thesis, and discussed in the coming section 6.4.

We might now elaborate with some figures in order to assess potential quantities of user-generated observations (UGO) of weather. The empirical results provide some information on volumes of contribution based on the artifact designed during the studies, and they may be compared to other available research. I will here summarize some figures on potential contributions based on generalization of the empirical results. The network of people interested in traffic weather that participated in the empirical studies was highly motivated to purchase weather information, and they also contributed input relatively evenly distributed over its members: During a time period of about two weeks, on average, they provided 1 report/respondent and 1.6 reports/active respondent (see Paper V). Lower figures were achieved during Demonstration 1b where corresponding figures were 0.3 and 0.7, partially explained by winter holidays (Paper V).

If fluctuations are neglected, we can adopt a motivation rate M=0.5 reports per week and node. The results also reflect that 10-20 % were more active in terms of providing multiple reports (for instance, over half of the 65 SMS reports came from 13 users that reported more than once, see Paper V), in contrast to findings on distribution of content contributors in other communities where 2-4 percent of the users create the major volume of the content. This might, again, be explained with reciprocity and the rewards in terms of weather forecasts, representing the major difference between this network and networks addressed by earlier research. Although it is inconvenient to generalize, based on these results, a global community of “weather sharers” would have the following appearance: first, the content contributions would be more evenly distributed over a larger fraction of users. Second, users would contribute at least twice per month, and 10-20% would be more active (which was also supported by findings of Paper VIII, Study II). Paper V concluded that a network of 200 individuals was sufficient to meet the requirements of WMO (10km and 3h; see 5.2.1 and Table 7, p.138), while the number of nodes should be increased in order to meet the requirements of meteorological applications such as road weather (1km and 0.25h) (see 5.2.1).

As an answer to research question Q2 – why individuals might be motivated to contribute UGO of weather – it can be suggested that both interactions, and rewards (such as the weather alert service), might encourage motivation. Other incentives that should be regarded when designing “share weather” systems are features that enable considerable exposure of individual observers, feedback in terms of making the results of users' contribution and work perceivable, and elements of learning. Additional features may be designed to make most possible use of the fact that human beings enjoy socializing and belonging within a larger context. Finally, other existing ties and relationships may encourage participation and interactions in "share weather" networks. For instance, other relationships may exist between the subjects, who were obviously already connected through having the same profession as farmers (Paper VII), or belonging to the community of car drivers, residents of Stockholm, users of a web service trafiken.nu, participants in a scientific project, a community of radio listeners, not the least representing a homogeneous group of middle-aged men with long distances to work (see Paper II, Paper IV, Paper V, Paper VI).

6.4 How can a "share weather" solution be designed? (Q3)

The final research question will here discuss design features of "share weather" systems, based on theory and insights gained while addressing Q1 and Q2 and some new theory developed in Chapter 4. The question of how "share weather" can be designed can be addressed by designing and evaluating a "share weather" artifact. I use an objective-centered approach (see 5.4.3) based on the design science research methodology DSRM (Peffers et al., 2007) presented in 5.4. The general objectives are defined by a set of features used to collect Input, Process data, and present the Output (Table 7, p.138). According to Table 7, we are interested in: how system properties such as processing and collection methods can utilize the input (UGO) in order to produce the best output. I start by producing a list of features for increased motivation in "share weather" networks (6.4.1). Thereafter, Processing is discussed (6.4.2).

Chapter 3 and Chapter 4 previously derived a set of desirable properties that should be attributed "share weather". These are summarized in for instance 4.6 and displayed in Table 8 (p.176) and Table 10. Further, adequate input formats that allow processing with relative ease are required (4.6).

It also follows from Table 7 that "share weather" must meet certain criteria in order to improve weather information. "Share weather" should supply a relatively constant flow of weather data for a particular geographical area (see 2.4 and Table 7). Either the spatial density should be very high, compensating for low levels of motivation or motivation levels must be that high to generate weather observations evenly distributed over time. Based on the results of section 6.2, it can be concluded that "share weather" most probably must rely on a large community of more or less devoted individuals that make occasional contributions. However, it is probable that motivation levels will fluctuate due to the magnitude of events (see for instance 3.7.1 and Table 5, p.105), questioning the final result, i.e., the quality of "share weather" output.

6.4.1 Design features for increased motivation

Drawing from previous findings, the design should contain features that offer user experiences related to:

- Weather services (forecasts)
- Recognition of members and their creations
- Socializing
- Learning
- Attention
- Connections to other social media applications and networks of practice
- Appropriate task granularity

The first finding – that weather services should be introduced as rewards – was addressed by Paper II, which presents iteration 1 of the design process associated with customization/personalization of traffic weather alerts. It suggests that "recent weather" observations should be introduced (se also 5.3.2).

In Chapter 4, I found strong support for the finding that recognition is one of the most prominent forces that drive online participation (4.3 and 4.6). This requirement might be exceptionally important as "citizen science" meets the additional challenge of making the results of participants' work perceivable (see 4.5 and 4.6; Nov et al., 2011). "Share weather" should meet requirements such as exposing contributors for instance by publishing information (e.g., name), and providing immediate feedback on one's work (e.g., publishing individual weather observations).

The other issue associated with the context (of a scientific project) is identifying appropriate tasks that individuals can fulfill with ease (see 4.5).

One potential obstacle identified in Paper IV is drawing attention to weather, because observing weather might compete with other activities. This could be addressed by designing (interfaces) for particular groups that possibly have more dispensable time, knowledge, or stronger weather-dependence (see the time-consumption model, Paper IV). Additional services might also create opportunities to become more attentive (e.g., SMS, Paper II, Paper VI).

A related finding was shown when analyzing motivation for participation in online networks and the importance of social cues: participation in "share weather" networks may be amplified through connection to social cues, and engagement and social learning processes present in communities/networks of practice might be utilized (3.4.3).

Exploring "share weather" also provided insight into the social abilities of the online environments, but "share weather" can also be based on affiliative ties. Connecting "share weather" with other social applications might, however, be interesting.

Findings of Paper II in addition suggest that other user data are required in order to fully personalize a weather service (Paper II): user data on travel, habits, preferences, socio-demographic properties, psychological profile/personality, and the user's own weather observations, all of which provide information of recent weather experiences and perception of weather. Due to theory on driver cognition and psychology (e.g., "bad" memory regarding weather) (Paper II and 5.3.2), recent weather experiences are imperative for perception of weather and, accordingly, also user preferences and perception related to weather services such as forecasts. For example, if a system can acquire data on where the user has been positioned, what the user usually does, and, most important, how the user perceives the weather, a system can create a service adjusted according to user needs and user perception. Therefore, Paper II concludes that input providing user data (travel, habits, perception of weather), i.e., different user-generated content (including UGO), is a precondition for full personalization of the service.

When regarding this conclusion from the scope of the thesis and the design process addressed in Q3, it illustrates an interesting symbiosis between Web 2.0 solutions and personalization: evaluation of the weather service pointed out that interactivity should be introduced in terms of "recent weather" observations recorded by users. Using UGO as input addresses both personalization and "share weather" design. Data such as position, habits and perception may partially be derived from UGO. This, of course, involves some integrity and privacy concerns described in 5.3.9.

Learning is a probable source of motivation and is instantiated with the introduction of the concept of community of practice. Because "share weather" is assumed to possess similarities with communities of practice, I conclude that learning is not only a potential drive, but also it might generate benefits associated with the association with natural resource management networks of practice (see also 4.6).

6.4.2 Design of user interfaces and filtering

Early in the design process, "peering" was identified as a filtering method (see for instance Paper III), according to a certain analogy with knowledge creation (see Table 4). Empirical testing and evaluations of UGO in Paper IV and Paper V provided evidence supporting this hypothesis. It was, for instance (see paper IV and V), manifested how small groups of children (3-5) improved their observations through peering, compared to the individual observations. Paper III and Paper V therefore also addressed design of collection methods of UGO input that may be subject to peering.

"Peering" may only be applied to weather information if data are collected in a format that enables comparison between descriptions of weather phenomena. The second requirement is task granularity: tasks performed by users should preferably be expressed as modules in order to integrate the smaller entities of user-generated content into one larger entity, and the tasks should be divided into smaller tasks or sets of tasks meeting the needs of different users with different levels of motivation, i.e., task granularity (Benkler, 2006; Nov et al., 2011). Finally, convenience, attention/awareness and potential competition from other activities (Paper IV) should be addressed. The idea of taking pictures with a mobile camera is an example of how user needs are met in terms of convenience. Analysis of time consumption in Paper IV manifesting a broad range of individual task-performance in everyday life indicates that "share weather" design should also take into account different needs manifested among different user groups. Therefore, different interfaces were offered: school children, adults in traffic, and new users (the dental clinic). Examples of interfaces are available at www.shareweather.org.

In the papers, I argue that "share weather" system requirements (see Table 7) should be designed to meet the requirements of the current format of weather data used in meteorological applications (see Paper V). Eventually, this resulted in a UGO collection method based on text phrases and pictures (see www.shareweather.com and Paper V). The evaluation provided that this method can be used to process data collected by "share weather". Moreover, in those cases when the collection method is technically simple, and other systems of comparable performance are dependent on complex programs, comparing the Outputs is the only adequate method. Such systems might be appropriate for applications within the area of UGO, where users *observe* features in the environment, and "share weather" is an example domain.

6.4.3 The design process

Paper V describes the entire design process. Application of design science methodology (see 5.4) provides objectives corresponding to research question Q3. These are addressed in three iterative steps (see Fig 3, p.136):
-Iteration 1: Design, demonstration and evaluation of the "recent weather" method
-Iteration 2: Design, demonstration and evaluation of a collection method that can be applied in "share weather" information applications
-Iteration 3: Evaluation of Motivation

Iteration 1 – the "recent weather" method – is addressed in sections 5.3.2. Iteration 2 – the collection method – is performed as follows (Paper V): existing methods (WMO) are combined with common phrases in media, and a consensus is reached for a series of text phrases. In addition, pictures are suggested for identification of cloud type (Paper III), and mathematical expressions are adjusted to common language and knowledge. Customization toward user groups is also performed: the text phrases and other material are adjusted to children's language and knowledge level. Peering is used for filtering (Paper V). The design of the collection method is available at www.shareweather.com and described in Paper III and Paper V. The "Shareweather" system provides a reward: whenever the user provides UGO, a new weather forecast is generated, based on UGO, NWP, and other observations (e.g., RWIS).

It is important to note that choosing the filtering method "peering" was determinant for the final outcome of the design of the collection method, and it was based on the fact that text phrases are comparable and may be filtered, whereas free text messages provided through SMS (Paper IV) cannot be subject to efficient "peering". As pointed out in 5.4, design is a dynamic iterative inductive process that results in a unique product defined by the context; different context, or performing iterations in a different sequential order might result in different designs.

The aim was, however, reached as demonstrations and evaluation steps of the design process confirmed that the collection method was feasible.

6.4.4 Summary: the "Shareweather" artifact

The design process described in the papers (see Table 7, p.138) resulted in creation of an artifact "*Shareweather*" presented in Table 10. This artifact was used to address the research questions, including the research questions of the summary of the compilation thesis Q1-Q3. It is therefore important to acknowledge existence of other "share weather" solutions, based on different assumptions and different contexts. The research approach in the compilation thesis resulted in a specific design ("*Shareweather*", www.shareweather.com) including some theoretical findings. The theoretical findings are summarized in Table 10 and may be regarded more general than the specific "Shareweather" design presented at www.shareweather.com.

Table 10, in addition, provides an overview of the findings of the compilation thesis. Research questions are paired with major outcomes with reference to papers or sections of the compilation thesis where the theory is developed. I finally provide a summary of results – design and evaluation of a new Web 2.0 concept "share weather" – organized in three dimensions of the network cyberspace:

individual, structural, and contextual, in accordance with Table 3 (p.50) and Table 9.

Table 10. Summary of research findings of the compilation thesis

INPUT	PROCESSING	OUTPUT	
Quantity	**Quality**	**System properties**	
Motivation (Q2)	**User bias (Q1)** **Collection & Filtering (Q3)**	**Design**	
THE COMPILATION THESIS			
Q2 +	**Q1 + Q3 ->**	**DESIGN and EVALUATION of the CONCEPT of "SHAREWEATHER"**	
MOTIVATION -Rewards (services) In: *Paper II, Paper VI, Summary of Compilation Thesis* -Learning -Recognition -Socializing -Connections to other communities -Task granularity -Technology In: *Summary of the Compilation Thesis*	FILTERING: -UGO filtering and quality In: *Paper II-Paper VII* -Peering In: *Paper II, Paper III, Paper V* -Comparison with WMO and other official sources In: *Paper I, Paper II, Paper IV* -Filtering according to VOS In: *Paper III?* COLLECTION: -Text phrases In: *Paper II-Paper V* -Pictures In: *Paper III, Paper V* -Personal data In: *Paper II* -Task granularity In: *Paper V* -Technology In: *Paper II, Paper V*	COLLECTION (Individual dimension; personalized and user-centered) Text phrases Pictures Personal data SERVICES (Individual dimension): Weather forecasts Learning Other services Environmental and climate data	INDIVIDUAL
		INTERFACE (structural dimension) Recognition Socializing Connections to other networks (e.g., hiking, sailing, golfing, gardening) SPACE and TIME (structural dimension) $D_S < 1$km, (D_T) < 1h Environmental data $D_S < 10^{-2}$m, (D_T) < days/weeks	STRUCTURAL
		DESIGN (Contextual) Task granularity Technologies for collection: web, mobile applications Technologies for distribution (rewards): SMS, web, mobile applications FILTERING (Contextual): Comparison with WMO and other Filtering according to VOS Methods combining environmental data from experts and volunteers Peering	CONTEXT

Chapter 7
Conclusions

In this section, I present some conclusions based on further discussion and generalization of the results presented in Chapter 6. First, I return to the original question of the compilation thesis, namely: how might the concept of "share weather" improve weather information? I discuss this, in 7.1, on the basis of findings of the compilation thesis in Chapter 3, Chapter 4 and Chapter 6. Given the sustainability approach of this thesis, I also ask: how might the results of this thesis contribute to sustainable development? Doing this, I try to advance the question to a higher level of its domain, and generalize my findings to the domain of environmental information, or: sharing environmental information. Here, I refer to the "natural environment".

Drawing on the results of this compilation thesis, studying "share weather" can contribute useful knowledge that can be applied within several areas. I reflect over some of the limitations of this thesis, general conclusions on methodology (Chapter 5), and how "share weather" might be further explored. I present some suggestions on future research, including discussion of the limitations in my exploration of "share weather" elaborated in this thesis. In the final section, 7.2, I discuss limitations and future work.

7.1 Implications: How might "share weather" improve weather information?

In this section I start by reflecting on some sustainability aspects of "share weather" and practical implications of "share weather" outputs regarded from a sustainability perspective (7.1.1). Next, I try to assess how "share weather" might improve weather information in practice (7.1.2). Given the delimitations defined by the thesis, I also address other possible solutions for improving weather information (7.1.3). Finally, I explore the domain of the natural environment and how the knowledge gained in this thesis can be applied in environmental information in general, including the question of generalizing "share weather" designs to other domains of environmental information (7.1.4). The final issue presented in this section regards one of the most important goals in dealing with environmental problems, namely (see 5.1): can "share weather" motivate participation in environmental issues (7.1.5).

Introducing a wider range of environmental data sets modifies the contextual dimension, although many similarities and synergies are present, as will be argued below. First, I aim at generalizing the results of Q1, Q2 and Q3 in order to effect a comparison with other solutions and other methods for weather forecasting; this is an extension of Q1 that conducted an inventory of potential performance of the "share weather" artifact compared to other solutions. Here, I also draw on my results on Q2 and Q3. As a second generalization, I apply findings on the design of "share weather" to the domain of environmental data.

7.1.1 A societal approach: The "good" of "share weather"

Some of the most important implications of "share weather" are associated with its advantages compared to current solutions (WMO SYNOP; see 2.2). People are capable of observing weather (Q1). Perhaps more important, individuals may be spatially distributed in a way that might be impossible to achieve with current solutions. For instance, precipitation data were collected with the help of local farmers in Sudan, arranged by Sudan Meteorological Authority and Food and Agriculture Organization of the United Nations (Paper VII). In this geographical area, as in many development countries and rural areas, the WMO SYNOP network is characterized by lower spatial density. This problem was addressed by the local authorities through introduction of a "share weather" system for collection of weather data with farmers that volunteered or were offered compensation. In order to illustrate the benefits of this "share weather" project, the few (less than ten) stations that are part of the current WMO SYNOP network may be compared with the 100 farmers that participated. Guided by this example, we conclude that "share weather" methods are sometimes necessary. Volunteer observations provided input based on WMO standards (after some training and adequate equipment). The information can be used for better input to NWP, improving nowcasting (2.4.4) and data assimilation (2.4.2), and, in this case, precipitation data can be used as input to agricultural forecasts, climate data, and possibly even other environmental models and parameterizations (2.3).

This study indicates that using humans as observers can be a feasible approach in developing countries. It also reveals that mobile technology – a Web 2.0 technology – is a precondition for some of these activities. Given that the number of users of mobile phone users is rapidly increasing, with a penetration rate of over 60% over the African continent and almost 90% in developing countries (ITU, 2013), "share weather" systems based on mobile technology may represent an excellent alternative to expensive investments in traditional WMO networks in developing countries (see problem identification of the thesis in 5.4.3; see also WMO, 2009b), in addition providing monetary compensation to farmers (Paper VII). This example therefore indicates additional values that "share weather" might generate. They are related to global development, investments and equality issues, in addition to the previously highlighted advantages of user-centered services. Weather is a global phenomenon, and collection of weather data worldwide represents the first step behind all weather forecasts. Weather is global, and so is Web 2.0.

Here, Paper VII reasons that, if a "share weather" network is global, the value of an observation in Africa is comparable to the value of an observation in Switzerland. "Share weather" networks might not only equalize the social status (3.5), but also equalize the economic status. Because weather (including climate change) is global, UGO are "goods" or "commodity" (e.g., Paper I, Paper VII) independent on the geographical coordinates, or distribution of monetary resources. From a sustainability perspective, this is encouraging, since environmental sustainability is a result of processes occurring in three dimensions: economic, social, and ecological. This means that linkages towards improved environmental sustainability can be created by using social, and economic, incentives.

Another aspect of "share weather" and UGO of weather as a "good" should be noted: weather forecasts are of substantially higher value to individuals than climate information. Sharing time-critical information, for instance described in Paper II, is associated with higher motivation than collection of climate information (see Table 5). This is because the environment can be regarded as a "common good" and the "tragedy of the commons" therefore rarely motivates action (4.4.1). I suggest that this is not necessarily the case with the products of "share weather". The outline in Chapter 6 (6.2.1 and 6.3) shows that weather can be associated with both socializing and reciprocity according to human dependence on weather on short time perspectives (4.5 and Table 5).

I summarize with the idea that a link can sometimes be created between the economic dimension and goals enhancing environmental sustainability, through "share weather", by: saving investments (e.g., investments in new observation networks in developing countries), or protecting property (e.g., transportation in daily life) (see Table 5 and Table 9). While this section discussed how incentives issued in the economic dimension (property) might impact environmental sustainability through "share weather", in 7.1.5 I will further analyze the social drives that potentially might enhance environmental sustainability.

7.1.2 How might "share weather" improve weather information in practice?

I will first try to evaluate how "share weather" might improve weather information in practice. This can be done by assessing the potential volumes of contribution.

Concrete outcomes of the empirical studies may be cautiously generalized in order to suggest how UGO may respond to the demands defined by official systems, that is, WMO and national weather institutes. These were the objectives of a solution addressed in the design process (Table 7, p.138). From the perspective of implications of "share weather", however, and with the *user-centered* approach adopted in section 5.4.1, it would be more justifiable to regard the actual *experienced* quality (5.5.4) due to perception of the user and utilities drawn from the service. In this section, I discuss the empirical findings in relation to user actual *needs* (the individual dimension). What are the requirements if the structural and contextual dimensions are combined?

In analogy with Paper V, a limit was set on the requirements of the system performance manifested in current numerical weather prediction models (NWP). Their outputs provide weather information at 100 square kilometers on an hourly basis. (The background is provided in Paper V and Chapter 2, e.g., 2.4.1.) Paper V concluded that the requirements of NWP can be met based on a hundred users within a spatial area of 100 square kilometers. However, "nowcasting", a method often used in weather forecast expert systems for further improving short-term forecasts (see 2.4.4), corresponds to densities of RWIS, D_S<1km and D_T<0.25h (Table 7), or approximately 10 observations per 100 square kilometers and one hour (Paper V). "Share weather" should meet these criteria while collecting weather data within the context of transportation in daily life, "road weather" and the built environment. In the empirical study based on 270 users in Group A (see Paper V), between 0.1 and 2.5 observations per 100 km^2 and hour were acquired. It follows that UGO reporting was not uniform and constant in time. While WMO requirements of just a few reports per day might be sufficient, forecasts for traffic have higher requirements. A system only based on volunteer UGO reports would hardly fulfill these requirements.

However, a user-centered approach responding to user actual "needs" suggests that weather information is personalized due to the "recent weather" method (5.3.2). The user-centered "recent weather" method assumes that the size of change in weather characteristics will be reflected in user perception of weather (5.3.2). Through the popularity of weather alerts (Paper II, Paper IV-VI), it was shown that the service based on "recent weather" managed to meet the requirements of a relatively accurate and useful user-centered service, at least judging from users' perception and subjective opinion. No evidence rejecting this claim was found. In contrast, the respondents considered the alert frequency satisfactory (Paper II), and measurements of subjective opinion showed that they preferred the service over other sources of weather information. Information regarding actual user needs can be drawn from this: weather alerts were issued only a couple of times per month, with 3 alerts per week at the most, and with at least 48 hours, in rare cases 24 hours, between the alerts (see for instance Fig 1 in Paper II, examples of alerts in Paper VI, and www.shareweather.org). I conclude that the lowest temporal density manifested in the empirical results (0.1 reports per 100 km^2 per hour) is higher than the temporal density of weather alerts which was 0.042 (1 report per 24 hours). This result is very important. It suggests that a system entirely based on UGO can provide weather alerts to a network of hundred users or more, without intervention of an expert in meteorology. This supports the findings in section 6.2 addressing Q1, namely, that a large number of individuals *can* surpass the performance of current weather information services and forecasting systems. Unfortunately, this finding is strongly context-related; within a different context, for instance a wind energy plant, the requirement on the updating frequency is far greater than occasional weather alerts.

If we want to assess potential volumes of contribution that can be generalized, a different approach is needed. The question is how many individuals are required to meet the second, and also stronger, requirement, RWIS and nowcasting (see 2.4.4 or 5.1.2). Results from Paper V show that an assembly of 270 individuals per 100 km^2 temporarily tangled the requirements of RWIS at large, which means that "share weather" might collect UGO input to expert systems such as road weather predictions, under certain premises. However, a network of 270 traffic-interested individuals cannot reach the requirements of a steady flow of 10 observations per 100 km^2 per hour. In fact, approximately 27,000 nodes are required if they are attributed the lower reporting frequency achieved in the study. This result is, however, somewhat misleading; the requirements also depend on how often input is *needed* according to user perception of weather events, and variability of local weather. This can be illustrated with an example: If A observes that the road is slippery in front of the local supermarket, he/she does not need to get local information from B, unless road weather conditions change for the better (or worse). So how often do such conditions change? Traffic weather phenomena such as ice on roads may occur within 0.25 up to about 8 hours (10 p.m.–4 a.m., corresponding to night temperature changes when for instance freezing often occurs), but these changes do not occur all the time. A couple of reports every morning, in order to confirm or reaffirm fair road conditions, are consequently sufficient most of the time. Therefore, a more justifiable figure is somewhere between 1,000 and 27,000, over an area of 100 km^2. In Stockholm, this would correspond to between 0.1 and 3% of the population. In larger cities worldwide, this figure would be lower, while contribution of UGO in rural areas would depend on how many individuals pass through that area (e.g., the number of vehicles onroad, or the number of hikers on a mountain slope).

The weather cases in the empirical study (see Paper V) were chosen according to relatively uniform, however extreme, weather conditions (bad weather prevailed for several hours, or days). This may imply that the respondents were driven by other incentives than sudden change of state. How often would they contribute if the weather changed? Study III in Paper VIII suggests that the weather type possibly increases the motivation to contribute. In addition, based on analysis of motivation sources (6.3 and Paper VIII) and other evidence such as expressions of emotions in free-text, users can also be driven by intrinsic motivation and the "social capital" accumulated due to interactions and receiving a service they find trustworthy. All this indicates that contribution levels might be higher than the lowest levels acquired in the study on 270 users in Paper V.

These conclusions seem encouraging for achieving a relatively constant flow of UGO over time based on user needs. Moreover, when weather events occur, individuals are motivated to report changes, and at the same time this improves the output of "share weather" systems on those occasions when most required.

7.1.3. Is there a better solution for sharing meteorological data?

One important question is the validity of my results, attending to the studied context. First, because the concept of "share weather" is based on weather observations performed by humans, one must ask whether "share weather" is better than alternative methods. One obstacle in this analysis is that we simply cannot know what technologies might be available in the future, and what practices might be embraced. What one might analyze are current alternative solutions. If we want to envision solutions that may offer weather monitoring using other media technologies, due to analogies with for instance citizen science, opportunities with crowdsourcing should be discussed (see 3.8.3 and Table 4, p.61). The second obvious alternative is comparing "share weather" with technologies that use instruments instead of humans. I will here, first, make some reflections regarding other media technologies. Thereafter, I address sensor technologies.

It is convenient to suggest SNS and crowdsourcing as potential new ways of collecting weather information. These concepts were presented in Chapter 3 and aimed to capture the range of possibilities to collect weather observations from individuals, in different formats, using different technologies and practices. An overview of technologies for "share weather" and related domains (Table 4) suggested: distributing news through microblogs (e.g., Twitter), discussion forums (for weather enthusiasts), civic action, emergency response, citizen science (online sharing of data from weather stations). None of the associated domains, however, correspond to the context of "share weather" in terms of the motivational and practical premises they might create. The first is related to the type of participation required, whereas the second concerns the format of UGO.

Crowdsourcing (Howe, 2009) can be suggested as a complementary method for occasional collection and sharing of specific weather information. A market agent can initiate collection of weather data from individuals *outside* the "share weather" network/community as well. This means that the number of nodes might be increased, but that collection of weather information faces a couple of new challenges. This potential form of organizing networks for improving weather information could address very large audiences. Tasks of low granularity enabling occasional participation by a fraction of a very large network might result in contributions meeting the requirements presented in Table 7 (p.138). In research and practice, such examples are found in activities related to instantaneous consumption of news and entertainment, such as elements of audience participation in entertainment and reality shows (e.g., Jenkins, 2006). However, it might be difficult to draw a parallel between weather and popular culture associated with escape and diversion. Other obstacles are that a system should be able to rather accurately determine users' geographical location, and preferably also their personal properties (e.g., perception).

Socializing and online conversations are associated with other challenges. People might enjoy online discussions on weather, but their format is highly inconvenient. In addition, they can hardly create a constant flow of input to a system aimed at improving weather information. This excludes SNS and discussion forums from the scope of this compilation thesis (3.8.2). It should, though, be kept in mind that it is credible that individuals will pay attention to weather and become engaged and motivated during extraordinary events (3.7.1), if related to activities that concern them personally (Table 5), if they are rewarded with a fee or price (e.g., the DARPA challenge), or, if they might protect personal investments (see 4.3.4). In addition, the events must occur within limits of the timescales presented in Table 5.

The question is then how many individuals in the external cyberworld would participate without prior ties to the "share weather" community, if the weather type signaled uninteresting news. Drawing on the study of patients at a dental clinic (Group D in Paper V), both attention and interest might be significantly reduced. However, the contextual dimension of "share weather" creates an interesting opportunity, namely, people are geographically clustered, and so is the weather type. This means that user needs (the individual dimension) are associated with time and space (the contextual dimension). General characteristics of social networks' spatial distribution reveal that users with similar location, type of content created and other characteristics interact and diffuse content throughout Twitter and Facebook to a greater extent than users who are geographically distant (see 3.5). For instance Java et al. (2007) found that the geographic distribution impacts: daily chatter, conversations, sharing information and reporting news. Weather is a specific type of personal news in online conversation. These findings suggest that, for instance, "weather Tweets", "weather status updates", or "weather discussions" in discussion forums can be very useful.

From this outline, it can be concluded that extraction of weather information from various online social networks would have to address free text interpretation. Moreover, identification of weather-related information, new unconventional weather expressions, time and place references, may represent a real challenge (see findings on SMS in Paper IV and Paper V). On the other hand, both SNS and crowdsourcing conflict with the need to meet the requirements of time-critical information and uniformly distributed, relatively constant, flow of UGO input to "share weather" systems. It follows that alternative "share weather" crowdsourcing solutions and designs instead could be built on other social network applications with a large audience reach, providing a powerful alternative that might be applied occasionally.

A strong alternative to "share weather" based on human volunteers is represented by sensor networks. For instance the CWOP project proves the concept of "share weather" networks based on technical instruments. Another example is the RWIS network used in the empirical studies; RWIS also serves an input to the "*Shareweather*" system (www.shareweather.com) which was drawn while designing the "Shareweather" artifact (see Table 10). However, my claim is that, while sensors are very good complements to existing networks, at least at the time of finalizing this compilation thesis, the human eye and human perception are still superior to sensors for measurement of meteorological variables that would contribute the greatest value to current NWP and other weather services. Some examples are clouds (see Paper III and 2.3). Issues may also be presented in association with precipitation and radar data applying measurement methods based on substitute variables (Paper III). Another important aspect is the user-centered approach. A user-centered system is based on user perception, and the outputs can be adjusted accordingly. For instance, the user defines values of weather variables as they are perceived: "much colder/warmer than yesterday" (see www.shareweather.com); such user-specific user-generated data cannot be captured by an instrument but need new algorithms to translate meteorological variables into user-centered design are needed. Other advantages with "share weather" are users' mobility and the fact that humans might provide important information through a selective process based on human intelligence (e.g., Paper V).

Nevertheless, we must not neglect the important, and necessary, contributions sensor networks can make to "share weather" systems: sensor technology and UGO complement each other and can both be utilized in "share weather" systems (as in the "Shareweather" artifact designed in the compilation thesis). Second, sensor networks of the future might utilize a large number of nodes with advanced sensor technology, even surpassing our expectations when it comes to accuracy, dissemination, integration with other technologies, and mobility (e.g., the car industry). Sensor technologies of the future might by far exceed current spatial densities, and there is also an opportunity to integrate sensors with vehicles, mobile phones and infrastructure. Again, the quality of the data must be analyzed and automation may generate errors. I will illustrate the advantages with human observers with the fair quality of wind observations conducted by children using the "Beaufort scale" (see paper V), compared to the challenge of designing mobile applications for accurate and convenient wind measurements. Measurements of variables describing atmospheric motions should, for instance, not be disturbed by objects radiating heat (e.g., all living beings), providing wind shields (e.g., buildings), or sudden changes in pressure (e.g., elevators). In addition to quality, sensors should also address quantity. In this respect, sensors possess certain advantages; the concept of "share weather" – networks of human observers – demands higher levels of effort and time investment. On the other hand, joining sensor networks may also demand some effort, as the user must enter an agreement with conditions of use or actively download an application. In addition, the social aspects of "share weather", including motivational factors such as learning, recognition, and intrinsic motivations, may not be as pronounced as in "share weather" where the user may activate a larger number of social cues. Compared to keeping a weather station in one's backyard, sharing pictures taken with mobile cameras is a better way of interacting in a social dialogue.

Finally, there is one strong advantage that justifies sensor networks over human observers, and it is associated with the format of the Input: while user-centered services would benefit from user-generated content of different types, the wider implications in terms of improving weather forecasts and NWP through integration of UGO into the data-assimilation process (see 2.4.2) would require standardized formats (c.f. Volunteer Observations from Ships VOS in Paper III and Paper V). These arguments propose further research on the role of sensor networks in "share weather" networks in a broader sense.

7.1.4 Can "share weather" designs be generalized to other domains of environmental information?

Because the area of application associated with the "weather information" domain – Meteorology – belongs under environmental research, and the natural environment can be observed by humans, in this section I explore the domain of "environmental information". "Share weather", a Web 2.0 based concept for collecting UGO of weather, is here generalized to "Share environment".

Chapter 2 (summarized in 5.1.2) described how weather and environmental data share the same list of objectives, although the perspectives are slightly different. The differences are mainly manifested in respect to time and spatial scales, which follows from comparison between objectives listed in section 2.3 and 2.4, respectively. The challenge of addressing environmental issues is manifested in the long time-perspectives of environmental change, such as climate change (see Table 5). Changes in the conditions for agriculture might indeed be perceivable within shorter time perspectives (days, months, years), but most people do not practice agriculture. Environmental problems may therefore seem distant and out of the reach of everyday life in modern societies.

Environmental research and policy-makers might regard these problems from an entirely different perspective. In addition, the problems facing researchers in environmental modeling create even stronger needs for local observations due to the great complexity of the environmental system (2.3.4). Field studies are therefore common in environmental science as a basis for different parameterizations (2.3).

"Share weather" is similar to a tool for field studies: it collects nominal data that can be transformed into numerical values (Paper V), the data can be stored in databases and create time series. Most of the time environmental processes are influenced by weather. While numerical equations describing weather can be simplified through, for instance, neglecting coupling effects between the air and biosphere, many environmental systems cannot neglect weather. Soil, rivers, and species are affected by weather conditions, sometimes resulting in floods, droughts, or effects on ecosystems. Weather operates on time scales of hours and several kilometers, while climate change may impact the environment on very local level. Some differences are also illustrated in the time and spatial scales of model outputs: NWP outputs and meteorological applications (e.g., nowcasting, 2.4.4) provide weather information at a hundred square kilometers on an hourly basis with special densities (D_S) < 1-10 km and temporal density (D_T) < 1h (see Table 5), whereas environmental models require higher resolution but are more complex. Therefore, all environmental processes cannot be modeled. In nature, processes are seldom linear; they are subject to threshold values that may cause rapid changes of state (see 2.3), and this is one reason the problem with climate change is so complex.

These objectives provide a range of arguments questioning generalizability from the "share weather" domain to "share environment". They reveal that weather information is more time-critical since weather information can be modeled and produce accurate weather forecasts. Environmental processes are too complex to be subject to dynamic modeling. On the other hand, this is why field studies provide such an important input. There is an urgent need to collect data because the knowledge regarding processes (see parameterization, 2.3.3) is sparse and the systems beyond reach of fair representation in models. It has been suggested that some solutions may involve the public and volunteers (see 3.7.3). This indicates that there is a need for solutions based on ideas similar to "share weather". In addition, environmental research has a long history of using observations recorded by non-experts (3.7.3). In the light of methods applied in environmental research, I generalize the "share weather" concept using the same objectives provided as a result of research question Q1: discussion on motivational factors (Q2) and design (Q3).

The design of a "share weather" artifact for collection of environmental data from individuals is presented in Table 10, "share environment" being displayed in green. My discussion below includes collection methods, filtering, spatial and temporal requirements as well as other issues related to designing artifacts for sharing UGO of the environment:

The format of environmental data is similar to that of weather data. For instance, researchers may want to measure specific physical variables expressed numerically and describing soil humidity, river flow and run-off, populations of species, rate of change of species, and land degradation. "Share weather" is suitable for collection of environmental data that can be acquired in a format of numerical values, text phrases, and pictures. For instance, collecting data on how soil humidity changes over time in the garden or how often an insect or deer is observed represent environmental data (see Paper III). A long record of data on when spring blooming occurs provides information on climate change. This can, for instance, be compared to the format used for observation of titi birds: many "titi" harvesters kept written records of weather, moon conditions during each hunt, and the rate of catch (Kitson, 2004), in many instances going back for decades (see 3.7.3).

In the introduction to this thesis, I posited that the value of "share weather" should be in that it can reach beyond current methods of collection of weather data since experts and expert systems cannot observe the weather everywhere all the time. Neither can ecologists measure the impacts of climate change everywhere or go back in time and conduct measurements at particularly interesting sites. What is, however, possible, is to collect stored data (e.g., decades or centuries) created through "storytelling". In this way, researchers use data based on traditional ecological knowledge or marine logbooks (substitute variables) to estimate past climate change. Observing the climate and environment may occur instantaneously. For instance, Darwin observed phenomena typical of La Niña episodes and from a rather small data set of collected indices on the existence of El Niño (3.7.3).

The collection method based on text phrases can be related to pioneer work by Linnaeus and Georg Rumphius' (e.g., *Herbarium Amboinense*) (see 3.7.3; p.69; Taylor, 2008; Koerner, 1999) including the plant's name, illustrations, description for nomenclature, place, discussion of the plant's use to the local inhabitants, stories, folklore, and religious practices. Some new variables can be introduced, based on consequences rather than causes of environmental change (cf. the "rate of catch" of titi birds; Kitson, 2004).

Filtering of environmental data may be addressed in the same way as weather data: through comparison with official sources and by "peering". The magnitude of user bias can be assumed comparable to biases when observing weather (e.g., classification of clouds using pictures), and, since the empirical results presented in the papers showed that most users, even children, can observe weather accurately, environmental data can be addressed with equivalent methods. Linnaeus' claim that "both learned and lay people" could participate in mechanized classification of plants (see 3.7.3, p.69) illustrates how non-experts already participated in scientific work centuries ago. Web 2.0 facilitate such participation. Collection of other user data may, as in "share weather", be utilized in order to validate user biases due to individual perception.

The next objective is motivation (Q2). I here suggest that motivation may be partly addressed through providing services, as in "share weather". Interestingly, synergies are easily created between the different domains of User-Generated Observations, the natural environment and the built environment. I previously referred to this as a window of opportunity that may create important synergies between collection of weather data and environmental data (see 3.7.4, 4.6 and Table 5). Rewards in terms of user-centered personalized services may provide incentives to observe weather, and a user may instantaneously focus on the environment. Recording flowers and insects is somewhat analogous to traffic weather observations: road weather phenomena are consequences of weather on the ground (e.g., the road that freezes due to a chain of weather events), while occurrence of biological species also represents a consequence of weather/climate (weather affects the composition of the Earth surface and ecosystems).

Guided by the results acquired through the design process (Q3), a feasible solution for collection of UGO of the environment might be suggested. Features for increasing motivation to participate are: features that expose members and their work, socializing, learning, connections to other communities of practice and interest, and finally rewards and feedback in terms of services. These features may attribute new values within a new context. The component of learning was previously recognized as an imperative element in natural resource management (section 4.4.2), and, most important, a parallel can be drawn between "share environment" and communities of practice (see 4.6).

Drawing this parallel creates an opportunity to further analyze "share environment" and the social processes taking place, with potential linkages towards pro-environmental behavior. This is analyzed in the next section.

7.1.5 Can "share weather" enhance public participation in environmental issues?

I will here make use of two important, previous findings: perception of environmental problems (Table 5), and known contexts where environmental problems were successfully managed (3.7.3, 4.4.2).

Sections 4.4.1 and 4.5 concluded that environmental data may face a unique problem: the benefits of contributing to the cause of improving the environment must be perceivable, whereas our perception of environmental problems such as climate change are challenged by the time perspective displayed in Table 5. In the search for explanations why environmental concerns do not attract enough attention from all groups in society and why they are not easily solvable, I introduced some established research on pro-environmental behavior (4.4.2). It was summarized that pro-environmental behavior can be explained in terms of social learning (e.g., Olsson et al., 2004) or a process of rule evolution in social networks including social influence and intrinsic rewards (Jaeger et al., 1993). Individuals need benefits experienced on perceivable time-scales. People in general are more concerned about the weather (forecasts) than climate change (Stern and Easterling, 1999). This suggests that pro-environmental behavior might be encouraged in the social networks in which people carry on their *everyday lives* (Jaeger et al., 1993). For instance individuals may be motivated to share traffic weather data. Previously we also concluded that learning through participation encourages pro-environmental behavior (Lee, 1993; Folke et al., 2003; Olsson et al., 2004), which can be compared to the "situated learning" process manifested in communities of practice (section 3.4.3).

Based on these findings, I propose that "share weather" may create incentives and opportunities to share environmental data. Due to the social learning processes that may be activated, "share weather" might potentially trigger the social learning that encourages pro-environmental behavior. Namely, sharing UGO of the environment may be a peripheral activity in the "share weather" community of practice (see 3.4.3; Lave and Wenger, 1991). UGO of environment, such as observing both the weather and different species during a hike, can be introduced in "share weather" with relative ease. This creates opportunities to access community resources and interact with other members (Lave and Wenger, 1991) (learn more about weather and climate and find out what others do and think considering the subject); and finally, through practice and interaction, new members gradually learn about the community's goals and organization, and they build skills and experiences (become aware of climate change, adaptation and alternative choices in daily life).

The same result may be applied regardless of the motivation theory approach: individual, or structural. If we regard the individual dimension, motivation is understood in terms of needs and social cues. The structural approach, instead, regards interactions and creation of identities. Features of "share weather" such as recognition, exposure, socializing (see Table 9) create incentives to interact. The initial purpose may, for instance, be to acquire road weather information. Once joining a "share weather" network, an individual may start interacting in many different ways. Individuals start sharing UGO of the environment driven by a mixture of incentives (intrinsic and extrinsic); participation creates new ties and, eventually, an identity shared between network nodes. Increased perception and awareness also starts creating environmental concern. Although this does not mean that the learning component may attract users at first; the structural dimension may, through new interactions and learning, create incentives for sustained participation in the "share environment" network. Drawing on motivational theory and the structural dimension of networks (e.g., 4.1.1 and 4.1.3), interactions that have occurred due to participation will encourage new interactions. This may imply that observing the built environment encourages observations of the natural environment and that these interactions (observations) increase with time in the impersonal/entrepreneurial collective action space (see Flanagin, Stohl and Bimber, 2006). Members of a network may feel a sense of affiliation with the group. New identities, associated with affiliative ties, create a sense of identity. This might represent an example of unintentional transfer over well-marked boundaries between private and public domains described by Flanagin, Stohl and Bimber (2006): a public issue that may become more personal. This process can potentially address obstacles associated with the time perspective (Table 5).

I conclude that the social process of learning manifested in networks can be used to address both perception of environmental problems, and increased participation in solving environmental issues. Under these assumptions, "share weather" may be regarded as a tool for both communication between officials and the public and climate change adaptation that requires public participation in environmental issues (WMO, 2010; UN, 1992; IPCC, 2007).

With these conclusions, some new questions are altered regarding the structure of networks for sharing UGO of the environment. Research in natural resource management suggests that some individuals, "key stewards", are attributed particular importance (Blaikie and Brookfield, 1987; Berkes et al., 2003). This may indicate that some key nodes, through their engagement and background knowledge, may have other (stronger) incentives or needs to share environmental data. Activists (see 4.4.3) are also individuals that actively engage in transferring public environmental interests to the public sphere. Research suggests that ideology often is driven by intrinsic incentives, not least in research on open source (4.3.2). Volunteering theory, however, also accounts for extrinsic rewards and social influence, which should be justifiable within the context of "share environment", because the social processes within the network can create values associated with new pro-environmental ideologies. This justifies introduction of several levels of instrumentality: intrinsic, and extrinsic (see the motivation framework in Table 9). Key stewards may then be described as individuals with larger amounts of "social-ecological capital". With the structural dimension approach (social capital is the property of a group), interactions issued during active participation in "share weather" create structured links that affect future behavior (and attitudes). With the presence of a "key steward", other members of the network build a cognitive type of social-ecological capital through active participation and learning. The social-ecological capital becomes integrated with a person's identity; later, the social-ecological capital can be used in other contexts such as behavior in daily life, which potentially might encourage pro-environmental behavior. I conclude that, through sharing environmental data together with others that possess more knowledge on environmental issues, individuals' understanding, attitudes, and future behavior can potentially be modified towards pro-environmental behavior.

This knowledge can now be applied in order to analyze differences between online and offline networks (see 3.5). I have previously stressed that online settings are different from offline networks. Natural resource management often occurs within the context of offline interaction. Earlier research acknowledges the power of social network building. It is sometimes argued that the capacity to deal with the interactive dynamics of social and ecological systems requires the entire network of interacting individuals and organizations at different levels (Westley et al, 2002). Here, we might draw some parallels between natural resource management and network theory, namely, many findings that showed the importance of strong ties (see 4.1.1 and Coleman, 1994) were acquired while studying offline collaboration, whereas research on online networks revealed that weak ties are more important, and that sometimes new properties such as "affiliative" ties might emerge (3.5, 4.1.1). "Share environment" is an online phenomenon. With the background of the motivational theory presented in Chapter 4, it might be suggested that "share environment" networks are more efficient. The theory might also contradict some earlier findings on offline networks with the introduction of the new online "share environment" concept. For instance, Westley et al. (2002) suggest that it is necessary to establish a network of interacting individuals and organizations at different levels in order to address environmental problems. What happens if these networks are brought online? Motivation theory on online networks suggests that the bridging between weak links in cyberspace might provide shortcuts that are far more efficient than top-down management or entire networks of interacting individuals. Prior research confirmed that vertical linkages (between the community and, for example, governmental agencies) are more difficult to establish than horizontal linkages (e.g., municipality-municipality) (Wesley et al., 2002). Generalizing these findings on offline networks to online "share environment" can produce mistakes, because, in online networks, vertical connections (bridging between weak links) are stronger than horizontal (bonding between horizontal links). This suggests (in line with Paper I) that it would be desirable to involve decision-makers in "share weather", although they should not take a leading role.

I conclude that participation in "share weather", once established, may enhance learning related to environmental problems and increase awareness of environmental problems, or even create new identities. This is based on the assumption that "share environment" functionalities are integrated with "share weather". "Share environment" might also attract key stewards that possess particular knowledge and engagement in environmental issues and policy-makers that might also participate. The challenge is, still, how to motivate initial participation of a broader audience. From Table 5, which displays the difference between the context of climate/environmental change and changes in everyday life, such as traffic, it can be suggested that user-centered weather services could attract new users. The empirical studies of this compilation thesis (e.g., Paper VII) show that rewards provided to individuals in everyday life, such as traffic weather alerts, or other weather services that might be perceived as immediately useful, might attract a large audience who would otherwise not engage in sharing UGO of the environment or environmental issues. In this way, incentives associated with rationality can be applied to cultivate more environmental-friendly values and behavior.

7.2 Conclusions and future work

In this thesis, I explored a new concept, "share weather", through design and evaluation of a "share weather" artifact. "Share weather" means that individuals share weather information through a network, and I suggested that this might contribute to improved weather information. My research questions therefore addressed two critical issues: the quality of User-Generated Observations (UGO) of weather (Q1), and the potential quantities that might be achieved (Q2). During the research process, I developed a "*Shareweather*" artifact in order to evaluate the concept of "share weather" (Q3). This section aims at providing some final conclusions regarding my contribution to Media Technology research (7.2.1). In addition, I take the opportunity to highlight some limitations and recommend directions for future work (7.2.2 and 7.2.3).

7.2.1 Summary of this thesis contribution to Media Technology research

Science exploring new media technologies is confronted with questions regarding the validity of research conducted within this field. The work on this thesis, therefore, started with exploration of the context of "share weather", in order to later relate my findings to other research findings within Media Technology. I suggested that "share weather" might be regarded as a subdomain of knowledge creation and User-Generated Observations (UGO) of the environment (see Table 4, p.61). This approach contributed some interesting sustainability aspects on the results including difficulties this might imply.

The practical arrangements when studying "share weather" were centered around time-critical traffic-weather information addressed in a longitudinal study, but several other groups were also studied, for instance children (Paper IV and Paper V) and African farmers (Paper VII). The empirical studies conducted within these contexts showed that UGO of weather can be accurate, that individuals can be motivated to participate and engage in sharing their local observations of weather, and that trust might be created within a network for sharing weather information.

Motivation constituted a key question in the summary of the compilation thesis. I developed some new theory by merging existing motivation theories (individual and structural perspectives) and through exploration of the context. This resulted in a motivation framework based on the individual, structural, and contextual dimension, including three different levels of instrumentality: intrinsic, extrinsic, and rational (Table 9). This framework can be generalized to other domains. Other contributions to Media Technology research were: testing Design Science Research Methodology (see DSRM, 5.4), some new methodology (e.g., "scoring", 5.3.3), new methods for service design ("recent weather", 5.3.2), and new empirical results on participation in networks by studying the context of "share weather". The results support previous findings on networks and communities, although rewards in terms of weather forecasts somewhat changed the common patterns in network contributions and behavior and engaged a larger fraction of participants in providing content. This is explained with the social capital that was added in terms of trust regarding the weather service, which participants found beneficial and trustworthy. Drawing on the results of this compilation thesis, I would like to highlight some findings on motivation. The results confirmed the importance of socially-related intrinsic drives, such as social acceptance (see Study I in Paper VIII), often highlighted in Media Technology research (e.g., UGT, see 4.1.2). I also found evidence of ideology as a positive driving force which justified the sustainability approach and, in addition, might draw an interesting parallel to open source movements (4.3.2). Also, I concluded that results of individuals' performances should be perceivable in order to engage in tasks that contribute to scientific progress. Here, I found that creating rewards in terms of weather services might enhance participation.

I summarized these results with a discussion on potential implications of "share weather" networks. This outline, as well as my analysis of the meaning of "scientific" and justification of the research topic (5.1), were given a sustainability approach. In my final discussions, where the empirical results were generalized to the domain of UGO of the natural environment (7.1), I suggest that "share weather" might encourage increased public participation in difficult environmental issues. A summary of the contexts of human interest in weather presented in Table 5 (p.105) suggests that thinking of weather within the context of everyday life and useful services for transportation may tend to be both more appealing and directly useful, compared to the context of climate change confronted with the problem of "tragedy of the commons" (4.4.1). In the postmodern world everything tends to happen quickly; everything we measure considering our wellbeing and wealth relates to short time perspectives, even when compared to the temporal duration of a human life (50-100 years). Modifications of climate perceivable on large time scales is, consequently, beyond the reach of the reality of our daily lives where our attention is captured within a time perspective of hours and days. "Share weather" might here create linkages between climate change and events in our daily life. This is because weather represents one of the favorite subjects of conversation, and extreme weather events issuing perceivable changes experienced in daily life are considered important.

The compilation thesis studied the context of traffic in everyday life during Scandinavian winter conditions. It was shown how "share weather" may attract participants under such conditions and that meteorological forecasts might be improved based on a couple of hundred participants. With a higher number of nodes, it would even be possible to improve the outputs of meteorological applications (e.g., transportation and agriculture) to higher requirements. What makes this interesting and intriguing is that the transport sector and environmental protectors share a common interest, namely affecting user behavior in a positive way. The compilation thesis suggested a way of achieving some useful synergies. In this way, this thesis addresses two sustainability issues: social and economic sustainability in cities, and sustainability of the natural environment. The concept of "share weather" might potentially contribute valuable knowledge on processes between air, water, soil and vegetation, address the everyday life needs of citizens in traffic, provide better information to stakeholders in the transportation sector, and increase public participation in environmental issues.

Finally, I would like to point at the contribution of this thesis to the related research area of Intelligent Transport Systems (ITS), with the service that was created and evaluated. Weather services based on "recent weather" can affect drivers' behavior during extreme weather, which might lead to reduced traffic jams and accident rates. Despite considerable progress, weather services are not yet adjusted to user psychological profiles, personality, and perception. In this thesis, I suggest a method that might address related variables and perception of weather in traffic, while "share weather" is offered as a solution that can improve local weather information in services that individuals in everyday life might find useful.

7.2.2 Limitations

With the outline in the previous section, I contributed knowledge that can be further exploited and developed. Doing this, it is important to acknowledge the many limitations associated with the context. Conducting the work in this thesis required interpretation and comparison between different contexts: how previous findings might relate to "share weather" and how findings on "share weather" can be interpreted as a manifestation of potentially general phenomena. In this section I intend to provide guidance for future work, while also highlighting some limitations that should be taken into consideration when interpreting the results of this thesis. Doing so, I will first focus on limitations of this work related to findings on motivation, followed by some issues regarding design of "share weather" artifacts.

First, in respect to the research topic, i.e., user-generated content and motivation in online communities, some limitations are associated with the characteristics of the respondent group compared to the general population, since the thesis aims to generalize the results to the general public. How can the results be generalized? The generalized levels of motivation (see 7.1.2) may, naturally, be a subject of discourse due to several intentional simplifications made in order to estimate potential future contributions. Motivation categories (see 6.3.4, 6.3.9) can be assumed to be general, since supported by other research. However, the results suggested that motivation to participate might be stronger than expected compared to previous research, in particular the core contributors usually representing only a few percent. I also suggested a larger range of instrumentality (6.3.3).

Some details associated with the empirical tests must be carefully considered: the chronological order of interactions (the respondents were subject of several parallel studies (e.g., Paper II, Paper V and Paper VI), the nature of interactions representing a mixture of: e-mail communication, interviews (i.e., Paper II); survey participation (i.e., Paper II, Paper IV Paper V, and Paper VI); evaluation of the service (i.e., Paper II and Paper V). In addition, a series of methodological issues, including obligation and compliance, may have biased the responses (5.3.5). This was a result of a compromise by me as an "involved researcher" (see p.120, 5.5.4 and 6.3.5). The most obvious limitations of the results presented in this thesis are associated with the weather-dependence of the context: the studies were performed during severe weather, and the properties of the sample reveal that it consisted of individuals with particular interest in weather information.

Understanding this set-up of empirical studies is essential when generalizing the results. For instance, the compilation thesis concludes that a "share weather" network may engage a higher number of core contributors, up to 10-20%, compared to a few 2-4 % found in research on other networks. The organization of the studies, however, implies that the context was unique. For instance, the weather preconditions are not easily met everywhere. The weather may be too uniform in some parts of the world, although, for instance, the Sudan case (Paper VII) shows that countries with uniform weather might need input regarding climate data such as rain quantities (it *is* raining is a fact, but information on *how much* is unknown). Furthermore, people may not be interested in weather at all. Although transportation systems operate at the level of their performance capacity (Paper II), some groups may not consider themselves affected by the negative impacts of weather. The empirical results are, in this case, not valid, because the sample was created from volunteers that already expressed particular interest in road weather information. However, due to the strong component of socializing in many communities and networks, and weather constituting a part of our social conversations, it is justifiable to assume a level of interest not below the participation levels observed in other networks (2-4%).

The weather-dependence of the context – extreme weather and weather-related properties of the sample – represents considerable limitations. I therefore recommend that the empirical studies should be repeated within a different context that may highlight important variables and more accurately predict expected participation levels. The limitations issued by the properties of the sample are obvious, reading from the results on their demographics, preferences, transportation habits, and recruitment process. This is reflected in the time-consumption model presented in Paper IV, addressing both different groups' convenience and interest to observe weather. Further analysis of weather-dependence should be conducted on different samples. The studied context of transportation and severe weather that encouraged participation also suggests new studies of longer time series.

One important finding was associated with rewards; the compilation thesis concludes that results such as high participation figures and growing trust can be attributed to the rewards (weather alerts) supplied to the network nodes. Future research might address design of "share weather" components that enhance participation: learning, recognition and socializing (see Table 10). The theoretical aspects of this research might also deserve some attention: exploring the theoretical framework, motivation sources categories, and not least comparison with other research findings. One interesting track is exploration of models that can account for different instrumentalities, such as the one proposed based on three dimensions: individual, structural, contextual (Table 9).

I think it would also be of interest to study social networks and networks for collection of UGO where rewards are provided in terms of different services. Because prior research suggests that only a small core of addicted users would contribute the larger fraction of all user-generated content, future research should investigate the interplay between weather forecasts (or other, intrinsic and extrinsic, rewards), including more accurate estimates of frequent contributors and motivations driving such behavior. One important inquiry is studying different levels of instrumentality. In Paper VIII, it is indicated that frequent contributors are not driven by reciprocity, which is confirmed by, for instance, research on Wikipedia (4.3.3). It is often pictured that there are "fanatics" with high addiction to the community goals. On the other hand, in many open source communities, ideology is recognized as a strong drive (4.3.2), and it is believed to be associated with altruism. Generalizing this regarding the "weather information" domain would mean that only "fanatics", perhaps "weather fanatics", would contribute UGO. However, the tests showed that a larger fraction engaged, probably according to the received benefits, obligation, and/or a sense of belonging (identity). Participation in "share weather" could not be explained by plain altruism. The occurrence of several levels of instrumentality, manifested in the same type of behavior, deserves some attention in future research. This can be illustrated with the example of "ideology". I suggested that ideology is a possible source of motivation (see Study I in Paper VIII). However, one might recognize that motives driven by ideology can exist on three, or at least two, levels. This is because the context of "weather information" can be associated with "climate change", a problem that might engage individuals for several reasons: social influence by other members of the community, social learning processes in natural resource management, protection of investments and concern of loosing property. In this case, "ideology" is a result of values shaped by reciprocal motives that are different from altruism. What does this mean for research on online networks? I propose that a range of motivations of different instrumentality should always be regarded. Occurrence of new phenomena cannot be truly valid until tested over a long period of time and within different contexts.

Finally, some crucial contextual limitations are associated with technology. Research on "share weather" must consider that new technologies may become available in the future, which naturally changes the conditions for sharing weather information. Choice of technology defines the context in both user experiences (the individual dimension) and spatial and temporal structures (the context-related dimension). Properties of media technology delivery channels are modified with the technology used: SMS, e-mail, web applications, mobile applications. For instance, mobile smartphone applications, which were on advance during the course of the empirical studies (2008-2011), offer different temporal and spatial structures compared to SMS and web forms used in the empirical studies, and a considerable different design. However, some advantages with SMS should not be overlooked; although simple, SMS may feel personal and this technology is suitable for notifications. Different technologies might also be combined in collection and distribution (of rewards) respectively. However unsurprisingly, figures on respondent media use pointed at an increasing use of mobile applications (e.g., Paper IV), whereas Study III in Paper VIII evidenced that most reports were submitted using smartphones and mobile applications based on the "*Shareweather*" artifact (e.g., Shareweather for Android). The existence of several billion mobile subscribers worldwide implies that this ought to be addressed in future research.

Unfortunately, one can never be sure of the generalizability of the conditions that were measured if applied to new contexts. This might be particularly important regarding the rapid development within the research field of Media Technology. Will findings on "share weather" be valid in 10 years? This is as relevant as asking: will the open source "movement" (e.g., Chesbrough et al., 2008), or Facebook, persist in their current shape?

7.7.3 Future "share weather" applications

Design is an inductive process that cannot be replicated. This compilation thesis also extended our knowledge regarding use of design methods (see 5.4) by designing a "*Shareweather*" artifact. I conclude that the research findings are valid provided that similar approaches are used, if repeating the design steps within another context. It is, therefore, possible that a different approach, for instance not offering rewards or not offering a user-centered service, would not only provide different volumes of contribution, but also a different design. However, some conclusions can be drawn theoretically: regardless of alternative design processes (for instance launching an application for collection of UGO, without giving rewards in return), it is probable that research would point at a need or expectations of rewards in terms of user-centered weather forecasts. However, it is also true that, sometimes, good solutions are rejected. One example is using SMS technology for collection of UGO. The "share weather" collection method based on predefined text phrases was introduced parallel to other collection channels. SMS was offered as an alternative, and it contributed considerable volumes (Paper IV and V). Despite its popularity, SMS was excluded in the design process due to additional requirements associated with processing. However, an additional reason was convenience and lack of appropriate low-cost methods for integration of SMS technology. This argument is particularly interesting, since it is strongly contextual, and the cost-benefits of this technology have already been modified at the time of summarizing this compilation thesis. Also, some other strong arguments would oppose the choice of SMS. In particular, it represents a serious concern in traffic and a proven source of increased risks for hazards while driving (e.g. Paper VI), already legally prohibited in many countries. Does this mean that free-text is not convenient? The answer is that the context of this study rejected SMS, although another context might point in a new direction. There are probably other ways of addressing car drivers. Most important, there are other user groups that should be considered. "Share weather" should be tested within various contexts, with new technologies and samples. For instance, future design and evaluation of "share weather" might be realized within contexts suggested by Table 5 and the time-consumption model (see Paper IV), for instance, spare time activities (such as gardening, golf, sailing, hiking) and agriculture.

Rapid changes in media technology indicate that the input to the design process described in Fig 3 (p.136) is generally dynamic: what is valid today will not be valid in ten, and perhaps not even five, years. Collection and processing methods and technology used by WMO are one example of a solution designed on the basis of technology available at the time (1950s). Demands for new design are created as technological opportunities arise to design better solutions. I suggest that future research should proceed towards integration of additional sources of input of weather information and that this may include two directions.

The first direction addresses new technology that should be integrated in current methods for improving weather forecasts, weather services, and related services. This not only includes research on how sensor networks might be used as input to "share weather" networks, but also filtering and collection of weather data available on the World Wide Web. Future "share weather" systems will probably combine all available sources of weather information, including individuals. Design of the "*Shareweather*" artifact in this compilation thesis is based on the assumption that we want to integrate "share weather" with current methods applied in weather forecasting. Predefined text expressions were drawn on the basis of the results defined by existing collection methods and the possibility of integrating all data into one system, which requires weather information in a format comparable to official sources in order to be assimilated (see for instance data assimilation, 2.4.2, and nowcasting 2.4.4). With sensors and the Internet of Things, one should consider new sources of weather information that might improve weather information together with several billion connected individuals.

The second direction would look into integration of "share weather" designs with other applications such as SNS and other social networks. Humans are social beings, and weather is evidently social. Because this compilation thesis aimed at making a contribution to our knowledge regarding participation in online networks, I also recommend that this research may proceed with research inquiries associated with participation in networks for sharing user-generated observations of weather, the natural environment, and the built environment, including exploration of new media technologies and practices.

This thesis makes a contribution to current technological basis, and I believe that future development will push our knowledge on both "share weather" and online networks in general, beyond the results presented in this thesis. I also hope that the opportunities that may be offered to use "share weather" as a tool in future work for sustainable development and confronting environmental challenges will be thoroughly explored. Potential solutions offered with the window of opportunity of synergies between the natural and built environment will most probably be discovered.

This compilation thesis manifests the power of Web 2.0, and it shows that interactive media technologies can be used to create useful information and "goods". Weather information is an example of how interactive media may contribute to knowledge creation. I do, however, believe that there are several other information domains that should be explored within, and outside, User-Generated Observations (UGO). History of weather information and Meteorology, as well as many other areas began with observations performed by humans. Under the course of the industrial development, media technologies brought the weather into our homes via media technologies such as photography, movie pictures, radio and television, weather events that became accessible to everyone. Finally, through overbridging time and space, media technologies have helped humans experience them live. At the same time, technological revolutions progressed meteorology and environmental science with the help of new measurement methods.

With social media, our relationship with the weather might be about to change. Anyone may now observe the weather and share observations through cyberspace. This compilation thesis concluded that weather storytelling might, again, as previously in history, contribute to improving weather information.

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