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Web Weather 2.0: Improving Weather Information with User-Generated Observations

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Abstract

Introducing web weather 2.0, this paper suggests that active participation by civil society may arise through sharing of environmental data through observations of weather and other measurable variables in the environment performed by individuals. Collecting data from individuals is here suggested for improving weather data currently used by weather research centers and practitioners. Extending these current sets of weather data by using web 2.0 may address some issues stated by the World Meteorological Organization (WMO) regarding spatial and temporal resolutions of meteorological data including knowledge on different processes between the air and other environmental systems. To test the concept of web weather 2.0, the usability of weather data collected from individuals and the expected quantities of such data need to be determined. In addition, collection methods should be developed. Aiming at the design of an artifact that can meet these needs, this paper presents some important steps of the design process of a "share weather" system, including several demonstrations and experiments performed on different user groups, i.e. school children performing weather observations as a part of their daily tasks and education, and adults interested in weather due to their daily dependence on traffic conditions. This paper provides new knowledge about user-generated observations of weather, including quality and motivation to contribute, and guidance on how future systems for collection of environmental data from individuals may be created. After testing the feasibility of the designed "share weather" artifact, we conclude that the potential role of individuals in producing valuable information beneficial to society should be considered within several branches of environmental sciences as well as policy-making.

Keywords: Web 2.0, weather, climate, user-generated content, observation, network, collaboration

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INTRODUCTION

From the Telegraph to Web 2.0

This paper suggests that an old idea of "seeing the weather together" may be realized with Web 2.0 technology. No one, including experts, knows everything, but everyone knows something. Applied to meteorology this means that experts and technologies alone are not able to observe the weather everywhere, all the time. Everybody can, however, observe some of the weather.

Exchange of real-time weather information was first enabled by the invention of the telegraph representing a major breakthrough for meteorological observations, theories, models and weather predictions. Web 2.0 may permit a further technology breakthrough because new human networks across cyberspace can act as carriers of important information, especially in the case of emergencies like earthquakes, floods and extreme weather. Participatory culture (e.g., Jenkins, 2006) implies that volunteer contributions can be used in the creation of many artifacts as well as useful knowledge. Drawing on the above, it is apparent that Web 2.0 collectives can contribute information valuable to society.

Meteorological measurement instruments are expensive and depend on different preconditions set by the physical environment. Past developments have very much pointed toward replacing human power with instrumentation and technology. However, few researchers have explored how humans can be used as resources when collecting environmental data.

The fast progress of weather forecasting techniques in the 20th century suggested that forecasting can be managed by modeling techniques and computational power, and that weather observations may be performed by instruments replacing human observers of the global "SYNOP" weather observation network (WMO, 2010). However, human skills to observe weather could be an underestimated resource. Using Web 2.0 could enable fast transactions of large amounts of weather data by individuals.

Current Needs for Improved Weather Information

In modern society, weather represents an important factor for efficiency of fundamental infrastructure components, such as energy supply, transportation and food production. Adverse weather causes traffic flow decline and increased risks for hazards (Eisenberg, 2004), and heavily disturbs or even destroys core functions of society. Nearly 80% of natural hazards are linked to climate extremes (WMO, 2009a).

Sampling of climatic information for climate research and daily weather forecasts produced by Numerical Weather Prediction (NWP) models strongly depends on the spatial coverage of their input and the accuracy of data describing the current state (Holton, 1992; Park and Xu, 1999; Solomon et al., 2007). Because a NWP represents a time integration of an initial state problem, the ability to make skillful forecasts requires that the model is a realistic representation of the atmosphere, and also that the initial conditions are known accurately (Kalnay, 2003). Among ways to help resolve these issues, the World Meteorological Organization (WMO, 2009a) recommends information sharing and active participation by civil society regarding climate change issues, while national meteorological centers require improved data quality concerning observational techniques and NWPs.

Introducing Web Weather 2.0

By the end of the 20th century, Web 1.0 had drastically increased the amount of available weather data, including volunteer contributions of data collected by private low-price weather stations, and unrestricted distribution and efficient dissemination of weather data through the Internet. Currently, the global exchange of weather data administered by WMO consists of more than 10,000 SYNOP weather stations, many of which are still operated by human observers (WMO, 2009b). The number of individuals connected through Web 2.0 drastically increases the potential number of nodes to billions, including hundreds of millions of smartphones (ITU, 2012).

Reflecting on past and recent developments, it becomes evident that Web 2.0 will impact the weather information market, as weather data are being widely spread and disseminated, and sometimes even observed, by non-experts. This trend can evolve into Web 2.0 practices where weather data are not only distributed to, but collected from, the general public. For instance, cloud pictures taken with mobile cameras might correspond to a new type of "satellite picture" taken from below, and thus improve the current contributions of space technology.

We posit that Web 2.0 data collection methods could be integrated into WMO's standardized set of weather data currently serving as input to NWP models and climate modeling. Moreover, additional benefits with such systems may accrue. Since methods based on social media do not require large-scale initial investments, Web weather 2.0 would represent an alternative to increased investments in national meteorological services for strengthening existing networks.

Research Questions and Methodology

Our research questions are:

RQ1: From a problem identification perspective, what parameters should be reported and what are the requirements regarding the temporal distribution and distribution in space?

RQ2: How should the same parameters be represented in order to meet the needs of the user, and how will the artifact address the spatial and temporal distribution while maximizing the volume of reliable user-generated data?

Based on design theory, this paper presents the design process and results of some demonstrations of a “share weather” artifact (application) that can collect weather data from non-experts. We conclude from issues discussed above that some particular properties of this artifact require special attention. A “share weather” application must be designed so that it possesses the ability to produce relevant and usable data. In addition, the feasibility of the artifact should be thoroughly tested.

In this work, we apply methodology for conducting Design Science (DS) Research in Information Systems (IS), or DSIS, developed by Peffers et al. (2007). According to the DSIS methodology, a design process may be profoundly defined by the following (iterative) steps or activities: (I) Problem identification, (II) Definition of the objectives of a solution, (III) Design and development of the artifact, (IV) Demonstration, (V) Evaluation, and (VI) Communication.

As activity I (problem identification) was addressed above, we will further discuss steps II through V of the design process; our presentation is step VI. Empirical evidence from studies on perception of weather was applied throughout steps III, IV, and V. A pre-study consisting of telephone interviews with seventeen adults and earlier questionnaires in 2008-2009 served as input during the design and development activity III. Activities II and III were based on some well-established theories within meteorology and human cognition, some of which are introduced in the next section.

With about 290 adults and 60 children, we performed three demonstrations to accomplish steps IV and V. In the evaluation, step V, we introduce some new methods. The method of “scoring” is intended to indicate respondents’ perception of weather in comparison to official sources and an area (meteorology) expert (one of the authors of this paper). The official sources consisted mainly of NWP outputs from US National Centers for Environmental Prediction (NCEP) and weather observations acquired from the Swedish Road Weather Information System (RWIS) observation network of about 700 observation points over Sweden (an area of 450,000 square kilometers), but higher density in urban areas of up to 10 observations per 100 square kilometers. Besides weather data such as temperature and precipitation, RWIS measures parameters related to perception of weather in traffic such as surface temperature and road surface type.

OBJECTIVES OF A “SHARE WEATHER” APPLICATION (STEP II)

The “share weather” application may be defined as either objective-centered or design-centered (Peffers et al., 2007). An objective-centered design process “could be triggered by an industry or research need that can be addressed by developing an artifact” (p. 56). A design-centered approach “would result from the existence of an artifact that has not yet been formally thought through as a solution for the explicit problem domain in which it will be used” (p. 56). Based on the problem identification provided in the previous section, we chose a design-centered approach to build a Web 2.0 application that could facilitate gathering weather data from non-experts. These data would add new inputs to weather forecasting and climate modeling. According to this framework, the design of the application must include both problem-oriented and user-oriented perspectives.

Objectives: Real-time Weather Observations

Starting with a problem identification perspective, the content format must be designed with respect to both problem definition issues, namely, acquiring real-time data and performing computational modeling. Real-time meteorological observations are used to define the present state of the atmosphere: pressure, temperature, humidity, wind speed and wind direction.

Meteorology is, however, an environmental science closely related to its sister sciences such as hydrology and oceanography due to coupling effects between, for instance, atmosphere and ocean temperature, evaporation from soil into the air, or exchange of heat and water between snow and air (Deaton and Winebrake, 2000; Peng et al., 2002). The “share weather” artifact should thus be designed not only for collection of weather data, but also to handle environmental data of different kinds.

The other important aspect of the defined problem relates to the temporal and spatial distributions of observations. The objective is to collect a range of environmental, including atmospheric, data on a temporal scale denser than 3 hours and a spatial scale of 10 kilometers (WMO, 2010). In addition, the data should be delivered to the “share weather” application within minutes of occurrence; however, the delivery time of environmental data collected in order to improve knowledge on different processes and climate is irrelevant. The Web 2.0 observation sites are presumed to be mobile and, in some regard, more flexible. Mobility may be regarded as a potential drawback because individuals cannot be assumed to report instantly after observing a weather phenomenon. Yet, in providing information about previously observed occurrences, a person may consciously select interesting phenomena that otherwise may be lost outside the records due to the fact that instruments only present snapshots of reality.

An important question is how to define the format of the set of weather data collected using the Web 2.0 application. Social science is continuously faced with the problem of heterogeneity of individuals. It can thus be assumed that the reported weather will be biased by individual perceptions of weather, which is related to some specific properties. While professional observers have received advanced training to minimize their biases, an arbitrary individual cannot be assumed to have any particular skills. The content format design of the “share weather” artifact must be adjusted to suit different individuals’ skills and perceptions.

In summary, a “share weather” artifact must operate in several dimensions to achieve desired outcomes. The first is the nominal value/accuracy due to user perceptions and measurement factors. The second dimension is temporal distribution/reporting frequency. The third dimension is the spatial component which may vary due to mobile properties of the sources. Considering the fact that weather observations from users are generated on a volunteer basis, the spatial and temporal dimensions strongly depend on motivation to provide a weather report. This includes the challenge of designing an artifact that has the ability to maximize the motivation of volunteers to reach a satisfactory number of reports, distributed over a particular spatial area and over a limited time interval. While NWP outputs provide weather information at 100 square kilometers on an hourly basis, “nowcasting” is a method for further improving short-term weather forecasts corresponding to densities of RWIS: 10 observations per 100 square kilometers and one hour. The “share weather” application will aim to meet these criteria while collecting weather-related data, other environmental variables, and knowledge about the relationships between air, water, soil/ground and vegetation.

DESIGN (STEP III)

To complete the design of the “share weather” application, we engaged in an iterative process of developing requirements and testing them in various contexts. As such, we conducted some iterations between Activity III and Activity IV (Demonstration) to determine some properties and preferences of different user types. In this section we explain the initial design and in the following section we report the format of the demonstrations and the resulting design changes. Three aspects of the design are related to: motivating users to provide inputs, assessing the biases of the inputs, and producing outputs.

User Motivation

Most weather variables may be observed by human senses. Weather is a favorite subject of conversation, and as such, it may feel natural to people to capture and share weather and environmental data. Social media technologies may further encourage this sharing. However, although it is a popular subject of conversation, weather represents a small fraction of media content. A weather event must be of some particular relevance to an individual’s personal life in order to attract the attention of that individual. For example, Schneider and Laurion (1993) found that personal relevance affects what people remember after listening to the news. Secondly, interest itself may not be enough to create motivation if favorable preconditions to perform a weather report do not exist.

In order to explore how individuals perceive weather and what would motivate them to observe weather phenomena, a pre-study was conducted (see Elevant, 2009). We recruited respondents from a group of 267 individuals that later participated in demonstrations. In December of 2008, we conducted seventeen semi-structured interviews, including questions about travel habits, means of transportation, and acquisition of weather information. The results indicated that the respondents had high interest in weather effects (in this case transportation-related), new technology, a weather dependent hobby (e.g., sailing, equestrian, golf), or weather in general. Questionnaires distributed in March and November of 2009 (involving 70 and 150 respondents, respectively) provided additional empirical evidence regarding interest in weather information and perception of weather.

User Bias and Perception of Weather

Previous results suggest that observing weather may improve skills to conduct future observations. The interviews and questionnaires, for instance, suggested that long distance travelers may be more attentive to weather phenomena (e.g., Elevant, 2009). Thus observers may collect their own data that they may use during future observations.

Research on cognition about weather indicates that people may have strong experiences of weather in the present. Although “weather memory” may be very short, this may depend on the type of weather. For instance, a study conducted by Forgas et al. (2009) showed that people more easily remember “bad” weather. On the other hand, studies on driver behavior and cognition point to great problems related to drivers’ lack of awareness of risks and perception of bad weather in the present, leading to increased accident frequency during the early winter season (e.g., Norman et al., 2000). Individuals’ belief adjustment and revision of hypotheses based upon new evidence (Einhorn and Hogarth, 1985) is manifested as a “surprise effect” related to the number of days with “fair weather” conditions they experienced prior to severe events (Eisenberg, 2004).

Thus, the user’s observation of weather is a function of current weather and recent weather (referring to a period shorter than months). We assume that the time window for remembering weather is equal to, or less than, two weeks. This is based on survey results that show that recall of events older than two weeks are considered to be unreliable (e.g., Lazar et al., 2010). Memory of weather may be even shorter if the respondent experiences several changes of state. From these findings, it is suggested that, given previously observed states of weather, in a set of locations representing the spatial area in which the observer/respondent has been positioned during recent (< 14) days, the observed weather is only a function of the respondent.

Results from the questionnaires (of Elevant, 2009) implied that the individuals in the sample (the majority were middle-aged men travelling by car to work) were able to recall past weather events in particular if they travelled longer distances. The “share weather” artifact should thus be designed to collect user-generated personal data (e.g., in a user profile) such as: age, gender, travel habits (car, bicycle, public transport), hobbies, and geographical position/area. In addition, the latest observation provided by a particular user can be used to improve and personalize real-time information that is given back to the user as a service. The value of receiving personalized weather information may serve as an important driver to increase participation and sharing of weather observations.

Creation of an Output

The potential power of crowdsourcing of weather data is illustrated by the fact that some weather observation variables can be easily measured by humans. One analogous experience is peer-viewing of pictures of objects in space by the NASA clickworkers (Benkler, 2006), a demonstration of efficient crowdsourcing based on “peering” in which a large number of individuals efficiently performed the work of experts. Another example of peering of environmental data is the collection of geological information in gold mining (Tapscott and Williams, 2006), which manifested somewhat surprising levels of accumulated knowledge on the local habitat and environment driven by individuals’ personal interests. One advantage of shared weather data is that official sources such as SYNOP and RWIS are available for comparison. We therefore suggest that the “share weather” artifact should apply methods of peering along with comparison with observations created by other sources of weather information.

The “Share Weather” Application

Because peering is suggested as a method for capturing weather data, the “share weather” application design included tools for easily supplying weather information in a desired, feasible format. The application included the following features: (1) collection of user-generated weather observations, (2) user profiles and data (habits and personal observation records), (3) peering and collaborative filtering, (4) comparison with real-time data (e.g., SYNOP and RWIS), (5) calculation of mean errors, and (6) personalized outputs for users. Each output may be personalized by calculations including: the actual forecast, historic observations, and real-time observations.

Design of the “Share Weather” collection method

Although not equipped with technical instruments, the individual may be regarded as an unexplored resource naturally equipped with senses that can observe weather in a way similar to advanced instruments. The design step in which we discussed the creation of outputs suggested filtering humans as nonhomogeneous sources by applying previous experiences such as Wikipedia (peering). Adopting the method practiced by Wikipedia would suggest that users edit observations provided by others. However, this method may be considered inappropriate because Wikipedia stores knowledge representing historical information, while the “share weather” artifact must handle real-time information. A solution based on time-demanding editing would require an unrealistically large number of very efficient observers, in accordance with the previously discussed spatial and temporal dimensions. Because components of the system are based on comparisons between different sources of weather information, some kind of simple format with nominal values is required.

Temporal aspects such as time shifts due to convenience and conflicts with other activities suggest that the "share weather" interface must provide tools for choosing current geographical position and the time of observing the weather. The method should be based on plain visual experiences and other perceptions. Literature is full of both personal and professional descriptions of weather. In fact, climate research uses literature and other documentation such as marine logbooks (Wilkinson et al., 2011) to estimate nominal values of weather variables during the preindustrial era, based on different document artifacts. Another example referring to the pre-industrial era is the Beaufort wind scale, which uses words in order to describe signs in terms of tree leaf movements and movements on the sea surface that correspond to a wind speed interval. For example, a wind speed of 5 Beaufort corresponding to "fresh breeze" (8.0 to 10.7 meters/second), is described as "Moderate waves of some length. Many whitecaps. Small amounts of spray." Or, "Branches of a moderate size move. Small trees in leaf begin to sway." Here, weather information is documented based on solely visual expressions, and the recipient of the information may interpret it based on previous experiences.

Table 1 lists the variables that are available to "share weather" users, and where applicable, the set of values that can be chosen. Figure 1 shows the "Shareweather.com" interface.

Table 1: List of "Share Weather" Variables and Values

Variable	Values
Temperature	Nominal values OR Phrases describing current temperature compared to recent temperature
Cloud Cover	0, 0-25%, 25-50%, 50-75%, 75-100%, 100% OR Text descriptions such as "decreased cloudiness" and "clouds over land/west, clear sky over sea/east" OR Pictures that can be confirmed or rejected
Wind Speed	Beaufort scale
Wind Direction	Nominal values
Cloud Type	Pictures provided by users OR Selected pictures
Precipitation	Common expressions (e.g., showers, drizzle, rain, thunderstorm) plus adverbs/adjectives (e.g., light, heavy) and temporal descriptions (e.g., temporary)
Visibility	Estimating the appearance of a visible object (e.g., bridge, church tower)
Road Weather	Road surface descriptions (e.g., hoar frost, ice) plus adverbs/adjectives describing intensity (e.g., local, severe)
Environment	Common names and pictures of species (e.g., flowers, insects, birds)

DEMONSTRATION (STEP IV)

The "share weather" artifact was created and tested within a Swedish research project, and demonstrations occurred during the winter season of 2009/2010. Adults interested in road weather information (Group A), children (Group C), and patients at a dental clinic (Group D) were recruited on different premises to participate in three different demonstrations (see Figure 2). A member of Group A took part in the Group C demonstration as an observer. One of the authors of the paper, a weather expert, provided Group A with a service consisting of traffic weather forecasts and took part in providing weather seminars to Group C. None of the individuals in these demonstrations (other than the expert) had been trained to conduct weather observations. Figure 2 illustrates a summary of demonstrations.

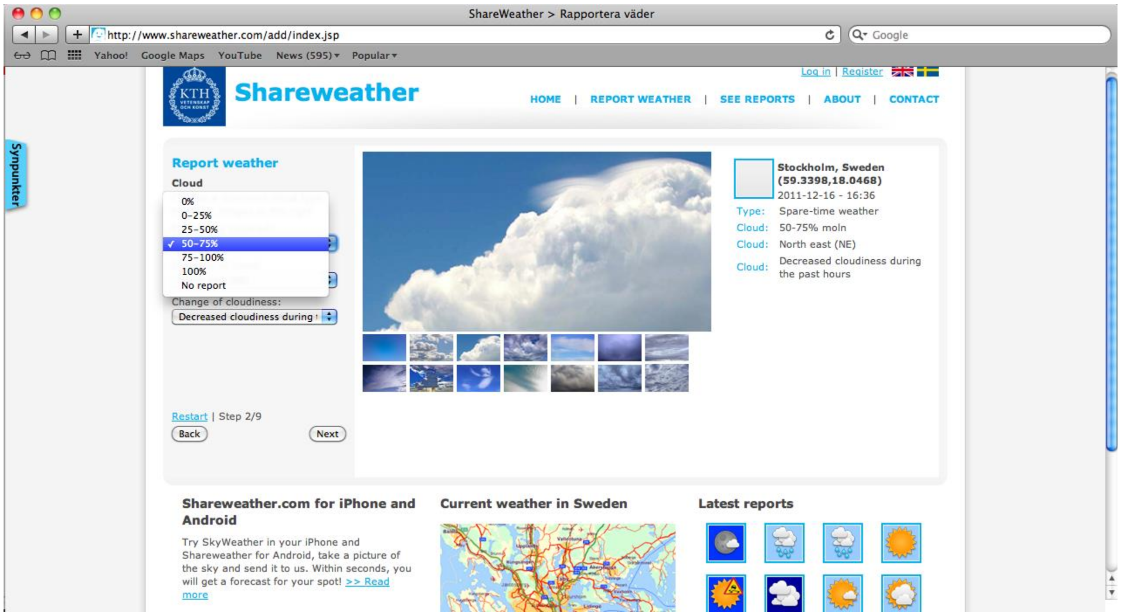

Figure 1: The "Shareweather.com" Interface

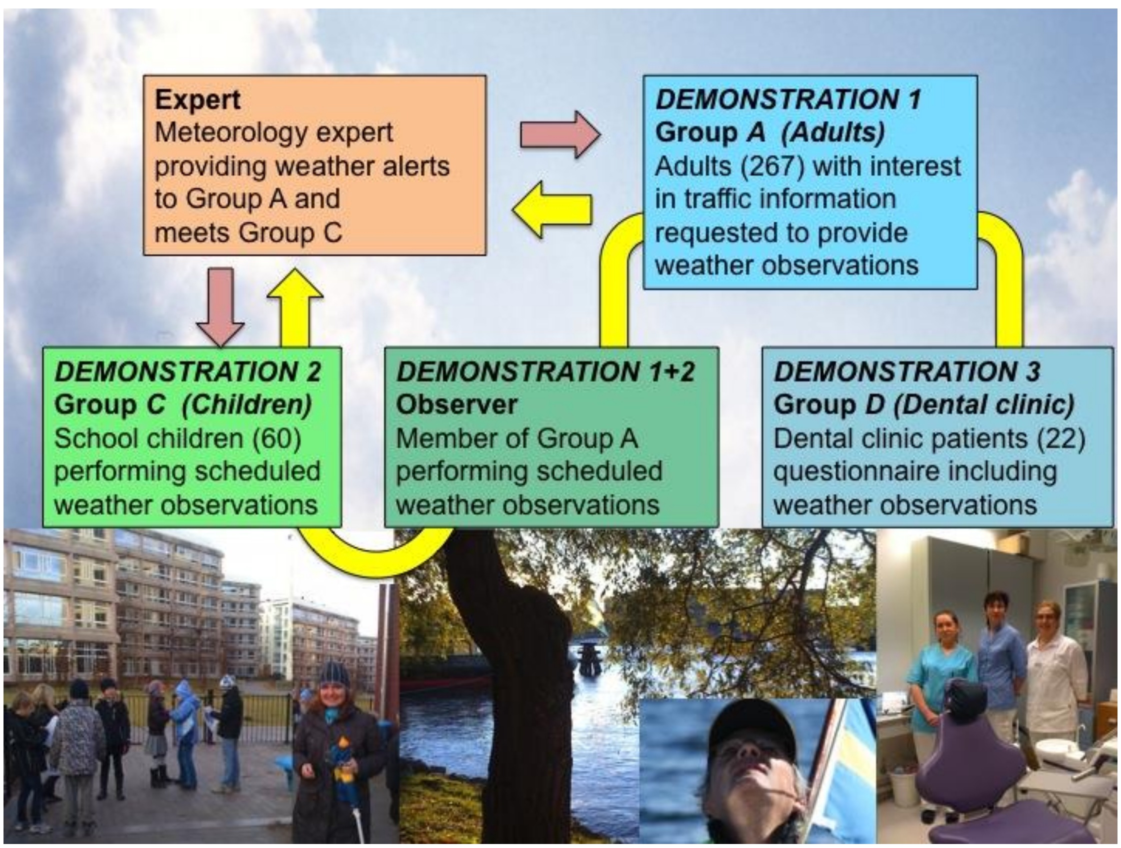

Figure 2: Summary of Demonstrations

Demonstration 1: Two Experiments on Group A

The group of individuals in Demonstration 1 had previously volunteered to participate in tests with the main goal of improving traffic weather services. As such, this group represented a community of individuals interested in traffic weather. Beginning in October of 2008, individuals in the County of Stockholm were recruited to participate in an information sharing network. By April of 2010, over 340 people had volunteered, 267 of these participants comprised

Group A. Prior to the demonstrations of the “share weather” application from January to February of 2010, Group A had participated in a survey that gathered data regarding their habits and preferences considering weather information and transportation.

Demonstration 1a started on 1/27/2010 when the weather fulfilled conditions of spatial coherence (intense snowfall for almost 24 hours), while Demonstration 1b related to weather events that followed after 2/19/2010, later considered the most severe event of this season that had been accompanied by great traffic delays. The respondents received a request in an ordinary SMS/e-mail weather alert to provide weather reports to the expert. The weather information supplied by the expert to Group A consisted of a rather personal text message including a weather forecast (see http://shareweather.org) based on information the expert collected from participants and official weather information sources.

Alternative ways of reporting weather were available to the participants: web (form), SMS, and e-mail. The “share weather” weather report form had a simple design with no additional features. The content consisted of 25 predefined text expressions based on the design presented in the Design section above. An example of the questionnaire is provided at http://shareweather.org/webform.htm. In SMS and e-mail, the respondents were, by contrast, able to freely choose which variables to report and how to describe the variables.

Demonstration 2: Weather Observations Provided by Group C

About 60 elementary school children, aged 7 to 9, were given a weekly task to report weather without receiving payments or rewards. Children were assumed to represent the group of respondents with the least possible experience of weather phenomena, thus reflecting the minimum level of quality that may be achieved from individuals observing weather conditions. In order to compare observations created at different points in time and space, a member of Group A with a record of providing reliable observations (confirmed by a pre-study during the fall of 2009) volunteered to observe weather once a week. The observer was less than one kilometer from the location of Demonstration 2.

The children used a “share weather” paper form containing several sheets with a set of questions, numbered cloud pictures, and pictures of a compass (see http://shareweather.org/printedform.htm). Additionally, some environmental variables (trees and flowers) were introduced. Compared to the web form used by Group A, the paper form was simplified to accommodate a child’s vocabulary and experiences. To create input to the questionnaire, data on Group C’s experiences and understanding of weather phrases were collected prior to the demonstration right after the expert participated in two lectures with the children. Data gathered after the first lecture (in October of 2009) was used as inventory and input to customize the “share weather” artifact for children. Expressions were modified to match a child’s vocabulary (e.g., “intense snowfall” became “large snowflakes”, and “0% cloudiness” became “no clouds at all”). There was also the opportunity for dialogues, questions, and conversations about weather phenomena.

Another lecture about two weeks later introduced the “share weather” artifact including measurement methods and simple training. Because they were completing an assignment, the children did not voluntarily participate. Another important difference compared to Group A was that the children worked together in small groups of 3 to 5 prior to delivering the results of their weather observations to the teachers.

Demonstration 3: Group D

Twenty-two visitors in a patient waiting room at a dental clinic attended a third demonstration during December of 2009 and January of 2010. We chose this group to represent the general adult population that was not clearly interested in traffic-related weather. Demonstration 3 applied a printed question form (see http://shareweather.org/printedform.htm) very similar to the paper form Group C used, including cloud pictures and a picture of a compass with indications of the geographical position of the dental clinic. Group D was encouraged to look out the window in order to perform an observation and respond to personal questions on habits regarding weather information acquisition, travel, and interest in weather.

Weather Cases

Because it is not possible to control weather conditions, cases were chosen by occurrence, that is, by waiting for a proper case to occur. There was one proviso, namely that the weather variables should be relatively uniform over a large area. All three demonstrations were naturally impacted by the prevailing weather conditions, representing an uncontrollable variable. However, we argue that the actual weather conditions would not impact our evaluation. The winter of 2009/2010 in Sweden was cold and rich in snow; the frequency of adverse weather events was double that of 2008/2009. However, as noted earlier, theory regarding behavior and conservativeness when revising a hypothesis due to sources of new evidence (Einhorn and Hogarth, 1985) implies that perception is most affected by relative changes in weather on temporal scales of days rather than months. Thus, the occurrence of extreme average values enduring over periods of months should have had only a minor effect on our demonstrations.

EVALUATION (STEP V)

The demonstrations were used to evaluate the design of the “share weather” artifact with respect to user motivation, temporal and spatial distribution of reports, user bias, filtering processes and output. Data were derived from survey answers, frequency counts of user reports, times and locations of user reports, and information included in user observations.

Evaluation of Demonstration 1

The questionnaire response rate ranged from 63 to 70% with the exception of February (48%), which may be explained by winter holidays. These figures are still considered high, compared to general expectations regarding participation in surveys (e.g., Lazar et al., 2010). In addition, the rate of response to open questions implied a high level of engagement compared to typical survey response rates within social science. For example, Demonstration 1a resulted in 49% of the respondents writing comments, expressing personal opinions and feelings (e.g., complaints on local road administration). From a qualitative analysis of those comments, it was also evident that some recipients wanted to manifest their knowledge regarding weather related phenomena (e.g., by explaining current road conditions and physical and chemical processes behind different phenomena). These results imply an existing need to share experiences and knowledge. The social dimension may be explained by “self-development” and “enjoyment” manifested in communities of interest (Pink, 2009; Nov et al., 2010). In addition, comments in open questions were analyzed with respect to personal motives such as hobbies or weather-related activities. A qualitative analysis provided evidence of motives driven by hobbies, although they were not represented as strongly as in earlier questionnaires. This may have been due to severe weather conditions and/or the particular time of year (winter), in that the amount of respondents’ hobby-related activities may have declined seasonally. In contrast, and not surprisingly, concern about property and life was more pronounced. Survey participation rates overall show that the respondents were willing to invest time into improving the service the expert delivered.

A total of 555 observations were collected from the respondents, 241 of which were retrieved from questionnaires prior to Demonstrations 1a and 1b. Because the questionnaires contained additional questions related to the evaluation of the service and user preferences and habits, the motives to provide weather observations cannot be separated from other factors that contributed to high survey response rates, for instance a sense of obligation toward the expert and self-interest as improving the service from which they benefitted. The majority of the reports (314), however, were the result of conscious actions as the respondents were specifically asked to report their local weather observations unaware of the purpose of the study. We can hypothesize that, if the respondents are fully aware of the real purpose - sharing weather information in order to improve the weather forecast - the response might increase. One methodological concern was that respondent groups participating in different questionnaires were not identical, as new respondents were continuously added during the winter. During Demonstration 1a, and based on 230 respondents, 224 weather reports were issued; while Demonstration 1b resulted in 90 reports based on 267 respondents.

The higher number of reports issued in Demonstration 1a (1 report/respondent and 1.6 reports/active respondent) compared to Demonstration 1b (where the corresponding figures were 0.3 and 0.7) may be explained by winter holidays during Demonstration 1b. Another interpretation is that the weather was extreme to such an extent that no measures, such as changed decisions or better information regarding the weather situation, would reduce the experienced inconvenience. Uniformity and intensity of the weather event might therefore have reduced the motivation to share and acquire updated weather information.

In addition, the distribution of volunteer reports that included multiple reporting was uneven. Over 102 respondents manifested multiple web reporting instances during demonstrations and over half of the 65 SMS reports came from 13 users that reported more than once; 6 of these users belonged to the minority (70) who had participated in pre-studies. The results thus imply the existence of a small group of more active community members, with stronger motivation to participate. It may also be suggested that social interaction with the expert and time of participation in the project are correlated to the volumes of contribution, although stronger evidence is required in order to confirm a correlation.

However, all observers may not be active all the time. Looking at the temporal distribution of user-generated reports, we identified several important factors: time-delay, daily temporal distribution, and temporal density in respect to the weather character. First, real-time data may only be useful for the purpose of forecasting and “nowcasting” if provided within a time-frame of minutes rather than hours, which means that the reported observations should be very recent. The time of sending of web surveys and SMS reports confirmed that the majority of the respondents reported weather almost instantly: 68% were reports on current weather or “right now,” 15% concerned observations during the past hour, while 17% of observations were older than one hour. Surprisingly, the respondents tended to perform and report weather observations during working hours and commuting.

During Demonstration 1, 111 observations were emitted between 2/21/2010 at 11 p.m. and 2/24/2010 at 11 p.m. using the “share weather” artifact web form, corresponding to a mean value of 1.5 reports per hour. However, the number of reports per hour varied significantly. For example, 20 SMS reports were sent on 1/27/10 between 4 a.m. and 2 p.m., while 10 were sent between 2/3/10 5 a.m. and 2/4/10 9 a.m., corresponding to 2.0 and 0.6 reports per hour, respectively. These differences may not be explained by impacts of interactions with the expert alone, but may be correlated with the experienced severity of the event.

Our point is that the goal of a “share weather” artifact for the Stockholm area is to generate more than the standard provided by weather stations, that is, 1 observation per 100 square kilometers. While the system did exceed the standard at times, the level of motivation or the number of community members would need to be increased to meet the system goals.

It can be concluded that during extreme weather, motivation to contribute weather information is strong enough that it is worth considering actively engaging people in weather observation, which they are willing to provide despite other obligations. This demonstrates the importance of weather in everyday life in temperate climate zones like Scandinavia. It can therefore be concluded that weather-dependent individuals may benefit from information created by groups with large amounts of spare time, such as non-working groups.

Under Demonstration 1, over 60% of the respondents (Group A) scored the expert forecast “as predicted”, while only 20-55% scored “other” forecasts, referring to other available weather forecasts (TV, radio, Internet), “as predicted”. Between 90 and 100% were within the range from “slightly better” to “slightly worse”, indicating that the respondents reached a consensus with the expert’s opinion through their own observations. Separate evaluations of the alert service confirmed that, due to the respondents’ perceptions, the forecasts were accurate, that is, they were considered to be of higher quality than other sources (Elevant, 2009; Elevant, 2013a). In addition, the respondents manifested increased trust as their behavior during severe weather was increasingly affected the longer they participated (Elevant, 2013a). Scoring “as predicted” was, however, not correlated with the time of participation, which implies that scoring is an indicator of perception rather than trust.

Early season weather cases manifested a clear shift from “as forecasted” (usually 60-70%), toward “slightly better”; however the sum of the two was about equal (over 85%) (see Elevant, 2013a). Yet, a qualitative analysis of reports provided by group A confirmed the severity of early season events, for instance supported by official sources records of traffic accidents and incidents (e.g., the closing of the “Johanneshov” bridge just south of the city core of Stockholm and 30 traffic accidents on December 2, 2009 between 6 a.m. and 9 p.m.). Because the occurrence of severe events was well documented by external sources of evidence, local variability of microclimate is of particular importance. While these results imply possible drawbacks for “share weather” web 2.0 solutions due to the problem of separating user perception from actual weather, at the same time they illustrate the potential power of improving local weather information based on a few consistent reports from adjacent observers.

SMS free text expressions were consistent with forecasts and weather alerts. This result is based on a qualitative analysis of the 65 SMS and e-mail reports we received, including classification of their content due to the same classification applied to the text descriptions of the “share weather” web form. For example, the word “snow” was mentioned 49 times, “slippery” occurred 8, and “windy” 6 times. In most cases, the message contained the following variables: time (in all but one case referring to “now”), position, description of state (weather variables), particular road conditions (road weather-related variables), personal greetings and comments. Compared to equivalent web reports with predefined text, it was evident that self-composed SMS texts contained very personal, sometimes dramatic descriptions indicating that the “share weather” artifact method of using predefined text expressions is more convenient. For example, some expressions created by the respondents were not consistent with expressions used in media: “snow-polished,” “a little powder”, and “middle windy”. A system would therefore have difficulties interpreting these expressions and translating them into adequate nominal values for comparison with other sources.

It can be argued that the “share weather” method of using predefined text expressions may be misused due to lack of knowledge of the phenomenon (e.g., clicking “black ice” because it is seen as a novel expression). Results from SMS reports, however, showed the advantages of the “share weather” artifact pre-defined text phrases. The “share weather” artifact can, in that respect, be regarded as an educational tool, as learning might be encouraged by participation in communities of interest and performing different tasks (Lave and Wenger, 1991).

Results from the SMS test were also useful regarding the iterative design process, identification of potential new expressions, further personalization of the text expressions and customization toward different groups and user profiles. Some important findings on perception may have been uncovered. Because the category “snow” appeared with high frequency in SMSs, it can be suggested that people are more aware of what is visible (in the air), than to processes on the ground (e.g., slipperiness), which is in line with earlier findings on drivers' perception of weather, and in particular in darkness (Kilpeläinen and Summala, 2007).

Evaluation of Demonstration 2

Qualitative analyses of school children's reports, based on simultaneous reports provided by the individual from Group A and an analysis conducted by the expert, provided evidence that children can contribute useful information. For example, the expert could, upon reading the children's observations of a "wet" road surface, determine the risk of a black ice event in November. Supposing that the expert did not possess all information necessary to provide an accurate local forecast, the children (non-experts) could have provided necessary input information.

The children improved their skills during the demonstration, which was revealed by better classification of clouds from cloud pictures and improved knowledge of terminology like visibility, point of the compass and wind direction. The experience from participating in weather experiments was combined with other educational activities such that the children showed increased attention and learning induced by their participation, suggesting elements of situated learning (Lave and Wenger, 1991).

The results from Group C suggested some improvements of the "share weather" design had occurred. In particular, the children displayed some difficulties regarding wind direction, while they managed other factors (i.e., road surface, cloud type, cloud cover, precipitation) more easily. Visibility, which had high consistency, was, however, strictly defined based on the appearance of the church tower nearby, while wind direction was determined by using a compass, holding a flag, and identifying the direction the flag was pointing. Consistent with results provided by the SMS messages, these findings point toward strict definitions leaving less room for subjective opinions. The church tower method, numbered cloud pictures, and the classic wind speed method introduced by Beaufort in the 19th century proved useful.

The methodological approach of using Group C as an estimate of minimum quality provided results supporting the claim that individuals who have limited experience with weather reporting may perform useful observations. Some exercises applied on data provided by Group C showed that good filtering was achieved by calculating the mean value or choosing the most frequent answer (presenting the mode).

Evaluation of Demonstration 3

Our conclusions regarding severe weather were further confirmed by other results regarding the temporal distribution of Group D's participation. The majority of Group D's reports were provided closely after, or during, severe weather. However, Group D provided weather observations of varying quality, and the performance of some respondents from Group D was in that respect far less satisfactory than that of the school children. Reports provided by Group D were particularly inaccurate regarding the previous week's weather. The limited number of occasions during which Group D demonstrated consistency within the group and with other groups coincided with issued weather alerts (an ice warning and two snow alerts), consistent with previous findings on impacts of "bad weather" on perception (Forgas et al., 2009).

Group D manifested the highest consumption of weather information through traditional channels, in particular TV, with very limited usage of new technology. Television represented the main source (50 %) of weather information. Results from Group A, based on three different surveys 2008-2010, by contrast, showed that the Internet acted as an important source of weather information (40% of total acquisition), while, for Group D, use of the Internet was four times less frequent.

IMPLICATIONS

Some of the basic challenges of modern meteorology include, in accordance with the above issues recognized by WMO, improving weather forecasting methods and climate modeling. The main problems are related to insufficient spatial sampling of data, data assimilation, and parameterization of physical processes (Holton, 1992; Kalnay, 2003; Park and Xu, 1999; Peng et al., 2002). Besides contributing to theories within the research fields of design and collaboration, this paper aims to make a contribution to the field of meteorology regarding new, unexplored methods for improving weather information.

It is evident that arrangements with group A concerning the service and respondents' participation in creation of local weather observations did have components of a (weak tie) network. Although not actively communicating with each other, the respondents developed motivations similar to those developed in virtual communities. Explanations of their motivations may be recognized as related to reciprocity and trust created between the expert and the users through the service and other interactions, however intrinsic motivations may also be present (Elevant, 2013b)

Because different levels of quality are exhibited among different groups of users, we suggest that data generated for a “share weather” application should be filtered based on a model adjusted to a default member of a user group. Consequently, the platform needs information about users. Historical data may be collected, or a classification system can be established to sort users into groups such as the ones used in this research: “long distance car driver in urban area” (Group A), “child of age 7-9” (Group C), or “new user” (Group D).

This paper makes a contribution to design theory by introducing a method for designing web 2.0 artifacts for the collection of environmental data. We believe it is possible to generalize our principles of modifying existing observation collection methods to other situations. That is, we recommend (1) making use of expert communities and established collection formats, (2) describing phenomena through words, pictures and mathematical symbols with expressions shaped by common use of media (imagined communities) however suitable for comparison with established formats, and (3) customizing the collection method due to different target groups (communities of interest).

Regarding participation and creation of useful environmental data in today’s globalized world, mobile web weather 2.0 represents an opportunity to create valuable meteorological and environmental data in cities as well as remote areas and even in developing countries. While in industrialized countries, web weather 2.0 can engage and gather individuals with a special interest in weather due to weather dependence, in developing countries individuals’ specific knowledge about local weather phenomena in their narrow environment (e.g., farmers) might be regarded as useful. Weather and other environmental data may, in addition, be used for research and policy-making. Existing mobile networks and human resources may represent a substitute for large investments in conventional systems, as no expert system can observe the weather everywhere, but everyone can observe the weather and its consequences - the sky, land, and plants - somewhere.

CONCLUSIONS

Evaluation of the “share weather” artifact, based on three demonstrations performed on different groups, provides important knowledge regarding the objectives of future “share weather” artifacts, while confirming their potential to collect and create useful data. We conclude that groups that have larger amounts of dispensable time capital (e.g., school children, unemployed, pensioners) might represent a resource in the world of web weather 2.0, although weather-dependence, including severe weather events, were found to be the strongest incentives to make volunteer contributions. Properties related to socializing, co-creation, social media, and situated learning, may, however, attract other groups.

Under certain extreme weather conditions, motivation to share weather information may arise, including spatial and temporal resolutions. From the acquired empirical evidence (e.g., at times exceeding two observations per hour in Stockholm), based on 200 respondents, we conclude that the “share weather” application can produce meaningful data, and recommend further studies on collaborative weather observations. It is, however, evident that a larger number of respondents are required to achieve a solid ground for continuous input independent of the weather. Another limitation is that the “share weather” application will not provide data from rarely visited places.

Because our evaluations of these demonstrations imply fair motivation to contribute (under certain conditions), and the quality of the provided reports was satisfactory, we suggest “share weather” artifacts as new input to administrators of meteorological data. The demonstrations presented here imply that about 100 active reporters would be required for an urban area of 100 square kilometers, where the degree of activity is about one report per severe event. Larger volumes would be required to meet the needs of some specific applications such as road micro-climate. Provided that a satisfactory number of weather sharers can be recruited, “share weather” artifacts may make important contributions.

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REFERENCES

Benkler, Y. (2006) *The Wealth of Networks: How Social Production Transforms Markets and Freedom*. New Haven: Yale University Press.

Deaton, M. L. and J. J. Winebrake (2000) *Dynamic Modeling of Environmental systems*. New York: Springer.
Einhorn, H. J. and R. M. Hogarth (1985) "Ambiguity and Uncertainty in Probabilistic Inference," *Psychological Review* (92) 4, pp. 433-461.
Eisenberg, D. (2004) "The Mixed Effects of Precipitation on Traffic Crashes," *Accident Analysis & Prevention* (36) 4, pp. 637-647.
Elevant, K. (2009) "Customization by Sharing Weather Information: A Study on Winter Road Weather Warnings," *The 5th World Congress on Mass Customization and Personalization.* Helsinki: Aalto University.
Elevant, K. (2013a) "Trust-networks for Changing Driver Behavior during Severe Weather," accepted for publication in *IET Intelligent Transport Systems* (Working paper)
Elevant, K. (2013b) "Why Share Weather? Motivational Model for "Share Weather" Online Communities and Three Empirical Studies," in *Proceedings* of *46th Hawaii international Conference on System Sciences,* pp. 781-790. Grand Wailea, Maui. Janurary 7-10, 2013.
Forgas, J. P., L. Goldenberg, and C. Unkelbach (2009) "Can Bad Weather Improve Your Memory? An Unobtrusive Field Study of Natural Mood Effects on Real-Life Memory," *Journal of Experimental Social Psychology* (45) 1, pp. 254-257.
Holton, J. R. (1992) *An Introduction to Dynamic Meteorology*, 3rd edition. London: Academic Press Ltd.
ITU (2012) "Measuring the Information Society." Retrieved November 6, 2012, from http://www.itu.int/ITU-D/ict/publications/idi/material/2012/MIS2012_without_Annex_4.pdf
Jenkins, H. (2006) *Convergence Culture: Where Old and New Media Collide*. New York: NYU Press.
Kalnay, E. (2003) *Atmospheric Modeling, Data Assimilation and Predictability*. Cambridge: Cambridge University Press.
Kilpeläinen, M. and H. Summala (2007) "Effects of Weather and Weather Forecasts on Driver Behaviour," *Transportation Research Part F: Traffic Psychology and Behaviour*, (10) 4, pp. 288-299.
Lave, J. and E. Wenger (1991) *Situated Learning. Legitimate Peripheral Participation*. Cambridge: Cambridge University Press.
Lazar, J., J. H. Feng, and H. Hochheiser (2010) *Research Methods in Human-Computer Interaction*. Chichester: Wiley.
Nov, O., M. Naaman, and C. Ye (2010) "Analysis of Participation in an Online Photo-Sharing Community: A Multidimensional Perspective," *Journal of the American Society for Information Science and Technology* (61) 3, pp. 555–566.
Norman, J., M. Eriksson, and S. Lindqvist (2000) "Relationships between Road Slipperiness, Traffic Accident Risk and Winter Road Maintenance Activity," *Climate Research* (15) 3, pp. 185–193.
Park, S. K. and L. Xu (1999) *Data Assimilation for Atmospheric, Oceanic and Hydrologic Applications*. Springer. ISBN: 978-3-540-71055-4
Peng, G., L. M. Leslie, and Y. Shao (2002) *Environmental Modelling and Prediction*. Springer. ISBN: 3-540-67422-5
Peffers, K., T. Tuunanen, M. A. Rothenberger, and S. Chatterjee (2007) "A Design Science Research Methodology for Information Systems Research," *Journal of Management Information Systems* (24) 3, pp. 45-77.
Pink, D. H. (2009) *Drive: The Surprising Truth about What Motivates Us*. New York: Riverhead Books.
Schneider, S.L. and S. K. Laurion (1993) "Do We Know What We've Learned from Listening to the News?," *Memory & Cognition* (21) 2, pp. 198-209.
Solomon S., D. Qin, M. Manning, M. Marquis, K. B. Averyt, M. Tignor, H. L. Miller, Jr, and Z. Chen, (2007) *Climate Change 2007: The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.
Tapscott, D. and A. D. Williams (2006) *Wikinomics*. London: Atlantic Books.
Wilkinson, C., S. D. Woodruff, P. Brohan, S. Claesson, E. Freeman, F. Koek, S. J. Lubker, C. Marzin, and D. Wheeler (2011) "Recovery of Logbooks and International Marine Data: The RECLAIM Project," *International Journal of Climatology* (31) 7, pp. 968–979.
WMO (World Meteorological Organization) (2009a) "Report of the World Climate Conference-3." Geneva: UN WMO. Retrieved January 18, 2011, from http://www.wmo.int/pages/gfcs/documents/wcc3_summary_report_web_EN.pdf
WMO (World Meteorological Organization) (2009b) "The World Meteorological Organization at a Glance." Retrieved January 18, 2011, from http://www.wmo.int/pages/about/documents/WMO990.pdf
WMO (World Meteorological Organization) (2010) "Manual on Codes." Volume I.1, Annex II to WMO Technical Regulations, WMO-306. Geneva: UN WMO. Retrieved March 15, 2013, from http://www.wmo.int/pages/prog/www/WMOCodes/WMO306_vI1/VolumeI.1.html, ISBN: 978-92-631-0306-2

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