Adv. Sci. Res., 19, 97–103, 2022
https://doi.org/10.5194/asr-19-97-2022

Advances in Science & Research
Open Access Proceedings

Requirements for the use of impact-based forecasts and warnings by road maintenance services in Germany

Jasmina Schmidt[1,2], **Nikola Tietze**[1,2], **Lars Gerhold**[1,2], **and Thomas Kox**[2,3]

[1]Working Group Interdisciplinary Security Research, Freie Universität Berlin, 12165 Berlin, Germany
[2]Hans-Ertel-Centre for Weather Research, 12165 Berlin, Germany
[3]Department of Geography, Ludwig-Maximilians-Universität Munich, 80333 Munich, Germany

Correspondence: Jasmina Schmidt (jasmina.schmidt@fu-berlin.de)

Received: 11 February 2022 – Revised: 22 August 2022 – Accepted: 23 August 2022 – Published: 2 September 2022

Abstract. Impact-based forecasts and warnings (IBFs) are seen as important drivers for adequate anticipation and assessment of potential threats to public safety as they give a better understanding of the weather event's impacts. To prepare for impacts of weather events and prevent weather-related accidents, road maintenance services are actively using weather information in their daily work routine. This paper looks into the requirements that road maintenance services have for IBFs and how weather forecasts are used at the moment. The study is part of an interdisciplinary research project and follows a qualitative social science research approach. Findings show that the following factors are general user requirements: relevance of information, recognition of spatial and temporal requests, acceptability, comprehensibility, and technical demands. These are also applicable to IBFs with the extension to provide a benefit for road maintenance services in situations that rarely occur and where no embodied knowledge in the organization is existent.

1 Introduction

Road transportation is considered the most vulnerable mode of transport in terms of weather impacts (Molarius et al., 2014). Extreme weather events like winter storms, heavy rain, or black ice can have a significant impact on driving conditions and thus, on the safety of road users. The vulnerability of the road sector stems from the high and hardly controllable traffic volume on roads (e.g. number of cars on a specific public and freely accessible road at the same time) compared to other modes of transport, for instance in air traffic, where a management centre decides upon the number of planes taking off and landing. Additionally, road transportation is mostly a slow self-adjusting, geographically widespread, and dispersed system, whereas for example air traffic control or rail traffic management can make centralized decisions and adjustments (Kiel et al., 2016, p. 73). In Germany, an estimated 8 % of all accidents on roads are weather-related or caused by an obstacle on the road (Statistisches Bundesamt, 2018). Additionally, seasonal and daily changes in traffic volume or commuter flows influence the occurrence of accidents as the accident probability rises with more vehicles on the road.

The responsibility to assure safe roads lies in the hands of public road maintenance services. Their main tasks include measures for the immediate repair of damage to the road and road structures, which could affect traffic safety and the timely clearing and gritting of roads during wintertime. They use weather information to prepare for weather events, especially for planning personnel and adjusting equipment. The maintenance service depots may differ in terms of personnel and equipment varying from having 24/7 standby to relying on contractors. Weather information for road maintenance services in Germany is provided through the road condition and weather information system (SWIS) by the German weather service *Deutscher Wetterdienst* (DWD). It contains data of air temperature, road temperature, precipitation, and condition of the road (e.g. dry, wet; see Fig. 1) as well as written reports, and "provides observations and associated road weather forecasts at around 1500 German road weather stations, with a 27 hrs lead time" (Fundel et al., 2019, p. 218). This information gives a clear overview of the weather condi-

Published by Copernicus Publications.

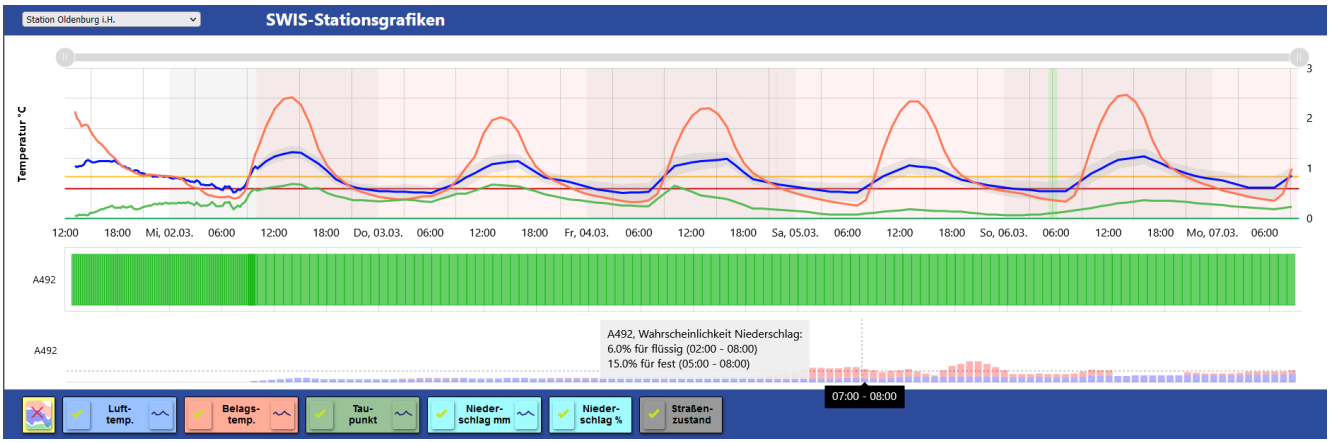

Figure 1. Screenshot of SWIS showing data for the city Oldenburg i.H. including air temperature (blue), road temperature (orange), dew point (green), precipitation (light blue; not visible here because too little precipitation forecasted) in the upper panel, condition of the road (green indicating dry conditions) in the middle panel, and probability of precipitation in the lower panel; © Deutscher Wetterdienst.

tions on the roads but not what impacts those conditions can have on traffic and road safety. This gap could be filled by using impact or impact-based forecasts and warnings (IBFs). They constitute a shift from providing meteorological conditions alone to weather forecasts that incorporate information about impacts linked to the meteorological conditions (Kox and Lüder, 2021; Potter et al., 2018; World Meteorological Organization, 2015). IBFs are associated with a better understanding of the warnings as well as an increased intention to take protective action (Casteel, 2016). Potter et al. (2018) also show that using IBFs lead to a higher perception of risk among the public than phenomenon-based warnings. Kox et al. (2018a) state that information about traffic obstructions caused by weather events can be helpful support for action for emergency services due to its practical relevance. Although weather impacts are a major trigger for weather related decision-making among emergency services (Kox and Lüder, 2021), Potter et al. (2018) could not observe that IBFs lead to a higher level of action among the public.

Therefore, it is necessary to take a closer look at the relation between weather forecasts and warnings, actual weather impacts and warning responses. To achieve a higher level of action in response to weather warnings, information is needed about the actual end-user requirements. The research question addressed in this paper is: what are the needs and requirements of road maintenance practitioners in Germany regarding to the future implementation of IBFs and how are weather forecasts currently used. To answer this question, focus group discussions and semi-structured interviews were conducted with highway and road maintenance service managers as well as representatives of road and transport authorities, following an exploratory approach. The study is part of an ongoing interdisciplinary research project in collaboration with the DWD and follows a qualitative social science research approach. In the following sections we introduce the methods used in this study, show the results and draw conclusions.

2 Methods

For this study, three focus group discussions (12 people in total) and additional 10 semi-structured interviews with highway and road maintenance service managers and representatives of road and transport authorities were carried out between October 2020 and December 2021. Due to contact restrictions caused by the COVID-19 pandemic, they were held as video conferences or by telephone. Participants were selected from various road maintenance depots and linked authorities. The participants and their road maintenance depots differ in terms of local topography and the likelihood of regional weather events (e.g. heavy snowfall or rain, landslides, floods), as well as different organizational settings such as road types and size of area of responsibility, and thus the potential traffic volumes. Focus group discussions and interviews revolved around the topics of the role of weather in their work practices, the use of weather information, practices to prepare for and prevent impacts of extreme weather events, and experiences with extreme weather events. The collected data was analysed following a structuring content analysis to reduce the amount of material related to the key aspects of the discussions in an iterative process.

3 Results

Based on workshops with meteorologists and members of different professional end-user groups in Germany, Kox et al. (2018b) identified the following general user requirements that could improve the communication of weather forecasts and warnings: relevance of information, recognition of spatial and temporal requests, acceptability, comprehensibility

and technical requirements. This section describes the key requirements and needs formulated by the interviewed road maintenance managers and is structured by the categories mentioned above.

3.1 Relevance of information

"Weather determines our work" – this quote from an interview with a road maintenance manager puts into perspective why weather information has such relevance to road maintenance services. Weather influences road managers' short- and long-term work practices and decision making, for example in summer the rainfall radar data affects the decision whether general road maintenance can be conducted within the next few hours, or the deployment (or safeguarding) of staff and technical equipment in advance of potential extreme weather events. These decisions depend on e.g., the hazard, the size of the area of responsibility, the type of technical equipment and other organisational factors. Although most decisions are not directly dependent on certain weather or warning thresholds, they are indirectly influenced by a combination of weather information and specific organisational guidelines, in particular the duty to clear the road from snow within 3 h after an event, as emphasised by the interviewees. The interviewees stressed the general importance of weather forecasts for the deployment of vehicles and staff, and that efforts are being made to answer the questions of when, how many, for how long, and to what extent? Hence, "accuracy" of the forecasts is demanded in order to optimize the use of resources. For IBFs, this leads to a plea to receive relevant information specific to road management practices, e.g. information about the impact of wind gusts on road signs or empty trucks. Particularly temporary and detached roadworks signs are named as a potential danger for road users during strong wind gusts. Additionally, wind gusts are oftentimes recounted as the cause of truck accidents by interviewees, especially when the trucks are empty. Generally, additional information about rare events is highly valued because in those instances no or only few practices are yet established. Especially in the case of extreme weather events that have not yet been personally experienced, further information is required to better understand what is happening or could possibly happen. We derive that information about comparable past events (i.e. with a similar magnitude) could evoke memories of media reports and thus could help to better grasp the forecasted event.

The participants of this study could be divided to two groups regarding the question about what constitutes a relevant information for them. On the one hand, those who are responsible for road maintenance and who are confronted with road conditions on a daily basis and have extensive experience "on the ground", do not see much benefit in additional information to what is currently received. The participants justify this with their proclaimed experience and their ability to conclude possible impacts by themselves. On the other hand, representatives of road administration units in the federal ministries prefer further information in any form to facilitate decision-making. These different preferences could be due to the aforementioned first-hand experience and road maintenance managers' daily contact points, which people in the administration lack, but also due to the different allocation of responsibilities in the organizational structure.

3.2 Recognition of spatial and temporal requests

A road maintenance depot in Germany is covering from 70 km (in the case of highway depots) up to around 430 km public road (Die Autobahn GmbH des Bundes, 2022; Landesbetrieb für Straßenbau Saarland, 2021). This often encompasses areas with different orographic and geographical conditions, where weather forecasts and actual weather events can differ vastly in intensity and type. Due to the uncertainty where the weather event and its impacts will materialize, preparations are restrained and thus, reaction instead of preparation is favoured. Interviewees stressed situations of forecasted storm events when the necessary equipment, e.g. vehicles and chainsaws to chop up fallen down trees and branches, is prepared to be ready at hand. However, the interviewees indicated that road maintenance services only take further action once weather impacts have occurred and respond by travelling long distances instead of already placing equipment close to the area in question. According to the interviewees, the forecasts are too spatially vague for road maintenance services to rely on in their preparation, so they prefer a reaction-based approach (for further discussion on proactive and reactive decision making see Kox et al., 2018a). Although road maintenance services would like to see higher spatial accuracy, they are aware that small-scale weather events such as thunderstorms and heavy rainfall are difficult to predict accurately in terms of their spatial occurrence. Hence, there is an understanding about forecast uncertainty, false alarms, and the variability in time, space, and intensity in general.

According to the road maintenance services interviewed in this study, important factors to consider when developing IBFs are "vulnerable locations" (original phrasing by interviewee in German as "*neuralgische Punkte*") in the road infrastructure, i.e. curves, forested areas, or bridges. Those sections are often the first to be inspected for black ice when low temperatures are forecast. Incorporating local vulnerable locations in IBFs have thus the potential to give the end-users more assistance in decision-making processes. This goes hand in hand with the identification and inclusion of "geospatial data overlays of exposure and vulnerability" (Campbell et al., 2018) that the WMO proposes for IBFs. In the case of road management services, the road infrastructure's exposure and vulnerability to extreme weather events are predominantly embedded in the working knowledge of staff. It would be of great benefit to make use of this already existing knowledge, e.g. through intensified cooperation between the

actors involved and continuous evaluation of the communication process (cf. Scolobig et al., 2022).

Different work regulations and administrative organization involved in road maintenance lead to different time scale requirements in terms of warning response. Most highway (*Autobahn*) maintenance services are occupied with at least one person 24/7 and thus, have a far shorter response time than those operating federal and secondary roads which do not have staff available 24/7 apart from winter season when extreme weather is forecasted. This results in the need for a longer warning lead time, especially in summer weekends. Kox et al. (2018b) report that road managers desire a warning lead time of more than 12 h and consider the organisations' geographically larger area of responsibility and time-consuming work tasks as the reasons. Respondents in this study expressed that a lead time from two to three days would be ideal to be best prepared, especially in the case of the first snow and black ice event of the season. Many federal road maintenance services use external companies (contractors) with own staff and vehicles for winter services, which requires additional lead time to inform and convene them.

In their daily work, the participants of this study rely on short-term forecasts of upcoming weather events (thunderstorms, snowfall, black ice, etc.) and longer-term forecasts for personnel planning. They were aware that forecasts three days in advance might still change over the course of time. Nevertheless, they expect that forecasts 24 to 48 h in advance would be "relatively accurate", as organizing standby duties and work schedules are based on these forecasts. Interestingly, weather warnings in summer are perceived as more "accurate" by the participants than forecasts in winter. In summer, weather conditions in Germany are indeed more stable than in winter, and forecasts are consequently more reliable (Deutscher Wetterdienst, 2009). Two findings in the data material might explain this perception beyond the actual forecast quality: (1) summer events such as thunderstorms require less preparation than winter events that might require mobilization of additional contractors to clear the roads of snow and ice and sending them home when nothing happens after all. (2) Winter services such as clearing roads of snow and ice are one of the main tasks and public duty of road maintenance services, so public pressure and pressure from the organizational leadership eases during summer months. This leads to less compulsory action as most practices in summer are carried out after the event, such as clearing the roads of fallen trees and branches after a severe thunderstorm. Although these remarks are subject to the general weather forecasts and warnings, the temporalities of organizational structures are also relevant for IBFs and should be looked into for each end-user group.

3.3 Acceptability

Generally, it can be said that road maintenance services trust the weather information they receive from DWD via SWIS. Weather information is an important decision-making tool for the deployment of staff and other resources and the interviewees accepted that weather information is subject to uncertainty. Nevertheless, SWIS is not the only used source of information, and especially in cases of doubt and high uncertainty (e.g. weather conditions for black ice) several different sources for weather information, e.g. commercial weather websites and apps, are compared and merged individually into a personally created forecast that fits expectations and the current, observable weather conditions. Weather information from SWIS is perceived as "safer" and more "conservative" (i.e. more false alarms, but less missed events) than others, and is therefore preferred if different sources are inconsistent in the conveyed information. However, participants of the study mentioned an "inflationary use" of the term "extreme weather event", thus, being on stand-by when nothing happens (cf. "cry wolf effect", a hesitation to respond to warnings when faced with a high false alarm rate; LeClerc and Joslyn, 2015). Nonetheless, the participants in this study favoured a higher false alarm rate rather than missing an event. This tolerance to false alarms could be due to the high negative consequences of not acting on a missed event and thus putting the lives of road users at risk (cf. Fundel et al., 2019, also for further discussion of use of uncertainty). Road maintenance services in Germany are public services responsible for road safety, and their resources stem from tax money. This is one of the reasons they perceive high pressure from outside as well as inside the organisation to take the "correct" decisions (Schmidt et al., 2022).

3.4 Comprehensibility

Managers of road maintenance services are not a homogeneous group of end-users. Their existing knowledge and understanding of the weather information can differ vastly depending on work experience, personal interests and other individual and organisational factors. While some of the study's participants have a good understanding of weather phenomena and are able to draw their own conclusions from the available meteorological and roadway data, other interviewees, however, stated that they lack specific meteorological knowledge to extract important information that is not explicitly included in the weather forecast. Hence, statements that are not made explicit in the weather information, but are potentially important for the preparation of an upcoming weather event, are crucial for the comprehension of the forecast. Especially for weather events that rarely occur – participants named e.g., precipitation of more than $100\,\mathrm{L\,m^{-2}}$ in 24 h – additional information is deemed important to be able to envision possible impacts.

It is necessary for road maintenance services like other users of weather information and warnings to receive the information, pay attention to them (thus, not only receive them via SWIS but actively review them) and finally, comprehend them including the information about potential im-

pacts they entail (Lindell and Perry, 2012). It cannot be assumed that all end-users possess a similar understanding of weather phenomena and forecasts. This has to be taken into consideration when providing impact information as some people might deem impact information common knowledge or a logical consequence. Current warnings for instance include general impact information like "branches may break" which some participants regarded unnecessary because information about the wind strength tells them what they need to know, while others claimed those statements to be helpful to better assess the upcoming weather event. To better understand whether the weather information requires action, further explanations would be helpful which could be looked up as needed. The possibility of obtaining additional information, e.g. via a supplement web-link, is important here, as the weather reports are already perceived as "overloaded". This goes hand in hand with the plea for direct contact with weather services and the possibility to ask in situations of high uncertainty and in case of doubt. Whether road maintenance service personnel prefer further information through personal contact or readable content depends highly on their already existing communication patterns with DWD.

3.5 Technical demands

As the German road management services are organized across different federal states and road types and thus are subject to different legislations, they have varying technical equipment at hand when it comes to receiving weather information, spanning from fax reception to equipping staff with smartphones. One constant during the interviews was the participants' wish to receive weather information from SWIS via an app to their individual work phones which possibility did not exist at the time of the study. Apps were highlighted as an easily accessible and quick tool for decision-making, especially for organizations that do not operate 24/7 and where no staff is on stand-by duty. Some federal states use an information service during night times where all warnings in the area are transferred to and whose phone operators are alarming the person in charge. The operators' task is not to assess the warning but to pass it directly to the person on duty. This person must then assess whether it is a relevant alarm and whether it should be acted upon. Therefore, quick access to further information is considered important for the evaluation of the situation.

It was also pointed out during the study that IBFs would not only be of interest for road maintenance services but road users in general. Many accidents occur due to driving behaviour that is not adjusted to the road conditions (Statistisches Bundesamt, 2018). Some interviewees highlighted the chances that modern technologies in cars could offer, e.g. those that allow weather (and weather impact) information to be passed directly to the driver. This is hoped to influence the road users to adapt their driving accordingly and thus to improve road safety.

4 Conclusion

To sum up, in order to prevent road accidents and improve road safety in general, weather information is essential for road maintenance services in their daily work and in preparing for extreme weather events. IBFs could have the potential to improve decision-making and the anticipation of potential hazardous weather events. For road maintenance services, weather impact information becomes relevant when it includes the impacts on road conditions (e.g. impact of wind gusts on temporary road signs or empty trucks) and consequently have an influence on their work practices and the optimal use of resources. IBFs could become particularly relevant in situations that occur infrequently and where there is little knowledge within the organization about the possible impacts. Relevance further implies that temporal and spatial occurrence of the weather event is forecasted as "accurately" as possible. Nevertheless, forecast uncertainty is generally acknowledged by all participants. The relevance of the information is further increased the more local conditions are addressed by means of vulnerable locations, e.g. bridges, forested areas, and highly frequented roads. Mainly due to work regulations and convening contractors, it can be noted that most road maintenance services required a 48 h warning lead time in order to be optimally prepared.

In terms of the potential acceptability of such forecast products, participants in this study made it clear that reliability (i.e. few false alarms) is of high importance. The ability to validate the information (i.e. that impacts can be observed) and the consistency, over a multiplicity of forecast products are also emphasised. Finally, all information needs to be easily understood regardless of meteorological background and experience.

How can these requests be addressed now? Fundamentally, many of the requirements mentioned could be achieved by additional retrievable information and making use of the possibility to personally contact the weather service.

Particularly, personal contact and direct communication can have considerable influence on the different user requirements and ultimately on the valuable use of IBFs. Especially establishing contact with actors where not much communication is taking place can be of great benefit. A bilateral, continual exchange of weather services and road maintenance services builds up trust and adds to an understanding of processes in both directions. Meteorological training is also a valuable tool for building understanding and should be advertised throughout. However, they are mostly unilaterally focused on promoting the meteorological knowledge of road maintenance services, rather than being designed as an interaction between the different actors.

Information about vulnerable locations should be included. Once again, a mutual exchange is crucial, as it can be assumed that definitions about what is considered to be a vulnerable location may differ. The development of a common database in cooperation with stakeholders could be helpful

in this regard. Individual customisation of information, i.e. the ability to determine which information is received based on the person's level of knowledge, would also be a good approach to address the requirements and strengthen trust in IBFs.

This paper explored the road maintenance services' requirements for impact-based forecasts based on their experiences with currently received weather forecasts and. It provided also a hypothetical view on the use of IBFs. This raises the question of how IBFs would be used in the actual decision-making of road maintenance services and opens up room for further research into this topic. Further work should look into the different requirements depending on organisational structures, cultures and personal preferences to get a fuller picture of this group of end-users.

Data availability. Due to privacy and ethical concerns, neither the data nor the source of the data can be made available.

Author contributions. JS lead the investigation and was responsible for the original draft preparation. JS and NT carried out the data analysis. JS and TK conceptualized the research. LG and TK were responsible for the funding acquisition and JS and TK reviewed the paper.

Competing interests. The contact author has declared that none of the authors has any competing interests.

Disclaimer. Publisher's note: Copernicus Publications remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Special issue statement. This article is part of the special issue "21st EMS Annual Meeting – virtual: European Conference for Applied Meteorology and Climatology 2021".

Acknowledgements. The authors would like to thank all interview partners for their time.

Financial support. 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 German Federal Ministry of Transport and Digital Infrastructures, BMVI (grant no. DWD2014P3A).

We acknowledge support from the Open Access Publication Initiative of Freie Universität Berlin.

Review statement. This paper was edited by Virve Karsisto and reviewed by three anonymous referees.

References

Campbell, R., Beardsley, D., and Tokar, S.: Impact-based Forecasting and Warning: Weather Ready Nations, WMO Bulletin, 67, 10–13, https://public.wmo.int/en/resources/bulletin/impact-based-forecasting-and-warning-weather-ready-nations (last access: 22 August 2022), 2018.

Casteel, M. A.: Communicating Increased Risk: An Empirical Investigation of the National Weather Service's Impact-Based Warnings, Weather Clim. Soc., 8, 219–232, https://doi.org/10.1175/WCAS-D-15-0044.1, 2016.

Deutscher Wetterdienst: Wie gut sind Wettervorhersagen, Qualitätsprüfung beim DWD, Deutscher Wetterdienst, 2009.

Die Autobahn GmbH des Bundes: Niederlassung Nordbayern, https://www.autobahn.de/nordbayern, last access: 10 February 2022.

Fundel, V. J., Fleischhut, N., Herzog, S. M., Göber, M., and Hagedorn, R.: Promoting the use of probabilistic weather forecasts through a dialogue between scientists, developers and end-users, Q. J. R. Meteorol. Soc., 145, 210–231, https://doi.org/10.1002/qj.3482, 2019.

Kiel, J., Petiet, P., Nieuwenhuis, A., Peters, T., and van Ruiten, K.: A Decision Support System for the Resilience of Critical Transport Infrastructure to Extreme Weather Events, Transp. Res. Proc., 14, 68–77, https://doi.org/10.1016/j.trpro.2016.05.042, 2016.

Kox, T. and Lüder, C.: Impacts as Triggers for Weather-Related Decision Making: Observations at the Berlin Fire Brigade Control and Dispatch Center, Int. J. Disast. Risk Sc., 12, 610–615, https://doi.org/10.1007/s13753-021-00356-4, 2021.

Kox, T., Lüder, C., and Gerhold, L.: Anticipation and Response: Emergency Services in Severe Weather Situations in Germany, Int. J. Disast. Risk Sc., 9, 116–128, https://doi.org/10.1007/s13753-018-0163-z, 2018a.

Kox, T., Kempf, H., Lüder, C., Hagedorn, R., and Gerhold, L.: Towards user-orientated weather warnings, Int. J. Disast. Risk Re., 30, 74–80, https://doi.org/10.1016/j.ijdrr.2018.02.033, 2018b.

Landesbetrieb für Straßenbau Saarland: Straßen- und Betriebsmanagement, https://www.saarland.de/lfs/DE/themen-aufgaben/strassen-und-betriebsmanagement.html (last access: 10 February 2022), 2021.

LeClerc, J. E. and Joslyn, S. L.: The cry wolf effect and weather-related decision making, Risk Anal., 35, 385–395, https://doi.org/10.1111/risa.12336, 2015.

Lindell, M. K. and Perry, R. W.: The protective action decision model: theoretical modifications and additional evidence, Risk Anal., 32, 616–632, https://doi.org/10.1111/j.1539-6924.2011.01647.x, 2012.

Molarius, R., Könönen, V., Leviäkangas, P., Zulkarnain, Rönty, J., Hietajärvi, A.-M., and Oiva, K.: The extreme weather risk indicators (EWRI) for the European transport system, Nat. Hazards, 72, 189–210, https://doi.org/10.1007/s11069-013-0650-x, 2014.

Potter, S. H., Kreft, P. V., Milojev, P., Noble, C., Montz, B., Dhellemmes, A., Woods, R. J., and Gauden-Ing, S.: The influence of impact-based severe weather warnings on risk perceptions and intended protective actions, Int. J. Disast. Risk Re., 30, 34–43, https://doi.org/10.1016/j.ijdrr.2018.03.031, 2018.

Schmidt, J., Tietze, N., Gerhold, L. and Kox, T.: "They just won't listen" – The role of blame in narratives of past extreme weather events for anticipating future crisis, J. Conting. Crisis Man., accepted, 2022.

Scolobig, A., Potter, S., Kox, T., Kaltenberger, R., Weyrich, P., Chasco, J., Golding, B., Hilderbrand, D., Fleischhut, N., Uprety, D., and Rana, B.: Connecting Warning with Decision and Action: A Partnership of Communicators and Users, in: Towards the "Perfect" Weather Warning, edited by: Golding, B., Springer International Publishing, Cham, 47–85, https://doi.org/10.1007/978-3-030-98989-7_3, 2022.

Statistisches Bundesamt: Unfallentwicklung auf deutschen Straßen 2017: Begleitmaterial zur Pressekonferenz am 12. Juli 2018 in Berlin, Statistisches Bundesamt, Wiesbaden, https://www.destatis.de/DE/Presse/Pressekonferenzen/2018/Verkehrsunfaelle-2017/pressebroschuere-unfallentwicklung.pdf;jsessionid=37279DD680B9F4801995B1FA53561CCF.live722?__blob=publicationFile (last access: 22 August 2022), 2018.

World Meteorological Organization: WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services, World Meteorological Organization, Geneva, ISBN 978-92-63-11150-0, 2015.