ARTICLE

Anticipation and Response: Emergency Services in Severe Weather Situations in Germany

Thomas Kox^{1,2} · Catharina Lüder¹ · Lars Gerhold¹

Published online: 12 March 2018

© The Author(s) 2018. This article is an open access publication

Abstract Communicating meteorological uncertainty allows earlier provision of information on possible future events. The desired benefit is to enable the end-user to start with preparatory protective actions at an earlier time based on the end-user's own risk assessment and decision threshold. The presented results of an interview study, conducted with 27 members of German civil protection authorities, show that developments in meteorology and weather forecasting do not necessarily fit the current practices of German emergency services. These practices are mostly carried out based on alarms and ground truth in a superficial reactive manner, rather than on anticipation based on prognoses or forecasts. Emergency managers cope with uncertainty by collecting, comparing, and blending different information about an uncertain event and its uncertain outcomes within the situation assessment to validate the information. Emergency managers struggle most with an increase of emergency calls and missions due to the impacts of severe weather. Because of the additional expenditures, the weather event makes it even harder for them to fulfill their core duties. These findings support the need for impact-based warnings.

Keywords Emergency services · Forecast uncertainty · Germany · Weather warning response · Weather warnings

1 Introduction

Hydrometeorological processes are the most common causes of natural hazards like storms and floods in Germany (GDV 2016). Primarily impact refers to a loss of life and injuries, damage to the environment, infrastructure, and private property, often followed by secondary effects like psychological trauma, or disruption of workflow and traffic. Mitigation and prevention measures are generally summarized under the term “disaster risk management.” The United Nations International Strategy for Disaster Reduction (UNISDR) defines disaster risk management as a “systematic process of using administrative directives, organizations, and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of hazards and the possibility of disaster” (UNISDR 2009). Measures include “land-use controls, insurance, engineered protection works and construction standards, disaster response plans, and emergency warning systems” (Mileti and Sorensen 1990, p. 1). The disaster management cycle represents a systematic approach to dividing the risk management process (Alexander 2000; Weichselgartner 2002; Dikau and Weichselgartner 2005). This widely used concept in the emergency management community is adopted by various organizations for different hazards. The cycle describes successive phases of post- and pre-disaster situations that a society would undergo and the measures that emergency management would need to take in order to improve resilience and mitigate the impacts of natural hazards. The phases are not clearly distinguished from each other, but overlap from time to time. Additionally, any post-disaster measures are essential parts of a pre-disaster situation, as the circular pattern implies. The number of phases and the terminology differ, but most authors suggest

✉ Thomas Kox
thomas.kox@fu-berlin.de

¹ Interdisciplinary Security Research, Institute of Computer Science, Freie Universität Berlin, 12165 Berlin, Germany

² Hans-Ertel-Centre for Weather Research, Optimal Use of Weather Forecasts, 12165 Berlin, Germany

three to four phases (Alexander 2000; Dikau and Weichselgartner 2005; Edwards 2009).

In this article, we follow Dikau and Weichselgartner (2005) and distinguish between pre-disaster mitigation and post-disaster emergency management. Mitigation includes short- and medium-term measures of preparedness and medium- and long-term measures of prevention. Emergency management, during or shortly after an event, includes measures of response and recovery. The response phase is characterized by emergency relief and rescue measures to cope with or limit impacts. The recovery phase focuses on measures for reconstruction and restoration. To lessen disruptive impacts, both the public and governmental authorities, that is, the emergency management services, take different adjustment measures. The distinction between pre-disaster mitigation and post-disaster emergency management is used here to understand different theoretical perspectives and as a guideline for the analysis of the qualitative data generated from this study.

1.1 Anticipation of Future Hydrometeorological Events

Pre-disaster mitigation measures always have an anticipatory component. The aim is to “get hold of something which has not (yet) happened” (Neisser and Runkel 2017, p. 170). Anticipation is therefore a central concept of risk (Anderson 2010; Hutter 2010). Anderson (2010) focused on three types of anticipatory action concerning risk: precaution, preemption, and preparedness. While precaution is a rather regulatory concept and can be understood as a preventive logic used in, for example, environmental law and spatial planning after the identification of a threat and before any harm occurs (Klinke and Renn 2002; de Goede and Randalls 2009), the logic of preemption can be understood as “prevention based on suspicion” (Suskind 2007, p. 150). The latter is a logic where a 1% chance of harm must be treated as a certainty in a potential high-magnitude, low-probability future where you cannot wait until a threat materializes, where firm evidence—of either intent or capability—is too high a threshold (Suskind 2007; Anderson 2010; Daase 2011). Finally, preparedness involves measures during the propagation of effects or impacts of an event through the “development of capabilities and resiliences that will enable response” (Anderson 2010, p. 792). According to the disaster management cycle, phases of response and recovery are strongly connected with the stated types of pre-disaster mitigation. The most significant articulation of response remains the formalized emergency services, that is, firefighters (Anderson 2016).

We will argue that in the case of severe weather, in addition to mitigation measures and the removal of

damages (for example, broken trees, water damage), the main aim of actions taken by civil protection and emergency services is to maintain their ability to respond. In order to anticipate disruptive severe weather events, they have to be “articulated, measured and detected as a risk” (O’Grady 2015, p. 133). Emergency services need to be aware of the situation and thus need information about the potential threat before it manifests. Delays in response are a main matter of concern (Anderson 2016) and weather forecasts may become a highly relevant source for preparing action. In this context, several authors stress the importance of (lead) time. They see the main goal—and simultaneously the major challenge—of warnings as obtaining command over the time factor, which highly depends on the length of forewarning or lead time (Clausen and Dombrowsky 1984; Drabek 1999; Hoekstra et al. 2011).

In order to lessen the impacts of disruptive events, “a range of practices have been invented, formalized and deployed for knowing futures” (Anderson 2010, p. 783). In terms of hydrometeorological hazards, weather forecasts are one way to anticipate the future development of the atmosphere (Fine 2007) and, with respect to certain phenomena, give hints about potential events like thunderstorms, extreme winds, and floods. (Weather) forecasts must be distinguished from warnings and alerts. While forecasts are a prognosis of future developments, warnings carry a certain message that increasingly indicates potential impact and gives guidance for adequate response. Alerts are just wake-up-calls. A warning without a context (about a specific hazard, a location and time, and lacking behavior guidance) is thus simplified to a prognosis. With relation to time, warnings happen before a disruptive event occurs, alerts right after an event (Clausen and Dombrowsky 1984).

1.2 Communicating Weather Information and Uncertainty

Weather information is always afflicted by uncertainty about, for example, the temporal and spatial occurrence of the potential event. The uncertainty arises from a lack of knowledge and incomplete observations, called epistemic uncertainty, and from the inherent stochastic variability and randomness in known and observable phenomena, called aleatory uncertainty (NRC 2006; Kox et al. 2015). Forecasting uncertainty quantifies intrinsic limits to deterministic (for example, yes or no) weather forecasts. Improvements in science and technology—for example, computer models—have made it easier to calculate possible outcomes of the future. A prominent example is the introduction of numerical weather prediction (NWP) and the use of ensemble prediction systems (EPS) over the last

decades (Hirschberg et al. 2011; Wernli 2012). These EPS are one way to make estimates about the uncertainty of weather forecasts, by capturing, for example, the uncertainty of current initial atmospheric conditions to provide quantitative probability forecasts (Wernli 2012; Demeritt et al. 2013). This development has partly led to an improvement in the spatial and temporal accuracy of weather forecasts (Hirschberg et al. 2011).

The EPS have a huge impact on the forecast of large-scale and long-lived severe weather phenomena such as hurricanes and winter storms, because the model output sometimes can provide evidence a few days in advance. However, for small-scale and short-lived severe weather phenomena such as thunderstorms, hailstorms, flash floods, and tornados, EPS currently do not have a larger impact on whether weather warnings are issued by a forecaster or not. In recent years EPS have been used on small scales to delineate, for example, areas of potential of severe thunderstorms. Mostly, forecasters issue warnings right when an event starts to be measured, or when radar or other data give indications. Such a warning paradigm is called “warn-on-detection” or “warn-on-observation” (Stensrud et al. 2009, 2013). Therefore, the actual forecast lead time (the length of time between a warning being issued and an event occurring) is in most cases short. EPS forecasts are currently only used to state whether the atmospheric conditions make the occurrence of thunderstorms more likely or not. But in recent years, a warning paradigm shift from warn-on-detection toward warn-on-forecast has been postulated (Stensrud et al. 2013). Particular benefits are seen in the improvements of forecast lead times (Stensrud et al. 2013; NOAA 2015).

However, any “innovations in forecasting technologies are useless unless they are effectively communicated, understood, and acted upon” (Demeritt et al. 2013, p. 147) since impacts can be highly dependent on the warning process and the action taken by the receiver (Drabek 1999; Mileti 1995). Uncertainty in the context of the communication of warnings mainly relates to epistemic concerns, miscommunication, and misunderstanding of the situation. This is due to the fact that risk assessments (and assessors) use concepts with often probabilistic outputs, which are difficult to understand, even for sophisticated decision makers (Cornell and Jackson 2013; Kox et al. 2015). Good training in communication and use of such risk assessments is important, but fundamental political and institutional challenges in using such information might also exist (Demeritt et al. 2010).

We assume that such a transition to warn-on-forecast will not only change the role of the forecaster (Stuart et al. 2006), but will also affect the practices of forecast end-users and responders to a warning. It is not yet clear how the public or the emergency services would respond to a

much longer lead time, whether they can make use of it and whether it would reduce fatalities, injuries, and damage (Simmons and Sutter 2008; Hoekstra et al. 2011). Thus, a fuller understanding of the behavior of key organizations such as emergency management agencies in creating, using, and communicating severe weather information or warnings is needed (Stewart et al. 2004; NRC 2006). For this we have to look into the actual practices that are or will be carried out during the warning process (Créton-Cazavane and Lutoff 2013). The question is “how to deal with risk and uncertainty (in assessment and making decisions) as well as how to organise communication and enhance the integration and acceptance of measures” (Neisser 2014, p. 91).

1.3 Research Questions

Following this discussion, we ask whether and how emergency services can make use of recent improvements in technologies and of a postulated shift from “warn-on-detection” to “warn-on-forecast.” We take the shift from communicating a deterministic forecast to communicating probabilistic weather information into account and assume that providing uncertainty information allows users to think about the upcoming situation and take decisions at an earlier stage of time under the constraints of given uncertainties. Is there a paradigm shift from “(re)act-on-observation” to “act-on-forecast” or in other terms a “redefinition of [...] practice from alerts to prediction” (Bruzzone 2015, p. 179) on the ground? The aim of this article is to investigate this topic by analyzing the use of (weather) information by and the present logic of anticipation of the emergency services in Germany and to discuss the findings in relation to the question of how these services deal with forecast uncertainty and weather risks.

To address these questions, we need to know the current emergency services’ practice of dealing with severe weather situations and weather warnings in the sense of anticipating future events. We are mostly interested in learning how emergency managers integrate the weather information or warning (and its imbedded uncertainty) into decision making.

In the following section, we will first introduce the research design and method used for this study (Sect. 2). Section 3 focuses on how weather forecasts and warnings are disseminated to emergency managers by the German national weather service (Deutscher Wetterdienst, DWD) and what actions are taken by the emergency services to anticipate and respond to severe weather, with an emphasis on situation assessments. We discuss the measures taken and the relevance of various information sources like official weather warnings in decision making (Sect. 4), and draw conclusions (Sect. 5).

2 Research Design and Method

This article draws from a set of semistructured interviews that were conducted with 27 members of the civil protection authorities and administrations from the German states of Berlin, Brandenburg, and North-Rhine-Westphalia, as well as from the DWD. The sample reflects the institutional diversity of German severe weather forecasting, civil protection, and emergency management. Participants were selected based on their specific work tasks to reveal new information on the research topic and to help to make sense of their work experience (Froschauer and Lueger 2009; Longhurst 2009; Flick 2012). The following professionals were of special interest: persons who produce and/or issue forecasts and warnings or are responsible for the development and implementation of warning tools (forecasters, meteorologists working at DWD); persons who are responsible for the strategic orientation of civil protection (chiefs of fire departments, representatives of supervisory authorities, associations/unions); and persons who are responsible for the operational deployment of civil protection and emergency management (emergency managers at command and dispatch centers). This selection led to three groups of potential interviewees: (1) firefighters and emergency managers from both city and county levels, who have knowledge about measures and organizational routines based on their own participation and direct observation of organizational practices; (2) members of state or federal authorities who have expertise on organizational contexts based on indirect (or second order) observations (Froschauer and Lueger 2009) of organizational practices; and (3) members of unions, associations, and the DWD who have an external and indirect perspective on organizational routines.¹

The data were collected between 2012 and 2016 as part of the interdisciplinary research project WEXICOM (Weather warnings: from Extreme event Information to COMmunication and action) at Freie Universität Berlin, carried out in the Hans-Ertel-Centre for Weather Research (Simmer et al. 2016). Following common qualitative procedures, interviews were conducted and analyzed in an iterative way in order to react to new developments during the interviews (Flick 2012). The interviews followed a semistructured guideline (Witzel 2000), with a focus on key topics of interest like strategies and measures of dealing with routine and severe weather situations, weather communication tools and content, dealing with uncertainty in weather forecasts, decision thresholds, and lead times.

¹ Please note that all interviewees had experience with several disruptive weather events. Germany regularly experiences severe thunderstorms nationwide during the summer season, with local hailstorms and occasional urban flooding. Severe winter storm events are also common and occur regionally.

All interviewees were informed about the general aim of the research and the funding agency at the beginning of the conversation. Given the sensitivities involved in civil protection and emergency management, confidentiality was important to ensure that interviewees felt safe enough to speak frankly about their experiences (Longhurst 2009). Quotes and paraphrases² are therefore anonymized and contain only the profession and, if necessary, the locality.

A qualitative content analysis approach (Mayring 2015) was applied in an iterative and inductive-deductive process (Schreier 2013) to develop a system of categories and corresponding text segments that appeared to be relevant for further examination. The analysis was performed with the support of MaxQDA software, a program designed for computer-assisted qualitative and mixed methods data, by the first author and co-coded in consensual coding (Kuckartz 2014) together with the second author. In total, 85 codes and sub-codes, with a total of 2341 codings, were assigned.

3 Response to and Anticipation of Severe Weather by Emergency Services in Germany

To make an informed decision on allocating human and material resources, emergency managers need information about future developments of both the weather situation and its potential impacts.

3.1 Dissemination of Weather Information in Germany

Although several private weather companies also provide weather information to the public and special user groups, the DWD is the only agency to issue official warnings by law.³ The DWD regional offices, each covering one or more of the 16 German states, are responsible for producing weather forecasts and issuing warnings for their respective region during daytime (Fig. 1). The DWD functions as the official source of information and should give advice, but it is not responsible for deploying any action based on this information.

Official weather warnings in Germany are organized in a three-step process (Table 1) following an increasingly more sophisticated temporal and spatial resolution:

² All interviews were conducted, transcribed, and coded in German. Paraphrases and codes were finally translated into English by the authors. Interviewee citations are referenced as such.

³ The respective law “*Gesetz über den Deutschen Wetterdienst*” (Law on the German Weather Service) is currently undergoing a revision.

Fig. 1 Schematic map of the German national weather service (Deutscher Wetterdienst, DWD) regional offices in Germany

1. Early warning information (*Frühwarninformation*) on expected severe large-scale weather phenomena, based on numerical models, is integrated by the DWD into a 7-day assessment on the intensity and probability of medium-term weather hazards.
2. A weather watch (*Vorwarninformation*) is issued up to 48–12 h before an expected regional event. These forecasts are provided five times a day with different reports (*Warnlageberichte*) for the whole country, as well as for different regions, to provide users with an overview of the development of the situation (intensification, weakening) within the next 24 h, including

observation data of present events. Besides the regional report a specific severe weather watch (*Vorabinformation Unwetter*) is issued, which should either be followed by a warning or be revoked.

3. Official (severe) weather warnings (*(Un-)Wetterwarnungen*), follow a color code (intensification from yellow, to ochre, red, and purple) and are issued at the municipality level (at the county level until 2016). The lead times depend on the kind of weather event, with a maximum of 12 h. Severe weather warnings are issued for heavy continuous rain, hurricane gale force winds, heavy snowfall, heat, black ice, thaw periods, and thunderstorms. During severe weather situations, updates on the development of the situation are compulsory. No probabilistic information is communicated in terms of numbers. Verbal descriptors are used instead.

DWD forecasters communicate weather warnings to the users as textual information via e-mail and fax, and with additional visual information via the DWD website and a mobile-phone app (*WarnWetter*). Fax is widely regarded as the most secure transmission by the interviewed DWD forecasters and managers because this method allows an acknowledgment of receipt. Because the question remains whether the recipient has noticed the warning regardless of the used tool, it might be appropriate to check via phone whether an urgent warning has been noticed.

Some special government agencies such as flood forecasting offices receive raw meteorological data and model outputs they can include as input into their own hydrological models. Other user groups such as road maintenance services and emergency services have access to special DWD online portals, such as FeWIS (*Feuerwehr Wetterinformationssystem*, fire brigade weather information system) that provide information tailored to their specific region, including up-to-date observational data, satellite and radar imagery, “nowcasting” tools for

Table 1 Official weather warning steps in Germany

Lead Time	> 48 h	12–48 h	0–2 h
Warning	Early Warning Information 'Frühwarninformation'	Weather Watch 'Vorwarninformation'	(Severe) Weather Warnings '(Un-) Wetterwarnungen'
Types of information	7-day assessment 'Wochenvorhersage Wettergefahren'	Reports 'Warnlageberichte'	Official (severe) weather warnings 'Amtliche Warnungen'
Area	Germany	States	Municipality

tracking thunderstorm cells and their movement (KONRAD—KONvektive Entwicklung in RADarprodukten, a software for the automatic detection, tracking, and prediction of storm cells based on weather radar data), and the official textual warning with visual and sound notification.

The warning recipient within an emergency service organization may vary due to organizational structures and responsibilities within the organizations. Within a fire brigade control and dispatch center, for example, the commanding firefighter (*Lagedienst*), who is responsible for overseeing the coordination and deployment of vehicles and personnel, usually receives the warning.

In the conducted study we asked several commanding firefighters about their experiences in handling warnings and weather reports. Surprisingly, they reported that rather traditional ways of communication, like using the telephone services operated by the DWD regional offices, are an essential communication tool. The phone calls serve as an addition to the automatically distributed weather warnings without any direct user contact and provide the possibility of an oral consultation on present and developing weather situations. The DWD ensures that all incoming calls from emergency services have priority status compared to other calls.

Emergency managers in the control and dispatch centers report that they have nonoperational and more organizational duties, and have a gateway role to process and forward the weather warnings. Thus, they serve as information hubs for other authorities:

We are information brokers. We pick up [information] and pass it on. (Commanding firefighter, control and dispatch center, county)

The forwarding of weather-related information usually follows established formal or informal distribution channels to either subordinated or affiliated organizations. The interview partners named several prime examples: weather-related information is forwarded to voluntary fire brigades to be on the alert and prepare themselves for action; to departments of sport and recreation to inform outdoor public sports grounds; to departments of parks to organize pruning work; and to building authorities and public order offices as licensing authorities for outdoor events and venue operators. The information recipients are in most cases decision makers within agencies, but sometimes just receptionists, janitors, or facility managers of governmental buildings who maintain mailing lists for further dissemination. In most cases, the forwarded information does not include weather watches, but is instead limited to the higher threat levels, the official severe weather warnings with the color code red or purple.

We also receive weather watches [...]. However, we cannot jump into action with every notice. Only when we have concrete warnings that give us concrete indications: OK, something is going to happen sometime soon. (Commanding firefighter, control and dispatch center, county)

Forwarding information to local fire stations, subordinate departments, and other governmental agencies aims strongly at inspecting and securing buildings, vehicles, and other assets, for the main purpose of occupational safety or self-protection to avoid any workflow disruption and ensure readiness to act if the weather should affect an agency itself.

3.2 Warning Responses

Warning responses and related decisions on whether to take any protective measures depend on a number of different criteria. In general, the warning response is influenced by the message, the contextual event, and the receiver characteristics (Drabek 1999). Decisions are not singular moments (Hacker and Weth 2012), they must rather be understood as a process of “differentiated, affectively registered, transformative, and ongoing actualisation of potential” (McCormack and Schwanen 2011, p. 2801). Decision making may therefore also work through deferral and denial (Adey and Anderson 2011).

Message characteristics usually refer to the content (hazard, location, time, guidance, and source) and format of the warning message as described above. Event characteristics refer to the hazard’s frequency, its magnitude or (physical) impact, speed of occurrence, length of potential warning lead time, event duration, spatial extent or sphere of action, damage potential, predictability, and controllability (Burton et al. 1993; Alexander 1999; Dikau and Weichselgartner 2005). The interviews revealed that commanding firefighters must transfer every single information aspect about an event into an overall context of action to take decisions:

The decisive factor is the damage, not the strength of the storm. (Commanding firefighter, city)

Such contextual characteristics refer to intervening factors like local topography, demography, building structure, vegetation, and traffic situation, and differ from the characteristics of the event itself. They may vary temporally and spatially, for example, due to the traffic situation during rush hours or seasonal plant cover. In addition, the equipment and characteristics of emergency services may vary considerably, depending on, for example, the size of the work force, the size of the area of operation, and the available (financial and material)

resources. Interviewees from state authorities and county fire departments uniformly reported that demographical change in rural areas, for example, causes problems in their volunteer emergency workforces during the week, as people tend to commute to the city for their regular jobs.

Besides individual risk perception and willingness to act, which are influenced by various factors such as sociodemographics, experience, and cultural background (Mileti and Sorensen 1990; Kox and Thieken 2017), organizational factors affect warning response. They include uncertainty about the (time and place of the) impact and a tendency to wait until a threat materializes; an informational overload during severe events; and a lack of attention due to a high false alarm rate, or an underestimation of risks (George and Holl 1997; Meyer et al. 2010). Limited warning response in cases of a high false alarm rate seems to be more of a problem of expectation than of reality. As some research suggests (Mileti and Sorensen 1990; Dow and Cutter 1998) this does not hold in real life situations as most warning response will follow once the threat is accepted as such. Confronted with the handling of false alarms (due to forecast uncertainty), emergency managers did state their discomfort but indicated that they would respond to the warning. From the interview data, it still seems to be a major concern for commanding firefighters and other emergency managers regarding the warning response of their subordinates or voluntary units.

You can call-in the volunteer fire brigades at any time. Of course, you must do that with a certain delicate touch—you may have also realized that on Thursday they were not so happy because they were not called into action. (Commanding firefighter, control and dispatch center, city)

The firefighters acknowledge the inherent uncertainty of weather forecasts. Emergency services are by profession trained to regard every warning with awareness because they consistently deal with potentially life-threatening situations. Some of them compare a weather warning to a fire detection system. It is common practice that firefighters always respond to the alarm of a fire detection system with the necessary power of force (vehicles, personnel, equipment) as if there is a fire, although in many cases detection systems give false alarms.

You have to take every [warning] message seriously. When a fire detection system is activated, it is generally assumed that there is a fire and we will trigger an alarm immediately. Even if the system triggered false alarms three times on the same day [...]. You have to deal with weather reports quite similarly, you do not know what is happening, you must always take [the potential consequences] into consideration.

(Commanding firefighter, control and dispatch center, county)

The consequences of not responding to an alarm or responding with less commitment and thus fewer vehicles, less personnel, and less equipment, would be too costly. It could ultimately result in the fire spreading, leaving many people injured or possibly dead. Therefore, in such cases of life and death, even a high degree of uncertainty about the event taking place would be sufficient to take action. This attitude is comparable to the treatment of weather warnings and, in exceptional cases, may lead to a very preemptive approach to forecast uncertainty as some commanding firefighters reported:

When I get a [warning] message, I start the full program. Then I am also on the safe side. (Commanding firefighter, control and dispatch center, city)

3.3 Measures Taken by Emergency Management

Emergency management in Germany follows the principles of federalism and subsidiarity and is organized at the county level (Fig. 2). Counties and major cities are responsible for everyday and less severe events like local fires, small accidents, and regular ambulance services. In weather-related situations, preparatory actions taken by emergency management prior to a disruptive event will typically include closing windows, inspecting roofs, scaffolds, and culverts, and tying up loose objects on the premises, mainly for self-protection and to avoid any surprises or disruptions of the workflow. All this applies only to public spaces and buildings. At this level of severity, private actors, for example local outdoor venue operators, are responsible for making their own decisions on which actions to take.

During a weather event, measures predominantly aim at coping with the disruptions caused, that is, securing damaged buildings and infrastructure, pumping water from cellars, (un)blocking access to streets and public places, and so on. Most of these actions are reactive, meaning that the firefighter units receive alerts from their control and dispatch center to respond to the damage because warnings can only lead to preparative measures in the sense of preparing for action:

You can only prepare. Trees cannot be sawn off beforehand for safety reasons. That does not work. And I can only pump water away when it has flooded. (Commanding firefighter, control and dispatch center, county)

Preparing means that fire brigade control and dispatch centers have the duty to notify their units during an event.

Fig. 2 Schematic illustration of civil protection and emergency management in Germany
 Source: Based on Geier (2017)

Once a center receives an emergency call, it must decide which units from which area will be alerted and sent to scenes of action. To not reach the units' limits,⁴ measures are generally only taken immediately if the alerts imply a threat to life and property.

What is important are the things that [...] represent an imminent threat or disturb infrastructures. Such things must be removed immediately. A tree on a forest path can be left there for three days. That will not bother anyone much. (Commanding firefighter, control and dispatch center, county)

The commanding firefighter has the duty to oversee the situation within his or her area of responsibility, usually a city or county to ensure and maintain the ability to act. If necessary, that means prioritizing missions (the right balance of the best mitigation with the available resources), reallocating staff, vehicles, and technical equipment, and calling-up off-duty units or extending the length of service. In severe weather situations and with an increasing number of missions,⁵ interviewees reported that it might also be necessary to adjust operational procedures to ensure the statutory response time. Typical adjustments to the alarm and response regulations include prioritizing specific alarm keywords, bundling missions by location, reducing the obligatory number of vehicles to deploy, and adjusting the obligatory number of people on a vehicle.

If we do not have the necessary means in that situation, then, obviously, we cannot address the missions

in time. That's the consequence. (Commanding firefighter, control and dispatch center, city)

While some commanding officers reported that they would begin to call in off-duty staff at the ochre warning level, others would only begin at a red or purple level. This type of pre-alarm is both a physical stand-by and a mental preparation and usually takes less than 1 h. The so-called "cold situation" (commanding firefighter, control and dispatch center) involves non-personnel preparatory measures concerning vehicles and equipment (for example, submersible pumps or chainsaws) and personnel preparatory measures like calling in additional dispatchers to the command center, reallocating staff within the jurisdiction, or activating special units like wild fire units. Some fire brigades report that they make use of "scouts" (*Erkunder*), usually one person (with emergency management qualification) in a small vehicle. That person takes a closer look at the reported disruption and decides whether (and with what priority) or not any actions should be taken if the information provided by the emergency call remains uncertain. Not all fire brigades take such stand-by measures, and they are more common in cities than in rural areas. During an event it might be necessary to issue a second alarm, which means extending personnel's length of service, reallocating personnel, or calling in off-duty units and volunteer firefighters.

Some of the measures are formalized in operational plans and special guidelines for actions during severe weather situations.⁶ These plans specify the measures for different alert levels based on an event's magnitude (wind

⁴ For example, not being able to make the statutory response time between receiving an emergency call or alert and arriving on the scene.

⁵ This does not indicate a declaration of a state of emergency.

⁶ One example is the 2002 guideline "*Umgang mit Wetterwarnungen*" (Dealing with Weather Warnings) of the German Fire Protection Association (GFPA)/Vereinigung zur Förderung des Deutschen Brandschutzes (vfdb).

speed, water level) or the extent of impact (number of casualties, number of deployed personnel). However, not all departments have such plans prepared and available, and some organizations have developed their own, often unformulated, procedures based on experience. A typical example of a general guideline is the “*Feuerwehr Dienstvorschrift 100*” (FwD100), a regulation or manual best compared with the U.S. Incident Command System (Bigley and Roberts 2001). The FwD100 provides guidance for management, coordination, and control of mass-casualty incidents and other emergencies. Such plans regulate how information is processed, what actions are taken, and who is responsible. Like Bigley and Roberts (2001) show for the U.S. Incident Command System, the FwD100 is not a rigid framework. Rather it is adaptive, very loosely worded, providing room for interpretation and allowing flexibility (Ellebrecht and Jenki 2014).

3.4 Situation Assessment: Collecting Weather and Impact Information

The interviewees reported different sources for situation assessment. In addition to weather warnings, news broadcasts, personal contacts, and emergency calls provide relevant information for situation assessment. The interviewed commanding firefighters emphasized that a comprehensive situation assessment is of paramount importance for preparing their response:

The fire brigade’s response does not depend on the warning, but on the assessment [of the situation].
(Commanding firefighter, state)

The term “situation” usually refers to the period shortly after or during an event when the responders have to deal with the impact. The assessment, therefore, includes all available information about the current and future weather development, as well as the current impact, that is, the damage and disruptions caused. If early signs of a potential disruptive event are visible beforehand, it is desirable that the assessment should start at an earlier point in time.

We always try to get a bit ahead of the situation by collecting information, evaluating different networks, to have information early on, preferably before an event. (Commanding firefighter, control and dispatch center, county).

In addition to the DWD information described above, the responsible officers in the control and dispatch centers use weather reports on TV, radio, or the Internet. If the weather situation is uncertain, or the initial information or warning text is unclear, some emergency managers stated that they contact the weather service’s regional office for further advice. The consulting service offered by the

meteorologists from the regional offices is a low-threshold service as described above and the additional information often serves as a decision template.

[...] having an expert explain it properly once again. Is it as I think it is, or will it develop a bit differently? It is more about getting confirmation. None of us are [weather] professionals. (Commanding firefighter, control and dispatch center, city)

Some interviewees reported that they prefer to consult their “own sources.” This includes units on patrol, who are potentially more exposed to the weather, or local ambulance helicopter crews, who get specific flight weather data that contains more detailed information. In addition, some interviewees indicated that their own exposure to the weather, either during work shifts or during their leisure time, contributes in some way to the assessment and verifies the current weather situations by simply “looking out of the window” (state police officer) or “feeling the mugginess” (commanding firefighter).

During an event, situation assessment builds on additional information about impacts. In the case of a major event, media coverage will soon start after the first disruptions become visible. The commanding firefighters reported that they begin to pay more attention to the news to gain information about what is going on outside. Additionally, they may contact other fire stations further upstream of a storm track that might already be affected by the event and mirror the impending impacts to their own region by extrapolating the (thunder-) storm (cell) track on the precipitation radar or KONRAD.

And if something is approaching from the west, it would be interesting to know how it looks right now in [name of city]. And if we learn from the control center that they are being deluged, the chance is relatively high that it will also happen to us. That would be reliable information. (Commanding firefighter, control and dispatch center, city)

Local impact information is based mainly on mission reports and emergency calls. Usually, (written) mission reports provide ex post facto information about an event, its impacts, and an analysis of the coping measures. They fulfill the purpose of post-processing and training. Conversely, ad hoc reports, based on local situation assessment and feedback from local officers-in-charge, can provide ground truth about the impact during an event. “Scout” reports, although not considered as missions per se, fulfill the same objective. In addition, most control and dispatch centers have information technology that provides them with information about the occupancy of their vehicles. Such information is primarily used to adjust measures if not enough capacities are on hand to respond within the

statutory response time. However, occupancy information is also a good indicator of impact.

Similarly, emergency calls have two different features: They are both a source of information about the impacts, and, because of the event, a disruptive impact (of the daily routine) for the emergency services themselves. The number of emergency calls varies in space and time. The interviewees reported that there are regional differences (for example, city-rural) in when and how often people make an emergency call, and temporal differences between day and night. Especially damages to property, like loose roof tiles or flooded cellars, are often not recognized after dusk and reported only in the morning. Another peak in calls occurs in the late afternoon when people come home from work.

4 Discussion

As shown, apart from the coordination and deployment of missions as a response to an event, most measures taken prior to or during emergencies aim to achieve and maintain an organization's ability to act. While long- and medium-term warnings and weather watches enable emergency organizations to prepare for responding to a potential event, short-term warnings, nowcasting, and regularly updated observational data of the ongoing event enables an organization to act accordingly during an event. Providing information on meteorological uncertainty, such as the probability of rain or the probability of exceeding a certain threshold such as a warning level, makes it possible to deviate from the temporal restrictions of official warnings and to provide information on possible events already in the temporal domain of a weather watch. This allows forecasters "to derive products tailored to specific customers" (Stuart et al. 2006, p. 2). The desired benefit is that this enables end-users of forecast information to start sooner with preparatory protective action based on the end-user's own risk assessment and decision threshold. However, those developments in meteorology and weather forecasting do not necessarily fit the current practices of the emergency services, that is, rescue and firefighting, as the presented results show. These practices are still mostly carried out based on alarms and ground truth in a superficial reactive manner, rather than through anticipation based on prognosis or forecasts. This is mainly because the specific characteristics of the basic tasks of rescue and firefighting are not predictable per se. Or as Apelt (2014) pointed out, it is unpredictable at what intervals a fire must be extinguished and people must be saved. Demeritt et al. (2013, p. 154) raised more institutional concerns when they linked "legalistic traditions of expert management" with the "tendency to wait for confirmation before acting on

medium-term alerts from EPS." Nonetheless, in the data there are several examples of anticipatory action, including preparatory measures of personnel planning and deployment of equipment. Other measures show signs of a both proactive and reactive character that is preparedness and response. Actions like pre-alarm and adjustments to operational procedures are preparatory—they enable the preparedness to respond. At the same time these actions are reactive, because they are only taken as a response to a manifested event, when a level of tolerance is exceeded (that is, the number of emergency calls, deployments, or missions), or as a response to first indications for an event, more exactly a particular probability of occurrence or a warning level.

That does not mean that emergency services take measures only if the impacts reach a certain threshold of tolerance. In contrast, it seems that most kinds of actions take place almost all the time during the development of an event as they compare their different information sources. Severe weather events are a common hazard and there is a consciousness and knowledge about what might happen as the potential impact of such an event. In general, reactive behavior seems to be due to the self-understanding of the organization since it has to be lightly "proactive" when it is permanently on stand-by, ready for an alarm and ready to act. Likewise, Demeritt et al. (2013, p. 154) argued in the context of European flood forecasting that one reason "agencies have sometimes set quite high confidence thresholds for issuing flood warnings is that their statutory responsibility is public safety." Thus, they focus on short-term warnings to support response measures such as public evacuations, rather than on medium-term forecasting in supporting mitigation (Demeritt et al. 2013). It seems that in this context, the weather warning only serves as confirmation of what is already planned and decided on.

As outlined in the introduction, weather information always includes uncertainty, including about the expected place and time of occurrence, the intensity of an event, the extent of impacts, and the warning response. In addition, there is uncertainty concerning issues of misunderstanding and misinterpretation of the warning message content.

The interviews reveal two different approaches to dealing with uncertainty. First, there is a recognition of hazards and uncertainties, which results in a temporizing or observant and rather reactive behavior, and adaptive coping measures. Such adaptive behavior aims mostly at the preservation of the organization's function to ensure the preparedness to respond and the organization's ability to act in a timely manner. This aim is also reflected in the significance of occupational safety for decision making and the choice of measures. Emergency services will always protect themselves first to be able to help others. This behavior is typically found in routine and often trained

situations. When receiving a warning, commanding firefighters, police officers, and other emergency managers cope with uncertainty by collecting, comparing, and blending different information about the uncertain event and its uncertain outcomes within the situation assessment to validate the information.⁷ However, even if misinterpretations of weather forecasts are revised, uncertainty about the potential outcome and thus the controllability of response measures always remains. To combat this uncertainty, emergency managers stated that they consult different sources in addition to the DWD meteorologists. Some commanding firefighters consult colleagues upstream of a storm track to gain ground-truth evidence of impacts that have occurred there and try to extrapolate this to their own region to anticipate potential impacts. These findings are in line with other studies on collaborative cross-checking and confirmation-seeking in emergency management (Baumgart et al. 2006; Demeritt et al. 2013).

The second approach can be described as a “zero-risk strategy,” in which even the lowest probability of occurrence is too much of a risk and thus has to be avoided. This is mainly due to the nature of most of the potential hazards emergency services have to deal with: They can always lead to deaths. Another reasonable explanation is the self-understanding of the organizations as ensuring public safety and responding adequately to any given risks. Therefore, such preemptive behavior can be found especially with regard to high-magnitude, low-frequency events with known but potentially catastrophic consequences, such as fire. The usual way of responding to the automatic alarm of a fire detection system in a school building or a tower block is a typical example that was repeatedly noted by the interview partners. In these situations, “when failure isn’t an option” (Hillmann et al. 2005), not acting on a warning is seen as a risk not worth taking. Even if it is recognized that—despite all measures—the attempt to generate maximal safety is an illusion, the principle “better safe than sorry” prevails. Or in the words of Adey and Anderson (2011, p. 2884): “Within the logic of preparedness, harm may be a consequence of something done or not done in response.”

While measures of preparedness are based on warnings, most actions occur as a response to or during an event and are mainly based on observational weather data and ground truth. This includes measurements like wind speed or the amount of precipitation, impact reports from neighboring

communities, fire brigades and media broadcasts, traffic reports or by noting the increased operational pressure and thus personnel expenditures due to an increase in emergency calls and missions. In these cases, the problem is not the weather event itself, but rather that other non-weather-related missions (responding to a heart attack, stroke, and so on) have to stand in line and face possible delay. Due to the additional expenditures, the weather event makes it even harder to fulfill these core duties. It seems that the characteristics of the specific weather phenomena, that is, whether the precipitation results from a large-scale event or from a small-scale convective event, do not play a key role from the emergency-management perspective. The decisions and measures rather depend on the impact, not on the precipitation itself, but on flooded basements, overflowed streets and overflowing sewer systems that cause the disruption to the organizational routines.

5 Conclusion

These findings support the need for impact-based warnings. Concentrating on the importance of communicating weather impacts rather than characteristics of events alone points away from a process-oriented toward an impact-oriented situation assessment. Additionally, a shift from deterministic to probabilistic weather warnings would emphasize preparedness in risk management. This would mean accepting uncertainty and dealing with weather hazards in an adaptive manner. The so-called warn-on-forecast paradigm is one explicit example for anticipating the future around disruptive severe weather events. Such a transition in warning behavior of national weather services would also imply a paradigm change concerning the current practice of response to weather warnings for most emergency organizations. Only then could emergency managers benefit from longer lead times.

Acknowledgements This research was carried out in the Hans-Ertel-Centre for Weather Research. This research network of universities, research institutes, and the Deutscher Wetterdienst is funded by the BMVI (Federal Ministry of Transport and Digital Infrastructures). The authors would like to thank all interview partners for their time and efforts. The research design was outlined by the first and third author. The interviews were conducted by the first author, coding was handled by the first and second author. The theoretical framework and the discussion of the results were written by the first author.

Open Access This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

⁷ As shown, decision makers may as well base their weather-related decision making on private life situations, as non-extreme weather events are daily experiences, and the confidence in the weather forecast is often proven and can be self-verified moments later. However, even emergency managers, especially in most parts of Europe, are seldom exposed to very extreme weather events like tornados (Doswell 2003).

References

- Adey, P., and B. Anderson. 2011. Event and anticipation: UK civil contingencies and the space—times of decision. *Environment and Planning A: Economy and Space* 43(12): 2878–2899.
- Alexander, D. 1999. *Natural disasters*. London: UCL Press.
- Alexander, D. 2000. *Confronting catastrophe: New perspectives on natural disasters*. Harpenden: Dunedin Academic Press.
- Anderson, B. 2010. Preemption, precaution, preparedness: Anticipatory action and future geographies. *Progress in Human Geography* 34(6): 777–798.
- Anderson, B. 2016. Governing emergencies: The politics of delay and the logic of response. *Transactions of the Institute of British Geographers* 41(1): 14–26.
- Apelt, M. 2014. Organizations of emergency and rescue: An introduction from an organizational and sociological perspective (*Organisationen des Notfalls und der Rettung: Eine Einführung aus Organisationssoziologischer Perspektive*). In Organizations and experts of emergency: On the transformation of technology and culture in the fire and rescue services (*Organisationen und Experten des Notfalls: Zum Wandel von Technik und Kultur bei Feuerwehr und Rettungsdiensten*), ed. M. Jenki, N. Ellebrecht, and S. Kaufmann, 69–84. Berlin: LIT Verlag (in German).
- Baumgart, L.A., E.J. Bass, B. Philips, and K. Kloesel. 2006. Emergency management decision-making during severe weather. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 50(3): 381–385.
- Bigley, G.A., and K.H. Roberts. 2001. The incident command system: High-reliability organizing for complex and volatile task environments. *Academy of Management Journal* 44(6): 1281–1299.
- Bruzzone, S. 2015. Risk forecast as work practice: Between codified and practical knowledge. *Journal of Risk Research* 18(2): 170–181.
- Burton, I., R.W. Kates, and G.F. White. 1993. *The environment as hazard*, 2nd edn. Hoboken: Guilford Press.
- Clausen, L., and W.R. Dombrowsky. 1984. Warning practice and warning logic (*Warnpraxis und warnlogik*). *Zeitschrift für Soziologie* 13(4): 293–307 (in German).
- Cornell, S.E., and M.S. Jackson. 2013. Social science perspectives on natural hazards risk and uncertainty. In *Risk and uncertainty assessment for natural hazards*, ed. J. Rougier, S. Sparks, and L.J. Hill, 502–547. Cambridge: Cambridge University Press.
- Créton-Cazanave, L., and C. Lutoff. 2013. Stakeholders' issues for action during the warning process and the interpretation of forecasts' uncertainties. *Natural Hazards and Earth System Science* 13(6): 1469–1479.
- Daase, C. 2011. The politics of risk and the illusion of predictability (*Risikopolitik und die Illusion der Berechenbarkeit*). *Zeitschrift für Politikwissenschaft* 21(3): 479–485 (in German).
- de Goede, M., and S. Randalls. 2009. Precaution, preemption: Arts and technologies of the actionable future. *Environment and Planning D: Society and Space* 27(5): 859–878.
- Demeritt, D., S. Nobert, H. Cloke, and F. Pappenberger. 2010. Challenges in communicating and using ensembles in operational flood forecasting. *Meteorological Applications* 17(2): 209–222.
- Demeritt, D., S. Nobert, H. Cloke, and F. Pappenberger. 2013. The European flood alert system and the communication, perception, and use of ensemble predictions for operational flood risk management. *Hydrological Processes* 27(1): 147–157.
- Dikau, R., and J. Weichselgartner. 2005. The restless planet. Man and the forces of nature (*Der unruhige Planet. Der Mensch und die Naturgewalten*). Darmstadt: Primus Verlag (in German).
- Doswell, C. 2003. Societal impacts of severe thunderstorms and tornadoes: Lessons learned and implications for Europe. *Atmospheric Research* 67–68: 135–152.
- Dow, K., and S.L. Cutter. 1998. Crying wolf: Repeat responses to hurricane evacuation orders. *Coastal Management* 26(4): 237–252.
- Drabek, T.E. 1999. Understanding disaster warning responses. *The Social Science Journal* 36(3): 515–523.
- Edwards, C. 2009. *Resilient nation*. London: Demos.
- Ellebrecht, N., and M. Jenki. 2014. Organizations and experts of emergency: A research overview (*Organisationen und Experten des Notfalls: Ein Forschungsüberblick*). In Organizations and experts of emergency: On the transformation of technology and culture in the fire and rescue services (*Organisationen und Experten des Notfalls: Zum Wandel von Technik und Kultur bei Feuerwehr und Rettungsdiensten*), ed. M. Jenki, N. Ellebrecht, and S. Kaufmann, 11–48. Berlin: LIT Verlag (in German).
- Fine, G.A. 2007. *Authors of the storm: Meteorologists and the culture of prediction*. Chicago: University of Chicago Press.
- Flick, U. 2012. Design and process of qualitative research (*Design und Prozess qualitativer Forschung*). In Qualitative research: A handbook (*Qualitative Forschung: Ein Handbuch*), 9th edn., ed. U. Flick, E. von Kardorff, and I. Steinke, 252–265. Reinbeck bei Hamburg: Rowohlt (in German).
- Froschauer, U., and M. Lueger. 2009. Expert talks in interpretive organization research (*ExpertInnengespräche in der interpretativen Organisationsforschung*). In Expert interviews: Theory, methods, fields of application (*Experteninterviews: Theorien, Methoden, Anwendungsfelder*), ed. A. Bogner, B. Littig, and W. Menz, 239–258. Wiesbaden: Verlag für Sozialwissenschaften (in German).
- Geier, W. 2017. Structures, responsibilities, tasks and actors (*Strukturen, Zuständigkeiten, Aufgaben und Akteure*). In Civil protection: Emergency preparedness and crisis management in theory and practice (*Bevölkerungsschutz: Notfallvorsorge und Krisenmanagement in Theorie und Praxis*), ed. H. Karutz, W. Geier, and T. Mitschke, 93–128. Berlin, Heidelberg: Springer (in German).
- George, A.L., and J.E. Holl. 1997. *The warning-response problem and missed opportunities in preventive diplomacy. A report to the Carnegie Commission on preventing deadly conflict*. New York: Carnegie Corporation of New York.
- GDV (Gesamtverband der Deutschen Versicherungswirtschaft e. V.) 2016. Natural hazards report 2016: The damage timeline in numbers, voices and events by the German insurers (*Naturgefahrenreport 2016: Die Schaden-Chronik der deutschen Versicherer in Zahlen, Stimmen und Ereignissen*). Berlin (in German).
- Hacker, W., and R. von der Weth. 2012. Thinking-deciding-acting (*Denken - Entscheiden - Handeln*). In *Human factors*, 2nd edn, ed. P. Badke-Schaub, G. Hofinger, and K. Lauche, 83–99. Dordrecht: Springer (in German).
- Hillmann, M.R., P. Dongier, R.P. Murgallis, M. Khosh, E.K. Allen, and R. Evernham. 2005. When failure isn't an option. *Harvard Business Review* 83: 7–8.
- Hirschberg, P.A., E. Abrams, A. Bleistein, W. Bua, L.D. Monache, T.W. Dulong, J.E. Gaynor, B. Glahn, T.M. Hamill, J.A. Hansen, D.C. Hilderbrand, R.N. Hoffman, B.H. Morrow, B. Philips, J. Sokich, and N. Stuart. 2011. A weather and climate enterprise strategic implementation plan for generating and communicating forecast uncertainty information. *Bulletin of the American Meteorological Society* 92(12): 1651–1666.
- Hoekstra, S., K. Klockow, R. Riley, J.A. Brotzge, H.E. Brooks, and S. Erickson. 2011. A preliminary look at the social perspective of Warn-on-Forecast: Preferred tornado warning lead time and the

- general public's perceptions of weather risks. *Weather, Climate and Society* 3(2): 128–140.
- Hutter, B.M. 2010. Anticipating risk and organising risk regulation: Current dilemmas. In *Anticipating risks and organising risk regulation*, ed. B. Hutter, 3–22. Cambridge: Cambridge University Press.
- Klinke, A., and O. Renn. 2002. A new approach to risk evaluation and management: Risk-based, precaution-based, and discourse-based strategies. *Risk Analysis* 22(6): 1071–1094.
- Kox, T., and A.H. Thieken. 2017. To act or not to act? Factors influencing the general public's decision about whether to take protective action against severe weather. *Weather, Climate and Society* 9(2): 299–315.
- Kox, T., L. Gerhold, and U. Ulbrich. 2015. Perception and use of uncertainty in severe weather warnings by emergency services in Germany. *Atmospheric Research* 158–159: 292–301.
- Kuckartz, U. 2014. Qualitative content analysis. Methods, practice, computer support (*Qualitative Inhaltsanalyse. Methoden, Praxis, Computerunterstützung*), 2nd edn. Juventa Paperback. Weinheim: Beltz Juventa (in German).
- Longhurst, R. 2009. Interviews: In-depth, semi-structured. In *International encyclopedia of human geography*, ed. N.J. Thrift, and R. Kitchin, 580–584. Amsterdam, London, and Oxford: Elsevier.
- Mayring, P. 2015. Qualitative content analysis. Foundations and techniques (*Qualitative Inhaltsanalyse. Grundlagen und Techniken*), 12th edn. Weinheim, Basel: Beltz (in German).
- McCormack, D.P., and T. Schwanen. 2011. The space—times of decision making. *Environment and Planning A* 43(12): 2801–2818.
- Meyer, C.O., F. Otto, J. Brante, and C. de Franco. 2010. Recasting the warning-response problem: Persuasion and preventive policy. *International Studies Review* 12: 556–578.
- Mileti, D.S., and J.H. Sorensen. 1990. *Communication of emergency public warnings: A social science perspective on state of the art assessment*. No. ORNL-6609. Oak Ridge, TN: Oak Ridge National Laboratory.
- Mileti, D.S. 1995. Factors related to flood warning response. U.S.-Italy Research Workshop on the Hydrometeorology, Impacts, and Management of Extreme Floods. Perugia (Italy), November 1995. <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.322.4179&rep=rep1&type=pdf>. Accessed 28 Feb 2017.
- NRC (National Research Council). 2006. *Completing the forecast: Characterizing and communicating uncertainty for better decisions using weather and climate forecasts*. Washington, DC: National Academies Press.
- Neisser, F., and S. Runkel. 2017. The future is now! Extrapolated riskscapes, anticipatory action and the management of potential emergencies. *Geoforum* 82: 170–179.
- Neisser, F.M. 2014. 'Riskscapes' and risk management—Review and synthesis of an actor-network theory approach. *Risk Management* 16(2): 88–120.
- NOAA (National Oceanic and Atmospheric Administration). 2015. Warn on forecast. <http://www.nssl.noaa.gov/projects/wof/>. Accessed 28 Nov 2016.
- O'Grady, N. 2015. Data, interface, security: Assembling technologies that govern the future. *Geoforum* 64: 130–137.
- Schreier, M. 2013. *Qualitative content analysis in practice*. London: Sage.
- Simmer, C., G. Adrian, S. Jones, V. Wirth, M. Göber, C. Hohenegger, T. Janjić, J. Keller, C. Ohlwein, A. Seifert, S. Trömel, T. Ulbrich, K. Wapler, M. Weissmann, J. Keller, M. Masbou, S. Meilinger, N. Reiß, A. Schomburg, A. Vormann, and C. Weingärtner. 2016. HERZ: The German Hans-Ertel Centre for Weather Research. *Bulletin of the American Meteorological Society* 97(6): 1057–1068.
- Simmons, K.M., and D. Sutter. 2008. Tornado warnings, lead times, and tornado casualties: An empirical investigation. *Weather and Forecasting* 23(2): 246–258.
- Stensrud, D.J., M. Xue, L.J. Wicker, K.E. Kelleher, M.P. Foster, J.T. Schaefer, R.S. Schneider, S.G. Benjamin, S.S. Weygandt, J.T. Ferree, and J.P. Tuell. 2009. Convective-scale warn-on-forecast system: A vision for 2020. *Bulletin of the American Meteorological Society* 90(10): 1487–1499.
- Stensrud, D.J., L.J. Wicker, M. Xue, D.T. Dawson II, N. Yussouf, D.M. Wheatley, T.E. Thompson, N.A. Snook, T.M. Smith, A.D. Schenkman, C.K. Potvin, E.R. Mansell, T. Lei, K.M. Kuhlman, Y. Jung, T.A. Jones, J. Gao, M.C. Coniglio, H.E. Brooks, and K.A. Brewster. 2013. Progress and challenges with Warn-on-Forecast. *Atmospheric Research* 123: 2–16.
- Stewart, T.R., R. Pielke, and R. Nath. 2004. Understanding user decision making and the value of improved precipitation forecasts: Lessons from a case study. *Bulletin of the American Meteorological Society* 85(2): 223–235.
- Stuart, N.A., P.S. Market, B. Telfeyan, G.M. Lackmann, K. Carey, H.E. Brooks, D. Nietfeld, B.C. Motta, and K. Reeves. 2006. The future role of the human in an increasingly automated forecast process. *Bulletin of the American Meteorological Society* 87(11): 1–6.
- Suskind, R. 2007. *The one percent doctrine: Deep inside America's pursuit of its enemies since 9/11*. New York: Simon & Schuster Paperbacks.
- UNISDR (United Nations International Strategy for Disaster Reduction). 2009. Terminology on disaster risk reduction. http://www.unisdr.org/files/7817_UNISDRTerminologyEnglish.pdf. Accessed 20 Feb 2017.
- Weichselgartner, J. 2002. Natural dangers as social construction. A geographical observation of the social discussion of natural risks (*Naturgefahren als soziale Konstruktion. Eine geographische Beobachtung der gesellschaftlichen Auseinandersetzung mit Naturrisiken*). Aachen: Shaker Verlag (in German).
- Wernli, H. 2012. Weather, chaos, and probabilistic weather forecasts (*Wetter, Chaos und probabilistische Wettervorhersagen*). *promet* 37(3): 3–11 (in German).
- Witzel, A. 2000. Das problemzentrierte Interview. *Forum: Qualitative Social Research* 1(1): Article 22.