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Title: Communicating High Impact Weather: Improving warnings and decision making processes

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Abstract:

Around the world, high impact weather events continue to represent a serious threat to lives and livelihoods threaten lives, health, wellbeing, property and infrastructure. Effective forecast and warning systems can play an important role in reducing the harm caused by these events. However, in order for continuing improvements in the science of weather forecasting to support disaster risk reduction, forecast information must be communicated in a way that is accessible, understandable and provides a useful input into decision making processes. In keeping with this, the papers featured within this special issue focus on: 1) the move towards providing impact based weather warnings to better support decision making processes; 2) trust and its relationship with forecast uncertainty; 3) tailoring forecasts and warnings to meet the decision needs of different user groups; 4) the emerging role of social media in the dissemination and verification of weather warnings; and 5) the wider behavioural, social, cultural and political context in which weather warnings and forecast information are used in decision making. Together they highlight both the challenges of communicating about high impact weather in different contexts, and the potential ways to address them.

Across the world high impact weather events pose a threat to life, livelihoods, health, wellbeing, property and infrastructure. The need to find effective ways to mitigate the harm caused by these events is embedded within the Sendai Framework for Disaster Risk Reduction's core goal of bringing about a "substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries" (UNISDR, 2015). Effective weather forecasts and warning systems

can play an important role in this by helping policy makers, members of the public, emergency responders, and decision makers across multiple sectors take appropriate action. However, in order for these forecasts and warnings to have value, the information created must be appropriately communicated to people at risk, received, understood, and used. Recognising the importance of identifying and developing good practice in the area, the World Meteorological Organisation (WMO) has made communication as a core theme of its High Impact Weather (HIWeather) initiative, which aims to develop both the science and understanding of user needs required for improved early warning systems n (WMO, 2017). This special issue brings together insights from academic research and operational practice within meteorological services to identify, examine and address communication challenges surrounding high impact weather.

While all of the papers within this special issue focus on the challenge of communicating high impact weather events, they employ a broad range approaches to doing so. Methodologies represented include interviews (Bostrom et al., 2018; de la Poterie et al., 2018), surveys (Bostrom et al., 2018; Morss et al., 2018; Potter et al., 2018), judgement and decision experiments (Casteel, 2018; Ihti et al., 2018; Losee et al., 2018; Morss et al.; Potter et al.), participatory stakeholder workshops (Kox et al. 2018), case studies (Gladfelter, 2018), ethnography (Balay-As et al., 2018), conceptual reviews (Anderson-Berry et al., 2018) and social media analysis (Rossi et al., 2018). However, despite the diverse range of perspectives represented, common themes are clearly identifiable. Namely: 1) the move towards providing impact based weather warnings to better support decision making processes; 2) trust and its relationship with forecast uncertainty; 3) tailoring forecasts and warnings to meet the decision needs of different user groups; 4) the emerging role of social media in the dissemination and verification of weather warnings; and 5) the wider behavioural, social, cultural and political context in which weather warnings and forecast information are used in decision making.

Impact based warnings to support decision making

By definition, the term "high impact weather" emphasises the consequences of severe weather. In recent years a shift from forecast provision focussing on meteorological conditions alone, to forecasts that incorporate information about their associated impacts has begun. This approach has been endorsed by the WMO, who have produced guidance on the development of impact based forecasting systems (WMO, 2015). National meteorological and hydrological services are increasingly starting to use both impact based forecasting approaches and communications that emphasise impacts. In keeping with this, several papers in this special issue highlight the benefit of providing information about the consequences of severe weather.

Four papers systematically test anticipated responses to impact based forecasts. Mu et al. (2018), for instance, use an economic experiment to examine the extent to which changing the format of the risk based warnings issued by the UK Met Office's National Severe Weather Warnings Service affects decision making. Their results indicate that increasing the information content of

warnings may not always lead to improved decision making. Focussing respectively on tornado and hurricane warnings in vulnerable regions of the USA, both Casteel (2018) and Morss et al. (2018) find that intention to take protective action is higher for warnings that emphasise severe impacts than warnings that emphasise lower intensity impacts (Casteel, 2018) or meteorological conditions alone (Morss et al., 2018). While Potter et al. (2018) do not find a consistent effect of impact based wind warnings (versus warnings for meteorological phenomena only) on intention to undertake protective behaviour amongst members of the public in New Zealand, they do find greater concern, sense of threat, and understanding of the threat amongst those presented with the impact based warnings. Interestingly, both Casteel and Morss et al find that adding additional language specifically designed to elicit fear, or emphasise the potentially catastrophic nature of the threats, does not further increase intention to act on impact based warnings. In the context of a wider body of literature suggesting that fear appeals – while effective in certain circumstances – may induce fatalism, paralysis or perceived sensationalism in others (O'Neill et al, 2009; Perreault et al., 2014; Witte et al. 2000), this indicates that care should be taken in deciding whether it is necessary to supplement information about the threat of severe weather impacts with fear based language.

More broadly, a need for warnings and forecasting services that provide information about weather impacts is expressed in contributions focussing on very different national and user contexts. Reporting on the findings of participatory workshops bringing together forecasters and emergency responders in Germany, Kox et al. (2018) note a desire for forecast information that directly facilitates decision making about how to respond to the potential impacts of severe weather events. This is echoed in de la Poterie et al.'s (2018) contribution which, examining the use of El Nino forecasts by NGOs operating in five African countries, identifies a need for predictions to be communicate in terms of the potential consequences for agriculture, water resources, and disaster risk reduction. In a paper mapping key events that have affected the weather warnings landscape in Australia, Anderson-Berry et al. (2018) outline a conceptual end-to-end multi-hazard warning systems model that translates information about meteorological conditions to information about the potential consequences of these conditions, and clear recommendations for action.

Trust and uncertainty

Trust in forecasts and forecast providers is a theme mentioned by a number of papers in this issue. In their experimental study, Losee et al (2018) find that trust in forecast information predicts intention to take protective action. While this is in keeping with the findings earlier studies (Sherman-Morris, 2005), this paper goes beyond earlier work to explore the antecedents of trust, linking greater trust to forecast consistency and expected severity of the forecast event. As forecast information can and does change across lead times, this raises questions as to how trust can maintained in the face of forecast uncertainty and forecast updating. This challenge is directly raised by participants in Kox et al.'s (2018) workshops, who identify inconsistencies between forecasts from different source as a barrier to trust. As the author's note, this highlights

the importance of effectively communicating the probabilistic nature of forecasts to users. While there have historically been concerns that providing information about forecast uncertainty may diminish trust and lead to misunderstanding, recent work has suggested that providing information about forecast uncertainty can actually attenuate the loss in trust caused by false alarms (LeClerc et al. 2012). Indeed, within the papers in this special issue different groups express a recognition and acceptance of uncertainty. Bostrom et al. (2018) for instance, find that while residents in hurricane prone areas may trust forecasters, they do not necessarily expect them to be able to accurately predict precise points of landfall. At seasonal climate timescales, where the communication of both the probabilistic nature of forecasts and the reliability (or 'skill') of the forecasting system is vital, the representatives of humanitarian agencies interviewed by de la Poterie et al. (2018) expressed trust in international forecasts, while acknowledging that they would like to receive forecasts with higher skill.

The potential of purely deterministic forecasts to mislead the public is illustrated by Ihji et al.'s (2018) experimental study, which systematically comparing four different ways of visualising tornado polygons. The findings of this study indicate that without accompanying information about storm cells or levels of relative risk within the polygon, people tend to infer that risk will be greatest at the dead centre of the polygon, despite it not being forecasters' intention to convey this message. Even with the provision of additional risk information, misinterpretations were reduced rather than eliminated entirely, emphasising the need for further work on the visualisation of tornado risk and uncertainty.

Different users, different needs

Tailoring forecast information to meet the needs of diverse user groups with different technical capabilities and different decision contexts represents another key theme amongst these papers. Focussing on five African countries, de la Poterie et al. (2018) identify between country differences in NGOs and governmental agencies' capacity to utilise forecast information in planning and decision making. In Germany, Kox et al. (2018) highlight the different information needs of decision makers in different sectors (e.g. road maintenance requiring longer lead times than emergency response), as well as the different technical capabilities of different users. Likewise, Bostrom et al's (2018) mental models study of Miami residents' understanding and interpretation of hurricane risk identifies key differences between residents' understanding and priorities, and those of hurricane professionals. The fact that public audiences cannot be treated as a monolith is highlighted by Anderson-Berry et al. (2018), who note that differences in factors such as community cohesion may influence the weather warning requirements of members of the public in different regions, as well as the protective responses available to them. Going beyond traditional models of forecast provision and use, Balay-As et al. (2018) question the distinction drawn between indigenous knowledge and scientific knowledge. In ethnographic research with three communities in the Northern Philippines, they find that community members do not

necessarily delineate the two sources: combining their own environmental observations with information from radio weather forecasts.

Social media

The rise of platforms such as Facebook and Twitter, means that information (and potentially misinformation) about weather, weather warnings and weather forecasts can now be disseminated on mass between members of the public. This marks a change from communication paradigms where forecasts and warnings are assumed to be disseminated to the public through media channels. The emerging role of social media in weather warnings communication is highlighted by two papers in this special issue. Reviewing the Australian weather warnings landscape, Anderson-Berry et al. note the role that social media communities have in disseminating weather warnings, and psychologically supporting those in at risk areas. Rossi et al. (2018) meanwhile, approach social media from another perspective: exploring whether data gathered from the microblogging service Twitter can be used to help verify the occurrence of high impact weather events, and provide additional details about these events. Focussing on the 2016 Piedmont floods in northern Italy, their findings suggest that data crowdsourced from the public in this manner has the potential to both verify forecasts and provide enhanced information to agencies responsible for emergency response.

Wider context

The fact that weather warnings are generated, provided and used in a wider social and institutional context, is noted in contributions from Balay-As et al. (2018), Bostrom et al. (2018), Gladfelter (2018), Kox et al. (2018), Anderson-Berry et al. (2018), and de la Poterie et al. (2018) All of these papers stress the fact that warnings and forecasts are only one input into decisions about responses to and preparedness for high impact weather. Focussing on the seasonal climate timescale, de la Poterie et al, highlight the fact that even with reliable forecast information, political and financial constraints can limit humanitarian agencies ability to prepare for potential flooding and drought. Likewise, Anderson-Berry et al. (2018) note that different communities and households can differ in both their capacity to respond to high impact events, and their preferred approach to managing the risk posed by high impact events such as wildfires (e.g. evacuating versus staying and defending). At a household level, the effect of prior experience on hurricane response is noted by Bostrom et al. (2018), highlighting the fact that individual perceptions of weather risk are shaped by factors other than the information provided by weather services.

The broader social and political context in which flood warnings are obtained and disseminated in the context of a community based early warning system, is the focus of Gladfelter's (2018) contribution to this special issue. Using the case study in Nepal, this paper outlines the challenges that NGOs can face in balancing the need for initiatives that reduce vulnerability to severe events amongst marginalised communities, with avoiding placing an undue burden on these communities and inadvertently perpetuating existing inequalities.

Looking forward

Taken together, the papers comprising this special issue reflect the state of the art in our understanding of high impact weather communication. In terms of operational practice, they show the critical importance of ensuring that forecast information is delivered to its intended users in a way that is accessible, understandable, and provides useful input decision making processes. Moreover, they illustrate techniques that can be used to identify what the forecast needs of different user groups are, and how these users interpret and respond to different ways of presenting this information. The need for forecasts that effectively communicate the potential consequences of severe weather, rather than meteorological variables alone, is highlighted throughout this special issue; a theme that resonates strongly with recent developments in impact based forecasting (e.g. WMO, 2015). Forecast information does not, of course, exist in a vacuum, and these papers also urge us to examine the broader organisational, political, social and cultural contexts in which weather forecasts are provided and utilised. Addressing challenges in disaster risk reduction that stem from institutional practices and social inequalities may be beyond the remit of those providing forecast information. However, through better understanding the nature of these challenges they can both reduce the risk of unwittingly perpetuating them, and increase the extent to which developments in the science of forecasting benefit forecast users. The October 2017 World Meteorological Organization (WMO) "Science Summit on Seamless Research for Weather, Climate, Water, and Environment" in Geneva, reiterated the need to improve research collaboration, improve the links between WMO and other international research initiatives, develop an appropriate WMO research agenda, and ensure societal benefits from the research.

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