IMPROVED UNDERSTANDING OF AND TECHNIQUES FOR DECISION MAKING

The ability to effectively mitigate the impacts of weather-related hazards resides, in part, in the ability to understand and improve the decision-making process carried out by disparate stakeholders, with particular focus on understanding impacts, leveraging proper tools and techniques, and translating data into actionable information.

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ABSTRACT

The growing population, its spatial distribution, and its reliance on increasingly complex, integrated infrastructures and networks are just a few of the many factors that play a role in the multifaceted problem of addressing and mitigating the impacts of weather-related hazards. While there has been considerable improvement over the last few decades in the ability to predict and assess high-impact weather events, the effective application of weather-related data and information in critical decision making often remains below acceptable levels. There are a number of challenges surrounding the use and application of weather data including, but not limited to, disparate stakeholder requirements, forecast uncertainty, the need for actionable information, a better understanding of weather impacts, and the effective use and incorporation of weather data and information into the decision-making process. The weather community has recognized these and other deficiencies, and work is steadily progressing to close key gaps associated with weather-based decision making. Central to these efforts is research and development that is focused on enabling and enhancing new technologies, capabilities, and services that will foster decision-level information for mitigating weather-related hazards and impacts.

INTRODUCTION

Maximizing safety, mobility and efficiency, while minimizing associated costs, is a common goal of many weather forecast users across a number of industries and market sectors, as well as the general public. Statistics reveal that significant improvements in weather research and, consequently, weather forecast quality have been achieved over the last several decades. As one general reference (e.g. Nurmi et al, 2013), the atmospheric predictability has improved by approximately 1 day *per* decade during the past 20 years. Nevertheless, the global population remains quite vulnerable to weather-related hazards. In a study conducted by Lazo et al. (2011), it was determined that the economic impact due to variability in weather (precipitation and temperature) was as much as 3.4% of the 2008 U.S. gross domestic product or $ 485 billion. Since 1980, European economic losses associated with extreme weather have been in excess of € 400 billion (based on 2010 values), with the majority of this loss related to storms and flooding (Hov et al., 2013). Such figures can be attributed to the weather-related impacts that occur throughout several sectors including transportation, agriculture, energy, construction, retail, finance, and insurance. In some sectors such as transportation, these losses are associated with the loss of life and injury. For example, data released by the Federal Highway Administration in the United States suggest that weather is responsible for over 1 million vehicle accidents each year, resulting in more than 6000 fatalities and over 400,000 injuries. In Europe, it was found out in the recent EU funded research project EWENT (Extreme Weather impacts on European Networks of Transport) that the annual road accident costs amount to over € 20 billion and the estimated savings based on current weather services are c. € 3.4 billion (Nokkala et al., 2012). The question is how much of the c. € 17 billion difference could be gained with improved understanding of and techniques for the weather information delivery chain and decision-making process. All these figures point to the fact that more needs to be done to mitigate the impacts of weather hazards, particularly in the face of climate change. One key success factor is the ability to bridge the gap between the science and end users (professionals and laypeople). This means delivering data and information in a manner that better supports weather-critical decision making.

Weather forecasts and warnings are useless unless people base decisions on them, but effective decision-making requires stakeholders to understand the potential impacts of predicted weather. To aid better decision-making, many forecast providers are attempting to issue risk-based forecasts and warnings - risk being a combination of Probability and Impact. The probability aspect of risk may be addressed by modern forecasting systems involving ensemble prediction, but the estimation of impact, which depends on the vulnerabilities of stakeholders and may be measured in terms of human safety, economic costs or other factors remains a huge challenge involving the crossover between physical and social science. Many research projects (e.g., EU FP7 projects EWENT and MOWE-IT) have addressed societal impacts of weather-related hazards, but while huge progress has been made in probabilistic hazard prediction, progress with impacts has been relatively modest. Impact modelling requires a deep understanding of the user's business, and simple cost/loss decision rules rarely reflect real world complexity – users make multiple decisions at different lead-times and levels of risk.

A fundamental requirement for improving the use of forecasts of environmental hazards is an understanding of the potential impacts of the hazard, whether those impacts are related to public safety or to the efficient and cost-effective operation of government or businesses. Some stakeholders will be much more vulnerable to particular hazards than others, depending on many factors including economic resources, physical location and protection. Stakeholders' attitude to risk will also depend on the metrics they use to assess impacts which may be based on threats to life or economic costs, for example, so that different users may make very different decisions when threatened by the same probability of a hazard. For forecast providers to maximise the effectiveness of decision-making from their forecasts or warnings they (1) need to engage closely with stakeholders to understand their vulnerabilities and attitudes to risk, and (2) then develop communication strategies which enable the users to take effective and timely decisions and actions. Forecasts are always subject to uncertainty, whether assessed objectively or subjectively, and an important part of the discussion with stakeholders is the level of confidence required for them to take protective action. Such discussions should be taken in advance so that categorical decisions can still be taken in real-time despite the uncertainty.

DECISION SUPPORT STRATEGIES

Weather data and forecast providers such as national meteorological institutes and private sector companies have begun to focus more on addressing the gaps that exists between their offerings and end users' operations. In some cases, this has been a conscious undertaking and in others it has been driven by market demands. In either case, these efforts are manifesting themselves in two primary areas, decision support services and decision support systems. Decision support services involve a consultancy structure in which the forecast provider develops a deep understanding of the end user's operations in order to facilitate real-time, two-way communication and interaction that targets the weather-dependent operational aspects that are most important to the end user before, during and after an event. A decision support system is a tool that, in its most mature form, uses decision models to couple weather forecasts with data and information concerning an end user's operations to deliver objective, repeatable guidance that will support decision making (Petty et al., 2010). The services and systems being developed and employed attempt to address the aforementioned need to cultivate a more comprehensive understanding of end user operations through stakeholder engagement and advance effective communication strategies. Although considerably more work is required, there are a growing number of emerging examples where collaborative efforts between end users and forecast providers have resulted in very novel methods and techniques that deliver considerable value in terms of weather-based decision making.

A number of countries now issue their Public Weather Service (PWS) warnings in a risk-based framework, often employing a "traffic-light" colours scheme to communicate levels of risk and therefore levels of response action in a simple pre-arranged language. The UK National Severe Weather Warning Service (Neal et al., 2013) uses such a matrix taking account of both likelihood and impact (Figure A). This framework was agreed in collaboration with key stakeholders responsible for civil protection such as fire and rescue services; while those stakeholders are likely to have specific planned responses to levels of warnings such as having extra staff on stand-by or deploying extra flood defences, for example, the public are given very simple messages to "Be aware" (Yellow), "Be prepared" (Amber) and "Take Action" (Red). Assessment of impact in the UK is still largely subjective and based on the accumulated experience over many years of the types of impact associated with different strengths of wind, rainfall accumulations etc. Neal et al. (2013) describe how an ensemble-based first-guess warnings system uses a number of thresholds to estimate warning colours objectively. Thresholds vary across different regions of the UK according to the climatology and resulting vulnerability to levels of hazard.

All transport sectors (i.e., aviation, maritime, road, and rail) are known to be highly weather dependent. The European MOWE-IT project (www.mowe-it.eu) (Management Of Weather Events In The Transport System; under the EU 7th Framework Programme, FP7) has among its goals the development of methodologies that will assist transport authorities and transport system end users in mitigating the impacts of natural hazards and extreme weather phenomena on transport system performance. MOWE-IT has just recently published a set of five mode-specific guidebooks for Aviation, Rail, Road, Inland Waterway and Maritime transport[2], which are directed at decision-makers and other stakeholders having the objective to reduce the extreme weather impacts on transport. Road transport is a prime example of a transportation sector that has become increasingly weather reliant due to constantly increasing traffic volumes and frequency of hazardous weather events affecting the roads. Consequently, the MOWE-IT "Guidebook for Enhancing Resilience of European Road Transport in Extreme Weather Events", focuses on the road transport mode[3]. It is envisioned that information contained in all of the guidebooks will enable forecast providers and forecast end users to understand the types

[2] See www.mowe-it.eu/wordpress/deliverables
[3] See www.mowe-it.eu/wordpress/wp-content/uploads/2013/02/MOVE-IT_road_guidebook_final.pdf

and magnitudes of impacts expected from disparate weather hazards across different transportation sectors. Leveraging this information in collaborative ways will support the creation of plans, services and tools that can aid in mitigating weather-related impacts through enhanced decision making.

Another EU FP7 project, FOTsis (Field Operational Test on safe, intelligent and sustainable road operation) is a large-scale field testing of road infrastructure management and end user systems piloted along nine selected European highways. Weather-driven solutions and services have a fundamental role in FOTsis, because adverse weather accounts for some of the most notorious disruptions in road transportation addressing thus huge economic impacts (Nurmi et al, 2013). In a similar manner to the UK National Severe Weather Warning Service described above, the FOTsis end-to-end weather applications do not deliver customary weather forecasts like rainfall or weather symbols but, rather, employ weather-related information as explicit "traffic-light" kind warning alerts against potentially adverse weather events jeopardizing traffic conditions and safety. Hence, the end users will not receive direct meteorological information at all, but explicit impact messages providing guidance for their actions. To produce such alerts shown in Figure B (aka "minimize/control your speed", "stop driving"), the critical threshold values for all required meteorological variables were assigned taking carefully into account the specific local climatology at each of the pilot highways (the example in Figure B is for the A2 Highway in central Spain).

In the United States, the National Weather Service (NWS) has embarked on a multiyear strategic initiative designed to build a "weather ready nation" in which the country is more resilient to weather-hazards as a result of improved preparedness and more effective response in the face of high-impact weather. As part of this plan, the NWS is instituting a services framework that includes Impact-based Decision Support Services (IDSS) wherein enhanced interpretation and consultation, along with more focus on societal impacts, will be leveraged in an attempt to improve the decision-making process of key stakeholders (NWS, 2013). It should be noted that these steps will be carried out in concert with other fundamental activities such as improvements in the science and technology used to produce forecasts and warnings, including information on forecast uncertainty derived from ensemble-driven modelling and post-processing. These NWS activities are consistent with some other national meteorological institutes and forecast providers and demonstrate the organization's commitment to high-quality decision support through effective stakeholder engagement and enhanced communication strategies.

FORECAST UNCERTAINTY

To allow society as a whole to make best use of forecasts for effective decision-making requires communication of uncertainty information to the public. Since every forecast user has their own personal vulnerabilities to the weather, and also a personal view on risk averseness, no single best-estimate forecast can serve the decision-making requirements of all users. The only way to serve all needs is to communicate the full information known on forecast uncertainty. There are many ways to summarise such information, but for many purposes an effective summary might be a most-likely value (often from an ensemble mean or median) plus the probabilities of a one or more extreme (high-impact) thresholds. A common perception among meteorologists and communicators is that people ("the public") do not understand probabilities. While there is some evidence that many people are confused or concerned by the term *probability*, there is growing research evidence that most people (at least in advanced developed countries) can make better decisions when provided with uncertainty information. Joslyn and Savelli (2010) found that the public in the U.S. understood that forecasts were uncertain, and when forecasts were presented without uncertainty information would make their own judgements of uncertainty, often wrongly, especially in relation to extreme weather events. Decision-making could therefore be greatly improved by providing explicit uncertainty information with the forecast.

Both Roulston and Kaplan (2009) in laboratory controlled experiments, and Stephens et al. (2011) using an on-line game, found that people from a range of backgrounds and academic disciplines were able to make better decisions when forecasts were presented with uncertainty than when a simple deterministic forecast was presented. Stephens et al. (2011) used a range of presentations of varying complexity and found that people made the best decisions with the most complex (and information-full) information. A recent survey conducted on behalf of the Met Office Public Weather Service, which ran a number of focus groups with members of the UK public, found that people were broadly accepting of the need and reasons for communicating uncertainty, and receptive to simple presentations. People did find some of the more complex presentations confusing and *too scientific*, but the use of a percentage figure was considered to be "'the most succinct and easily grasped way of conveying probability" and were able to relate information on uncertainty to the sort of day-to-day decisions that they might take.

Much like the potential confusion and lack of understanding of uncertainties or probabilities by the public, the same can be said about understanding forecast verification information. However, information on forecast quality, whether it be probabilistic, deterministic, categorical or the combination of these different forecast types, should always be communicated to all forecast end users, not forgetting the general public. This will improve their general confidence in the forecasts, allow them to identify situations in which forecasts can be considered reliable, and help them identify the extent to which forecasts are useful as basis for decision-making in weather sensitive activities (Ebert et al, 2013). There is some early evidence (Joslyn, 2013) that non-experts in meteorology already understand basic verification metrics and graphics. However, greater efforts are needed to develop better and more intuitive forecast verification measures and products for end users to improve their background understanding for decision-making.

CONCLUSION

Successfully reducing the impacts of weather-related hazards is dependent on several factors; however, the weather-critical decisions made by end users are a fundamental element in impact mitigation. Improvements in weather-based decision making will ultimately result in advances in areas such as operational safety and efficiency. Research and development aimed at improving the decision-making process will benefit from collaborative input from a broad range of professionals (e.g., physical and social scientists, usability practitioners, etc.). Particular focus should be given to societal impacts, which entails working closely with forecast end users to better understand and quantify weather-related impacts, as well as developing strategies for communicating information that will enable end users to more effectively manage risk. Research and development activities should also include examining ways to produce and communicate forecast uncertainty. The delivery of uncertainty using probabilities is one method to support forecast end users, with recent research suggesting that end users, including the general public, are capable of using such information. Nonetheless, there are also ancillary techniques that should be explored. The combination of forecast uncertainty and impact information can lead to powerful decision-level services and tools for addressing weather-related hazards and impacts.

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TABLES AND FIGURES

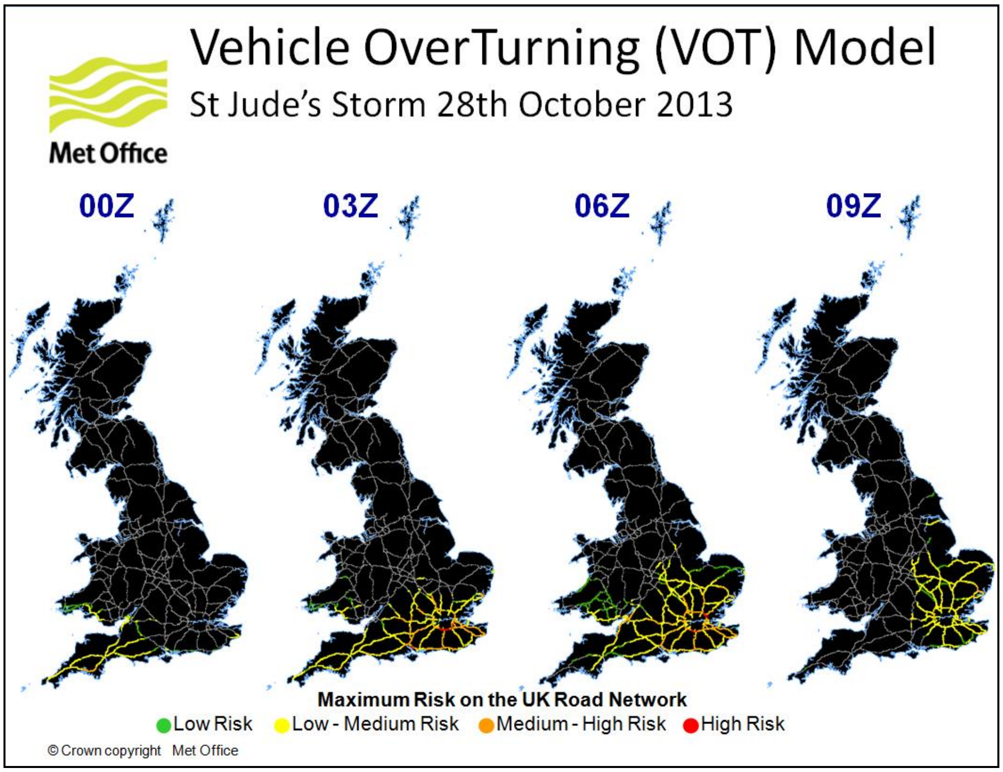

Figure A: Example of the vehicle overturning module of the Hazard Impact Model (HIM) developed by the Met office to estimate risk of transport disruption due to strong winds over-turning vehicles, showing how the risk evolves through time as the storm tracks across the UK.

Parameter/Event	Thresholds	Action message
Snow / Sleet	" Any snowfall, incl. hail "	" Minimize your speed "
	≥ 2 cm/h or ≥ 10 cm/6h or ≥ 1 cm/h + T ≤ -10C	" Stop driving "
Rain	1 - 5 mm/h	" Control your speed "
	5 - 10 mm/h	" Minimize your speed "
	≥ 10 mm/h	" Stop driving "
Freezing rain	Rain ≥ 1 mm/h + Tair < 0C	" Stop driving "
	Rain + Tsurface < 0C	" Stop driving "
Visibility	Visibility ≤ 400 m	" Control your speed "
	Visibility ≤ 250 m	" Minimize your speed "
	Visibility ≤ 80 m	" Stop driving "
Blizzard	Max wind gust ≥ 17 m/s & Tmean ≤ 0C (24 hrs) & Precip ≥ 10 mm (24 hrs)	" Stop driving "
Wind, mean	≥ 12 m/s	" Control your speed "
	≥ 17 m/s	" Minimize your speed "
	≥ 21 m/s	" Stop driving "
Wind, gust	≥ 17 m/s	"Control your speed"
	≥ 25 m/s	" Minimize your speed "
	≥ 32 m/s	" Stop driving "
Surface Friction	≤ 0.4	"Control your speed"
	≤ 0.3	" Minimize your speed "
	≤ 0.2	" Stop driving "
Surface condition	Damp	" Control your speed "
	Wet	" Control/Minimize your speed "
	Snow on the road	" Stop driving "
	Ice on the road / Black ice	" Stop driving "
Road maintenance		
Road surf temperature	< -7C	" Salting does not help "
Snow accumulation	> 3cm	" Time to plow "

Figure B: Meteorological variables and their thresholds leading to explicit action messages as guidance for road end users in the Spanish pilot highway within the FOTsis project (Nurmi et al, 2013).